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Protecting Personnel at Hazardous Waste Sites

Third Edition



William F. Martin
Michael Gochfeld

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Third Edition

William F. Martin

Michael Gochfeld

Editors

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Boston Oxford Auckland Johannesburg Melbourne New Delhi

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PREFACE

Professionals in environmental health, occupational health environmental management, and engineering have often noted the need for a well referenced health and safety textbook to prepare new workers for hazardous materials and hazardous waste cleanup activities.

This need is addressed in this third edition by the two editors, William F. Martin, P.E,. and Michael Gochfeld, M.D., Ph.D. by uniting 25 contributing authors from federal agencies, academia and industry. These authors average over fifteen years each in professional experience in teaching, regulating, consulting, and handling of hazardous materials. The first edition of this book was published in 1985 and the second edition in 1994 with excellent acceptance by academic, industrial and governmental colleagues.

Additional field experience and new regulations have prompted this third edition. Five chapters have been added to address the 1990s effort to cleanup and convert to civilian use major Department of Defense (DoD) and Department of Energy (DoE) lands and facilities. These chapters introduce radiation, unexploded ordnance, hazardous materials transport, monitoring wells, and ISO guidelines for the health and safety for site investigators, managers, supervisors and workers. The chapter on occupational risk assessment and toxicology has been expanded because classroom experience at educational centers all across the United States indicated that many professional people were being cross trained for hazardous waste occupations with very limited backgrounds in applied occupational health.

Many users of the first two editions had requested that the editors make available for classroom use more health and safety plans that had been used for a complex site cleanup. Three separate health and safety plans have been added in the appendixes.

The third edition has expanded and updated material in every chapter. References have been revised to reflect current sources. The main objective of this textbook continues to be its use as a resource book for training professionals in the practice of occupational safety and health in hazardous materials and waste activities. It is the strong feeling of the authors that anyone teaching or training hazardous waste workers should have thoroughly covered at least the content of this edition in an academic setting and have had considerable field experience under experienced supervision.

This edition is considered a minimum of academic exposure for trainers of the hazardous waste health and safety course commonly referred to as the Occupational Safety and Health Administration (OSHA) 40-hour or Hazardous Waste Operation and Emergency Response (HAZWOPER)

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training. The Environmental Protection Agency (EPA), Department of Defense, Department of Energy, U.S. Coast Guard and Occupational Safety and Health Administration regulations and contracts usually require this level of health and safety training for all on-site personnel. This textbook and professional reference is a companion to the worker training manual Hazardous *Waste Handbook for Health and Safety.*

Hazardous waste management is a challenging endeavor in our national effort to protect the quality of our environment. The authors of this book feel that this challenge can be met without sacrificing the health of those individuals and companies called on to accomplish the task.

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Recognition is given to the U.S. Public Health Service, especially the National Institute for Occupational Safety and Health (NIOSH) and the Center for Disease Control and Prevention (CDCP), the Occupational Safety and Health Administration (OSHA), the U.S. Environmental Protection Agency (EPA), the Department of Energy (DoE), the Department of Defense (DoD), and the U.S. Coast Guard (USCG) for their efforts under RCRA and Superfund to gather, develop, and make publicly available health and safety guidelines, publications, and contractor reports.

This practical hazardous waste health and safety textbook would not be possible without the previous work of many individuals, companies and government agencies. During the past 15 years, the authors have worked with a host of highly qualified professionals in the nation's efforts to contain hazardous waste spills, clean up abandoned landfills, control hazardous chemical threats to the environment and public health, and adequately disposed of solid and hazardous waste.

A greatful recognition is given to Steven P. Levine, Ph.D., C.I.H., University of Michigan, for his contribution in the original development of this book and his dedication to quality as coeditor for the first two editions. The following professionals made substantial contributions to the development of the earlier editions: Mark Puskar, Christopher O'Leary, David Weitzman, Barrett Benson, Rodney Turpin, Joseph Lafornova, Robinson Hoyle, Larry Payne, Clyde Strong, Margo Dusenbary, Kenna Yarbrough, Virginia Kiefert-Martin and Bryon Witmer.

Outside reviewers contributed substantially to the quality and focus of this edition. A special thanks to Professor Joe Ledbetter, Ph.D., University of Texas, for his specific review comments that improved the quality of this edition. The South Carolina Department of Health and Environmental Control, through the reviews of Shannon Berry, Ron Kinney and Harold Seabrook, was very helpful in keeping this edition practical and current. Paul Seligman, M.D., M.P.H., of the Department of Energy reviewed the appendix on DoE sites. An extensive review by William Keffer, Senior Engineering Advisor, EPA, was very helpful for the second edition, and also provided some excellent options for this edition. Previous review comments by Ray Bock and Larry Dunning of Rust International, Inc., helped to keep the textbook practical. The NIOSH staff, especially Stephen P. Berardinelli, Ph.D., Aaron W. Schoppee; Ph.D., Jim Spahr, and Dr. Belard in the Division of Safety Research, Morgantown, West Virginia, recommended a number of changes in the second edition

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relating to personal protective equipment that were incorporated into the present edition. The authors also recognize the following for their review comments on the first two editions that have been incorporated into the present edition: James P. Kirk, William R. Goutdie III, Steven J. Sherman, Vicki Santoro, Joseph A. Gispanski, and James B. Walters.

Michael Gochfeld's participation in editing this volume and Joanna Burger's contribution were supported by the Consortium for Risk Evaluation with Stakeholder Participation (CRESP) through a DoE cooperative agreement (DE-FC01-95EW55084).

Special thanks to Jeffrey A. Loy, Stephen L. Gurba, Ph.D., and Lynn Reid, Environmental Systems & Services, Inc., for technical contributions and administrative support during the production of the second edition. The editors and authors wish to thank Laurie Goodale of Priester & Associates for her desktop publishing skills in the production of this new edition.

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William F. Martin, P.E. holds a civil engineering degree from the University of Kentucky and a master's degree in environmental health engineering from the University of Texas. He served 22 years as a commissioned officer in the U.S. Public Health Service. He held positions with the Indian Health Service, U.S. Coast Guard, Federal Water Pollution Control Administration, and National Institute for Occupational Safety and Health. A registered professional engineer in Texas and Kentucky, he has presented and published numerous technical papers both foreign and domestic. He served on the Superfund steering committee made up of EPA, OSHA, NIOSH, and the U.S. coast Guard. He served as the NIOSH Hazardous Waste Program Director with primary responsibility for coordinating all Institute Superfund activities including research projects and the production of comprehensive health and safety guidelines, worker bulletins and training materials. Mr. Martin has consulted on environmental engineering and hazardous waste health and safety with Valentec International Corporation, Environmental Systems & Services, Inc. and Greenglobe Engineering, Inc.

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later Interim Commissioner, Dr. Priester developed and approved standards, procedures and methods for the safe handling and disposal of toxic wastes, and standards for toxic materials in drinking water and other human and animal pathways necessary to protect health and the environment.

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Charles F. Redinger is an Occupational Health Fellow at the University of Michigan's Erb Environmental Management Institute and a contract auditor with NSF International Strategic Registration Ltd. He has a Ph.D. in environmental and industrial health from the University of Michigan, a master's degree in public policy from the University of Colorado, and a B.A. in Chemistry from the University of Califomia. He is a member of the Public

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H. Randy Sweet has been a practicing hydrogeologist for 30 years. His experience in the field ranges from ground-water development in the Rajasthan Desert as a Peace Corps Volunteer in the 1960s to regulatory and consulting work. He has authored a number of articles on the nuances of ground water monitoring and served on EPA's National Task Force in the development of a uniform nationwide groundwater monitoring strategy in 1985. He has been directly responsible for hundreds and indirectly involved in the installation of thousands of monitoring wells throughout his career. Mr. Sweet is now semiretired and provides litigation support and expert testimony in the environmental arena.

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Paul J. Webb, C.I.H. has experience includes industrial hygiene positions with the North Carolina Department of Labor, Division of Occupational Safety and Health and within the pharmaceutical industry. He is currently president of Occu-Health Consultants, Inc., a Raleigh-based firm specializing in occupational health and safety. Over the past several years, his firm has worked with clients in private industry and municipal government in the development and implementation of emergency response programs and personnel training.

Mr. Webb received his B.S. in Biology and his M.P.H. in industrial hygiene from the University of South Carolina. He is certified in the comprehensive practice of industrial hygiene by the American Board of Industrial Hygiene.

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INTODUCTION: HISTORY AND FEDERAL PROGRAMS

William F. Martin, M.S., P.E.
Michael Gochfeld, M.D.,Ph.D.

HISTORY

This book is intended as a resource for the challenging and changing task of protecting workers engaged in hazardous materials management, particularly at hazardous waste sites. The problem of protecting personnel during hazardous waste operations may be viewed as being fundamentally the same as the problems encountered at traditional workplaces. The traditional industrial hygiene triad of recognition, evaluation, and control can be applied to diverse workplaces. Those principles can also be applied to hazardous waste sites and hazardous materials incidents. However, from the perspective of over two decades of practice at hazardous waste sites and hazmat emergencies, the industrial hygiene profession now has more experience and tools to protect the worker [Andrews, 1990]. The overall principles of industrial hygiene apply to such sites, but hazardous materials and hazardous waste site remediation offer significant challenges in worker protection.

On April 21, 1980, a fire broke out at an abandoned waste treatment facility called, ironically, "Chemical Control Corporation," in Elizabeth, New Jersey. The tens of thousands of leaking and burning drums at the site obviously posed a real industrial hygiene problem to the fire fighters and other emergency responders, and subsequently to site cleanup personnel. This incident, and previous incidents of the same type, caused EPA, NIOSH, OSHA, and the U.S. Coast Guard to agree to the development of two important guidance documents for environmental and industrial hygiene [NIOSH, 1982, EPA, 1982].

While these documents were very important from the perspective of training and general practice of good hygiene at hazardous waste remediation and emergency response sites, these documents had a more important impact. A four, agency occupational safety and health/Hazardous Waste Committee,

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had been established in the late 1970s to recommend safeguards for workers that could be employed to cleanup the nation's hazardous waste mess.

On February 26, 1980, President Jimmy Carter signed Presidential Executive Order (EO) 12196 requiring the federal government to comply with the General Industry Standards in Section 6 of the Occupational Health and Safety Act. EPA Order 1440, published on July 12, 1981 (to comply with EO 12196), required all EPA employees engaged in field operations to have 24-40 hours of relevant training prior to field activities. For those employees engaged in hazardous waste activities, EPA Order 1440 requires EPA employees to have 40 hours of hazardous waste health and safety training, which is essentially equivalent to following the guidelines set forth in the Standard Operating Safety Guides (SOSG) [EPA, 1988].

Although EPA, NIOSH, and OSHA felt that 29 Code of Federal Regulations CFR1910 and 29 CFR 1926 did address the health and safety needs for hazardous waste site workers, EPA required all public and private site workers involved in Superfund activities to follow, as a minimum, the EPA Office of Emergency and Remedial Response (OERR) Standard Operating Safety Guides (SOSG). These SOSGs became the de facto federal "regulation" for industrial hygiene practice by contractors engaged in emergency response or remedial action at hazardous waste sites. The regulatory authority for extending these SOSGs from federal employees to contractors was inherent in the EPAs power to write site-specific contract specifications. Implementation of the SOSGs rested with the on-scene coordinators (OSCs) who were either EPA employees posted to hazardous waste sites, or U.S. Army Corps of Engineers Resident Engineers under contract to the EPA. The U.S. Coast Guard had developed very similar guidelines for its personnel. EPA also delegated responsibility for certain sites to state agencies which were bound by the same guidelines.

The SOSG de facto "regulations" stood virtually unchanged for about ten years. The SOSGs contained specifications, for example, for worker training, air monitoring, personal protective equipment, site control, decontamination, and medical surveillance. They were an example of the use of a "guidance" document to produce de facto rule-making.

In 1983, a joint NIOSH, OSHA, EPA, and Coast Guard, draft guidance manual was released and then published in 1985 [NIOSH, 1985]. These four federal agencies had worked together through a formal multiagency committee, set up in the late 70s, to produce the occupational safety and health guidelines, share information, recommend federal regulation modifications, and suggest executive orders to protect workers at hazardous waste sites. In addition, a number of textbooks and conference proceedings on this subject were published in this period [Levine and Martin 1985; Gochfeld and Favata, 1990]. Many case studies were presented in those conference proceedings. In October 1985

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the four-agency health and safety guidelines were published for public disemination. A worker bulletin was published by the four agencies in 1983 to promote health and safety training for hazardous waste workers, (see NIOSH publication 83-100).

One of the historical points that has long been forgotten was the initial consideration of using the, Department of Defense, US Army Corp of Engineer's to take on the task of cleaning up the nation's abandoned and condemned hazardous waste sites. It was predicted that OSHA, EPA, NIOSH, DoD and Department of Energy, training programs could prepare the existing workforce and reserves for safe operations. The workforce could be medically monitored. One big problem was selecting the new hazardous waste disposal sites, from the hundreds of hazardous materials sites that the DoD was being asked to clean up and turn over to civilian use. The coincidence of timing, national need and available resources was too good to be true. However, when the Superfund legislation was finally passed a clause was inserted to prohibit the U.S. Army Corps of Engineers from doing the actual cleanup. The Army Corp of Engineers was relegated to the task of issuing the contracts for EPA to private contractors for the studies and the cleanup activities. Many of the military hazardous waste sites are still on the priority list awaiting cleanup funds so the sites can be transferred to other public and private owners/users.

The early estimates of the nation's cost to stabilize and/or remove hazardous waste from our communites was based on utilizing existing federal manpower and lands. The estimated $1.6 billion revenue from the new Superfund tax on chemical industry raw materials was predicted to be adequate for cleanup of the initial list of high priority Superfund sites. The task was to be completed in five years. As of 1998, the latest available Superfund information gives that cost at over 10 times the original estimate. As of 1997, there were over 1400 sites on the national priority list with construction underway on 477 and construction completions through fiscal year 1997 on 498. These numbers change every year, so the current status must be obtained directly from the EPA.

The way work is being done is changing as well. New configurations of companies develop from large construction engineering firms and small technology development firms. Workers who do not consider themselves hazardous waste workers may find themselves visiting sites for demonstrations, oversight, or other purposes. Regulations offer a framework for protecting workers, but good planning and adequate professional expertise in safety engineering, industrial hygiene, worker training, and occupational nursing and medicine are essential for implementation.

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CURRENT REGULATORY ACTIVITY

We are presently in a period of maturation of regulations and procedures for protecting personnel at hazardous waste sites. These regulations and procedures are important in the context of Superfund remedial actions, under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), Resource Conservation and Recovery Act (RCRA) activities and emergency response activities. While EPA is the lead federal agency, other federal and state agencies, such as the Department of Energy and the Department of Defense, are involved in hazardous waste site activities.

Under the authority of Section 126 of the Superfund Amendments and Reauthorization Act of 1986 (SARA), EPA and OSHA promulgated identical health and safety standards to protect workers engaged in hazardous waste operations and emergency response. The OSHA standard became effective March 6, 1990. These worker protection standards affect employers whose employees are engaged in hazardous waste operations and emergency response during:

- Cleanup operations at uncontrolled hazardous waste sites;
- RCRA corrective actions;
- Voluntary cleanup operations at sites recognized by federal, state or local governments;
- Hazardous waste operations at RCRA treatment, storage and disposal (TSD) facilities, and;
- Emergency response operations without regard to location.

The OSHA standard (29 CFR 1910.120), or equivalent state standards, protect all private, federal, and state and local government employees in states with delegated OSHA programs. The EPA standard (40 CFR 311) covers state and local government employees engaged in hazardous waste operations and emergency response in states that do not have an OSHA-approved state plan. Standard 40 CFR 311 defines "employee" as a compensated or non compensated worker who is controlled directly by a state or local government (including, for example, a volunteer fire fighter).

The OSHA standard addresses requirements for medical surveillance, training, environmental monitoring, planning, and several important site-specific activities, including site safety plans. One written health and safety plan (HASP) must be developed for each site to cover all contractors and all aspects of site operations. Chapter 9 of EPA 1440 requires the on-scene coordinator to be responsible for all health and safety requirements on a site. The standard can be divided into three primary parts: operations at hazardous

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waste sites; operations at RCRA TSD facilities, and emergency response operations conducted without regard to location. Strategies invoked for protecting hazardous waste workers include education and training, site health and safety plans, personal protection, environmental monitoring, and medical surveillance.

Additional regulatory action during this period includes:

- Rule making for accreditation of training programs for hazardous waste operations [*Federal Register*, 1955]. Public hearings in early 1991 were held in order to address the question of "what constitutes an adequate training program." This is a difficult problem that involves questions of credentials and experience of instructors, adequacy and relevance of course materials, and the equivalency of programs administered by industry, unions, consultants, governments, and academia.
- Letters of "clarification" and "guidance" from OSHA to field personnel and various interested parties [Scannell, 1990; Clark, 1990]. These letters and memos define important concepts so that the full intent of 29 CFR1910.120 can be understood and enforced. For example, "emergency response," "uncontrolled" and "incidental releases" are defined, "de minimis" criteria are spelled out, and scenarios are addressed.
- The Hazard Ranking System Final Rule was published December 1990. [*Federal Register*, 1990]. While this rule does not directly affect the issue of personal protection, it does provide a tool with which hazardous waste remedial action sites are placed on the National Priorities List, and thereby prioritized for cleanup. Thus, this document is important to occupational and environmental health professionals.

FEDERAL GOVERNMENT PROGRAMS

The federal government has historically taken an active role in providing technical assistance and disseminating information. These services are provided to the general public, academia, and state and local organizations in the form of research support, supplemental funding, training programs, and information programs. Provision of these services is usually mandated by legislation, and broad public access to the materials within federal agencies is ensured by the Freedom of Information Act of 1966.

The resources available on protecting worker safety and health from hazardous substances are as diverse as the many federal programs themselves. There has been a rapid growth of available resources due to the recent emphasis in three areas: (1) research; (2) the gathering of information

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nationwide for identifying health risks associated with hazardous substances; and (3) the production of publications to assist state and local organizations to recognize, evaluate, and control hazardous substances. Due to modern information storage, retrieval, and database management, this vast and ever-growing body of technical information is more readily accessible to the private sector than ever before. See Chapter 2 for more details on databases and information sources.

Even though a tremendous amount of technical data and other resources are available, much of the potential audience may never benefit from them. Some potential users will not know where they exist or how to access them, and an unfortunate few will never even know of their existence. For similar reasons, many of the users who do access federal programs will never receive the full benefits of these programs due to their diversity and variety of skills needed to access the information.

This chapter will attempt to provide potential users with information and insights that will assist them in becoming full recipients of the government services. It will, at best, serve as a starting point, since utilizing a federal program requires skill, knowledge, and tenacity. Potential users should obtain a basic knowledge of the programs responsibilities, purposes, and delivery mechanisms. Since this information is often provided in the legislation and public law itself, the following section, Legislative Background, will highlight some of the laws pertaining to hazardous substances and worker safety and health. Responsible agencies and their functions will be identified in the section Federal Programs Relating to Protection of Hazardous Waste Workers. The section, Accessing Federal Programs, provides insight into why familiarity with the programs is necessary, and also why tenacity is essential.

Legislative Background

Historically, most of the occupational safety and health laws were enacted by states. Prior to 1960, there were relatively few federal laws addressing worker protection, and those were applicable only to a limited number of employers or specific groups of employees [Bennett, 1982]. During the 1960s, there was an increase of concern about worker safety and health in this nation, and the result was a proliferation of federal legislation. Ultimately, a nationwide occupational safety and health program was designed through the Occupational Safety and Health Act of 1970 (OSHAct). The OSHAct extended safety and health coverage to most workers of business affected by interstate commerce.

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The OSHAct established three organizations:

1. The Occupational Safety and Health Administration. Located within the Department of Labor, OSHA is primarily responsible for the promulgation and enforcement of standards and worker training.
2. The National Institute for Occupational Safety and Health. NIOSH is located within the Department of Health and Human Services and is administratively under the Centers for Disease Control. NIOSH is the principal federal agency engaged in research, education and training, and disseminating information related to occupational safety and health.
3. The Occupational Safety and Health Review Committee. The OSHRC is an independent agency within the Executive Branch which adjudicates contested cases resulting from OSHA-initiated actions against employers.

Even though the OSHAct covers most businesses in the country, it was not specifically applied to hazardous waste handling until a 1982 amendment was made to the National Contingency Plan under Public Law 96-510, the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA or Superfund). In addition to OSHA and NIOSH, other federal agencies have specifically defined responsibilities in protecting workers from adverse health effects from hazardous wastes.

The number of diverse federal programs relating to hazardous waste is due to the complexities and the multidisciplinary aspect of hazardous waste management, and to the extensive amount of federal legislation addressing hazardous materials. Much of the legislation on hazardous substances that applies to worker safety and health was developed to regulate activities other than waste site management or remedial actions. The National Contingency Plan in 40 CFR Part 300 is a notable exception. Regulations and legislation applicable to worker safety and health include:

- The previously mentioned OSHAct of 1970 and the subsequent passage of regulations 29 CFR, notably Parts 1910 (Occupational Safety and Health Standards) and 1926 (Safety and Health Standards for Construction).
- The Resource Conservation and Recovery Act of 1976 (RCRA) and subsequent regulations in 40 CFR Parts 260 through 265, such as Section 265.16 (Personnel Training) and 265 Subparts C (Preparedness and Prevention) and D (Contingency Plan and Emergency Procedures).
- CERCLA of 1980 and its regulations (i.e., the National Contingency Plan) under 40 CFR 300.150 (Worker Health and Safety), stipulating which worker health and safety regulations and guidelines to follow, and subsequent amendments.

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- The Atomic Energy Act of 1954 and subsequent regulations in 10 CFR Part 20, stipulating standards for protection against radiation.
- Federal Mine Safety and Health Act (FMSHA) of 1977 and subsequent regulations in 30 CFR Part 11 (Department of the Interior, Bureau of Mines, Respiratory Protective Devices; Tests for Permissibility), providing the primary technical criteria for a permissible respirator.
- The Hazardous Materials Transportation Act of 1975 (HMTA) and regulations in 49 CFR Parts 100 to 199, which stipulate labeling, marking, packaging, placarding, manifesting, and shipping papers required for handling of hazardous materials during loading, transport, and unloading.

Potential users should familiarize themselves with these pieces of legislation. Other additional pieces of legislation will be of interest to the industrial hygienist working with hazardous material management; however, familiarity with those listed above will provide a good foundation for initially accessing federal programs and resources.

Federal Programs Relating to Protection of Hazardous Waste Workers

This section identifies and highlights many of the federal programs relating, directly and indirectly, to safety and health protection of hazardous waste workers. The informational and technical resources available through these programs will be emphasized, rather than their regulatory and policy-making functions.

Discussions of the programs will be brief, since the purpose of this section is to provide a guide for inquiry and access to services. An exception is made for the NIOSH discussion. NIOSH is engaged in research, education and training, and providing information related to occupational safety and health. NIOSH is thus a good source of information and resources on both worker safety and health and on hazardous substances found in the workplace [NIOSH 1997]. Table 1-1, located later in this chapter, provides pertinent program addresses and telephone numbers.

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U.S. Department of Health and Human Services (HHS)

Centers for Disease Control and Prevention (CDC)

CDC provides assistance through its National Center for Environmental Health. Technical assistance, publications, laboratory and analytical services, and health studies are available. CDC is the focal point for HHS responsibilities under CERCLA. It also includes NIOSH and ATSDR (see below).

National Institute for Occupational Safety and Health (NIOSH)

NIOSH was established to ensure safe and healthful working conditions, to develop occupational safety and health standards, and to carry out research activities. Key NIOSH services include:

1. Health Hazard Evaluations (HHEs), which provide on-site evaluation of potentially hazardous chemical, physical, and biologic exposures. HHEs have both medical and industrial hygiene components. Employers or representative groups of employees may place requests by calling 1-800-35-NIOSH.
2. Providing technical information, including NIOSH criteria documents, publications, and research reports. Criteria documents contain a review of the scientific literature, required medical controls, methods of sampling and analysis and probable safe atmospheric levels. In response to inquiries, NIOSH will search two databases that relate to toxic substances and worker safety and health (RTECS® and NIOSHTIC®).
3. Technical assistance in the areas of epidemiology, engineering, industrial hygiene, and occupational medicine.

Professional training courses, provided by NIOSH and by colleges and universities through NIOSH contracts and grants, include both degree and certificate granting programs. NIOSH supports 12 regional Educational Research Centers and many other academic programs through its training grants. Courses are available in the fields of occupational medicine, occupational nursing, industrial hygiene, and occupational health engineering (safety and ergonomics).

4. Respirator testing, called FIT testing, and certification to assure compliance with federal requirements (see Table 1-1).

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5. Because NIOSH is administratively under the CDC, inquiries to NIOSH often yield valuable environmental health information referrals to CDC programs and specific referrals to individual professionals.
6. Publication of a wide variety of documents on specific hazardous materials, occupations, and exposures, including its *Pocket Guide to Chemical Hazards* [NIOSH, 1997] including exposure limits, physical properties, health hazards, and protection guidance for over 650 chemical compounds.

Agency for Toxic Substances and Disease Registry (ATSDR)

ATSDR was created to prevent or to mitigate adverse human health effects and diminished quality of life resulting from exposure to hazardous substances in the environment. By congressional mandate, ATSDR establishes linkages between human exposure to hazardous substances and any increased incidence of adverse health effects by applying state-of-the-art scientific methods, creating and building relevant databases, and identifying appropriate target populations for investigation.

National Institute for Environmental Health Sciences (NIEHS)

NIEHS provides toxicological data, publications, technical assistance, and research programs to study the biological effects of potentially toxic substances found in the environment. There is an emphasis on health effects from chronic low-level exposures. It supports 15 regional centers of excellence as well as numerous independent researchers who conduct basic and applied studies and offer outreach to the public.

U.S. Department of Labor

Occupational Safety and Health Administration (OSHA)

In addition to its enforcement responsibilities, OSHA provides technical assistance, publications, and training courses and develops and promulgates occupational safety and health standards. OSHA also provides consultation to help businesses comply with safety standards. Most of these resources can be obtained through the 10 regional offices, or through area offices located in states that do not have their own state OSHA plans (see yellow pages under U.S. Department of Labor).

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U.S. Environmental Protection Agency (EPA)

EPAs goal is to prevent, control, and abate pollution in the areas of air, water, solid waste, pesticides, radiation, and toxic substances. The EPA provides technical assistance and publications on both the management of hazardous wastes and worker safety and health at hazardous waste sites. The Office of Emergency and Remedial Response is a major resource within EPA for technical assistance, training, and environmental protection support during hazardous substance incidents. The program areas of solid waste, surface and groundwater protection, and air pollution all have extensive technical experience and current research that directly relates to hazardous waste occupational safety and health. EPA, like OSHA, has 10 regional offices that can provide many of these services, or at least refer inquiries to the appropriate office within the agency.

U.S. Department of Transportation (DoT)

The DoT Office of Hazardous Materials Standards provides technical assistance and publications on the safe transport and loading of hazardous materials. DoT sponsors several hazardous materials transportation courses. They also operate the Transportation Safety Institute in Oklahoma City, which provides several training courses on hazardous materials transportation. DoT has a list of hazardous chemicals and requires appropriate manifesting and placarding of vehicles (see Chapter 17 on transportation safety).

U.S. Coast Guard

Although a branch of the uniformed services, the U.S. Coast Guard is under the jurisdiction of the DoT. The U.S. Coast Guard provides information and technical assistance in port safety. It is often the lead agency in response and remediation of spills and contamination in waters under its jurisdiction. Other functions include providing a National Response Center to receive reports of oil and hazardous substance spills, investigate spills, and monitoring responsible party cleanups. In environmental emergencies, the U.S. Coast Guard may provide a strike team and public information assistance. For persons involved in oil spill response, they offer a training course that includes spill planning and response and personnel safety.

Federal Emergency Management Agency (FEMA)

FEMA participates in the development and evaluation of national, regional, and local contingency plans. It monitors responses to these plans and evaluates

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requests for presidential designation of disaster areas. FEMA, along with 14 additional agencies of the National Response Team, has developed the *Hazardous Materials Emergency Planning Guide*. FEMA also sponsors the Hazardous Materials Information Exchange (HMIX), which is a computerized bulletin board designed especially for the distribution and exchange of hazardous materials information. The HMIX provides a centralized database for sharing information pertaining to hazardous materials emergency management, training, resources, technical assistance, and regulations. To learn about accessing the system, call 1-800-PLANFOR.

U.S. Department of the Interior

U.S. Geological Survey (USGS)

The USGS provides expertise on cartography, geology, hydrology, and soil sciences. An extensive collection of topographic maps and recent and historical aerial photography is also available. These maps, photographs, and many of the USGS reports may be useful in site selection and in remedial actions. The USGS also conducts investigations of groundwater pollution and identifies sources such as waste disposal facilities. The USGS Water Resources Divisions mission is to provide hydrologic information and understanding needed for the optimum utilization and management of the nations water resources. The National Biological Survey is now part of the USGS.

U.S. Department of Energy (DoE)

The DoE is responsible for more than 40 major and many minor sites in 33 states (see Appendix G "Hazardous Waste Management on DoE Sites"). The DoE operates the Technical Information Center at Oak Ridge, Tennessee, that disseminates its own reports as well as international nuclear science literature. The Office of Environmental Restoration and Waste Management provides centralized management for the department for waste management operations, environmental restoration, and applied research and development programs and activities. In 1989 the mission of the DoE began to shift from nuclear weapons production to hazardous waste site management and remediation. It currently spends about $6 billion annually on stabilizing and controlling hazardous waste and on site cleanups.

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U.S. Department of Commerce

National Institute of Standards and Technology (NIST)

The NIST provides publications on its own measurement programs in physical sciences and engineering and, from its reference collection of engineering standards and specifications issued by federal agencies, technical societies and trade associations. NIST carries out selected programs in public safety and health and environmental improvement.

National Oceanic and Atmospheric Administration (NOAA)

NOAA provides detailed state-of-the-art meteorologic data and scientific support, including expertise on living marine resources. This organization is conducting research on several topics on hazardous substances that will assist safety and health professionals. It also supports sea grant programs in the coastal states, which cover many aspects of coastal environmental quality including the impact of hazardous materials on ecosystems and fisheries.

General Services Administration (GSA) - Federal Information Center Program

The Federal Information Center Program is a clearinghouse for information about the federal government and can eliminate the maze of referrals that people have encountered in contacting the federal government. People with questions about a government program or agency, and who are unsure of which office can help, can call or write the center.

National Technical Information Services (NTIS)

This agency provides hard copy and electronic copies of federal documents after they are no longer available from the source agency.

American Conference of Governmental Industrial Hygienists, Inc. (ACGIH)

ACGIH is not a federal agency, but its membership is composed of industrial hygienists and toxicologists. ACGIH publishes annually a table of recommended threshold limit values (TLVs) for chemical substances [ACGIH, 1998] as well as biological exposure indices. These cover many commonly used industrial substances with references for additional information is also available. The 1968-69 list of TLVs was adopted by OSHA as its Permissible

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Exposure Limits (PELs) in the 1970s, but the PELs do not change automatically when the TLVs change.

International Standardization Organization

A global approach to occupational health and safety promoted by the International Organization for Standardization (ISO) has two standards that relate to hazardous waste operations ISO 9000 for quality and ISO 14000 for the environmental [Dyjack, Levine, et al., 1998]. These international guidelines are discussed in more detail in Chapter 18 on ISO 9000 and 14000 for hazardous waste operations.

Accessing Federal Programs

Government publications and resources in any subject area present problems for their actual and potential audiences due to their great number, their different distribution channels, and the number of organizations and programs producing them. In subject areas such as hazardous waste, these potential problems are exacerbated by the dispersion of responsible agencies throughout the federal bureaucracy, the multidisciplinary nature of the subject, and rapid growth resulting from public concern and changing legislation. Although these factors may complicate access, they are also indicators of the magnitude and diversity of the available resources. Once potential users identify these and other potential problems, strategies for accessing federal programs can be developed. Although each user will develop his or her own unique approach, the most effective strategies will be based on knowledge, planning, and interpersonal skills. See Chapter 2 for more details on information gathering.

Forethought will result in better service, less frustration, and less time expended. Planning will enable the user to obtain some familiarity with the legislation and programs related to the inquiry. It will also allow enough lead time for proper definition of the inquiry and contacts with local resource people. Potential users are urged to consult with librarians and information specialists at public, academic, and industrial libraries. Often librarians learn how to access such information only when responding to such requests. Thus each request has a multiplier effect, facilitating future access. The federal government has been modernizing in the last several years by employing information specialists to manipulate and manage their vast supply of technical information and data. These individuals are not only trained professionals, they are also "users" themselves with established methods of access. They can save both the potential and experienced user considerable time and frustration.

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Frequently, they can also provide sample output from automated information systems and refer users to specific individuals.

Planning should also include definition of the kind of information or services needed. Given the volume and diversity of the resources available, the user will be best served when the objective of the inquiry is clearly identified. Persistence in follow-up is as important in acquiring federal program assistance as it is in the sales business. Program changes and staff turnover necessitate a relentless pursuing and building of communication networks. The users skill and knowledge can be used and increased only if contact is maintained with individuals within the federal program. It is only through these contacts and dialogues that users obtain the most comprehensive and current level of assistance available.

One characteristic shared by all federal programs is change. All are subject to constantly changing personnel, available resources, program emphasis, computer facilities and administrative organization. These can range from minor modifications of the administrative organization to major restructuring of the program emphasis. Since even minor modifications can result in personnel transfers and new telephone and email listings, users must monitor the program fairly frequently.

Keeping up to date with any specific federal program requires obtaining pertinent information from the voluminous amount available. This is particularly true with changes in the federal administration. The outgoing administration attempts to push through legislation and programs in its final days (e.g., EPA's Superfund) and the new administration makes changes in key staff and administrative procedures in order to institute its own agenda. During this transition, there is considerable discussion and debate creating a vast amount of information that must be sorted through to track actual program changes.

The task of obtaining pertinent information is even more formidable with high level public interest programs like Superfund. The program's potential social, economic, and environmental impact can mobilize special interest groups, which further contribute to the available information. These groups can also affect rapid changes within federal programs through their support and lobbying activities.

Due to the current level of public concern and political sensitivity, hazardous waste programs can change more quickly than other government programs. These factors and the economic implications of hazardous waste management and remedial actions will result in further federal program modifications for some time. Even though this rapid rate of change will be a source of frustration for potential users, those tenacious enough to pursue their inquiries will be rewarded with the resources derived from changing programs. There has been a trend over the past few years to let the states exercise more

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freedom in cleaning up hazardous waste sites, responding to hazardous materials spills and emergency response preparedness. We anticipate major changes in the dissemination and exchange of technical information over the next five years. Allying this information to worker protection will be a welcome challenge.

Table 1.1 A Partial List of Federal Programs, Addresses, and Telephone Numbers That Can Provide Hazardous Waste Safety and Health Information

National Institute for Occupational Safety and Health (NIOSH) U.S. Department of Health and Human Services 4676 Columbia Parkway Cincinnati, OH 45226 (800) 356-4674 FIT Testing Information Morgantown, WV 26505 (304) 284-5713	Agency for Toxic Substances and Disease Registry (ATSDR) U.S. Department of Health and Human Services 1600 Clifton Road, N.E. Atlanta, GA 30333 (404) 639-0727
Centers for Disease Control and Prevention (CDC) U.S. Department of Health and Human Services National Center for Environmental Health 4770 Buford Highway Chamblee, GA 30341 (404) 488-7050	U.S. Environmental Protection Agency (EPA) Office of Emergency and Remedial Response 401 M Street SW (MC5203G) Washington, D.C. (703) 603-8830
Occupational Safety and Health Administration (OSHA) U.S. Department of Labor 200 Constitution Ave. NW (Rm. N3647) Washington, D.C. 20210 (202) 219-8151	National Institute for Environmental Health Sciences (NIEHS) U.S. Department of Health and Human Services P.O. Box 12233 Research Triangle Park, NC 27709 (919) 541-0752 or 541-3345
U.S. Department of Transportation (DoT) Office of Hazardous Materials Standards 400 Seventh Street, SW Washington, D.C. 20590 (202) 366-4488	Federal Emergency Management Agency (FEMA) 500 C Street SW Washington, D.C. 20472 (202) 646-4600 (800) PLANFOR (HMIX bulletin board)

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National Oceanic and Atmospheric Administration (NOAA) U.S. Department of Commerce Hazardous Materials Response and Assessment Division 7600 Sandpoint Way, NE Seattle, WA 98115 (206) 526-6317	U.S. Department of Energy (DoE) Office of Scientific and Technical Information P.O. Box 62 Oak Ridge, Tennessee 37831 (615) 576-1301 Office of Environmental Restoration and Waste Management (202) 586-6331
National Institute of Standards and Technology (NIST) U.S. Department of Commerce Gaithersburg, MD 20899 (301) 975-3058	U.S. Geological Survey (USGS) 12201 Sunrise Valley Dr. Reston, VA 22092 (703) 648-4460 (703) 648-5663 (NAWDEX)
EROS Data Center U.S. Geological Survey Sioux Falls, South Dakota 57102 (605) 594-6511	U.S. Coast Guard - U.S. DoT Marine Environmental Protection 2100 Second Street SW Washington, D.C. 20593 (202) 267-0518
Environmental Photographic Interpretation Center (EPIC) P.O. Box 1587 Warrenton, Virginia 22186 (703) 341-7503	Environmental Monitoring Systems Laboratory (EMSL-LV) P.O. Box 15027 Las Vegas, Nevada 89114 (702) 798-2525
Earth Science Information Center (ESIC) U.S. Geological Survey Box 25046, (MS504) Denver Federal Center Denver, Colorado 80225-0046 (303) 236-5829 ESIC 507 National Center Reston, VA 22092 (703) 648-6045 ESIC 1400 Independence Road, (MS231) Rolla, MO 65401-2602 (314) 341-0851	Federal Information Center Program General Services Administration P.O. Box 600 Cumberland, MD 21502-0600 (800) 347-1997 Eastern Time Zone (800) 366-2998 Central Time Zone (800) 359-3997 Mountain Time Zone (800) 726-4995 Pacific Time Zone (800) 733-5996 Hawaii (800) 729-8003 Alaska (800) 326-2996 TDD/TTY
National Climatic Data Center U.S. Department of Commerce Federal Building Asheville, North Carolina 28801 (704) 259-0476	Soil Conservation Service U.S. Department of Agriculture P.O. Box 2890 Washington, D.C. 20013 (202) 720-1820

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Although history has shown us that the general principles of industrial hygiene apply to hazardous waste workers as well as to those in more traditional industrial jobs, there are important differences in emphasis. Education and training are mandated for hazardous waste workers. Personal protection, an interim or temporary strategy in the industrial workplace, becomes a requisite strategy at the hazardous materials spill or waste site. The results of air monitoring play a pivotal role in the selection of personal protection. Medical surveillance, a secondary prevention strategy, plays a more prominent role in the quality assurance of the primary prevention strategies [Gochfeld, 1982]. Conversely, engineering approaches such as substitution or process modification and powered ventilation have more limited application in hazardous waste work, many are old sites in open areas.

The following chapters in this book will expand and delineate the occupational health and safety practices that can protect the personnel working with hazardous spills and hazardous waste. This new edition has incorporated the experiences of the past decade from sources in academia, industry and government.

During the 1980s, several studies were performed that showed that concentrations of air contaminants were usually very low during most hazardous waste activities [Costello and Mulius, 1981; Levine and Martin, 1985]. These studies were performed using traditional NIOSH/OSHA sampling and analysis methods based on adsorbent tubes and filters with which time weighted concentration air samples were taken and sent back to the laboratory. In addition, grab samples were taken using colorimetric indicator tubes.

Unfortunately, those investigators, including the authors of this chapter, and their sampling devices were invariably not present during rare but critical events. For example,

1. when acid was added to a lagoon that contained high concentrations of sulfide, which was then liberated as H_2S (Liquid Disposal Company, Utica, MI);
2. when water and concentrated H_2SO_4 were inadvertently mixed, causing massive releases of airborne H_2SO_4 (Lock Haven, PA);
3. when unknown vapors/gasses overcame guards outside the perimeter of a site during a night time period with calm winds (Chem-Dyne, Hamilton, OH);
4. when drums suddenly exploded during manipulation (Goose Farms, Trenton, NJ);
5. when workers or equipment fell into pits or trenches that were being examined or excavated, or when dramatic fires and explosions occurred (Chemical Control, Elizabeth, NJ).

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However, since there are still no "universal" real-time monitors useable under routine conditions, the IDLH (immediately dangerous to life or health) [NIOSH, 1997] criterion may still be used as the "default criterion" of choice. See Chapter 5 on air monitoring for more details

This new edition incorporates the experiences of the past decade from sources in academia, industry, and government. The overview provided in this introduction is expanded in subsequent chapters. Maintaining the health and safety of hazardous waste workers is an ongoing challenge as the nation pursues its goals of environmental quality.

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2

INFORMATION GATHERING, SITE CHARACTERIZATION, AND INFORMATION RESOURCES

Paul J. Webb, C.I.H.

INTRODUCTION

Hazardous waste sites, like other work environments, require occupational health and safety management of personnel who work at these sites. The purpose of this chapter is to provide guidance on gathering information about the site and characterizing the site in terms of the potential health and safety hazards, and to provide information on some relevant health and safety databases and references. While there is no standard method for gathering information, this chapter will provide a strategy that should help simplify the process.

Before we begin, let us briefly review some terms that are used throughout this chapter. OSHA's Hazardous Waste Operations and Emergency Response (HAZWOPER) standard represents the primary regulatory reference for health and safety procedures at hazardous waste sites. While the term *hazardous waste* is defined in great detail in both the EPAs Resource Conservation and Recovery Act (RCRA) and DoT Hazardous Materials (HAZMAT) regulations, OSHAs main concern is the protection of personnel from health and safety hazards; as a result, the term "hazardous waste" is more broadly defined to include all waste or combination of wastes as referenced by either EPA or DoT regulations (40 CFR 261.3 or 49 CFR 171.8). From this perspective, *hazardous waste* may be defined as any uncontrolled release of a hazardous substance or any hazardous substance that is treated, discarded, or stored for the purpose of treatment or disposal.

"Hazardous substance" is another important term and is comprehensively defined by OSHA as any substance in which exposure results or may result in adverse effects on the health or safety of employees, and is

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1. Referenced under section 101(14) of CERCLA.
2. Any biologic agent and other disease causing agent that after, release into the environment and upon exposure, ingestion, inhalation, or assimilation into any person, either directly from the environment or indirectly by ingestion through food chains, will or may reasonably be anticipated to cause death, disease, behavioral abnormalities, cancer, genetic mutation, physiological malfunctions (including malfunctions in reproduction), or physical deformations in such persons or their offspring.
3. Any substance listed by the U.S. Department of Transportation as hazardous materials under 49 CFR 172.101.
4. A hazardous waste as defined by OSHAs HAZWOPER standard, 29 CFR 1910.120.

Hazardous waste sites are locations where hazardous waste operations are conducted. Such a site can be further classified as either a "controlled" or "uncontrolled" hazardous waste site. Any site where hazardous waste is safely contained for the purpose of treatment, storage or disposal is considered a controlled site. Uncontrolled sites are contaminated with hazardous waste as a result of past production activities, dumping, or accidental release of hazardous substances.

Hazardous Waste Operations

OSHAs HAZWOPER standard addresses specific populations of workers who perform hazardous waste operations. These operations include:

- Cleanup operations required by a governmental body, whether federal, state, local, or other, involving hazardous substances that are conducted at uncontrolled hazardous waste sites;
- Corrective actions involving cleanup operations at sites covered by the Resource Conservation and Recovery Act;
- Voluntary cleanup operations at sites recognized by federal, state, local, or other governmental bodies as uncontrolled hazardous waste sites;
- Operations involving hazardous wastes that are conducted at treatment, storage, and disposal (TSD) facilities licensed under RCRA; and
- Emergency response operations for release of, or substantial threats of release of, hazardous substances.

As you can imagine, personnel who perform hazardous waste operations do so under varied conditions and circumstances. TSD facilities are similar to production operations in that the waste is "processed" by repacking,

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incineration, chemical neutralization, encapsulation, or by other means that reduce, eliminate, or isolate the hazard from people and the environment.

Cleanup and emergency response operations involve similar precautions and work preparation. For example, the site must be secured and work zones designated. Personnel and equipment that are involved in these operations must undergo decontamination procedures, and the highest levels of personal protective equipment is generally utilized for these operations.

INFORMATION GATHERING

Purpose and Scope of Hazardous Waste Site Activities

As we have discussed, hazardous waste sites cover a broad spectrum of conditions and operations. One of the first steps in the information gathering process is to determine the site status and activities required on the site. For example, is the site a TSD facility or an area requiring cleanup? What work activity is occurring or will be required at the site? The answers to these questions will determine the occupational health and safety requirements for that site. While the following questions are relevant to site inspectors, these questions may provide a useful starting point for anyone involved with the information gathering process:

- *Who* is going to the site? Have they been properly trained and informed about site activities?
- *What* conditions and hazards will you encounter upon entry? What types of hazardous waste may be present?
- *Where* is the site? Do you know how to get there? If so, have you informed your team?
- *How* could planned field activities affect your team, the area, and the public?
- *When* will you go, and what weather conditions do you expect?
- *Why* are you going? Have you adequately planned each site activity and are you prepared for unexpected difficulties?

For established hazardous waste sites, you will want to review any existing documents, such as correspondence, operating procedures, and the sites safety and health program. This program, if available, will provide much of the information that you will need to understand and evaluate the health and safety issues at that site.

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Site Safety and Health Program (SSHP or HASP)

OSHAs HAZWOPER standard requires that all hazardous waste operations develop and implement a written site safety and health program. The program should address how the site will identify, evaluate, and control safety and health hazards, including emergency response actions. Any existing safety and health programs can be used as long as the programs cover the program elements of OSHAs HAZWOPER standard which are outlined and discussed as follows:

Elements of an SSHP

- Site program organizational structure;
- Hazard communication and notification;
- Comprehensive work plan;
- Site-specific standard operating procedures (SOPs);
- Job/task assignment;
- Employee training requirements;
- Medical surveillance requirements;
- Personal protective equipment (PPE);
- Job safety analysis;
- Employee and air monitoring;
- Site control;
- Decontamination;
- Other safety and health considerations; and
- Emergency response.

ORGANIZATIONAL STRUCTURE

The SSHP should establish a chain of command and specify the overall responsibilities of supervisors and employees. At a minimum, the site should have personnel who can manage the sites hazard waste operations, the health and safety program, and emergency response actions. OSHAs HAZWOPER standard outlines the following chain of command requirements:

1. A general supervisor who has the responsibility and authority to direct all hazardous waste operations;
2. A site safety and health supervisor who has the responsibility and authority to develop and implement the SSHP and verify compliance;
3. All other personnel needed for hazardous waste site operations and

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emergency response and their general functions and responsibilities;
4. The lines of authority, responsibility, and communication.

NOTIFICATION REQUIREMENTS

In addition to employee training and communication of potential hazards, the hazardous waste site operator is required by OSHA to notify contractors, subcontractors, or their representatives of the site emergency response procedures and any potential fire, explosion, health, safety, or other hazards of the operation that have been identified by the SSHP. This program must be made available to any employee or contract personnel who will be involved with the hazardous waste operation, and the SSHP must be kept on-site at all times.

Standard practice is to include the SSHP as part of any bid package. Also, wording in contractual agreements should require compliance with the SSHP as well as compliance with all applicable local, state, and federal laws and regulations. A review of contracts can provide information about the site operators safety and health program. This review is essential if litigation is anticipated. The site operator should consult legal counsel when writing and revising contractual wording.

COMPREHENSIVE WORK PLAN

As part of the SSHP, the comprehensive work plan should outline the tasks and objectives of the site operations, and the logistics and resources required to achieve those objectives. The work plan should document any anticipated cleanup activities and reference applicable standard operating procedures. The work plan needs to document what personnel are necessary to conduct hazard waste operations as well personnel training, information, and medical surveillance requirements.

JOB SAFETY ANALYSIS

The health and safety risk should be assessed for any task that exposes personnel to a potential hazard. For example, drum handling can involve issues with back safety, abrasions from sharp surfaces, and foot and hand safety in addition to the potential hazards of the drums contents. The safety analysis should specify PPE to be worn, and work practices for the safe transport and handling of the containers. Some risks to be considered include exposures

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exceeding safe exposure limits (PELs, TLVs, IDLHs, etc.); potential skin absorption and irritation sources; explosion sensitivity and flammability; and oxygen-deficient conditions.

EMPLOYEE AND AIR MONITORING

The SSHP should include information about the frequency and types of air monitoring, personnel monitoring, and environmental sampling techniques and instrumentation to be used, including methods of maintenance and calibration of monitoring and sampling equipment.

SITE CONTROL

As part of the SSHP, the site control program should include a site map, site work zones, the use of a "buddy system" during work activities, and, site communications including methods for alerting personnel in to event of an emergency. In addition, procedures need to be in place to restrict site access only to authorized personnel.

DECONTAMINATION PROCEDURES

As part of the SSHP, decontamination procedures (decon) should be in place before any personnel commence hazardous waste operations. The procedure needs to outline how employees and equipment will be decontaminated, and the methods used to verify decontamination (wipe sampling, direct-reading monitoring, etc.).

OTHER SAFETY AND HEALTH CONSIDERATIONS

Depending on the activities that will occur at the site, it may be necessary to include procedures relevant to those activities. For example, if there is waste burial, then requirements of OSHAs trenching and excavation standard would apply. There may also be confined space hazards, which would also need to be addressed in the SSHP.

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EMERGENCY RESPONSE AND CONTINGENCY PLAN

Emergency response planning is necessary in the event of an uncontrolled release of a hazardous substance. These incidents represent the greatest risk to personnel who respond to the release. As a result, personnel who perform any aspect of emergency response are required by OSHA to receive specialized training. A written emergency response and contingency plan is an essential part of the SSHP.

Preparation is the best method for handling a response incident. By conducting pre-emergency planning, personnel can define roles and responsibilities, lines of authority, training, and communication. This organization structure and associated procedures is generally referred to as the incident command system (ICS). This system is necessarily rigid and relies on personnel understanding the limits and responsibilities of their role within the ICS. The ICS should be compatible with the site's organizational structure.

At a minimum, names and telephone numbers of the local police, fire department, ambulance, and nearest hospital should appear in the SSHP as well as by telephones. In some cases, activities at unsecured sites may warrant keeping emergency services on standby or even onsite. Evacuation routes from the site should be determined and there should be evacuation drills conducted at least twice per year.

Success of an emergency response program requires a mutual commitment by management and employee volunteers to intense and regular training. The cost in terms of equipment, training, medical surveillance, and release time are significant. An alternative strategy would be to rely on a municipal fire department with a hazardous materials (HAZMAT) unit or a spill response contractor. However, for most sites, an internal emergency response team (ERT) made up of volunteer personnel is generally more effective since these individuals are familiar with the site and operations. Also, internal ERTs can train and conduct drills for the most probable spill scenarios specific to the site.

SITE SURROUNDINGS

Information about the surrounding area is also important for emergency contingency planning. Sources of drinking water supplies in the area, both public and private, should be noted. It may be important to find out what kind of treatment system is used by the public water supply. Likewise, information should be gathered on the local sewer and storm drain systems to determine possible infiltration or potential discharge points.

General land use around the site should be studied. It is important to note population densities and distances to residences, schools, commercial buildings,

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and any other facilities in the vicinity of the waste site that may be occupied. Locations of any flammable or explosive waste, such as liquefied natural gas, stored near the site should be determined.

Climate and Weather Conditions

Local climate and anticipated weather conditions should be factored into emergency and contingency planning as well as routine operations. Temperature extremes, especially when combined with high humidity, can predispose workers to heat stress, cold stress, and/or fatigue. When airborne contaminants may be a problem, prevailing wind patterns and velocities should be considered and included in the site safety plan. The National Weather Service is a good source for wind and weather conditions. Their number can be found in the government section of most city phone directories in the U. S. Government, Commerce Department section. A weather radio provides immediate notification of inclement weather. Also, there are weather information sites on the Internet.

INFORMATION GATHERING: ADDITIONAL SOURCES

Other sources of information about the site can be found by researching the sites history and the hazardous waste generation process and previous waste management practices of the site.

Site History

State and local environmental agencies may have valuable information regarding specific sites, disposal practices, and other technical data. They may also have permit history or other regulatory history. If the site operator has applied for a permit, the application forms may provide considerable information on waste disposal at the site and the design of the facility. Information may also be available from state inventories of surface impoundments under the Safe Drinking Water Act (SDWA) or from the *Open Dumps Inventory* conducted in the early 1980s under RCRA.

If the facility applied for a solid waste permit, a considerable amount of information may be available from state files regarding geology, hydrology, and soils. Records of site visits should also be requested. State water quality agencies may have data on ambient surface water and groundwater quality.

If limited information on wastes is available from government sources, it may still be possible to form a hypothesis on the kinds of waste present at the

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facility. Where a landfill contains both municipal and industrial wastes, much of the waste probably comes from local industries. If approximate dates of operation of the facility are known, local officials or the Chamber of Commerce may be able to provide information on industries operating locally during that time period. In the case of an on-site (at the generator's site) facility, it may be possible to determine the type of waste present. Information on the composition of waste streams associated with various industrial processes may be obtained from the *Kirk-Othmer Encyclopedia of Chemical Technology*.

Hazardous Waste Generation Process and Management Information

Knowledge of raw materials and processes used on-site that may have generated hazardous wastes or other hazardous substances will assist in anticipating what level of protective clothing, equipment, or other precautions will be required. Examples of processes include manufacturing, cleaning, physical or chemical treatment, research and development, chemical analysis, petroleum refining, wood treating, electroplating, etc. Many processes have predictable chemical species associated with their operations.

Descriptions of past and present waste management activities will assist in determining logistics, work plans, hot zones, sampling locations, etc. This information will give some idea of what to expect regarding adequacy of design, conditions of tanks and containers, pollution control devices, past releases, general housekeeping, and known hazards such as unexploded ordinance, confined spaces, or exotic chemicals. A modern operating facility will probably have abundant information available and established safety practices that must be followed, in addition to your own standard operating safety procedures. However, entering an older, poorly designed facility or an uncontrolled hazardous waste site requires more research and guesswork, and more hazard planning.

SITE CHARACTERIZATION

Information gathering can generally be conducted off-site and involves a combination of document review, records research, and interviews. Site characterization involves on-site surveys for the purpose of identifying specific site hazards and determining the appropriate safety and health control procedures needed to protect personnel from the identified hazards. Prior to entry you will want to know the location and approximate size of the site, a description of the response activity and/or the job task to be performed, and duration of the planned work activity.

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If this is the first time visiting an uncontrolled hazardous waste site, a preliminary evaluation will need to be performed prior to site entry in order to select appropriate personal protective equipment. Immediately after initial site entry, a more detailed evaluation of the site's specific characteristics is performed to further identify existing site hazards and to verify PPE selection and engineering controls for any tasks that need to be performed.

While at the site, it is important to use the information that you gathered to identify and evaluate health and safety hazards at the site. Note all conditions that may pose an inhalation or skin absorption, or other hazard. Examples of such hazards include confined spaces, storage of explosive or flammable liquids, visibly damaged or corroded storage containers, any containers with distorted shapes, visible vapor clouds, or areas where there are biological indicators such as dead animals or vegetation.

PERSONAL PROTECTIVE EQUIPMENT (PPE)

Selection of PPE should be based on the results of the preliminary site evaluation and must be used during the initial site entry. If the preliminary site evaluation does not produce sufficient information to identify the hazards or suspected hazards of the site an ensemble providing equivalent to Level B PPE shall be provided as minimum protection, and direct-reading instruments shall be used as appropriate for identifying IDLH conditions. Please refer to Chapter 9, Personal Protective Equipment, for a more detailed discussion of this topic.

Initial Monitoring

As part of the site characterization process, it will be necessary to conduct initial monitoring. There are a number of ways to evaluate and measure health and safety hazards. Direct-reading instruments can detect and give instantaneous results of atmospheric conditions and concentration of air contaminants. Initial monitoring should utilize appropriate direct-reading instruments for measurement of ionizing radiation, combustible gases, oxygen deficiency, and toxic substances. Some direct-reading instruments of choice include the multigas meter, photoionization detector (PID) unit, radiation meter, and detector tubes to test for specific known contaminants. Potential air contaminants/hazards can include:

- Ionizing radiation;
- Organic vapors;
- Corrosive gases, vapors, and mists;

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- Poisons;
- Combustible gases and vapors;
- Oxygen deficiency; and
- Toxic dusts and fumes (asbestos, lead, etc.).

The purpose of initial monitoring is to determine the extent of health and safety hazards at the site.

Exposure Limits for Protection of Health

Air contaminant concentrations are evaluated by comparing their concentration against a regulated limit or some recommended value. OSHA regulates air contaminant exposure by assigning permissible exposure limits (PELs). Each year the American Governmental Conference of Industrial Hygienists (ACGIH) issues recommended limits for common occupational air contaminants called Threshold Limit Values (TLVs). Unlike OSHA PELs, TLVs are not legally mandated. The TLVs are generally more protective since these values are reviewed annually and adjusted to reflect current research findings.

An air contaminant exposure limit is based on a length of time that most healthy individuals may be repeatedly exposed, day after day, without adverse effect. In occupational settings, an 8-hour exposure period coincides with most work shifts. Therefore, PELs and TLVs are based on an average exposure concentration over an 8-hour period, or 8-hour *Time-Weighted Average (TWA)*. This average is calculated as follows

$$TWA_{8hr} = [(C_1T_1 + C_2T_2 + C_nT_n)/\text{Total Time})]$$

C = Concentration
T = Time

Depending on the acute effects of exposure, some compounds have ceiling and short-term exposure limits (STELs). A *ceiling limit* is a concentration that cannot be exceeded during any part of the work shift.

A *STEL* refers to a time-weighted average that is based on a 15-minute exposure period.

Air contaminant concentrations that are immediately dangerous to life and health are called *IDLH* conditions. Unlike PELs, exposure to IDLH concentrations will result in death or serious illness or injury.

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AIR CONTAMINANT LIMITS FOR SAFETY

Air contaminant concentrations greater than IDLH limits usually have safety implications such as fire and explosion hazards. For example, concentrations that are within the explosive range (LEL-UEL) are clearly a health hazard and can also be readily ignited.

In order to evaluate atmospheric conditions, it is necessary to measure the following parameters:

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AIR QUALITY PARAMETER	NORMAL CONCENTRATION	ACCEPTABLE METER READINGS	IDLH CONDITIONS
Oxygen (%)	20.8%	19.5 - 24%	<16%
Carbon Monoxide (ppm)	< 5 ppm	< 35 ppm	1200 ppm
Hydrogen Sulfide (ppm)	< 1 ppm	<10 ppm	100 ppm
Organics (ppm)	< 1 ppm	varies, depending on toxicity	varies, depending on toxicity
Combustible gases or vapors	nondetectable	<1%	>10% LEL

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DIRECT-READING INSTRUMENTS

The following discussion of direct-reading equipment is not comprehensive, but it does include some of the more common categories. The selection of equipment based on factors such as portability, sturdiness, simplicity of use, and cost.

Combustible Gas Indicator (Explosimeter or Hot-Wire Indicator)

This device is used to detect explosive or combustible gases in the air. The principle of operation is based on the measurement of heat released when a combustible gas or vapor is burned. Most meters contain a battery-operated electrical circuit. Air being sampled is passed over filaments that have been brought to a high temperature. If the air contains a combustible gas or vapor, the heated filaments cause combustion. The meter measures the amount of heat that is released and then converts this data to a percentage of the LEL.

All combustible gas meters require a brief initial warm-up period so that the battery can heat the filaments. Before conducting any sampling, it is necessary to inspect and calibrate the instrument to verify that it is functioning properly. This procedure must always be done in a clean-air area. First, check the battery charge. Do not use a meter that indicates a low battery charge. Follow the manufacturer's operation manual to calibrate the meter. Generally, a test gas of methane in air is used to calibrate the meter.

Oxygen Meters

The concentration of oxygen in the atmosphere is measured as a percentage. Readings between 19.5 and 23% are generally considered to be acceptable. Oxygen-deficient atmospheres are always a potential hazard when it is necessary to enter confined spaces or other areas of limited ventilation. Oxygen sensors operate by a number of mechanisms. One common principle of operation is the use of a galvanic cell sensor unit. The cell contains one gold electrode and one lead electrode in an electrolyte, and is encapsulated in inert fluorocarbon plastic. As oxygen diffuses through the plastic, it initiates a redox reaction, which generates a minute electrical current. The meter converts this current to a percentage that is proportional to the partial pressure of oxygen.

Multigas Meters

In recent years, manufacturers have been combining multiple sensors into one instrument. It is now common to find meters that will measure several parameters such as combustible gas, oxygen, carbon monoxide, and hydrogen sulfide.

Photoionization Detectors (PID)

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For measurement of organic and halogenated solvents, a PID unit is used to determine air concentrations of mixtures and/or unknown solvents. This meter measures concentration by ionizing an air contaminant using ultraviolet (UV) light. The degree of ionization is converted to a reading in parts per million. The accuracy of these instruments vary widely unless they are properly calibrated.

Colorimetric-Type Devices (Detector Tubes)

Air contaminant concentration is determined by pulling air through a small diameter glass tube that contains a sorbent that reacts to the contaminant by changing color. The amount of stain is proportional to the air concentration of the compound, generally within an accuracy of +/-25%. This method of sampling is ideal for spot checks of known substances. Sensidyne® GASTEC has a useful handbook that provides analytical information about each of their detector tubes. *Drager*, another major manufacturer of detector tubes and chemical sensing technology, also provides similar documentation for their detector tubes.

For corrosive hazards, pH paper can be used to assess liquids and container surfaces.

Ionizing Radiation

For initial screening, ionizing radiation can be measured using a Geiger-Mueller (G-M) meter. Other methods for personal monitoring include film badges and dosimeters. The level of radiation detected will depend on primarily the radioactive source and your distance to that source. Distance and shielding is the best exposure control strategy for ionizing radiation.

The main advantage of all of these measurement methods is that they provide immediate results and the equipment is portable and relatively easy to use. The disadvantage is that all of these devices need to be used by someone who is knowledgeable about monitoring procedures as well as the limitations of the monitoring equipment, and the potential conditions at the site.

Warning Properties: Odor Thresholds

Some compounds such as acetone and ammonia give off a distinct vapor odor. This odor can be used to detect the presence of certain air contaminants. Compounds that can be detected by odor at concentrations below the PEL are said to have good warning properties. For example, the PEL for ammonia is 50 ppm while the threshold concentration at which most individuals can detect an odor is 5.2 ppm. Odor threshold is an important characteristic and consideration when deciding on respiratory protection.

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Risk Identification

Once the presence and concentrations of specific hazardous substances and health hazards have been established, the risks associated with these substances will need to be assessed. Risks to consider include:

- Exposures exceeding safe limits (TLVs, PELs, STELs, ceiling values, and IDLH);
- Potential skin absorption and irritation sources;
- Potential eye irritation sources;
- Explosion sensitivity and flammability ranges;
- Radiation dose; and
- Oxygen deficiency.

REMOTE SENSING DATA

Remote sensing is the process of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation. Examples of remote sensing data include aerial photography and thermal infrared imagery. The use of remote sensing can provide the following information:

- Location of possible hazards to inspectors;
- Approximate volumes of solid and liquid waste disposal;
- Illegal or unauthorized dumping;
- Visible environmental effects from spills, surface runoff atterns, surface leachate flow, impoundment leakage, and damaged or stressed vegetation around disposal sites;
- Geological features at ground surface such as faults or fractures on or near the site;
- Container and tank storage locations;
- Disposal areas not visible or accessible from the ground;
- Facility configuration, boundaries, design, and operation; and
- Historical and present land use of the site and its surroundings.

Archival photography can be invaluable for determining the area extent and historical development of facility operations (e.g., the size and locations of old landfill cells). Usually, the requester must specify the latitude and longitude coordinates of the site when requesting photography. This information may be on file with the waste site operator or government agency.

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The U.S. government may also have topographical and other mapping information specific to the site and/or surrounding areas. The U.S. Census Bureau has as an Internet site (http://www.census.gov/ftp/pub/geo/www/tiger) that can provide users with access to a digital map database called the TIGER® system. This system provides support for the creation and maintenance of a digital geographic data base that includes complete coverage of the United States, Puerto Rico, the Virgin Islands of the United States, and other American Territories. The U.S. Geological Survey (USGS) is another agency with useful mapping information. Their Internet address at:

- http://info.er.usgs.gov/research/gis/title.html
- http://nsdi.usgs.gov/nsdi/

may also provide access to information about the physical features of the site.

HAZARDOUS MATERIALS HANDLING AND STORAGE

Material storage should be configured to isolate incompatible chemicals from each other. Hazardous substances need to be segregated by chemical class such, but not limited to, organic solvents, mineral acids, strongly alkaline (basic) compounds, compressed gases, radioactive materials, and biohazards. In addition to segregation, it is also important to note the condition of the storage area as well as the container. Hazardous waste mixtures are most problematic; if the constituents are known, it is appropriate to consider the most hazardous substance. Direct reading instruments are very useful for identifying and locating container leaks. Other considerations for reactive or flammable compounds include the following:

- Is the flammable material stored inside a building or shelter?
- Is the area adequately ventilated?
- Is the lighting and electrical system rated for flammable storage areas?
- During material transfer, are the containers properly bonded and grounded?

OSHA addresses these issues under 29 CFR 1910.106, 1910.110, and 1910.119.

The topic of hazardous material storage is too broad to be adequately addressed in this chapter. However, it is an important consideration and needs to be included in any site health and safety hazard assessment. The following section of Health and Safety Information Resources will help provide reference material concerning hazardous substance storage and compatibility. There are also Internet sites that offer information on this topic.

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HEALTH AND SAFETY INFORMATION RESOURCES

Whether you need to look up an exposure limit for a chemical substance or determine PPE requirements, having good reference sources at your finger tips is invaluable. This section discuses some useful information resources that are most relevant to safety and health aspects of hazard waste operations.

Selecting a Database

In most situations, you will want to work with summarized information. For example, a general knowledge of the physical and chemical properties of benzene will provide you with more useful information to protect yourself than, say, understanding the behavior of pi-bonds in aromatic hydrocarbons. As with any tool, selecting the right information resource makes the job a lot easier. There are several types of databases available in either electronic (CD-ROM, on-line, etc.) or in hard-copy format.

Ideally, a chemical substance reference source should include information such as:

- Physical properties (state of matter, color, vapor pressure, etc.);
- Chemical properties (reactivity data, flash point, corrosivity, etc.);
- Health effects (toxicology);
- Safety and handling;
- Spill response and clean-up methods;
- Environmental transport, fate, and effects;
- Federal air and water standards and
- CAS and DoT numbers.

Material Safety Data Sheets (MSDS) generally provide useful summary information that include most of the elements listed above. MSDS Database services such as the Canadian Center for Occupational Health and Safety (CCOHS) maintain a voluminous collection of MSDSs for chemical products in a CD-ROM format. The advantage of an electronic database, is that substances can be searched quickly and easily by product names, other product identification, manufacturer or supplier names, or any other term used in the MSDS. Also, electronic databases are updated periodically and do not occupy your entire bookcase or file cabinets. The disadvantage of electronic databases is that they require computer equipment and a general knowledge of computer use.

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Electronic Databases and Resources

If you have a computer, modem, and access to the Internet, there are several on-line services and web sites that are worth exploring. The National Library of Medicine (NLM) is an excellent source. The NLMs Hazardous Substances Data Bank (HSDB) has compiled information in areas such as chemical toxicology, emergency handling procedures, environmental fate, human exposure, detection methods, and regulatory requirements. In addition, each entry in the HSDB contains complete references for all sources utilized and is peer-reviewed. Federal agencies such as OSHA and EPA have web sites where you can go to get information on compliance assistance.

Databases are listed on the following pages. The most useful sources have been designated as major source, and other relevant sources have been categorized as minor sources. This designation is obviously subjective: as you "surf the net" to evaluate these and other resources, you will also find personal favorites that best meet your own information needs. Good luck and have fun!

FOR REFERENCE PURPOSES ONLY

MAJOR SOURCE NAME INTERNET ADDRESS ID/PASSWORD REQUIRED?	DATABASE HIGHLIGHTS	ACCESS HIGHLIGHTS
HSDB HAZARDOUS SUBSTANCES DATA BANK [NLM/TOXNET] http://www.nlm.nih.gov/pubs/factsheets/hsdbfs.html [This address gives a factsheet for HSDB, not access.] ID/Password Required? Yes	This file contains information on over 4000 chemicals consisting of substance identification, manufacturing, chemical/physical properties, Safety and Handling, Toxicity/Biomedical effects, Pharmacology, Environmental Fate/Exposure Potential, Exposure Standards and Regulations, and Monitoring and Analysis Methods. The Toxicity Effects section is divided in two subparts - human and animal data. One of the principal advantages of this source is the data is constantly being updated and each reference is peer reviewed by professionals.	• HSDB can be accessed by contacting the TOXNET computer system within MEDLARS. MEDLARS is the computer system of databases offered by NLM. • User must register by contacting NLM for a user I.D. and password and setup access through the FTS toll-free number (1-800-525-0216) or use local Telnet directly contact NLM for procedure using Procom Plus Software). On entering the TOXNET System, the user can locate HSDB from a menu by requesting a particular file "file HSDB." • An Alternate method of accessing HSDB is through "Telnet Services." This service is through the Internet address- medlars.nlm.nih.gov- but requires a "Telnet session without browser."
MEDLINE [NLM] http://nlm.nih.gov/PubMed (perform search) NLM home page - http://www.nlm.nih.gov (select "more databases" for more information on all NLM databases) ID/Password Required? No	Toxicology/Biomedical information, 1996 to date.	Recently available through Internet/PubMed
TOXLINE [NLM] http://www.nlm.nih.gov/pubs/factsheets/toxlinfs.html [Factsheet similar to HSDB but for TOXLINE] ID/Password Required? Yes	Toxline is composed of 19 subfiles and many come from the Medline TOXBIB subset.	Access is similar to HSDB procedure.

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MAJOR SOURCE NAME INTERNET ADDRESS ID/PASSWORD REQUIRED?	DATABASE HIGHLIGHTS	ACCESS HIGHLIGHTS
IRIS [EPA; through NLM/TOXNET system] http://www.nlm.nih.gov/pubs/factsheets/iris fs.html ID/Password Required? Yes	Integrated Risk Information System (IRIS). Contains information on some 500 chemicals; prepared by EPA and mounted on the TOXNET system. Information has been reviewed by EPA scientists and represents EPA consensus.	• Access through TOXNET (see HSDB)
MSDS Database on CD-ROM Canadian Centre for Occupational Health and Safety (CCOHS) http://www.ccohs.ca/ [This address gives a factsheet for the MSDS database, not access.] ID/Password Required? N/A 250 Main Street East Hamilton, Ontario, Canada L8N 1H6 1-800-668-4284 (toll-free in Canada and USA)	The MSDS database is a collection of over 88,000 Material Safety Data Sheets (MSDSs) for chemical products. It contains the complete text of MSDSs exactly as contributed directly by more than 600 manufacturers and suppliers. The MSDSs are contributed by North American sources, many from multi-national companies which market chemical products world-wide.	• DS-ROM format for MSDS database • Subscription fee required for access
TRI [EPA; through NLM/TOXNET system] http://www./nlm.nih.gov/pubs/factsheets/tri fs.html ID/Password Required? Yes	Toxic Chemical Release Inventory (TRI). Data collected by EPA and is on the TOXNET system. Data includes release of 300 chemicals into air, water, and land from specific sites.	• Access for TOXNET; need user ID password

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MINOR (SUPPLEMENTAL) SOURCE NAME INTERNET ADDRESS ID/PASSWORD REQUIRED?	DATABASE HIGHLIGHTS	ACCESS HIGHLIGHTS
CHEMID [NLM/ELHILL] http://www.nlm.nih.gov/pubs/factsheets/chemidfs.html ID/Password Required? Yes	Chemical Identification (CHEM ID). Contains registry numbers, molecular formulae, systemic names, synonyms, Medical Subject Heading (MeSH), name and fragments, lists of files where the material has been cited (locator field).	• Access via ELHILL computer system in MEDLARS by FTS toll-free number (1-800-525-0216) or TELNET directly (contact NLM)
RTECS [NIOSH; through NLM/TOXNET system] http://www.nlm.nih.gov/pubs/factsheets/rtecsfs.html ID/Password Required? Yes	Lists toxic effects of over 130,000 compounds. Some regulatory requirements and exposure levels are presented.	• Requires user ID and password for both methods.
Cancerlit http://cnetdb.nci.nih.gov/cancerlit.html ID/Password Required? Yes (if using NLM/ELHILL or FTS/Telnet)	Search retrieves references and may be printed online containing author, title, source, abstract, MeSH terms, language, publication type, year, address of study and chemical registry number.	• NCI: free through CancerNet website. • NLM/ELHILL system or FTS/TELNET: not free.
Chemical Abstracts http://info.cas.org Internet address for American Chemical Society: http://www.acs.org ID/Password Required? Yes	Regulatory data sets in the Scientific and Technical Information Network (STN). Reference files and chemical registry (RN) file are available from STN system (along with >200 other files). A registry number can be located in the RN file and crossed over to any STN bibliographic file to locate any pertinent records. Multiple files can be searched simultaneously with a RN and duplicated references removed if desired. (See Chemlist procedure)	• STN is accessed by user ID and password so costs can be processed to the user (call 1-800-753-4CAS)
Chemlist [STN; data set in STN system] http://stneasy.cas.org/html/english/help.CHEMLIST.html ID/Password Required? Yes	This file or regulator chemicals list contains information from TSCA inventory, EINECS (European Inventory of Existing Commercial Chemical Substances), Canadian/Korean/Japan plus Title III of Superfund, RCRA and other regulatory lists.	• Address in Internet describes this file and indicates telephone number to arrange usage-1-800-753-4CAS. • Direct Command Search for this file or others may be performed by http://www.stneasy.cas.org-but needs ID/password.

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MINOR (SUPPLEMENTAL) SOURCE NAME INTERNET ADDRESS ID/PASSWORD REQUIRED?	DATABASE HIGHLIGHTS	ACCESS HIGHLIGHTS
Biological Abstracts [available in either Dialog or STN systems] http://www.biosis.org/ ID/Password Required? Yes (if accessing Biosis)	Covers worldwide research in biological/biomedical sciences.	• Dialog: bluesheet describing database and how to access through Dialog can be seen on Internet or (call 1-800-334-2564) http://www.skrinfo.com/dialog/database/netscape1.1.bl0005 (This address is for the Biosis bluesheet description.) General search may be done with http://www.dialogweb.com (requires ID password.)
Government Sites: .Federal Register [GPO; through Internet] http://www.gpo.ucop.edu/dbresearch.html .OSHA; http://www.osha.gov U.S, EPA; http://www.epa.gov/ ID/Password Required? No	This Internet site allows selection of Federal Register for recent years by using keywords or phrases. The file is maintained by the University of California along with other available GPO publications. Searches are related to pending or final governmental actions.	
U.S. Department of Commerce National Technical Information Service (NTIS) (available through Dialog or STN systems) http://www.ntis.gov ID/Password Required? Yes	The Internet address describes NTIS in detail. The file is one of the principal sources for governmental documents or publications funded by the federal government.	• Access with ID/password for either Dialog or STN file. • Access to Internet address no ID/passwors required.
RTKNET http://www.rtk.net ID/Password Required? No	Right to Know database dealing with Toxic Releases; Superfund; Hazardous Wastes; and RCRA. (See file RTKNET)	

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MINOR (SUPPLEMENTAL) SOURCE NAME INTERNET ADDRESS *ID/PASSWORD REQUIRED?*	DATABASE HIGHLIGHTS	ACCESS HIGHLIGHTS
MedWeb http.//www.gen.emory.edu/MEDWEB/keyword/databases.html ID/Password Required? No	Data bases listed by Emory University Libraries can be found on the Internet.	Descriptions and instructions for accessing or searching are given for the databases dealing with Occupational Health or Public Health, etc.
EPA Libraries http://epa.gov/natlibra/liblists.html ID/Password Required? No	EPA National Library Network Program. Some 31 EPA libraries can be browsed by selecting on ecology, emissions, pollution prevention, air quality, and atmospheric sciences modeling to select references.	

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Additional Information on Accessing NLM or MEDLARS Databases:

As noted above, the National Library of Medicines (NLM) MEDLARS® databases are accessible through Telnet communications local network (Procomm Plus software) with an assigned user ID/password (obtained through NLM search assist desk). When entering the ELHILL or TOXNET computers, you can go to files in either computer and request a particular file (e.g., file Medline or file HSDB) More recently, PubMed on Internet allows free access to the Medline files but an ID and password are needed for files other than Medline. Cancerlit is also a free service. Things are changing rapidly at NLM and other databases may become free soon. The NLM phone number for additional NLM information is 1-800-638-8480; an expert can assist in routing an inquiry to the optimum source or field other questions.

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SUMMARY

This chapter discussed the safety and health aspects of information gathering, site characterization at hazardous waste sites, and information resources and databases. At the beginning of this chapter, we defined important terms such as hazardous waste and hazardous substance from a health and safety perspective. We also discussed the categories of work activities that may occur at hazardous waste sites and the importance of determining the purpose and scope of these operations as part of the initial phase of information gathering. The site safety and health plan as outlined in OSHA's HAZWOPER standard is the controlling document for conducting all hazardous waste operations. In this chapter, we briefly summarized each major section of the plan which included the following elements: organizational structure, notification requirements, comprehensive work plan, job safety analysis, employee and air monitoring, site control, decontamination procedures, emergency response and contingency plan, site surroundings, and climate and weather conditions. The site's history and previous waste generation processes were also discussed in this section as important sources of site information.

The purpose of the site characterization section was to discuss procedures and monitoring methods for identifying and evaluating the health and safety aspects at the site. This section defined terms related to air contaminant exposure assessment as well as summarizing the use of common monitoring equipment. We discussed the advantages of remote sensing technology for providing accurate mapping of the site. We also briefly discussed hazardous materials storage and segregation.

The purpose of the information resources section was to discuss databases and other sources relevant to health and safety at hazardous sites and emergency response. We identified some useful databases available electronically as well as in hard copy. The electronic databases were subjectively categorized as either a major or minor source. Major source databases provide relevant summarized information to personnel who are responsible for managing health and safety at hazardous waste sites. Databases listed under minor sites would be useful if there in a need for more detailed data. There are several hard-copy references that would be useful to have available.

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REFERENCES (Additional Sources of Hard Copy Information)

This section provides a partial list of hard copy sources of information,

1. *Chemical Hazardous Response Information System (CHRIS).* Four volume set. For sale by the Superintendent of Documents, Washington, DC (1986) (GPO# 0-169-147:QL 3).

2. *Encyclopedia of Occupational Health and Safety,* 3rd ed. Luigi Parmeggiani, ed., International Labor Office, Geneva, (1989) [Fourth edition due 1998.]

3. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Technology Innovation Office, Washington, DC. EPA-542-R-97-011, November, 1997.

4. *Kirk-Othmer Encyclopedia of Chemical Technology,* 4th ed, Multiple volume set, Kroschwitz, Jacqueline I., Exec. Ed. John Wiley & Sons, New York, (1991).

5. Lewis, Richard J., Sr. *Hazardous Chemicals Desk Reference.* 4th ed. Van Nostrand Reinhold, New York (1997).

6. *NIOSH Pocket Guide to Chemical Hazards.* U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, NIOSH, 97-140, June 1997.

7. *North American Emergency Response Guidebook.* U.S. Department of Transportation (1996). This book can be ordered through safety supply companies.

8. *Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities.* NIOSH/OSHA/USCG/EPA, DHHS, Public Health Service, Centers for Disease Control, NIOSH, DHHS (NIOSH) Publication Number 85-115 (October 1985).

9. Pohanish, Richard P. and Stanley A. Greene, eds. *Hazardous Substances Resource Guide.* Gale Research, Inc., Detroit, MI (1993).

10. Prager, Jan C. *Environmental Contaminant Reference Databook,* 3 vols. Van Nostrand Reinhold (1995).

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11. *Respirator Selection Guide 1992* 3M Occupational Health & Environmental Safety Division, St. Paul (1995).

12. Ryan, Robert P., and Theodore F. Shults, eds. *Occupational Desk Reference*. Quadrangle Research, Inc., Chapel Hill, NC (1993).

13. Sax, N. Irving, and Richard J. Lewis, Sr.. Three volume set. Sax's *Dangerous Properties of Industrial Materials*, 9th ed., New York; Van Nostrand Reinhold (1996).

14. *Standard Operating Safety Guides*, U.S. EPA, Office of Emergency and Remedial Response (June 1992).

15. *TLVs and BEIs: Threshold Limit Values for Chemical Substances and Physical Agents; Biological Exposure Indices*. American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, OH (1997).

16. Waxman, Michael F. *Hazardous Waste Site Operation: A Training Manual for Site Professionals*. John Wiley & Sons, New York (1996).

17. Wexler, Philip. *Information Resources in Toxicology*, 2nd ed. Elsevier, New York (1988).

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3

OCCUPATIONAL HEALTH AND SAFETY PROGRAMS FOR HAZARDOUS WASTE WORKERS

David L. Dahlstrom, M.S., C.I.H.
Paul W. Jonmaire, Ph.D.

INTRODUCTION

On a global basis, the generation and accumulation of hazardous wastes poses one of the most complex and expensive management control and environmental remediation tasks in history [Magnuson, 1980]. A point in case is the presently estimated 75,000 hazardous waste sites scattered throughout the United States that will require some level of remediation, to lessen the potential for harm to humans and/or the environment [Abate, Delnevo, et al. 1995].

Since the early 1970s, society's evolving recognition of the significant threats to health and the environment posed by improperly handled or disposed of hazardous wastes has resulted in the establishment of numerous governmental rules and regulations focusing on environmental controls and occupational health and safety. The implementation and enforcement of these rules and regulations by the various government entities around the world has created far-reaching effects on industrial operations, societal practices, and environmental management [NEPA, 1969]. In many respects, however, these statutes have only begun to prescribe the means and methods necessary to properly protect the employee who must investigate, handle, dispose, and control hazardous wastes [CERCLA, 1980].

Since the hazardous waste control and cleanup activities began in earnest in the 1970s, health and safety professionals from diverse industries that generate, store, transfer, remediate, and/or dispose of hazardous wastes continue to share their knowledge and lessons learned. From these collaborations, the business and technical management processes of adapting the administrative, engineering, and occupational health and safety (OHS) controls of the once traditional workplace have been focused on the means to more effectively address the varied and unique operational aspects of

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hazardous waste operations [Levine, Turpin, and Gochfeld,1991; Robinson, 1990; NIOSH, 1987]. This chapter presents the current approach to management practices and technology as applied toward the ultimate goal of insuring the continued good health and well-being of those who work with hazardous wastes. In particular, this chapter stresses the continuing need for a committed organizational management focus on OHS program effectiveness through the coordination and integration of multidisciplinary resources including: business management, finance, industrial hygiene, industrial and construction safety, environmental/occupational law, toxicology, engineering, and occupational medicine and nursing.

PROGRAM DEVELOPMENT AND IMPLEMENTATION: AN OVERVIEW

Administrative Policy and Goals of a Successful Program

For today's H&S professional, the development and successful implementation of a comprehensive Occupational Health and Safety Program that will provide protection for employees and contractors who work with hazardous wastes is a complex and interactive effort. This effort is supported primarily by a limited body of industry-specific codes and guidelines [29 CFR 1910.120, 1989]. As the starting point for such programs, the professional in the United States must develop an integrated understanding of five key, overlapping and interacting regulations that provide focus on operations involving hazardous wastes in the workplace. These five regulations are

1. Toxic Substances Control Act (TSCA);
2. Comprehensive Environmental Response, Compensation, and Liabilities Act (CERCLA);
3. Resource Conservation and Recovery Act (RCRA);
4. Superfund Amendments and Reauthorization Act (SARA); and
5. Occupational Safety and Health Act (OSHA) [Smith, 1992].

For most companies, the extent of development and implementation of the OHS program depends on the size of the facility (operating site); the number of employees involved; the types of operations being conducted; the variety of materials and potential hazards encountered at the work site; the type of business (consultant, waste transport, *cleanup* treatment, or disposal); and, most importantly is management's' overall commitment to effective health and safety systems [Levine, Turpin, and Gochfeld, 1991]. Irrespective of these variables, however, most successful OHS programs present a company policy

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on occupational safety and health that embraces certain key requirements. These requirements are

1. A formal OHS program, supported by written policies and procedures, that clearly explains and demonstrates to all employees, through orientation and training sessions and reinforced through daily work practices at all management and staff levels, a top-to-bottom commitment to OHS program goals and individual responsibilities.
2. A clear definition of OHS program performance objectives, schedule, and periodic evaluation criteria.
3. A company wide commitment to support the OHS program, that acknowledges both employee and management's responsibilities to the program.
4. A program systems approach that provides for workforce collaboration and representation from all functional levels within the organization in the setting of priorities and the implementation of OHS program objectives;
5. A clear definition of line and staff responsibilities and their reporting relationships. This is often best accomplished through the use of a functional organizational chart and associated job descriptions;
6. The requirement and procedures to periodically review the progress, accomplishments as well as the deficiencies of the OHS program [Udasin, Buckler, and Gochfeld, 1991].
7. An active quality assurance/quality control program that has the resources, authority, and responsibility to effectively review a representative cross-section of OHS program activities. [US EPA, 1989]

Just as company OHS programs vary in their respective size and scope, so do the overall goals of the program. Basically, it is imperative that the goals established for the program specifically reflect the priorities of the company with respect to employee and contractor health and safety. Further, these goals should serve as the basis or foundation for specific company policies and operating procedures, and should provide the philosophical framework for setting more specific management systems objectives. The extent to which these goals and objectives are accomplished determines the effectiveness of the OHS program, as it is evaluated over time.

Developing program goals and objectives that will result in a successful and dynamic OHS management system should not be a single-handed effort. A proactive OHS management team must solicit the assistance and frequent input of colleagues involved in industrial hygiene, safety, toxicology, engineering, regulatory compliance (legal), biostatistics, epidemiology, medical surveillance, loss control/risk management (insurance), environmental management, and

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especially the company's senior management team [Lange, Spence, and Rosato 1991].

The basic OHS program goals listed below. While not all inclusive, their implementation will help OHS professionals ensure the continued good health and well being of all employees who work routinely with hazardous waste materials.

1. *First and foremost,* maintain a safe and healthful work environment by properly placing all personnel in jobs according to individual physiological and psychological makeup, experience, and educational background.
2. Ensure program compliance with all appropriate and legal requirements as prescribed by the variously applicable federal, state, and local environmental, OHS regulations, and "standards of practice."
3. Provide sufficient and periodic training to the affected employees and contractor staff (if appropriate) in the proper application of company health and safety operating procedures and the use of associated equipment. The purpose of this training is to ensure a thorough understanding of the whys and wherefores of the job [Eisenhower, Oakes and Braunstein 1984].
4. Limit company and personal liabilities associated with hazardous waste operations by eliminating misinformation and individual negligence. This step can most easily be accomplished by keeping managers and employees alike informed of developments in such environmental and occupational laws as the Toxic Substances Control Act (TSCA), the Resource Conservation and Recovery Act (RCRA), the Occupational Safety and Health Act (OSHA), the Comprehensive Environmental Response, Compensation and Liabilities Act (CERCLA/Superfund), the Superfund Amendments of 1986 (SARA); and, the ever increasing, precedent setting cases known as "Toxic Torts" [SARA, 1996].

It is important that these goals correctly address the management priorities and current operating principles of the company. These goals must be clearly written, adhered to, and communicated frequently to all of the employees. Equally important, these selected program goals must remain current through frequent revision and update to reflect changes in related regulations or company policy and procedure.

For most organizations and OHS professionals, the first major task in developing and implementing a comprehensive OHS program is providing justification for its existence. All too frequently, the problem of absorbing the related costs of the required resources has proven to be a major obstacle to the program's success. This is especially true in the case of smaller companies, that generally turn to their trade association or a consulting firm specializing in

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health and safety to provide these services on an as-needed basis [Finch, 1977]. In any case, OHS program justification should be approached as an integration of business economics, corporate and individual liability; and the underlying responsibility of the company to its employees, its contractors, and the surrounding community [Bridge, 1979].

It is the responsibility of the OHS professional to demonstrate to corporate senior management, a sensitivity to "bottom-line" issues by implementing a "management systems" approach. This "systems" approach must present the balance between the amount of resources invested over time and the expected return on that investment (tangibles and intangibles) versus the potential and actual costs that can be attributed to, what we call, "negative" economics.

"Negative" economics refer to those costs to the company that can result from various legal liabilities pertaining to regulatory noncompliance, toxic tort litigation, or community/personal environmental damage suits. It is well documented that the settlement awards and court costs in these instances have continued to grow into the tens, if not hundreds of millions of dollars throughout the 1980s and 1990s. It has become increasingly evident that the management and technical efforts of the USEPA, USDOL-OSHA, and their state counterparts are being focused on the assurance of corporate compliance with the respective regulations through active and aggressive inspection of operating facilities and remediation activities throughout the United States. Similar efforts are apparent in the countries of the European Union, Asia, and the Pacific Rim.

Other important "negative" economic factors and/or to account for are the ancillary costs associated with public/employee/contractor injury or regulatory non-compliance suits. These company costs are those incurred due to the eventual increase in insurance premiums, property losses (third party or internal), and interruptions in production. There will be additional costs associated with labor problems that may result if the work site is perceived as being unsafe or unhealthy, and the costs associated with poor productivity due to low employee morale. Also included will be the actual and administrative costs of paying wages to injured workers who are not covered by insurance but are part of a collective bargaining agreement. Other costs that can detract from the bottom line are the costs attributable to regulatory fines and penalties; not to mention the eventual increase in OSHA/USEPA surveillance [Bridge, 1979]. Considering all these factors, it is far less costly for a company to invest in a proactive OHS program that is preventative in nature than to wait and hope an accident does not occur.

There is a growing trend today for large corporations to prescreen key venders, based on the presence and success of their own OHS programs. Many companies use extensive prequalification questionnaires with increased

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frequency to determine whether they will consider using specific contractors on their sites. These prequalifying questionnaires usually include topics covering:

- Corporate OHS program requirements;
- Quality assurance procedures;
- Regulatory compliance history;
- Substance abuse program;
- Employee and subcontractor training;
- Site staff qualifications;
- Hazard communications procedures;
- Workplace safety procedures;
- Site and equipment inspection programs;
- Equipment decontamination;
- Injury, illness, and accident statistics; and
- Written SOPs.

The additional investment of time and effort in scrutinizing contractor qualifications by large corporations is now a necessary part of a proactive corporate OHS program to ensure that only conscientious, safe contractors are providing services at their sites.

Regarding the responsibility of a company to its employees, its contractors, and the surrounding community, the various environmental and occupational statutes in force require the employer to provide its employees and contractor personnel with a safe and healthful workplace [OSHA, 1970].

Equally important to a company's economic health is the extent of its management efforts toward assuring that the surrounding environment and/or community is not adversely affected as a result of poor facility operations. Most companies who operate within the hazardous waste industry desire to maintain a positive community image and are sincerely interested in the well-being of their employees. Most corporate management organizations today readily recognize the kind of "negative" impacts that adverse publicity can have on the continued viability of the business of a permitted hazardous waste generator, treatment/storage/disposal facility, or cleanup company; not to mention employee efficiency, morale, and productivity. To avoid negative publicity and to maintain good employee relations, management should strive to communicate to its employees and the public the *positive* actions being taken to provide appropriate levels of health and safety protection [Eisenhower, Oakes, and Braunstein, 1984]. A sound OHS program is just such an action and can be used in a marketable fashion to demonstrate the positive and substantive commitments of the company toward protecting the employee, public health, and the environment [OSHA, 1970].

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As we have been discussing, a *total* commitment by a corporation's senior management, demonstrated through consistent management systems support and the provision of the necessary resources to the development and implementation of a comprehensive OHS program can be well justified. The proof of this justification presents itself in terms of good business economics and professional practices. This proactive approach by corporate management serves not only as an effective loss prevention measure; it provides the necessary level of protection of its workers and the surrounding community. The approach also can be shown to improve the firm's competitive posture in the marketplace for services and new employees as well as serving to further enhance the good name and asset value of the company and its shareholders.

ENCOURAGING WORKER COMMITMENT TO HEALTH AND SAFETY

Just as a total commitment by management is integral to the ultimate success of a comprehensive health and safety program, so too is the commitment of the workforce. This commitment by the workforce is dependent upon the manner in that policies are applied, and hence perceived, by the employee. To assist in creating a positive perception, it is essential to encourage employee involvement in achieving program goals and objectives [Dalton, 1980]. This can be done by incorporating into the OHS program the elements listed below. These elements will provide a solid foundation upon that a successful and effective OHS program can be built and maintained.

Creating a Work Environment That Is as Safe, Healthful, and Free From Recognizable Hazards as Possible.

Every effort must be made to provide the employee with proper and adequate training, equipment, and operating procedures with that to do his/her job safely. These efforts should be coupled with the installation of various engineering controls (e.g., positive ventilation, isolation, dust suppression) to minimize potential chemical or physical exposures. It is difficult to motivate employees to adopt safe work practices or to use protective equipment if management fails to provide an adequate work environment or fails to institute controls to protect employees from exposure to hazardous chemicals or operations.

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Ensuring That There Exists within the Program A Means For Clear and Open Communications.

The structure of the OHS program should allow employees and management alike to communicate not only problems and recommendations, but also any modifications in programs, policies, and procedures *that improve the performance of the program.* This can be best accomplished by including employee representatives, chosen by their co-workers, on the health and safety committee of the corporation. If suggestion boxes are used for purposes of communication, management must respond in a sincere, consistent, and meaningful fashion to reinforce the credibility of the program and management's commitment to it. Yet, it must be stressed, communications must be two way [Menefee, and Owens, 1988].

Establishing Both Staff And Line Responsibilities Designed To Facilitate The Fulfillment Of The Goals Of The OHS Program.

Line management must be given the direct responsibility of insuring employee health and safety and preventing needless property loss. The focus of line management should be on the fulfillment of their compliance responsibilities related to the various regulatory and OHS Program policies and procedures. The health and safety professional must be given the staff responsibility of assisting line management and the employee in fulfilling this goal.

The Goals And Objectives Of The OHS Management System Should Revolve Around The Concept Of Risk Management.

The OHS management has the ultimate responsibility of maintaining an accurate assessment of the associated health and safety risks within each work site [McCunney, 1988]. Management must develop the means of dealing with these defined risks in a reasonable, technical, and objective manner. This can be done through the determination of "acceptable risk". This determination entails the application of technically acceptable means of adequately evaluating and quantitating the level of chemical and physical hazard potential of a site; prioritizing these hazards in order of their probability to cause harm to the employees, surrounding environment, and nearby communities; and, the subsequent implementation of the appropriate administrative, engineering, and protective equipment controls in each instance to minimize the risks associated with each identified hazard [Levine, Turpin, and Gochfeld, 1991]. Even then, the risks to remediation workers may be substantially greater than the risks presented by the sites themselves [Hoskin, Leigh, and Plank, 1994]. Through

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the application of sound industrial hygiene management techniques in monitoring both the work site environment and personnel in a consistent and conscientious manner, the proper risk evaluation can be made.

Informing the Workforce of the Recognized Risks Within The Workplace.

Federal OSHA and SARA regulations, as well as those regulations of most states and localities now require compliance with the requirements of established worker and community "right-to-know" laws [29CFR1910.119, 1992]. Informing employees and the appropriate community services of the *potential* risks associated with the job to be performed and demonstrating that these risks are being minimized through proper engineering controls where possible, will encourage employee and community cooperation toward the accomplishment of the respective company's OHS program goals and objectives.

FIVE ESSENTIAL COMPONENTS OF THE HEALTH AND SAFETY PROGRAM

The specific components of an effective company OHS program are actually the bricks and mortar that solidify and structure it. Each member's role within the OHS management system should be specifically identified within the company's OHS program document. The specific authorities and responsibilities of the vice-president for health and safety, the director of H&S, any regional H&S coordinators, site safety officers, and each employee must be *clearly* delineated. The OHS management system protocols and documentation's must provide the specific practices and procedures by that each employee can be ensured of continued good health and a safe working environment. These operations protocols should specify protection through the incorporation of various administrative and engineering controls, and the use of personal protective equipment, as necessary, based on all of the hazards to be encountered in the course of the work to be performed [Hall, 1992]. These controls, instituted from the aspect of prevention, serve to minimize the potential for accidents and overt exposures to occur while maximizing the professionalism and proficiency of the employees. Of course, the degree of conscientiousness in that these components are applied will determine the structural integrity (and therefore the success) of the OHS program.

Within the hazardous waste industry, the effective implementation and management of the following program components has served to ensure the quality of the respective OHS program:

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1. A comprehensive and dynamic *Employee Health Surveillance System* designed to assess the specific hazards of the job and the workplace to be encountered by each worker;
2. A *Safety Program* consisting of specified and consistently enforced company guidelines and standard operating procedures, whose applicability and effectiveness are evaluated by periodic compliance auditing [Udasin, 1991], and the assignment of both company and site-specific OHS coordinators whose responsibility it is to ensure compliance with stated OHS Program requirements;
3. An *Industrial Hygiene Program* that has modified conventional exposure monitoring and evaluation techniques to recognize the unique setting of each hazardous waste operation conducted [Eisenhower, Oakes, and Braunstein, 1984];
4. A company *Health and Safety Advisory Committee* whose purpose is to assist the company's management in developing, maintaining and periodically evaluating a state-of-the-art health and safety program based on current technological and regulatory advances; and
5. An in-depth, hands-on *Training Program* that includes periodic refresher training on an annual basis, as a minimum [McCunney, 1988].

The remainder of this chapter discusses each of these components, except for training that is discussed in greater detail in Chapter 12.

HEALTH SURVEILLANCE SYSTEM

The health surveillance system should prescribe specific fitness criteria in conjunction with periodic medical evaluations to ensure that only physically and medically sound individuals participate in field operations involving hazardous materials. The focus of this system should be the assurance that the health status of these individuals is maintained. Therefore, the objective of this system is to detect any changes in the health status of individual workers or employee groups that might be related to the nature of the job performed and the substances with that the employee comes into contact with. In consideration of the nature and variety of chemicals (and mixtures thereof) related to hazardous wastes and the frequency for potential exposure to a variety of physical and chemical hazards, it is extremely important to provide a means by that the health of personnel who work at hazardous waste sites can be periodically assessed. Since this industry began in the 1970s, a significant number of the represented workforce are in their 40s and 50s, thus requiring OHS programs to also consider issues related to the degenerative illnesses attributable to the aging process.

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To properly monitor the health status of each employee, the specific items of data needed must first be identified [King, 1990]. It is equally important to ensure that all workers are evaluated using the same criteria for this determination [Abate, 1995]. Once the specific data needs have been identified, how this information is to be most effectively collected, collated, analyzed, used, and archived must be determined. It is essential that these steps be completed during the preplanning stages of surveillance system implementation so as to prevent the common mistake of collecting too much information (a scatter-gun approach); some or most of that will eventually prove to be unnecessary or inapplicable (e.g., annual heavy metal analysis or annual X-rays) [Enright, 1991]. Such a mistake can be costly in terms of both money, time, and materials spent. Considerable field experience over the last 20 years is now available to the OHS professional to help determine that clinical information is key to a health surveillance program versus that information has been collected and found not to be useful. Only essential pieces of data that will prove most beneficial and revealing, and respective of individual changes in health status, should be collected [Upfell, 1992]. Essential information to be collected is discussed below.

Notably, current HAZWOPER regulation does not mandate that all hazardous waste workers participate in a medical surveillance program. It is, however, in the best interest of the employer to do so. Failure to ensure that an employee is medically fit to perform work at waste sites leaves the employer vulnerable in a number of areas. If an employee working on a site is medically unfit, the employee is more likely to become ill or injured during times of stressful site activity. Depending on the reason for being unfit, the employee may lose consciousness or be unable to properly perform their assigned tasks. This could result in lost production, higher compensation premiums, poor morale, and increased regulatory scrutiny. Ensuring the employee is medically fit is the responsible route for the employer to follow.

Complete baseline data on the health status of the individual at the time of employment in order to ensure that each individual can perform their job safely [Burtan, 1991]. This should include information on:

1. Family and individual medical history;
2. Prior work history, including the types of chemicals the individual has worked with;
3. Any known individual abnormalities; personal habits, such as the use of alcohol, tobacco, or *illegal* drugs;
4. Prior surgeries, hospitalizations, and immunizations;
5. Reproductive history;

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6. Any abnormalities found during the initial pre-employment physical examination and laboratory screening; and,
7. The use of prescription and/or over-the-counter pharmaceuticals to treat existing health/physical problems.

- *Nature of the work to be performed.* This information should include types of activities to be performed, the types of personal protective equipment to be used, the types of chemicals to be encountered, exposure data as collected through site and personal monitoring, and accident data.
- *Individual identification data.* This information should include date of employment, name and social security number, date of birth, race and sex, and current address and phone number.
- *Follow-up data.* This information will include data collected during subsequent periodic (e.g., annual) physical examination and laboratory screenings.

The orderly collection of these data on a form designed with a coding scheme will permit the information to be easily collated and analyzed within a secured computer network, thereby easing the burden of OSHA required recordkeeping [Stockwell, et al. 1991]. In addition, it will ensure the confidentiality of medical records and provide for rapid access to records in case of emergency.

It cannot be overemphasized that the process by that the respective medical information is collected and analyzed be well thought out, organized, and designed to ensure its complete usefulness. It should also be recognized that the data collected must be consistent and complete. The same data points must be collected for each member of the workforce to ensure the proper program assessments on health over time. Extraneous information, not related to an employee's capability to perform in the field should not be collected or should be discarded if it is inadvertently obtained. If this is done appropriately, the relationship to work performed or exposures experienced and health status of the individual and the group can be easily and effectively correlated [Stockwell, 1991].

Access to confidential medical information must be strictly controlled and available to only authorized individuals on a "need-to-know" basis only [29 CFR 1910.20]. Development of a medical surveillance program should include identification of key team members who have access to the medical file of an individual and also should identify what type of information can and should be shared with others. For example, an employee might be undergoing chemotherapy. This may restrict the employee from certain field activities. The structure of the decision-making process within the medical program should be

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established during the initial design and implementation period that would define how a situation like this and similar situations (diabetes, hypertension, pregnancy) will be handled through communication with other management and field staff members.

At this point in this chapter, it should be clear that the development and implementation of an employee health surveillance system requires significant planning and workflow design from its inception. This preliminary work includes:

- The design of data collection forms;
- The development of a system for coding and collating data for computer input;
- The acquisition and formatting of the software application necessary to generate the desire reports and statistics;
- The design of procedures to monitor data processing, report flow, and data; and
- Storage in order to meet defined schedules and evaluation procedures [Stockwell, et al., 1991].

The medical surveillance management system also requires that a specific individual be designated as being responsible for coordinating all of these activities. This individual may either be a company employee, such as the corporate medical or health and safety director, or an occupational health consultant from outside of the company. The important factor is that a responsible, well trained and knowledgeable professional be specifically identified by the company to ensure that the medical surveillance program is properly administered, employee records are professionally assessed in a timely manner, that the respective records are maintained in a secure and confidential manner; and, that quality assurance of the system is maintained so as to provide each employee with the maximum level of health protection.

Once the requirements of data collection, collation, analysis, and retention have been determined and a responsible OHS professional identified, the components of the medical surveillance system can be defined. These components should include:

1. Each worker should be given an *initial medical examination* and their medical history assessed prior to the performance of hazardous waste site activities. This will establish each worker's medical baseline, and overall health status the ability to wear respirators as other protective equipment, and ensure that each individual is capable of undertaking the rigors of field operations. It will also aid in determining that job is best for that worker.

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2. Each worker should undergo *subsequent medical examinations* on a periodic basis (usually annually). The examination should be geared toward the worker's job classification and the chemical and physical hazards potentially encountered by each worker during the performance of their work. The parameters of this examination should be consistent with those of the initial examination and supplemented as necessary based on changing health status or work tasks, in order to ensure consistency in data evaluation.
3. An *exit examination* should be required of each individual either leaving the company or transferring to another job classification within the company not associated with a potential for exposure to hazardous materials. The results of this examination can serve to document the health status of the individual at that time.
4. The medical surveillance program plan should require the immediate and formal reporting of exposures or injuries by the affected employee and the manager in charge. The system should also provide procedures that specify the design and performance of *specific post exposure examination protocols* based on the types of chemical and or physical exposures encountered by the affected employee. A *facility or site emergency contingency plan* must include an emergency medical plan, that would include specific provisions for informing the attending physician with pertinent information regarding the affected individual, site monitoring data, and toxicological information specific to the chemical(s). The provision of this information to the attending emergency personnel and treating physician will facilitate proper and timely diagnosis and treatment. Each operating facility or work site should provide for an emergency analytical system that is capable of quickly analyzing collected samples of the chemical substances and mixtures to that an individual has been exposed so as to provide the physician and the toxicologist with the identity of these chemicals. The plan should also specify:

    procedures to ensure fetal protection to those employees who are pregnant or planning pregnancy including the provision for providing appropriate job reassignment to nonhazardous job responsibilities during the period of pregnancy and the period following delivery when breast feeding may be occurring; procedure of evaluating male and female employees to ensure their reproductive health; and procedures for the removal from relevant work site activities and responsibilities of any worker who shows a significant abnormality in their medical profile, at least until it has been determined that he or she has completely recovered and is in good enough health to resume work responsibilities [Trauth and Sorensen, 1981].

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5. Specific allowances must be made to assess the applicability and implementation of procedures designed to comply with OSHA's Americans with Disabilities Act and Bloodborne Pathogen Rule.

The implementation of such a medical surveillance management program is neither a trivial nor an impossible undertaking. It does require considerable attention and coordination in order to be successful, but the benefits to the company and its employees derived from an effectively designed and managed system, focused to be preventative in nature, are innumerable in terms of employee health, welfare, and productivity.

OCCUPATIONAL SAFETY PROGRAMS

The purpose of an occupational safety program is to protect the employee from both potential and recognized hazards of a particular work operation, whether chemical or physical in nature. Currently, the specific guidelines and uniform safety codes specific to the hazardous waste industry exist in the form of OSHA's respective Standard Industry and Construction Industry "Worker Protections Standards" (29 CFR 1910.120 and 1926.65), otherwise known as HAZWOPER, for the development and implementation of an acceptable hazardous facility/site safety programs [NIOSH, 1987].

Basically, the site/facility safety program should complement and be supported by the industrial hygiene and health surveillance systems. It must be an integral part of every aspect of site operations. Most successful facility/site safety programs, despite variations in organizational structure and technique of application, make worker safety a major priority with respect to company policy and action [Delta and Giustina, 1989]. This attitude of both company and site management, if demonstrated in a consistent and sincere manner, lends credibility to the program, encourages employee cooperation and support, and most importantly, minimizes the frequency and severity of accidents.

The critical elements of a successful occupational safety program are:

1. Significant employee involvement in the development and implementation of operational procedures [Menefee and Owens, 1988];
2. Openly demonstrated and consistently applied management support and leadership;
3. Assignment of responsibilities to specific persons within the corporate, divisional, and facility structures whose role it is to ensure compliance and employee understanding of company policies and procedures (e.g., OHS program director/manager);

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4. Development and implementation of standard operating procedures covering all aspects of the work to be performed;
5. A personal protective equipment program that defines the decision-logic to be used when performing a hazard evaluation necessary to ensure that proper respiratory and dermal equipment is provided and also provides for its proper use and maintenance [29 CFR1910.132];
6. An occupational safety communications management system that provides for the dissemination of explicit information to all employees regarding hazard identification, policy and procedural changes, and lessons learned ;
7. A comprehensive training program that provides for periodic classroom and hands-on training of the employee in the proper use of equipment, operational techniques, and company policy [2 9CFR1926.59];
8. An accident and exposure record and investigation program that not only will satisfy all legal requirements, but also will help prevent a similar reoccurrence [U.S. EPA, 1992];
9. An effective audit program to ensure consistent application of operational procedures and evaluate their effectiveness [Enright and Scanlon, 1991]; and
10. The maintenance of safe working conditions.

Many of these elements are self-explanatory and require no further discussion. The remaining elements are discussed in greater detail in subsequent chapters. It should be kept in mind, however, that the role played by the OHS professional in employee training often determines the effectiveness of the other elements and deserves further consideration in this chapter.

The importance of ensuring that the OHS program maintains a high level of visibility has already been alluded to. It therefore becomes the role of the local OHS coordinator, in concert with a consistent demonstration of management's unquestioned commitment to the program, to ensure this visibility at all levels within the organizational structure. All individuals involved in safety coordination, from the OHS program director of the company to the site safety coordinator, have the responsibility of ensuring the complete and total compliance by each employee with all of the requirements, policies, and procedures of the OHS program. OHS coordinators must develop, implement, and evaluate the effectiveness of site-specific safety plans, operational procedures, equipment usage, and employee performance within the work setting. In cooperation with the industrial hygienist and the engineer, the OHS coordinator must ensure the application of proper site and personal monitoring techniques so as to provide the employee with pertinent information regarding site hazards and the proper selection of appropriate protective equipment [Robison, 1990]. In this way, accidents can be prevented, thereby protecting the health and welfare of the employee and the surrounding public.

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In the event of an accident, the OHS coordinator must investigate the occurrence and prescribe preventative measures to preclude reoccurrence, and should maintain records of all accidents on-site to determine accident trends. Such records are required by OSHA and, no doubt, company management. Further, the OHS coordinator must strive to instill among employees a high degree of safety consciousness through ensuring employee participation, communication, and education.

To ensure that all employees are prepared to safely participate in all facets of waste site operations, a series of specific and specialized training programs must be established as an integral part of the overall health and safety program. These programs should include training the employee in a classroom setting as well as in a practical setting to allow hands-on experience. Periodic refresher courses are also important [RCRA, 1976].

Prior to performing work on-site, each employee should undergo training in a classroom setting. This training should provide the new employee with information regarding

1. Company policies and procedures;
2. Health and safety requirements;
3. Basic toxicology and chemistry of materials commonly encountered on waste sites;
4. The selection, use, and limitations of the various respirators and dermal protective equipment;
5. Techniques used in the decontamination of personnel and equipment;
6. Sampling techniques;
7. Legal requirements under "Superfund," OSHA and RCRA;
8. Heavy equipment operation (if applicable);
9. The health effects of heat and cold; and
10. Emergency procedures, including multimedia first aid and cardiopulmonary resuscitation.

Upon completion of the in-depth classroom training, each employee should be given the opportunity to gain actual hands-on experience in a field setting, under the watchful guidance of an experienced mentor, where the worker learns to put classroom concepts into practice. This experience will allow each employee to gain confidence in themselves as well as the equipment and procedures upon that they ultimately must rely. Moreover, this type of training builds on the "team" concept that is so important during work on hazardous waste sites.

Refresher training should be provided annually as a minimum [29 CFR 1910.1200, 1989]. The purpose of this training is to keep the employee informed of new techniques, policies, and procedures as well as to improve

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upon skills previously learned. The frequency and setting of refresher training will vary depending on the diversity of job settings and each employee's ability to assimilate the training provided.

The application of the elements presented earlier, in conjunction with consistent management support, will serve to maximize the employee's proficiency and professionalism in conducting work operations at hazardous waste sites.

SITE-SPECIFIC HEALTH AND SAFETY PLAN - INDUSTRIAL HYGIENE PRACTICES

During the performance of investigation and cleanup activities at hazardous waste sites, the primary objective is to minimize potential health hazards to site workers and the surrounding general public. To achieve this, a site safety plan providing specific standard operating procedures must be developed [29 CFR 1910.120, 1989]. An effective site safety plan should address several key operational areas including: the identification of key personnel; task-specific health and safety risk analysis, job-specific training requirements, activity-specific personal protective equipment, worker medical surveillance requirements, environmental and job-specific monitoring requirements, site control procedures, worker and equipment decontamination procedures, emergency contingency planning, hazard communications, safe equipment operations, trenching, excavation, and fall protection requirements. These a can be grouped into three aspects of assessment and implementation: *identification* of substances and work activities on-site and the hazard they represent; *evaluation* of the chemical and physical risks associated with those substances and operations; and *control* of their potential impact on site personnel.

Identifying and evaluating hazardous substances and related physical activities generally involves reviewing historical and monitoring data obtained during the performance of a preliminary assessment of site conditions. These data may include information obtained from waste manifests or facility records, initial site visits, and the results of off-site air monitoring and off-site drainage or leachate samples. Data from the identification and evaluation process provide the basis for evaluating possible physical and chemical exposure risks and determining measures to control potential impacts of exposure. These include ambient and personal monitoring, the proper selection and use of a variety of personal protective equipment, medical surveillance, safety training, and contingency planning. Proper consideration of these health and safety issues, including the provision for a peer review and sign-off approval by an experienced senior health and safety staff, prior to on-site

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activity, will result in more effective site operations [Eisenhower, 1984]. Appendix F contains a Table of Contents safety plan for an example site-specific health and safety plan.

The words identification, evaluation, and control in the preceding paragraph define the classic role of the industrial hygienist who, in conjunction with the OHS coordinator and toxicologist, is responsible for assisting in protecting the worker and the general public from the hazards encountered at hazardous waste sites.

The health and safety of the worker and the public should be of primary concern in all phases of investigative and remedial activity at hazardous waste sites, from the most routine site survey involving air, water, soil, or waste sample collection to the most complex site excavation or waste treatment schemes. Therefore, the scope and sophistication of the investigation activity, plus the level of on-site effort, largely dictate the breadth of the industrial hygiene services necessary [Robinson, 1990].

Effective implementation requires application of realistic protocols for hazard recognition, evaluation, and control, tied closely to the risks associated with the hazard potential posed by the site. *The potential risks associated with working in the hazardous waste industry are often much different from working in a traditional workplace since the worker has the potential to be exposed to many different materials under a variety of environmental conditions.* These risk evaluations can vary daily or more often as a project progresses: workers will move to new locations on-site that will result in changes in their proximity in relation to contaminated zones, and/or modification of work practices. As a result, the industrial hygiene and safety monitoring performed during investigative and remedial work at a hazardous waste site differs from conventional industrial hygiene and safety activities in several ways, including: (1) the varied scope of safety and health concerns involved in such an effort; (2) the need for real-time as well as time-integrated analytical data; (3) the dual focus (occupational and community) of the air monitoring program; (4) the unique, multimedia, continuously changing and often unknown, and difficult to quantify composition of the chemical contaminants and , (5) the adaptation of traditional monitoring and sample collection instrumentation to the specific field setting [Robinson, 1990].

It therefore becomes the role of the industrial hygienist to provide continued input during site operations to ensure operations are conducted safely. Early coordination during project planning is essential to integrate safety and industrial hygiene procedures into the operational aspects of the work plan. The industrial hygienist assists the OHS coordinator in developing a site specific health and safety plan that is specifically tailored to the level of effort and the hazards associated with the work. (This occurs only after a comprehensive data review of background information and relevant

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toxicological data has been conducted, and the conceptual operations plan that defines the scope of work has been clarified.) The criteria used in the selection of the appropriate scope of the industrial hygiene and safety field protocols prescribed in the safety plan include toxicity-related factors and exposure potential factors [Halley, 1980]. Each of these factors should be defined and considered in conjunction with each of the other factors so as to best characterize the site in a comprehensive manner.

Toxicity-Related Factors	Exposure Potential Factors
• Absence of chemical/background data	Job function
• Chemical agents	Job function
• Concentrations (background, episodic)	Proximity to zones of contamination
• Dose-response relationships potential	Accident-major release potential
• Physiologic/synergistic consequences	Level of activity
• TLV's ceiling limits, stels	Physical properties of the agents
• Odor thresholds	Frequency of exposure
• Percutaneous characteristics	Route of exposure
• Carcinogenic/mutagenic/teratogenic properties and characteristics	Atmospheric dispersion and weather conditions
• Synergy of site contaminants	Physical surroundings (inside and outside)
• Hazardous site operations (excavation, trenching, fall protection, etc.)	Job function

In addition to these risk assessment factors, the practical concerns of instrument limitations and sensitivity, sampling frequency and duration, and logistical implementation of the protocols will influence the overall focus and effectiveness of the industrial hygiene and safety program developed for each site.

As the investigation and eventual cleanup of the hazardous waste site progresses, the role of the industrial hygienist expands to address the various objectives of site operations. These objectives include:

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1. The upgrading and downgrading of the levels of dermal and respiratory protection on the basis of the physical hazards and the chemical contaminants encountered and their concentrations within the worker's breathing zone;
2. Documentation of ambient air and emission episodes for recordkeeping and information planning purposes;
3. On-site sample characterization using real-time portable gas chromatographs, photoionization, and infrared devices for the purposes of providing a periodic survey of chemical levels and to prescreen samples so as to reduce the analytical loads or to more accurately identify constituents on a real-time basis;
4. Monitoring of on-site personnel both for potential chemical overexposure and the effects of heat or cold stress or fatigue, noise, or ionizing and nonionizing radiation exposure;
5. The specification of engineering, administrative, or personal protective controls to mitigate any unacceptable hazards; and
6. Recommending corrective actions and subsequently evaluating their effectiveness to prevent exposures to on-site or off-site locations beyond the predetermined action levels designed to protect worker or public health.

Generally, separate instruments or monitoring procedures must be used to address each of these objectives because of the variable locations or time frames in that the data are needed [Levine, 1990].

In summary, the aspects of health surveillance, industrial hygiene, and safety must be integrated into a single program. The activities of each should serve to interrelate and support each other. Therefore, it is imperative to the success of the overall program that the roles and responsibilities of individuals in each of these areas be closely integrated.

QUALITY ASSURANCE

The importance of having a thorough quality assurance management program cannot be over emphasized. Experience and common sense have taught us that bad habits can develop, almost imperceptibly, and in some cases these may result in serious damage to the health and well-being of employees or interrupt the smooth operation of site activities. Each aspect of the health and safety program should be evaluated to determine how quality assurance principles can be applied. A written quality assurance program should then be developed and implemented.

The basic principles of quality assurance should be applied to the H&S program similarly to other types of activities. The objectives of the quality

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assurance program should be identified and agreed to by the key parties. The operations should be reviewed in light of the identified objectives. A plan should be put into place to achieve these objectives. The plan should include methods to achieve the objectives and responsibilities of the involved parties from the top to the bottom of the organization. Resources needed to implement the program, including manpower, budget, and relationship to line functions need to be defined. Standards by that the success or failure of the program can be measured are sometimes readily quantifiable (e.g. lost time accidents) other times they are not. Examples of benefits of a quality assurance program that are difficult to measure include high employee morale because they sense a sincere concern for their health and well-being, client confidence that they are dealing with a professional organization, and the OSHA citation that did NOT occur. Program reviews are a key component to implementation of a quality assurance program. Field and office audits are major tools of the quality assurance review procedures. They should be well-planned activities performed by knowledgeable individuals. Audits need to be sold as sincere attempts to maintain and improve the quality of the health and safety program. They are not meant to be an exercise in finger pointing. Audits should be done on a local basis by first or second level H&S personnel. This provides frequent immediate feedback and opportunities to catch small things quickly. Audits should also be considered a "corporate" function whereby the audit is performed by representatives outside the local organization. This helps add credibility to this activity and sends a message that upper-level management has genuine concern for their local staff. Lessons learned at one location can then be shared across the corporation and corrective actions taken wherever needed. The results of audits are important for the implementation of quality improvement activities. These activities are the normal course of doing business.

Lessons learned from the audits are but one of the factors that must be considered in updating the health and safety quality assurance program. There are other factors to be considered. Since health and safety is not a static field, equipment, regulations, the corporate experience base and operating procedures are ever-changing. Regular updating of these components of a quality assurance program is also called for. Peer review of policies, operating procedures, and documentation also should be considered as part of the quality assurance program updating procedures (Arter, 1989).

STAFFING AND ORGANIZATION

Size and Qualifications of Health and Safety Staff

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The size and organization of a health and safety staff of a company will depend on the size of the company; the types of jobs and the variety of hazards inherent in performing these jobs; and the amount of resources available for salaries, equipment, and consultant services. Generally, the larger the company, the greater the need to develop in-house health and safety capabilities. Many companies find it more practical and cost-effective initially to hire a consulting service during the preliminary stages of its OHS program development. A consulting company may also be needed for additional support during the various stages of program implementation and for assistance with specific problems that may occur once the program becomes operational. Once the OHS program is running smoothly, however, the use of consultants is generally relegated to those situations where their services simply augment rather than substitute for in-house capabilities.

As mentioned previously, the OHS program staff is generally composed of trained and experienced individuals from the fields of medicine, industrial hygiene, toxicology, engineering, and safety. The number of individuals within an organization possessing these capabilities will depend upon the size and needs of the company. Due to the current demands for such trained and experienced individuals, their recruitment may be difficult, if not initially overwhelming. Many companies therefore attempt to train existing staff members in some of these areas through the use of short courses or through company programs for degree level studies.

At a minimum, the OHS staff should include access to a board certified occupational physician (full time or consultant), a company OHS director, an industrial hygienist, a toxicologist (full time or consultant), a safety specialist, and an equipment manager. The role of the occupational physician, who may either be a full time employee in the case of a large company, or more commonly, a physician from a nearby hospital specializing in occupational medicine, is to provide the necessary examination and emergency services as well as to assist in the continued development of a sound health surveillance program.

The OHS director is responsible for the overall coordination and operation of the complete program. This individual generally reports directly to the company vice president in charge of environmental affairs and remains outside the regular management chain of command. He or she must understand the goals and objectives of the company and be able to develop and implement the necessary programs to achieve them. It is especially important that the director be given the authority to implement programs and procedures, to acquire the necessary funding and to make expenditures to maintain the program, and to delegate responsibilities to other personnel through their supervisors. The director must be familiar with the procedures and materials regarding all

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workplace operations and possess the knowledge to assess them properly based upon the principles of occupational safety and health.

The OHS director will usually be responsible for supervising a staff of industrial hygienists and safety professionals whose composition again is dependent upon the needs and the size of the company. These professionals obviously should be well trained and experienced, and must be thoroughly familiar with the types of operations being conducted on hazardous waste sites. Their roles within the company will be to fulfill the specific objectives of insuring worker health and safety at particular waste sites and to coordinate with and support the efforts of the OHS director. Generally, larger companies will hire separate individuals to fill these positions, while small companies will commonly rely upon individuals who possess these dual capabilities.

Obviously, a certain number of support staff will be necessary to assist the health and safety staff in the day-to-day operation of the program. Primarily, clerical staff can fill this gap as well as assist in program communications and budgeting.

Budget

The OHS director is usually made responsible for the preparation of the budget for these activities, receiving assistance from the accounting and clerical staffs. In order to develop a realistic budget that is adequate to meet the needs of the program yet still within the financial bounds allowed for by management, the costs related to specific services and activities must be identified. Generally, these costs are related to the following items [Gallagher, 1981]:

Labor

- Salaries - professional, clerical, and consultant;
- Social security payments;
- Unemployment and disability insurance taxes; and
- Fringe benefits.

Special training programs

- Classroom; and
- Hands-on refresher.

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Materials

- Capital expenditures - industrial hygiene, laboratory and safety equipment, supplies, and uniforms;
- Office supplies - desks, chairs, typewriters, computers, etc.;
- Replacement of expendable items; and
- Depreciation of equipment and repairs.

Overhead

- Rent, lights, heat, gas, water, ventilation;
- Telephone, postage, freight;
- Fire and theft insurance;
- Repairs, alterations, maintenance, calibration;
- Laboratory services;
- Liability insurance;
- Medical, toxicological, and industrial hygiene computer information services;
- Health surveillance examinations - initial, annual, post-exposure, and exit;
- Emergency care services; and
- Health and safety and other employee and advisory committees.

Contingency fund

- Petty cash.

Miscellaneous

- Travel, including transportation, lodging and meals;
- Professional journal and textbooks; and
- Special educational and professional advancement training.

Other factors to consider in preparing a budget may include

- The need for new safety and health equipment to allow for better and more efficient monitoring of the employees and the workplace;
- The addition of new health maintenance programs as technology advances;
- The addition of medical and associated services as operations expand to new geographic areas; and
- The addition of new personnel as the company expands.

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Due to the differences in methods of cost accounting, it is difficult if not impossible to quantify the average cost of a health and safety program for all companies within the hazardous waste industry. One company may charge the cost of certain overhead items to the health and safety department, while other companies will exclude these same items from operating costs. Therefore, how a company handles its bookkeeping items will influence the cost of the program. Generally, however, it is assumed that of the budget needed to operate a health and safety program, no more than 2.5 percent would be devoted to health and safety staff functions, while no more than 2.0 percent of the budget would be devoted to the various live organization functions, including the needed training time.

One final word is that it is important to recognize that since the OHS program is generally not a revenue producing operation, it will be easy for management to slight its budget when finances get tight. However, the benefits of a preventative health and safety program will lead to

- Increased employee productivity and efficiency;
- Reduced absenteeism and illness;
- Reduced workmen's compensation rates;
- Reduced insurance premiums;
- Reduced injury, severity, and frequency rates;
- Reduced legal liabilities;
- Improved employee morale and involvement; and
- Increased access to clients who mandate high quality OHS programs from their vendors.

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4

TOXICOLOGY AND RISK ASSESSMENT

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INTRODUCTION

Toxicology is the study of the harmful effects of substances on living organisms. Humankind has long known that there were harmful as well as beneficial consequences associated with taking materials into his/her body. Those materials that cause damage have been labeled poisons and are the subject matter of toxicology. Foreign substances not normally found in the body are called "xenobiotics," and almost any xenobiotic may be poisonous at a high enough dose [Ottoboni, 1984]. This chapter can only cover some basic principles of toxicology, and major references include [Ariens, 1976] as well as the 13 volume *Comprehensive Toxicology* [Sipes, et al., 1997].

The term "poison" is derived from a Greek word referring to the substance in which arrows were dipped. Industrial hazards or poisons have also been long identified. Clinical symptoms of lead poisoning were accurately described in 1st century a.d. literature regarding mining operations. French hatters of the 17th century discovered that mercuric nitrate aided greatly in the felting of fur, but such use led to chronic mercury poisoning so widespread among members of that trade that the expression "mad as a hatter" entered our folk language.

Our present day society is both chemically exposed and chemically dependent. The contemporary emphasis is placed not only on threats to humans, but also on threats to the environment, natural ecosystems, and the biosphere as a whole. The tremendous increase in the world population, industrial development, and urbanization has a strong influence on this aspect of toxicology. The urbanization of peoples has been accompanied by a strong demand for greater quantities of foodstuffs and industrial products and for an ever increasing standard of living. Production as well as consumption of energy produces large quantities and varieties of waste products, many of them highly toxic [Ariens, 1976].

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The intent of this chapter is to examine the methods of environmental toxicology as they may impact the health and safety of workers at hazardous waste sites.

DOSE-RESPONSE RELATIONSHIP

Toxicology or at least the murderous use of poisons has played a prominent role in society and politics [Gallo, 1996]. A significant contributor to the Age of Enlightenment, the physician Paracelsus (1493-1541) wrote: "No substance is a poison by itself, the right dose differentiates a poison from a remedy." Thus, the most important factor that determines the potential harmfulness or safeness of a compound is the relationship between the concentration of the chemical and its intrinsic toxicity to biological systems [Loomis, 1968].

Of the many thousands of chemical compounds known only a small fraction have been tested for their relative or specific toxicity. Depending on the compound, they may be tested by various routes (see below), in various formulations, and at various doses. Treatment can range from acute (single dose) to lifetime (e.g., 2-year feeding study in rodents).

In preliminary toxicity testing, death of the animals has been the response most commonly measured. Given a compound with no known toxicity data, the initial step is range finding. A dose is administered and, depending on the outcome, is increased or decreased until a critical range is found over which, at the upper end, all animals die and, at the lower end, all animals survive. Between these extremes is the range in which the toxicologist accumulates data necessary to describe the dose-response curve relating percent mortality to dose administered. The dose-response curve (Figure 4-1) has three features. It usually begins flat (below the threshold), then at some point (threshold), it begins to rise steadily from the baseline, and finally it reaches a plateau (maximal response), above which no further harm can occur (i.e., all animals have died or the maximal pathophysiologic response has occurred). With few exceptions it takes on the familiar exponential or sigmoid shape.

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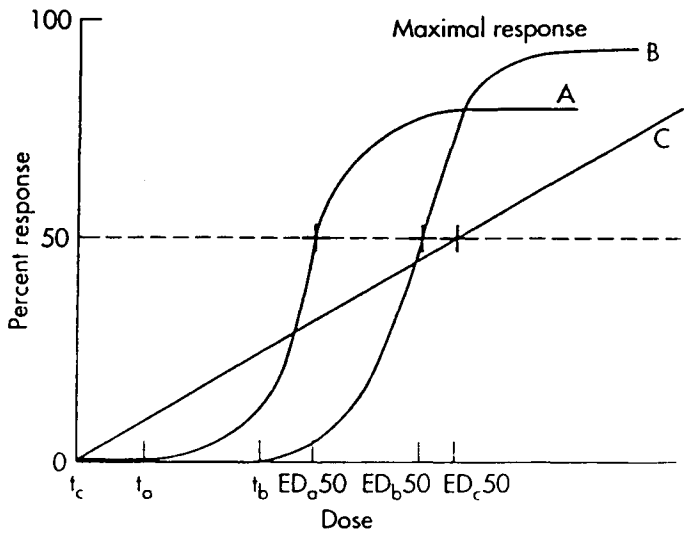


Figure 4-1. Typical dose-response curves. A and B are typical sigmoid curves differing in potency and efficacy. C is a linear, no-threshold curve presumed to be characteristic of the causation of cancer by ionizing radiation. B has a higher threshold, but also higher efficacy than A. Thresholds, indicated by "t", ED50s, and maximal response are indicated for each curve. (Courtesy Environmental and Occupational Health Sciences Institute).

From the dose-response curve, the dose that will produce death in 50 percent of the animals may be calculated. This value is commonly abbreviated as LD_{50}. It is a statistically obtained value representing the best estimation that can be made from the experimental data at hand. The dose is expressed as amount per unit of body weight. The species of experimental animal and the route of administration must be specified, as well as the vehicle used to dissolve or suspend the material, and the time period over which the animals were observed.

For example, a publication might state "For rats, the 24hr. ip LD_{50} for compound X in corn oil was 66 mg/kg (95 percent confidence limits 59-74)." This would indicate to the reader that the material was given to rats as an intraperitoneal (ip) injection of compound X dissolved or suspended in corn oil and that the investigator had counted the number of dead animals 24 hours after administering the compound. It does not mean that the dose of 66 mg/kg

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was actually used, rather this value was extrapolated from mortality at the doses actually use (for example, 0, 10, and 100 mg/kg).

If the experiment has involved inhalation as the route of exposure, the dose to the animals is expressed as parts per million, mg/m^3, or some other appropriate expression of concentration of the material in the air of the exposure chamber, and the length of exposure time is specified. In this case the term LC_{50} is used to designate the concentration in air that may be expected to kill 50 percent of the animals exposed for the specified length of time.

The simple determination of the LD_{50} or LC_{50} for an unknown compound provides an initial comparative index for the location of the compound in the overall spectrum of toxic potency. Table 4-1 shows an attempt at utilizing LD_{50} and LC_{50} values to set up an approximate classification of toxic substances.

Table 4-1 Toxicity classes based on lethal doses. This allows a general ranking of substances based on this measure of potency.

Toxicity Rating	Descriptive Term	Single Oral Dose Rates	LD_{50} wt/kg or 4-hr inhalation LC_{50} (ppm) in rats
1	Extremely toxic	less than 1 mg	10
2	Highly toxic	1-50 mg	10-100
3	Moderately toxic	50-500 mg	100-1000
4	Slightly toxic	0.5-5 g	1000-10,000
5	Practically nontoxic	5-15 g	10,000-100,000
6	Relatively harmless	15 g or more	>100,000

Over and above the specific LD_{50} value, the slope of the dose-response curve provides useful information. It suggests an index of the margin of safety, that is the magnitude of the range of doses involved in going from a noneffective dose to a lethal dose. Also, the slope of the dose-response curve

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may be of considerable significance with respect to establishing relative toxicities of compounds.

In modern toxicology, many endpoints besides death are studied, and the general term "effect dose" has largely replaced "lethal dose." Dose-response curves may be obtained for various endpoints, and an ED_{50} or EC_{50} value is obtained. This is the dose that produced the chosen effect in 50 percent of the treated animals. When the study of a toxic substance progresses to the point at which its action on the organism may be studied as graded response in groups of animals, dose-response curves of a slightly different sort are generally used. One might see, for example, a dose-response curve relating the degree of depression of brain choline esterase to the dose of an organic phosphorus ester or a dose-response curve relating the increase in pulmonary flow-resistance to the concentration of sulfur dioxide inhaled.

Thus for any given chemical in any species there may be a series of nested-dose response curve for different endpoints ranging from the most sensitive (early symptoms), to the least sensitive (usually death). Figure 4-2 shows a series of such curves for various endpoints from methylmercury poisoning in humans based on data from the Minamata episode in Japan.

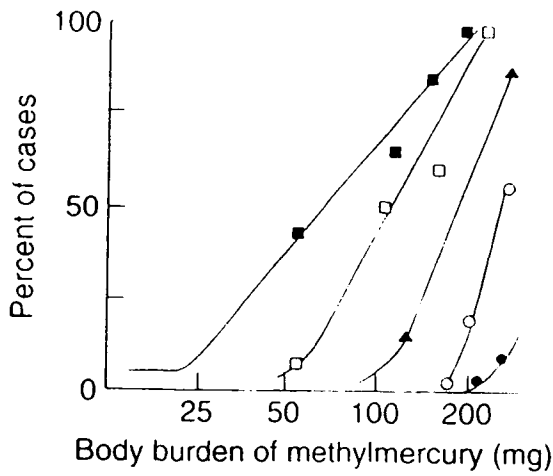


Figure 4-2. Nested dose-response curves for different clinical manifestations of organomercury poisoning based on the epidemic in Iraq, showing the relative progression in thresholds from the relatively minor sign of paresthesias (tingling in fingers) to lethality. Solid squares = paresthesias, open squares = ataxia, solid triangles = speech difficulty, open circles = hearing loss, solid circles = death. (Modified from [Takizawa, 1979], courtesy Environmental and Occupational Health Sciences Institute).

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ROUTES OF EXPOSURE

Whether exposure is unintentional or intentional (experimental or pharmacologic), toxic chemicals can enter the body by various routes. The chemical and physical properties of each compound largely determine the route by which intentional or accidental exposure occurs. The routes of *parenteral* (injection), *oral*, *inhalation*, and *percutaneous or transdermal* (skin) will be addressed [Amdur, 1973]. The use of personal protection by workers exposed to hazardous materials (whether in a factory or at a waste site), is intended to block the access of chemicals to these routes. Thus gloves and various protective suits block the dermal route and respiratory protective devices block the oral and inhalation routes.

Parenteral: Aside from the obvious use in administration of drugs, injection is considered mainly as a route of exposure for experimental animals. The injection can be into the skin (intradermal or id), beneath the skin (subcutaneous or sc), in the muscle (intramuscular or im), into the blood of the veins (intravenous or iv), or into the pleural cavity (intrapleural). The dose administered is known with accuracy. Intravenous injection introduces the material directly into the circulation, hence comparison of the degree of response to iv injection with the response to the dose administered by another route can provide information on the rate of uptake of the material by another route. When a material is administered by iv injection, the highest concentration of the toxic material in the blood occurs at the time of entrance. The organism receives the initial impact at the maximal concentration without opportunity for a gradual reaction; whereas, if the concentration is built up more gradually by some other route of exposure, the organism may have time to develop some resistance or physiological adjustment (including metabolism or excretion) that could produce a modified response.

In experimental studies intraperitoneal (ip) injection of the material into the abdominal fluid is a frequently used technique. The major venous blood circulation from the abdominal contents proceeds via the portal circulation to the liver. A material administered by ip injection is subject to the special metabolic transformation mechanisms of the liver, as well as the possibility of excretion via the bile before it reaches general circulation. If the LD_{50} of a compound given by ip injection is much higher (i.e., the toxicity is lower) than the LD_{50} by iv injection, this is likely because the material was being detoxified by the liver or that the bile is a major route of excretion of the compound. If the values for LD_{50} were very similar for ip and iv injection, it would suggest that neither of these factors played a major role in the handling of that particular compound by that particular species of animal.

Oral: Ingestion is a major route of exposure for many substances. Workers may even be exposed to workplace chemicals through eating or

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smoking with contaminated hands or in contaminated work areas. Secondary ingestion of inhaled materials also occurs, since one mechanism for the clearance of particles from the respiratory tract is the carrying up of the particles by the action of the ciliated lining of the respiratory tract. These particles are then swallowed and absorption of the material may occur from the gastrointestinal tract. This situation is most likely to occur with larger size particles although smaller particles deposited in the alveoli may be carried by phagocytes to the upward moving mucous carpet and eventually swallowed. The toxicity of orally administered chemicals will vary with the frequency with which they are given, and with the conditions under which they are given; that is, whether they are mixed with food or given on an empty stomach.

In experimental work, compounds may be administered orally as either a single or multiple dose given by stomach tube (gavage) or the material may be incorporated in the diet or drinking water for periods varying from several weeks or months up to several years or the lifetime of the animals. The dose the animals actually receive may be ascertained with considerable accuracy using gavage. Except in the case of a substance that has a corrosive action or in some way damages the lining of the gastrointestinal tract, the response to a substance administered orally will depend on how readily it is absorbed from the gut. This depends on how easily the particular chemical passes through the lining of the gut into the bloodstream, as well as its bioavailability in the particular vehicle in which it is administered. Certain kinds of soil, for example, do not release chemicals easily (low bioavailability), and much pharmaceutical research is aimed at enhancing bioavailability of active drugs. Uranium and elemental mercury, for example, are capable of producing kidney damage but are poorly absorbed from the gut and so oral administration produces only low concentrations at the site of action; both are absorbed more readily from the lung. On the other hand, ethyl alcohol, which targets the central nervous system, is rapidly absorbed and within an hour 90 percent of an ingested dose has been absorbed.

The epithelium of the gastrointestinal tract is poorly permeable to the ionized form of organic compounds. Absorption of such materials generally occurs by diffusion of the lipid-soluble nonionized form. Weak acids that are predominately nonionized in the high acidity (pH 1.4) of gastric juice are absorbed from the stomach. The surface of the intestinal mucosa has a pH of 5.3. At this higher pH weak bases are less ionized and more readily absorbed. The pH of a compound thus becomes an important factor in predicting absorption from the gastrointestinal tract.

Inhalation: Inhalation exposures are of prime importance to the industrial toxicologist, and account for most serious occupational exposure to workplace chemicals. Exposure to chemicals in the atmosphere is accomplished by unavoidable inhalation of such agents unless devices are used to remove the

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atmospheric contaminants before they enter the respiratory tract. In experimental work, the dose actually received and retained by the animals is not known with the same accuracy as when a compound is given by the routes previously discussed. This route depends on the ventilation rate of the individual (the volume of air breathed per minute). In the case of a gas, it is influenced by *solubility* and in the case of an aerosol (fine liquid droplets or solid particles) by *particle size.* The concentration and time of exposure can be measured and this gives a working estimate of the exposure. Two techniques are sometimes utilized in an attempt to determine the dose with precision and still administer the compound via the lung. One is intratracheal injection, which may be used in some experiments in which it is desirable to deliver a known amount of particulate material into the lung. The other is so-called precision gassing. In this technique the animal or experimental subject breathes through a valve system and the volume of exhaled air and the concentration of toxic material in it are determined. A comparison of these data with the concentration in the atmosphere of the exposure chamber gives an indication of the dose retained.

Percutaneous: Cutaneous exposure ranks first in the production of occupational disease, but not necessarily first in severity. In order to pass into the skin, the chemical must either traverse the epidermal cells or enter through the follicles. Although the transfollicular pathway provides access to the deeper layers of the skin via relatively permeable cells of sebaceous glands and the follicular walls, the pathway through the epidermal cells is probably the main avenue of penetration because this tissue constitutes the majority of the surface area.

The skin and its associated film of lipids and sweat may act as an effective barrier. The chemical may react with the skin surface and cause primary irritation. The agent may penetrate the skin and cause sensitization on repeated exposure. The material may penetrate the skin in an amount sufficient to cause systemic poisoning. In assessing the toxicity of a compound by skin application, a known amount of the material to be studied is placed on the clipped skin of the animal and held in place with a rubber cuff. Some materials such as acids, alkalis, and many organic solvents are primary skin irritants and produce skin damage on initial contact. Other materials are sensitizing agents. The initial contact produces no irritant response, but may render the individual sensitive and dermatitis may result from future contact.

Ethyleneamines and the catechols in the well-known members of the *Rhus* genus (poison ivy and poison oak) are examples of such agents, and field workers often come in contact with these plant toxins. The physicochemical properties of a material are the main determinant of whether or not a material will be absorbed through the skin. Among the important factors are pH, extent of ionization, water and lipid solubility, and molecular size. Some compounds,

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such as phenol and phenolic derivatives, can readily penetrate the skin in amounts sufficient to produce systemic intoxication. If the skin is damaged, the normal protective barrier to absorption of chemicals is lessened and penetration may occur. An example of this is a description of cases of mild lead intoxication that occurred in an operation that involved an inorganic lead salt and also a cutting oil. Inorganic lead salts would not be absorbed through intact skin, but the dermatitis produced by the cutting oil permitted increased absorption.

CRITERIA OF RESPONSE

After the toxic material has been administered by one of the routes of exposure discussed above, there are various criteria or endpoints used to evaluate the response. These criteria are oriented whenever possible toward elucidating the mechanisms of action of the material.

Mortality: Has been used mainly as an initial test to categorize toxicity and to choose dosages for subsequent testing. Mortality is also a criterion of response in long-term chronic studies. In such studies, the investigator must be certain that the mortality observed was due to the material under study; hence, an adequate control group of untreated animals subject to otherwise identical conditions is maintained for the duration of the experiment.

Organ Weight: This is often a useful gross indication of damage to one or more organs. Some toxic exposures cause edema or tissue proliferation or cellular necrosis, thereby altering the weight of an organ relative to the body. The ratio of organ weight to body weight, may be used as a criterion of response. In some instances such alterations are specific and explicable, as for example, the increase of lung weight to body weight ratio as a measure of the edema produced by irritants such as ozone or oxides of nitrogen. In other instances the increase is a less specific general hypertrophy of the organ, especially of the liver and kidney.

Organ Pathology: Organ toxicity covers a wide range of organ systems and toxic effects. The heart, lungs, kidneys, liver, pancreas, spleen, thymus, or skin may be affected. The effects on one organ system may be manifested throughout the body. For example, depression of thymus function may reduce the efficacy of the immune system and make the organism susceptible to infectious diseases. Effects may be more specific such as the skin lesion chloracne from chlorinated aromatic hydrocarbons. In some instances, the pathological lesion is typical of the certain toxic agents; for example, the silicotic nodules in the lungs produced by inhalation of free silica or the pattern of liver damage resulting from exposure to carbon tetrachloride and some other hepatotoxins.

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Growth: In chronic studies the effect of the toxic agent on the growth rate of the animals is another criterion of response. Levels of the compound that do not produce death or overt pathology may result in a diminished rate of growth. A record is also made of the food intake. This will indicate whether diminished growth results from lessened food intake or from less efficient use of food ingested. It sometimes happens that when an agent is administered by incorporation into the diet, especially at high levels, the food is unpalatable to the animals and they simply refuse to eat it. In humans, low birth weight is one of the endpoints of concern for populations exposed to hazardous waste [Vianna and Polan, 1984], reflecting reduced intrauterine growth.

Physiological Function Tests: Physiological function tests are a useful criterion of response both in experimental studies and in assessing the response of exposed workers. (For more information, see Chapter 7, Medical Surveillance for Hazardous Waste Workers.) They can be especially useful in chronic studies in that they do not necessitate the killing of the animal and can, if desired, be done at regular intervals throughout the period of study. The integrity of liver cells, for example, can be assessed by measuring certain enzymes, and their function can be estimated by endpoints such as albumin synthesis or bilirubin conjugation. The examination of the renal clearance of various substances helps give an indication of localization of kidney damage. The excretion of various low molecular weight proteins is being used to measure renal tubular damage. The ability of the kidney (especially in the rat) to produce a concentrated urine may be measured by the *osmolality* of the urine produced. This has been suggested for the evaluation of alterations in kidney function. Alterations may be detected following inhalation of materials such as chlorotrifluoroethylene at levels of reversible response. In some instances measurement of blood pressure has proved a sensitive means of evaluating response. Various tests include relatively simple tests that are suitable for use in field surveys as well as more complex methods possible only under laboratory conditions. Inexpensive peak flow meters can be used in the field to measure peak expiratory flow rate (PEFR), whereas spirometry to measure, forced vital capacity (FVC), and 1-second forced expiratory volume (FEV_1) require an office setting and trained personnel. More complex procedures including the measurement of pulmonary mechanics (flow-resistance, diffusion capacity and compliance), require a pulmonary function laboratory usually found in hospitals.

Biochemical Studies: The study of biochemical response to toxic agents leads in many instances to an understanding of the mechanism of action. Tests of toxicity developed in animals should be oriented to determination of early response from exposures that are applicable to the industrial scene. Many toxic agents act by inhibiting the action of specific enzymes. This action may be studied *in vitro* (literally meaning in glassware) and *in vivo* (using live whole

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animals). In the first case, the toxic agent is added to tissue slices or tissue homogenate from normal animals and the degree of inhibition of enzymatic activity is measured by an appropriate technique. In the second case, the toxic agent is administered to the animals; after the desired interval the animals are killed and the degree of enzyme inhibition is measured in the appropriate tissues. A judicious combination of *in vivo* and *in vitro* studies is especially useful when biotransformation to a toxic compound is involved. The classic example of this is the toxicity of fluoroacetate. This material, which was extremely toxic when administered to animals of various species, did not inhibit any known enzymes *in vitro*. Fluoroacetate entered the carboxylic acid cycle of metabolism as if it were acetic acid. The product formed was fluorocitrate, which was a potent inhibitor of the enzyme aconitase. Biological conversion in the living animal had resulted in the formation of a highly toxic compound. The term lethal synthesis describes such a transformation.

Molecular Studies: A rapidly growing field is the study of the effects of toxic chemicals on the molecular or genetic level. Many chemicals activate (or inhibit) enzyme synthesis by interfering at the level of gene regulation. Others interfer with mechanisms involved in the normal cycling of the cell. This is largely beyond the scope of this chapter, and readers are referred to various recent toxicology texts [Klaassen, 1996].

DETOXIFICATION MECHANISMS

The body has important ways of responding to toxic chemicals. As the bloodstream brings chemicals to the liver and other organs, cellular enzymes may metabolize the compound, changing it into new compounds (metabolites) which may be more or less toxic or carcinogenic than the parent compound. Chemical reactions may result in linking a chemical or its metabolite to carrier molecules that deliver it to the kidney in a form that can be excreted in the urine. Substances or their metabolites may be delivered to the organs where they do harm (target organs), or to other organs such as the bone (for lead) or the fat (for many organic compounds), which are not target organs. The latter serve as storage depots, and substances may remain there for months or years. Many chemicals have the property of inducing production of enzymes which act on them. Thus the body does not try to keep a full inventory of every enzyme in an active status, but produces enzymes as they are needed in response to an increase in their natural or non-natural substrates.

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TYPES OF TOXIC EFFECTS

Just as the exposures to toxic chemicals may be acute (one-time or short-term) or chronic, the adverse health effects induced by chemical exposures at work may be classified as *acute* or *chronic* (in-between exposures or effects may be labeled as *subacute* or *subchronic). Acute* health effects result in undesirable and sometimes irreversible health changes in short periods of time (in the order of magnitude of a few seconds or minutes or at most a day). *Chronic* effects reflect the cumulative bodily damage resulting from repetitive exposures that do not produce immediately irreversible consequences. The techniques for measuring the lower levels of exposure that typically produce chronic health effects frequently differ from those used to measure exposures which may result in acute effects. Because immediate decisions concerning protection are usually required, direct-reading instruments are ordinarily used to evaluate exposures likely to result in acute effects [Amdur, 1973]. (For more information, see Chapter 5, Air Monitoring at Hazardous Waste Sites.)

A particular chemical may produce an acute effect at one exposure level and a subacute or chronic effect at another. Despite these classification difficulties, it has been common practice to identify the different types of toxicity with one of the three time-course categories. Thus organ damage has been classified as an acute or subacute effect, and most other types of toxicity have been assigned to the chronic classification. The effects generally included in the chronic category are carcinogenesis, teratogenesis, reproductive toxicity, and mutagenesis.

Lung Toxicity: The lung can be acutely affected in various ways by toxic substances. Lung toxicity, for example, may be an acute, subacute, or chronic effect. Direct damage to lung cells and thereby lung function can be caused by inhalation of oxidizing gases such as oxygen, ozone, or nitrogen dioxide. Indirect lung damage can result from the ingestion of chemicals or via cutaneous absorption. An example of this indirect process of lung damage is seen in the results of exposure to paraquat (agricultural insecticide). This chemical causes lung cell damage following absorption through the skin or gastrointestinal tract.

In contrast, chronic lung damage can result from long term exposure to a toxicant. Two examples that are well documented are emphysema from smoking and asbestosis from prolonged exposure to asbestos. For example, respiratory illness in workers of an indoor Shitake mushroom farm was investigated by Lenhart and Cole [Lenhart and Cole, 1993]. Predominant symptoms were dry cough, nasal discharge, sneezing, productive cough and dyspnea. Shitake mushrooms are grown on logs, usually outdoors, but more recently indoors as well and are harvested in the mature state when there is active sporulatim. Upon reviewing the results of an acute symptoms

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questionnaire and learning that allergenic mold and mushroom spores were available for inhalation in high concentrations during harvesting work, the management decided to implement a respiratory protection program which included half mask air-purifying respirators, disposable uniforms, a medical surveillance program, and pulmonary function tests.

Kidney Toxicity: Toxicants that interfere with kidney function can produce severe adverse effects. The most common and well studied example is lead. The presence of lead interferes with kidney function, and allows increasing concentrations of damaging chemicals in tissues and organs throughout the body. Thus while the kidney is the original site of toxicity, the damage is more universal.

Carcinogenesis: Cancer is the chronic toxic effect that is of most concern to the general population and is the most well studied. Carcinogenesis results from uncontrollable cell proliferation and may result from toxic alterations of only a single cell. The study of the carcinogenic effects of a toxic chemical is a complex experimental problem. Such testing involves the use of sizable groups of animals observed over a period of two years in rats; their laboratory lifetime, because of the long latent period required for the development of cancer. Attempts to shorten the time lag have led to the use of aging animals. This may reduce the lag period one third to one fourth. Various strains of inbred mice or hamsters which are unusually susceptible to cancer, are frequently used in such experiments. Quite frequently materials are screened by painting on the skin of experimental animals, especially mice.

Industrial experience has revealed the hazard of cancer from exposure to various chemicals. Among these are many of the polyaromatic hydrocarbons such as beta-naphylamine (bladder cancer) as well as chromates, asbestos, and nickel carbonyl, which produce respiratory cancer.

A common industrial hazard is the process of welding. Metal fume fever is an acute respiratory disease that is usually of short duration [Welding, 1988]. Studies have taken into account the smoking habits of welders [Johnson, 1983]. As expected, welders and controls who smoked reported a higher frequency of respiratory symptoms than corresponding nonsmokers.

Reproductive Toxicity: Reproductive toxicity is a broad category that includes a variety of effects on the reproductive capacity of living systems. These effects can involve decreases in fertility, decreases in percent of conceptions leading to live birth (i.e., spontaneous abortion), or fetal or embryonic toxicity. Reproductive toxicity may be distinguished from teratogenicity in that the toxicity does not lead to birth defects, but instead, may lead to reduced birth weight or size, (e.g., alcohol and tobacco).

The effects of combined EGME (ethylene glycol monomethyl ether) and EGEE (ethylene glycol monoethyl ether) exposure on the reproductive potential of men working in a large ship-building facility was studied. The authors

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concluded that exposure to EBME and EGEE caused functional impairment by lowering sperm counts, in addition, when the results were controlled for the effects of smoking, there was an increased odds ratio for a lower sperm count per ejaculate. Similarly, men involved in the manufacture of the nematocide dibromochloropropane had complete or nearly complete, and in some cases irreversible, loss of sperm production (azospermia) [Whorton, et al., 1977].

A toxic material can have an effect on either male or female animals that will result in decreased fertility. In fertility studies the chemical is given to males and females in daily doses for the full cycle of oogenesis and spermatogenesis prior to mating. If gestation is established, the fetuses are removed by caesarean section one day prior to delivery. The litter size and viability are compared with untreated groups. The young are then studied to determine possible effects on survival, growth rate, and maturation. The tests may be repeated through a second and third litter of the treated animals. If it is considered necessary the test may be extended through the second and third generation.

Teratogenesis: Teratogenesis may be considered a special subset of reproductive toxicity. It is the formation of birth defects in offspring, often as a result of maternal or paternal exposure to a toxicant. It is usually classified as a chronic effect, even though the toxicity appears within a relatively short period of time (the term of the pregnancy). Since some birth defects caused by toxicity are inheritable, the time course is much longer. Chemicals administered to the pregnant animal may, under certain conditions, produce malformations of the fetus without inducing damage to the mother or killing the fetus. The experience with the birth of many infants with limb anomalies resulting from the use of thalidomide by the mothers during pregnancy alerted the toxicologists to the need for more rigid testing in this difficult area. Studies have reported the occurrence of hypospadias (malformation of the sexual organs) at birth in two boys whose mother had been occupationally exposed to EGMEA (ethylene glycol monomethyl ether acetate) during her pregnancies. She had worked in an industrial laboratory that produced lacquers and enameled wire [Welch, et al., 1988].

A nonoccupational example of teratogenicity is the effect of methyl mercury demonstrated in the incident of poisoning at Minamata Bay, Japan [Takizawa, 1979]. The study of the teratogenic potential poses a very complex toxicological problem. The susceptibility of various species of animals varies greatly in the area of teratogenic effects. The timing of the dose is very critical as a chemical may produce severe malformations of one sort if it reaches the embryo at one period of development and either no malformations or different malformations if it is administered at an earlier or later period of embryogenesis. In humans, for example, exposure to certain compounds during the first trimester may lead to spontaneous abortion or birth defects,

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while exposure to the same compounds after the 12th week may have no effect since the sensitive organs are completely formed. This poses a challenge for protecting pregnant workers, since the fetus is most vulnerable in the early weeks when pregnancy may not be recognized.

FACTORS INFLUENCING INTENSITY OF TOXIC ACTION

One of the factors influencing the intensity of the toxic action has already been mentioned (i.e., the route of exposure). For example, when a substance is administered as an iv injection, the material has maximum opportunity to be carried by the bloodstream throughout the body, whereas other routes of exposure interpose a barrier to distribution of the material. The effectiveness of this barrier will govern the intensity of toxic action of a given amount of toxic agent administered by various routes. Lead, for example, is toxic both by ingestion and by inhalation. An equivalent dose, however, is more readily absorbed from the respiratory tract than from the gastrointestinal tract, and hence produces a greater response.

There is frequently a difference in intensity of response and sometimes a difference even in the nature of the response between the acute and chronic toxicity of a material. If a material is taken into the body at a rate sufficiently slow that the rate of excretion and/or detoxification keeps pace with the intake, it is possible that no toxic response will result even though the same total amount of material taken in at a faster rate would result in a concentration of the agent at the site of action sufficient to produce a toxic response. Information of this sort enters into the concept of a threshold limit for safe exposure. Hydrogen sulfide is a good example of a substance that is rapidly lethal at high concentrations as evidenced by the many accidental deaths it has caused. It has an acute action on the nervous system with rapid production of respiratory paralysis unless the victim is promptly removed to fresh air and revived with appropriate artificial respiration. On the other hand, hydrogen sulfide is rapidly oxidized in the plasma to nontoxic substances, and many times the acute lethal dose produces relatively little effect if administered slowly. Benzene is a good example of a material that differs in the nature of response depending on whether the exposure is an acute one to a high concentration or a chronic exposure to a lower level. If one used as criteria the 4-hr LC_{50} for rats of 16,000 ppm, which has been reported for benzene, one would conclude that this material would be "practically nontoxic," which, of course, is contrary to fact. The mechanism of acute death is narcosis. Chronic exposure to low levels of benzene on the other hand produces damage to the blood-forming tissue of the bone marrow, resulting in aplastic anemia and

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leukemia, and chronic benzene intoxication may appear even many years after the actual exposure to benzene has ceased.

Other factors that directly influence the intensity of a toxic effect are the *age, state of health,* and *previous exposure history* of the worker. Some work environments also introduce environmental variables that have bearing on toxic intensity. (For more information, see Chapter 7, Medical Surveillance for Hazardous Waste Workers.)

Age: It is well known that, in general, infants and the newborn are more sensitive to many toxic agents than are adults of the same species. Elderly persons or animals are also often more sensitive to toxic action than are younger adults. With aging comes a diminished reserve capacity of many organ systems in the face of toxic stress. This reserve capacity may be either functional or anatomical. The excess mortality in the older age groups during and immediately following the well-known acute air pollution incidents is a case in point. There is experimental evidence from electron microscope studies that younger animals exposed to pollutants have a capacity to repair lung damage that was lost in older animals. Similarly DNA repair mechanisms which protect our cells from carcinogenic damage, decline with age, predisposing elderly people to cancer.

State of Health: Preexisting disease can result in greater sensitivity to toxic agents. In the case of specific diseases that would contraindicate exposure to specific toxic agents, preplacement medical examination can prevent possible hazardous exposure. For example, an individual with some degree of preexisting methemoglobinemia would not be placed in a work situation involving exposure to nitrobenzene. Since it is known that the uptake of manganese parallels the uptake of iron, it would be unwise to employ a person with known iron deficiency anemia as a manganese miner. It has been shown that viral agents will increase the sensitivity of animals to exposure to oxidizing type air pollutants. Nutritional status also affects response to toxic agents. Persons with liver, kidney, or lung disease, for example, are likely to be unusually vulnerable to hazardous chemical exposures. While those with immune disorders are vulnerable to biological hazards.

Previous Exposure: Previous exposure to a toxic agent can lead to either tolerance, increased sensitivity, accumulation in some organ, or make no difference in the degree of response. Some toxic agents function by allergic sensitization and the initial exposures produce no observable response, but subsequent exposures will do so. In these cases the individuals who are thus sensitized must be removed from exposure. In other instances, if an individual is reexposed to a substance before complete reversal of the change produced by a previous exposure, the effect may be more dangerous. A case in point would be an exposure to an organophosphorus insecticide that would lower the level of acetylcholine esterase. Given time, the level will be restored to normal. If

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another exposure occurs prior to this, the enzyme activity may be further reduced to dangerous levels.

Previous exposure to low levels of a substance may in some cases protect against subsequent exposure to levels of a toxic agent that would be damaging if given initially. This may come about through the induction of enzymes that detoxify the compound or by other mechanisms often not completely understood. It has been shown, for example, that exposure of mice to low levels of ozone will prevent death from pulmonary edema in subsequent high exposures. There is also a considerable cross tolerance among the oxidizing irritants such as ozone and hydrogen peroxide, an exposure to low levels of the one protecting against high levels of the other.

Environmental Factors: Physical factors can also affect the response to toxic agents. In industries such as smelting or steel making, high temperatures are encountered. Pressures different than normal ambient atmospheric pressure can be encountered in caissons or tunnel construction. Likewise exposure to mixtures of chemicals may alter the response to single chemicals, both quantitatively and qualitatively.

CLASSIFICATION OF HAZARDOUS MATERIALS

Hazardous materials are often divided into physical, biological, and chemical. Physical hazards include heat, vibration, and radiation (see Chapters 10 and 14). Biological hazards include infectious and allergenic agents. Toxic agents may be classified in several ways: by locus of action (local or systemic), by physical properties, chemical structure, by economic function, by toxic function, or by target organ. No one of these is of itself completely satisfactory.

Local versus Systemic: A toxic agent may have its action on the organ with which it comes into first contact (local action). Let us assume for the moment that the agent is inhaled. Materials such as irritant gases or acid mists produce a more or less rapid response from the respiratory tract when present in sufficient concentration. Other agents, such as silica or asbestos, also damage the lungs but the response is seen only after lengthy exposure. Other toxic agents may have an effect on the organ through which they enter the body, but exert what is called systemic toxic action when they have been absorbed and translocated to the site of biological action. Examples of such agents would be mercury vapor, manganese, lead, chlorinated hydrocarbons, and many others that are readily absorbed through the lungs, but produce typical toxic symptoms only in mainly organ systems.

Physical Properties: This classification is based on the form in which substances are present in the air: *gases* and *vapors* or as *aerosols*.

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1. *Gases and Vapors*: In common industrial hygiene usage the term *gas* is applied to a substance that is in the gaseous state at room temperature and pressure and the term *vapor* is applied to the gaseous phase of a material that is ordinarily a solid or a liquid at room temperature and pressure. In considering the toxicity of a gas or vapor, the solubility of the material is of the utmost importance. If the material is an irritant gas, solubility in aqueous media will determine the amount of material that reaches the lung and hence its site of action. A highly soluble gas, such as ammonia, is taken up readily by the mucous membranes of the nose and upper respiratory tract. Sensory response to irritation in these areas provides the individual with warning of the presence of an irritant gas. On the other hand, a relatively insoluble gas such as nitrogen dioxide is not scrubbed out by the upper respiratory tract, but penetrates readily to the lung. Amounts sufficient to lead to pulmonary edema and death may be inhaled by an individual who is not at the time aware of the hazard. The solubility coefficient of a gas or vapor in blood is one of the factors determining rate of uptake and saturation of the body. With a very soluble gas, saturation of the body is slow, is largely dependent on ventilation of the lungs, and is only slightly influenced by changes in circulation. In the case of a slightly soluble gas, saturation is rapid, depends chiefly on the rate of circulation, and is little influenced by the rate of breathing. If the vapor has a high fat solubility, it tends to accumulate in the fatty tissues that it reaches carried in the blood. Since fatty tissue often has a meager blood supply, complete saturation of the fatty tissue may take a longer period. It is also of importance whether the vapor or gas is one that is readily metabolized. Conversion to a metabolite would tend to lower the concentration in the blood and shift the equilibrium toward increased uptake. It is also of importance whether such metabolic products are toxic.

2. *Aerosols*: An aerosol is composed of solid or liquid particles of microscopic size dispersed in a gaseous medium (for our purposes, air). Special terms are used for indicating certain types of particles. Some of these are *dust*, a dispersion of solid particles usually resulting from the fracture of larger masses of material such as in drilling, crushing, or grinding operations; *mist*, a dispersion of liquid particles, many of which are visible; *fog*, visible aerosols of a liquid formed by condensation; *fume*, an aerosol of solid particles formed by condensation of vaporized materials; and *smoke*, aerosols resulting from incomplete combustion that consists mainly of carbon and other combustible materials. The toxic response to an aerosol depends obviously on the nature of the material, which may have as a target organ the respiratory system or may be a systemic toxic agent acting elsewhere in the body. In either case, the toxic potential of a given material dispersed as an aerosol is only partially described by a statement of the concentration of the material in terms of weight per unit volume or number of particles per unit volume. For a proper assessment of the

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toxic hazard, it is necessary to have information also on the particle size and distribution of the material. Understanding of this fact has led to the development of instruments that sample only particles in the respirable size range (see Chapter 5, Air Monitoring at Hazardous Waste Sites).

The particle size of an aerosol is the key factor in determining its site of deposition in the respiratory tract and as a sequel to this, the clearance mechanisms that will be available for its subsequent removal. The deposition of an aerosol in the respiratory tract depends on the physical forces of impaction, settling, and diffusion or Brownian movement that apply to the removal of any aerosol from the atmosphere, as well as on anatomical and physiological factors such as the geometry of the lungs and the airflow rates and patterns occurring during the respiratory cycle.

In the limited space available only one point will be emphasized here, namely, the toxicological importance of fine particles, particularly those below 1 μm in size. Aerosols in the range of 0.2-0.4 μm tend to be fairly stable in the atmosphere. This comes about because they are too small to be effectively removed by forces of settling or impaction and too big to be effectively removed by diffusion. Since these are the forces that lead to deposition in the respiratory tract, it has been predicted theoretically and confirmed experimentally that a lesser percentage of these particles is deposited in the respiratory tract. On the other hand, since they are stable in the atmosphere, there are large numbers of them present to be inhaled, and to dismiss this size range as of minimal importance is an error in toxicological thinking that should be corrected whenever it is encountered. Aerosols in the size range below 1.0 μm are also of major toxicological importance. The percentage deposition of these extremely small particles is as great as for 1μm particles and this deposition is alveolar. Particles in the submicron range also appear to have greater potential for interaction with irritant gases, a fact that is of importance in air pollution toxicology.

Chemical Structure: Toxic compounds may be classified according to their chemical nature. The most recent volume of the *Merck Index* is an excellent reference [*Merck Index*, 1996]. Thus chemicals can be divided into organic and inorganic. The former includes simple alkanes, alkenes, and aromatic compounds (benzene derivatives), as well as alcohols, organic acids, amines, aldeheyes, ethers, and polyaromatic compounds. Important structural properties are conferred by the presence of one or more halogens (mainly chlorine), such that chlorinated hydrocarbons, and polychlorinated aromatics are frequently singled out for attention. Inorganic compounds include many acids, bases, salts, and heavy metals.

Chemical Properties: Knowledge of the chemical nature of a compound (i.e., oxidizers, reducers, corrosives, etc.) is required by the user. Another

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approach more accessible to the health and safety personnel is the "NIOSH Pocket Guide to Chemical Hazards."

Economic Classification: In many circumstances it is convenient to classify chemicals by their economic uses for example, pesticides, solvents, food additive, or anesthetics. Knowing the uses to which they are put, is a first step at surmising their hazardous properties.

Physiological Classification: Such classification attempts to frame the discussion of toxic materials according to their biological action. These include irritation, sensitization, cytotoxicity, and mutagenesis.

Irritants: The basis of classifying these materials is their ability to cause inflammation of mucous membranes with which they come in contact. We describe this property in detail because it is a major problem for workers exposed to hazardous materials. While many irritants are strong acids or alkalis familiar as corrosive to nonliving things such as lab coats or bench tops, bear in mind that inflammation is the reaction of a living tissue and is distinct from chemical corrosion. The inflammation of tissue results from concentrations far below those needed to produce corrosion. As was indicated earlier in discussing gases and vapors, solubility is an important factor in determining the site of irritant action in the respiratory tract. Highly soluble materials such as ammonia, alkaline dust and mists, hydrogen chlorides, and hydrogen fluoride affect mainly the upper respiratory tract. Other materials of intermediate solubility such as the halogens, ozone, diethyl or dimethyl sulfate, and phosphorus chlorides affect both the upper respiratory tract and the pulmonary tissue. Less soluble materials, such as nitrogen dioxide, arsenic trichlorides, or phosgene affect primarily the lung. There are exceptions to the statement that solubility serves to indicate site of action. One such is ethyl ether and other insoluble compounds that are readily absorbed unaltered from the alveoli and hence do not accumulate in that area. In the upper respiratory passages and bronchi where the material is more readily absorbed, it can accumulate in concentrations sufficient to produce irritation. Another exception is in materials such as bromobenzyl cyanide that is a vapor from a liquid boiling well above room temperature. It is taken up by the eyes and skin as a mist. In initial action, then, it is a powerful lachrymator and upper respiratory irritant, rather than producing a primarily alveolar reaction as would be predicted from its low solubility.

Irritants in the respiratory tract can also cause changes in the mechanics of respiration such as increased pulmonary flow resistance or decreased compliance (a measure of elastic behavior of the lungs). One group of irritants, among which are sulfur dioxide, acetic acid, formaldehyde, formic acid, sulfuric acid, acrolein, and iodine, produce a pattern in which the flow resistance is increased, the compliance is decreased only slightly and at higher concentrations the frequency of breathing is decreased. Another group, among

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which are ozone, and oxides of nitrogen, has little effect on resistance, produces a decrease in compliance and an increase in respiratory rate. The irritant potency of a given material tends to increase with decreasing particle size as assessed by the increase in flow resistance. Following respiratory mechanics measurements in cases exposed to irritant aerosols, the histologic sections prepared after rapid freezing of the lungs showed the anatomical sites of constriction. Long-term chronic lung impairment may be caused by irritants either as sequelae to a single very severe exposure or as the result of chronic exposure to low concentrations of the irritant. There is evidence in experimental animals that long-term exposure to respiratory irritants can lead to increased mucous secretion and a condition resembling the pathology of human chronic bronchitis without the intermediary of infection. The epidemiological assessment of this factor in the health of residents of polluted urban atmospheres is currently a vital area of research.

Irritants are usually further subdivided into primary and secondary irritants. A primary irritant is a material that for all practical purposes exerts no systemic toxic action either because the products formed on the tissues of the respiratory tract are nontoxic or because the irritant action is far in excess of any systemic toxic action. Examples of the first type would be hydrochloric acid or sulfuric acid. Examples of the second type would be materials such as Lewisite or mustard gas, which would be quite toxic on absorption but death from the irritation would result before sufficient amounts to produce systemic poisoning would be absorbed. Secondary irritants are materials that do produce irritant action on mucous membranes, but this effect is overshadowed by systemic effects resulting from absorption. Examples of materials in this category are hydrogen sulfide and many of the aromatic hydrocarbons and other organic compounds. The direct contact of liquid aromatic hydrocarbons with the lungs can cause chemical pneumonitis with pulmonary edema, hemorrhage, and tissue necrosis. It is for this reason that in the case of accidental ingestion of these materials the induction of vomiting is contraindicated because of possible aspiration of the hydrocarbon into the lungs.

Asphyxiants: The basis of classifying these materials is their ability to deprive tissue of oxygen. In the case of severe pulmonary edema caused by an irritant such as nitrogen dioxide or laryngeal spasm caused by a sudden severe exposure to sulfuric acid mist, the death is from asphyxia, but this results from the primary irritant action. The materials we classify here as asphyxiants do not damage the lungs. Simple asphyxiants are physiologically inert gases that act when they are present in the atmosphere in sufficient quantity to exclude an adequate oxygen supply. Among these are such substances as nitrogen, nitrous oxide, carbon dioxide, hydrogen, helium, and the aliphatic hydrocarbons such as methane and ethane. All of these gases are not chemically unreactive and

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among them are materials that pose a major hazard of fire and explosion. Chemical asphyxiants are materials that have as their specific toxic action the ability to render the body incapable of utilizing an adequate oxygen supply. They are thus active in concentrations far below the level needed for damage from the simple asphyxiants. The two classic examples of chemical asphyxiants are carbon monoxide and cyanides. Carbon monoxide interferes with the transport of oxygen to the tissues by its affinity for hemoglobin. The carboxy-hemoglobin thus formed is unavailable for the transport of oxygen. Over and above the familiar lethal effects, there is concern about how low level exposures will affect performance of such tasks as automobile driving and so on.

In the case of cyanide, there is no interference with the transport of oxygen to the tissues. Cyanide transported to the tissues forms a stable complex with the ferric ion of ferric cytochrome oxidase, resulting in inhibition of enzyme action. Since aerobic metabolism is dependent on this enzyme system, the tissues are unable to utilize the supply of oxygen, and tissue hypoxia results, leading to death. Therapy is directed toward the formation of an inactive complex before the cyanide has a chance to react with the cytochrome. Cyanide will complex with methemoglobin and nitrite is effective in forming methemoglobin. Thiosulfate is also given as this provides the sulfate needed to promote the enzymatic conversion of cyanide to the less toxic thiocyanate.

Primary Anesthetics: The main toxic action of these materials is their depressant effect on the brain. The degree of anesthetic effect depends on the effective concentration in the brain as well as on the specific pharmacologic action. Thus, the effectiveness is a balance between solubility (which decreases) and pharmacological potency (which increases) as one moves up a homologous series of compounds of increasing chain length. The anesthetic potency of the simple alcohols also rises with increasing number of carbon atoms through amyl alcohol, which is the most powerful of the series. The presence of multiple hydroxyl groups diminishes potency. The presence of carboxyl groups tends to prevent anesthetic activity, which is slightly restored in the case of an ester. Thus acetic acid is not anesthetic, but ethyl acetate is mildly so. The substitution of a halogen for a hydrogen of the fatty hydrocarbons greatly increases the anesthetic action, but confers toxicity to other organ systems, which out-weighs the anesthetic action.

Occupational exposure limits (OELs) are set using a variety of criteria, but human experience, animal testing and analogy with similar materials are three primary sources of information. One study recently published in AOEH suggests that in the production of oil and gas, first alarm levels should be set at 10 percent of the LEL based on knowledge of narcosis onset. This criteria is drawn from studies of anesthetic gases and the literature from diving [*Merck Index*, 1996].

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Ethanol is the only alcohol that has widespread intentional human use. Ethanol is one of the oldest drugs recognized by man and is the primary alcohol present in beers, wines, and distilled spirits. Ethanol is a clear, colorless liquid that imparts a burning sensation to the mouth and throat when swallowed. Pure ethanol has a very slight, pleasant odor. It is freely soluble in water. Contrary to popular belief, ethanol is a powerful central nervous system (CNS) depressant that works primarily on the reticular activation system. In fact, its actions are qualitatively similar to those of the general anesthetics. It has a relatively low order of toxicity compared to methanol or isopropanol.

The exact mechanism by which ethanol produces its actions is not entirely understood. The CNS is selectively affected. Ethanol is thought to act directly on neuronal membranes and not at the synapses. At the membrane, it may interfere with ion transport. In vitro studies indicate that Na, K ATPase is inhibited by ethanol. Concentrations of 5 to 10 percent block the neuron's ability to produce electrical impulses. These concentrations are far greater than the concentrations of ethanol in the CNS in vitro.

The effect of ethanol on the CNS is directly proportional to the blood concentration. The first region of the brain affected is the reticular activating system. This causes disruption of the motor and thought processes. In addition, suppressing the cerebral cortex with ethanol will cause behavioral changes. Which specific types of behavior will be suppressed and which will be released from inhibition depends on the individual. In general, complex, abstract, and poorly learned behaviors are disrupted at low alcohol concentrations [ACGIH, 1997].

Ethanol depresses the CNS irregularly in a descending order from the cortex to the medulla. Table 4-2 illustrates the correlation between blood alcohol concentration and the area of the brain which is affected. Also, subjective feelings are noted based on blood alcohol concentration and the area of the brain where ethanol produces its effect.

Classification by Target Organ: A common classification is to group even diverse chemicals by the organ on which they have their most important effect(s). Thus many chlorinated hydrocarbons are toxic to many organs, but are mainly considered to be neurotoxic, hepatotoxic, and nephrotoxic.

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Table 4-2. Range of toxicity of ethanol as a function of increasing dose. This gives an example of the increasing severity of nervous system symptoms with increasing dose of this familiar neurotoxin.

Clinical Description/ Symptoms	**Blood Alcohol Concentration**	**Brain Region Affected**
MILD Decreased inhibitions Slight visual impairment Slowed reaction time Increased confidence	0.05-0.10 %	Frontal lobe
MODERATE Ataxia (unsteady gait) Altered equilibrium Slurred speech Decreased motor skills Decreased attention Diplopia (double vision) Altered perception	0.15-0.30 %	Parietal lobe Occipital lobe Cerebellum
SEVERE Impaired vision Disequilibrium Stupor	0.30-0.50 %	Occipital lobe Cerebellum Diencephalon
COMA Respiratory failure	>0.5 %	Medulla

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Hepatotoxic Agents: These are materials that have as their main toxic action the production of liver damage. Carbon tetrachloride produces severe diffuse central necrosis of the liver. Tetrachloroethane is probably the most toxic of the chlorinated hydrocarbons and produces acute yellow atrophy of the liver. Nitrosamines are capable of producing severe liver damage. There are many compounds of plant origin such as some of the toxic components of the mushroom *Amanita phalloides*, alkaloids from *Senecio*, and aflatoxins that are capable of producing severe liver damage and in some instances are powerful hepatocarcinogens.

Nephrotoxic Agents: These are materials that produce kidney damage. Some of the halogenated hydrocarbons produce damage to the kidney as well as to the liver. Most heavy metals are nephrotoxic. Uranium damages mainly the distal third of the proximal convoluted tubule, while mercury damages the straight segment of the proximal tubule, and also the glomerulus.

Neurotoxic Agents: These are materials that produce their main toxic symptoms on the nervous system, either centrally (brain) or peripherally. Some destroy cells, others interfere with nerve impulse transmission, and others interfere with normal development before birth and in early childhood. Among them are metals such as manganese, mercury, lead, and thallium. The brain is partially protected by a physiologic barrier, such that many chemicals have a low transfer rate from blood to brain. The CNS seems particularly sensitive to organometallic compounds, and neurological damage results from such materials as methylmercury, tetraethyl lead, and trialkyl tin. Manganese appears to interfere with dopamine production and causes Parkinsonism. Most short chain organics and simple aromatic compounds, including most organic solvents, are CNS depressants, and many of the halogenated hydrocarbons have been used as anesthetics because of this property.

Other chemicals act mainly on the peripheral nervous system. Lead and other metals can cause a peripheral neuropathy leading to decreased strength and sensation in hands and feet, and eventually to gain and other disturbances. The solvent n-Hexane, causes long nerve fibers to die. The organic phosphorus insecticides (such as parathion and chlorpyrifos), inhibit the enzyme acetylcholinesterase, and lead to an accumulation of acetylcholine and blockage of nerve transmission.

Agents That Act on the Blood or Hematopoietic System: Some toxic agents such as nitrates, aniline, and toluidine convert hemoglobin to methemoglobin. Nitrobenzene forms methemoglobin and also lowers the blood pressure. Arsine produces hemolysis of the red blood cells. Benzene damages the hematopoietic cells of the bone marrow and is known to cause leukemia.

Pulmonary Toxins: In this category are materials that produce damage of the pulmonary tissue other than by immediate irritant action. Fibrotic changes are produced by materials such as free silica, which produces the typical

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silicotic nodule. Asbestos also produces a typical damage to lung tissue and there is newly aroused interest in this subject from the point of view of possible effects of low level exposure of individuals who are not asbestos workers. Other dust, such as coal dust, can produce pneumoconiosis that, with or without tuberculosis superimposed, has been of long concern in mining. Many dusts of organic origin such as those arising in the processing of cotton or wood can cause pathology of the lungs and/or alterations in lung function. The proteolytic enzymes added to laundry products are an occupational hazard of current interest. Toluenediisocyanate (TDI) is another material that can cause impaired lung function at very low concentrations, and there is evidence of chronic as well as acute effects. Other substances that do not cause fibrotic changes may lead to chronic inflammation, reactive airway dysfunction syndrome, or asthma.

HEALTH AND SAFETY STANDARDS AND THEIR DEVELOPMENT

Historically, there was very little concern for protecting the health of the worker prior to 1900. The English Factory Acts of 1833 were the first example of government's interest in the health of the working man. This interest was related to providing compensation for accidents rather than prevention. In 1908, the U.S. government passed a compensation act for certain civil employees and by 1948 all states had passed such legislation. This focus on compensation led to the development of industrial health and safety as it became more profitable to control the environment than to pay for its negative health effects [Amdur, 1973]. In 1912, the U.S. Public Health Service was given the authority to investigate conditions relating to worker health and safety in many industries and to make recommendations for concrete, workable solutions.

A major change occurred with passage of the Occupational Safety and Health Act of 1970, which established the Occupational Safety and Health Administration (OSHA) as an enforcement agency, and the National Institute of Occupational Safety and Health (NIOSH) as a research and consultative agency. NIOSH, a division of the U.S. Public Health service develops criteria which are intended to help management and labor develop better engineering controls and more healthful work practices, and on which OSHA should establish its regulatory standards (but see below).

Because of the proliferation of chemicals in working environments and the resulting exposure of workers to potentially toxic substances, it has become necessary to establish some standards regarding the limits of contamination of the atmosphere which could be considered safe.

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Threshold Limit Values: (TLVs) are published annually by the American Conference of Governmental Industrial Hygienists (ACGIH) for approximately 400 substances [ACGIH, 1997]. TLVs refer to airborne concentrations, and represent conditions under which it is believed that nearly all healthy humans may be repeatedly exposed for a 40-hour workweek, without adverse effects. TLVs for air contaminants that exist as gases or fumes are expressed as ppm (parts per million parts of air by volume at 25°C and 760 mm Hg pressure). TLVs for respirable dusts, which are suspended in the air are in terms of mppcf (millions of particles per cubic foot of air). The TLVs are based ona time-weighted average (TWA). ACGIH also publishes short-term exposure limits (STELs), which are the maximum amount to which a worker could be exposed for 15 minutes.

Permissible Exposure Limits: The Occupational Safety and Health Administration adopted the TLVs that had been published in the 1968-69 as its permissible exposure limits. TLVs are recognized as guidelines, while the OSHA PELs can be enforced. Although the ACGIH periodically updates its TLVs, OSHA had done so for only a few compounds, since the process of changing their standards requires complex rule-making, subject to legal challenge. Thus where there is a discrepancy between the PEL and the TLV, the more protective level should be adhered to.

Biological Exposure Indices: The use of Biological Exposure Indices (BEIs [ACGIH, 1997]) provides a valuable adjunct to TLVs and PELs, which are based on air analysis. The analysis of blood, urine, hair, or exhaled air for a toxic material (e.g., Pb, As) or for a metabolite of the toxic agent (e.g., thiocyanate, phenal) gives an indication of the exposure of an individual worker. These tests represent a very practical application of data from experimental toxicology. Research in industrial toxicology is often oriented toward the search for a test suitable for use as a BEI that will indicate exposure at a level below which damage occurs. Biological monitoring determines both the occurrence of exposure and the uptake (or presence) of a particular substance or its metabolites in body fluids or organs; it can be used to estimate the dose to effector organs and possibly the concentration at binding sites (receptor compartment) in the critical organs. It may complement both medical surveillance and environmental monitoring [Gallo, 1996]. (For more information, see Chapter 7, Medical Surveillance for Hazardous Waste Workers.)

SUMMARY

This toxicology overview is intended to acquaint the reader with some of the terminology that health scientists use to communicate toxicological

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information to the public, industrial hygienists and environmental health workers. The reader should be aware throughout this overview of the complexity of the issue and the difficulty of establishing specific, definitive exposure limits to hazardous substances. The range of responses from individuals to the same toxic substance plus the imprecise process of extrapolating animal exposure to human tolerance must be appreciated by the hazardous waste worker. Great care should be taken to prevent and/or limit hazardous waste worker exposure to the lowest practical level.

Any program to protect the health and safety of hazardous waste workers will be made more effective by a basic understanding of the science of toxicology. The detection of potentially toxic substances before damaging concentrations are reached is important for the prevention of worker injury. The ability to recognize the workers' symptomatic responses to toxic exposures is fundamental for timely intervention. The perspective that toxicology provides to site supervisors, project managers and others involved in worker health and safety is an essential part of any successful health and safety program.

RISK ASSESSMENT

Introduction

Risk assessment builds naturally on our understanding of basic toxicology, but includes, in addition, the assessment of exposure and the estimation of risk to target populations. Potential toxicants are present in air, water, soil and food. "Toxicant" refers to any synthetic or natural chemical that can produce adverse health effects. Various federal and state agencies evaluate potential health effects and establish standards of exposure. Each agency uses a variation of a methodology generally referred to as risk assessment. This process includes:

- Characterization of the types of health effects expected;
- Characterization of exposure;
- Evaluation of experimental studies (animal and/or epidemiologic);
- Characterization of the relationship between dose and response;
- Estimation of the risk (synonyms: probability, frequency) of occurrence of health effects;
- Estimation of the number of cases expected in an actual or theoretical population;
- Characterization of the uncertainty of the analysis; and

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- Recommendation of an acceptable concentration in air, food, or water or a cleanup level in soil.

The controlling or reduction of risk is usually called risk management and is distinguished as a separate activity, informed by the risk assessment process [Presidential Commission, 1997]. Risk assessments are necessary for informed regulatory decisions regarding:

- Worker exposures;
- Industrial emissions and effluents;
- Ambient air and water contaminants;
- Chemical residues in foods;
- Cleanup of hazardous waste sites;
- Land use decisions for contaminated sites; and
- Naturally occurring contaminants.

The major impetus for conducting risk assessments comes from federal legislation. Major federal health and safety statutes have included a directive to control public health risks, for example

- Food, Drug, and Cosmetic Act (1938);
- Federal Insecticide, Fungicide, and Rodenticide Act (1947);
- Clean Air Act (1970);
- Occupational Safety and Health Act (1970);
- Consumer Product Safety Act (1972);
- Clean Water Act (1972);
- Resource Conservation and Recovery Act (1976);
- Safe Drinking Water Act (1976);
- Toxic Substances Control Act (1976); and
- Comprehensive Environmental Response, Compensation, and Liability Act (1980).

None of these statutes and their many amendments defined what degree of public health risk was acceptable or unacceptable. The task of determining acceptable risk was essentially left up to the federal regulatory agencies. In setting permissible exposure limits (PELs) for carcinogens, the Occupational Safety and Health Administration (OSHA) is guided by a 1980 Supreme Court definition of significant risk. The Court found a risk of 1/1000 to be significant. Neither the Supreme Court nor OSHA have stated what they consider to be an insignificant (acceptable) occupational risk. The Environmental Protection Agency's cancer risk management has often used a

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one in a million excess cancer risk as its criterion for acceptability. Most risk decisions fall between these extremes.

In risk assessment, it is especially important to determine the exposure conditions of the risk group so that the most pertinent experimental studies can be selected for risk assessment. "Risk group" refers to the actual or hypothetical exposed group for whom the risk assessment is being conducted. This group can refer to the general population or workers. "Experimental studies" refer to experimental animal or human epidemiology studies used to construct a dose-response model. One of the primary goals of risk assessment is to match risk group and experimental group dose and dose rates in order to obviate the need to extrapolate beyond the experimental dose. With appropriate matching, the health effects associated with exposure of any duration, up to and including lifetime, can be assessed. It is also very important where possible to match the biokinetics and mechanism of action for both the experimental and risk groups. In the absence of comparative biokinetic and mechanistic knowledge, prudence dictates that dose-response data from the most sensitive mammalian test species be used in risk assessment.

An important area of risk assessment is the mathematical treatment of dose-response data. Any equation can be used to fit the range of experimental dose-response data. The only requirement is that the equation must be a good predictor of response over the range of the experimental doses. When a risk group (also known as a target or receptor) is exposed to a dose that is within the experimental dose range, an estimate of risk can be calculated from the same equation used to fit the experimental dose-response data. Controversy arises when the exposure lies far below the range of experimental data requiring mathematical extrapolation.

Risk assessment can be divided into two major categories: the extrapolation approach used for carcinogens or other toxicants which are believed to act without a threshold, and a safety or uncertainty factor approach used for non-carcinogens or toxicants with a demonstrable threshold.

A threshold toxicant is presumed to convey no risk below some experimentally determined threshold dose and dose rate. Threshold toxicants are evaluated by estimating the threshold dose or dose rate, defining the values of relevant safety (uncertainty) factors, and calculating an acceptable concentration or exposure referred to as an acceptable daily intake (ADI) or as a reference dose (RfD).

Nonthreshold toxicants are evaluated differently because they are assumed to convey some risk at all doses above zero. An acceptable concentration is calculated on the basis of an acceptable risk or acceptable number of cases. For nonthreshold toxicants, the true shape of the dose-reponse relationship below the experimental dose range cannot be determined from experimental data. A very large number of subjects would be required to detect small

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responses at very low doses. Even if such a massive experiment were conducted, it would yield an equation for only one chemical [Staffa and Mehlman, 1979]. Hence, the form of the dose-response relationship in the subexperimental dose range must be assumed.

Several theoretical mathematical extrapolation models have been proposed for relating dose and response in the subexperimental dose range: tolerance distribution models (log-normal, log-logistic, and Weibull), mechanistic models (one-hit, multihit, and multistage), time-to-occurrence model, linear-quadratic-exponential model, and linear interpolation. A newer approach, attempting to account for more of the carcinogenesis process, is called the Moolgavkar-Armitage-Doll (MAD) approach. It is impossible to choose among these models based on their fit to experimental dose-response data, because several of the models may fit the experimental data with similar goodness. However, when these models are used to extrapolate below the experimental dose range, predicted responses (at a given dose) usually diverge by several orders of magnitude [Krewski and Van Ryzin, 1981]. These earlier models did not make optimal use of pharmacokinetic data, which is emphasized in recent risk assessments, under the rubric physiologically based pharmacokinetic models (PBPK) (see below).

The linear extrapolation approach uses linear regression to obtain the best fit within the actual dose range, and extrapolates downward to the origin. As dose is increased, the frequency of response will increase and eventually level off. In order to prevent underestimation of risk in the low-dose range, it is very important to interpolate from a dose-response point that does not reflect saturation of response.

It is highly likely that the line resulting from linear extrapolation will bound the true dose-reponse curve in the subexperimental dose range. Hence, linear extrapolation is unlikely to underestimate the true low-dose risk. When a model must be assumed for calculation of risk in the subexperimental dose range, the linear extrapolation model is recommended due to its conservatism, simplicity, and reliance on the single experimental dose-response data point which has the most ability to predict risk in the subexperimental dose range. The biokinetics and toxic mechanism operating at the lowest experimental dose are most likely to be similar to those that exist in the subexperimental dose range. Also, if biotransformation to a toxic metabolite is involved, the relationship between the toxicant dose and the concentration of the toxic metabolite at the site of toxicity is likely to be linear at low administered doses.

Since most linear extrapolations are done for known carcinogens, the mechanism of carcinogenesis has been incorporated into the extrapolation models. The EPA has relied on the linearized multistage model, a modification of the linear model, taking into account evidence that carcinogenesis is a

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multistage process involving initiation (damage to DNA), promotion, and proliferation. A refinement of this is the MAD model (see above).

Risk assessments constitute a significant input to the decision making process. It is very important that whenever possible all sources of uncertainty by identified and accompany a risk assessment so that the limitations of the quantitative results can be clearly understood. Uncertainty in a risk assessment can result from

- Poor specification of the experimental or risk group conditions of exposure, i.e. Concentration, duration, route, chemical species;
- Differences in biokinetics and/or toxic mechanism between species;
- Limitations of the low-dose extrapolation model;
- Exposure to multiple toxicants or confounders in epidemiology studies (for example smoking differences between groups) difference in age at first exposure between an experimental group and a risk group;
- Failure to diagnose or misdiagnosis of the cause of mortality in epidemiologic studies;
- Inappropriate control groups (particularly if some "controls" were actually exposed (i.e., misclassification);
- Use of an experimental study involving an inappropriate route of exposure; and
- Toxicant interaction with another agent.

Most risk assessments contain one or more of these sources of uncertainty. In some risk assessments, there will be sufficient information to carry out a quantitative evaluation of the impact of uncertainty. In other cases, it may be possible to carry out only a qualitative evaluation of the impact of uncertainty. In either event, the process of evaluating the impact of "what ifs" is referred to as sensitivity analysis.

Qualitative Evaluation of Human And Animal Studies

Control Data: Qualitative characteristics of human and animal studies must be evaluated in order to select the most appropriate studies for use in a risk assessment. For example, it is essential that a study has quantitative exposure and response data. Epidemiology studies usually do not have quantitative exposure data. However, qualitative epidemiology studies can be useful for assessing the association between exposure to a toxicant and disease.

The type of control group used in an epidemiology study is a major determinant of whether or not a statistically significant adverse effect can be

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detected in an exposed group. The ability to detect a health effect increases with increasing level of similarity between the exposed and unexposed groups on the bases of socioeconomic variables, lifestyle variables, and competing causes of death. In most epidemiologic cohort studies, the expected number of cases are computed on the basis of death rates for the general U.S. population. The following control groups offer improved matching of exposed and unexposed groups (in order of increasing preference):

- Regional general population;
- General population of a state;
- Local general population; and
- Workers in the same or a similar industry who are exposed to lower or zero levels of the toxicant under study.

It is much easier to match test and control groups in an animal bioassay since all variables can be matched (e.g., species, strain, sex, age, diet). However, sometimes an uncontrolled process may occur in the test and/or control groups which could confound the results of the bioassay. For example,

- Food or water avoidance due to high-level dosing;
- Abnormal metabolism caused by high-level dosing;
- Early mortality due to infectious disease; and
- Contamination of diet with some toxicant mixup in animals.

There are two standard ways of checking long-term bioassay data for uncontrolled effects: comparison of weight versus time and mortality (percent dead) versus time curves. Ideally, the curves for the test and control groups will be almost identical (i.e., superimposed). A divergence of weight versus time curves usually indicates that there was a disruption of normal homeostasis in the test animals. Disruption is most likely due to high-level dosing at the maximum tolerated dose (MTD). In the absence of unusual morbidity or premature mortality, large differences in weight gain may be the only indication that the test dose was too high. The greater the divergence in weight gain curves, the more likely it is that the results of the experiment are confounded by uncontrolled factors such as abnormal metabolism or food avoidance. The use of the MTD is toxicologic studies is controversial, and has recently been defended by a National Research Council committee.

A divergence of mortality versus time curves may indicate the presence of an uncontrolled effect. Premature deaths in the test or control groups may be caused by events such as contamination of a batch of animal feed, infectious disease, or a test dose that was too high. Some divergence of mortality curves

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is tolerable and is accounted for by adjusting the number at risk downward in the test or control group. For a delayed (i.e., latent) response, an animal is considered to be at risk of developing the response only if it survived from the time of first exposure for a period at least as long as the minimum latent period observed. Reducing the number at risk in the test group will increase the statistical significance of a positive finding. If there is no response observed in the test group, the validity of the study decreases as the number of premature deaths increases. Excessive premature deaths in the control group may necessitate comparing the results in the test group to those observed in historical controls. Historical control data for a particular species and strain are derived from years of observation of hundreds or even thousands of control animals.

Follow-up Period: An experimental study must follow the subjects beyond the length of the minimum latent period to observe all effects and cases associated with exposure. It would be incorrect to conclude that there is no response when the follow-up period is shorter than the minimum expected latent period. Under ideal circumstances, a study will follow subjects for their lifetime. While lifetime follow-up is sometimes a feature of animal studies, it is uncommon in epidemiology studies. Historical-prospective epidemiology studies sometimes have an adequate follow-up period. These studies identify exposures, which occurred in the past, and follow exposed individuals forward in time to determine their morbidity or mortality experience. When adverse effects are noted in an animal or epidemiology study that has less than lifetime follow-up, it should be noted that risk most likely has been underestimated.

Matching of Experimental and Risk Groups: In risk assessment, it is extremely important to select experimental studies (epidemiologic or animal) which match the characteristics of the human risk group (general population or workers) as closely as possible. The accuracy of a risk assessment increases with the degree of matching. The following is a list of variables that should be matched as closely as possible:

- Chemical species;
- Route of exposure;
- Age at first exposure;
- Dose;
- Dose rate;
- Fraction of lifetime exposed;
- Sex;
- Biokinetics (absorption, distribution, storage, biotransformation, and elimination as a function of time); and
- Toxic mechanism.

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Complete matching is difficult with animal data (especially on the bases of biokinetics and toxic mechanism). Relatively complete matching is theoretically possible, but difficult in epidemiologic studies.

Special Problems with Animal Studies: Animal studies are usually characterized by the dose, dose rate, and time of exposure to the parent compound. There is no universally agreed on method for estimating an equivalent human dose from an animal study. At least three methods have been proposed to obtain an estimate of the equivalent human dose. The first method seeks to calculate a simple equivalent human dose from an animal study by adjusting (scaling) the animal dose rate for animal body weight. In addition, this method can incorporates several possible safety (uncertainty) factors. The most important uncertainty factor is used to account for a potential difference in animal and human sensitivity to the compound. A difference in sensitivity could result from differences in biokinetics and mechanism of action. The magnitude of this interspecies uncertainty factor is arbitrary and is usually assigned a value of 10. Uncertainty is reduced whenever there is experimental evidence of concordance between animal and human biokinetics and mechanism of action.

The second method seeks to calculate a simple equivalent human dose from an animal study by adjusting the animal dose rate for difference in metabolic rates [Davidson, et al., 1986]. Since basal metabolic rate is directly related to surface area (more closely than to body weight), this method is referred to as the surface area adjustment or surface area scaling method. For the most common experimental animals (rats and mice), the first two methods yield about the same equivalent human dose. Whenever more than one uncertainty factor is used in the first method, the first method will yield a smaller equivalent human dose than the second method.

The third method seeks to calculate a target tissue exposure (concentration x time) using a physiologically based pharmacokinetic model (PBPK model) [NRC, 1987]. A PBPK model incorporates biological data (e.g., alveolar ventilation, cardiac output, blood flow in tissues, partition coefficients, body weight, and tissue volumes) and processes (e.g., tissue binding, Michaelis-Menten kinetics, parallel organ specific elimination, enzyme induction and inhibition, biliary recycling, diffusional resistance across cell membranes, and receptor number and affinity) [Paustenbach, 1989]. Implementation of a PBPK model requires sophisticated mathematical software. Calculation of the true effective target tissue exposure requires complete knowledge of biokinetics and the mechanism of action. This information is rarely known for animals or humans. Hence, it is almost impossible to confirm whether or not a PBPK model, for all its complexity, constitutes an improvement on the less complex calculations described above.

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Special Problems with Epidemiology Studies: Response data in epidemiology studies is reported in various ways: standard mortality ratio (SMR), relative risk (RR), odds ratios (OR), and proportionate mortality ratio (PMR). SMR and RR, and even OR data can be utilized in risk assessment. However, PMR data should be used with great caution [DeCoufle et al., 1980; Najarian, 1978; Walrath and Fraumeni, 1983; Wong, 1983]

Many epidemiology studies involve the collection of mortality data. Causes of death are obtained from death certificates. Only rarely are the listed causes of death confirmed by autopsy. Hence, death certificate data are recognized as having potential inaccuracies, which somewhat offsets the large sample sizes that can be gathered. Exposure data is usually problematic. It is frequently unavailable or compromised due to inaccurate or unrepresentative measurements. Sometimes there is multiple chemical exposure, which usually is not quantitated.

Epidemiology studies frequently lack the power to detect an association between exposure and health effects. Hence, a negative study needs to be evaluated for this design defect before a negative result is given much credence. The results of epidemiology studies are commonly evaluated by looking at certain probabilities associated with the null hypothesis [Beaumont and Breslow, 1981]. The null hypothesis contends that the frequency of response in the exposed group is equal to that of the control group. The probability of wrongly rejecting the null hypothesis is referred to as the level of significance, and the acceptable probability of this type of error is usually set at 5percent. The probability of wrongly accepting the null hypothesis is referred to as beta. Finally, the probability of correctly rejecting the null hypothesis is called the power of the study and is equal to 1 - beta. In the design of an epidemiology study, it is very important to maximize the power.

Classification of Toxicants by Health Effect and Dose-Response Character: There are several classes of toxicant-induced health effects:

1. Cancer due to genotoxic (DNA interactive) and nongenotoxic (non-DNA interactive or epigenetic) mechanisms operating in somatic cells (non-reproductive cells);
2. Hereditary effects due to genotoxic mechanisms operating in germ cells (reproductive cells);
3. Developmental effects due to genotoxic or nongenotoxic mechanisms operating on somatic cells and/or interfering with intercellular communication; and

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4. Organ/tissue effects (e.g., damage to reproductive organs, nerve tissue, liver, kidney, lung) due to nongenotoxic mechanisms operating in somatic cells. Organ/tissue effects can be immediate or delayed.

Dose-response relationships for toxicants are of two types:

1. A nonthreshold (or zero threshold) dose-response elationship is used for toxicants which are known or assumed to convey some risk of adverse response at any dose above zero. Nonthreshold toxicants include toxicants causing hereditary effects, genotoxic carcinogens, and genotoxic developmental toxicants.
2. A threshold (or nonzero threshold) dose-response relationship is used for toxicants that are known or assumed to produce no adverse effects below a certain dose or dose rate. Threshold toxicants include nongenotoxic carcinogens, nongenotoxic developmental toxicants, and organ/tissue toxicants.

Acceptable concentrations for nonthreshold toxicants are computed using the risk analysis method, whereas acceptable concentrations for threshold toxicants are established using the safety (uncertainty) factor method. Sometimes both types of dose-response relationships may apply to a toxicant which produces multiple types of health effects. Whenever both dose-response models apply to a single toxicant, the lowest acceptable concentration (calculated from either method) should be adopted for regulatory purposes.

Hierarchy of Data Selection: Human and animal dose rates are frequently reported in terms of the following abbreviations: NOEL, NOAEL, LOEL, and LOAEL. These are defined as follows.

- NOEL (no-observed-effect level in mg/kgCd) is the highest experimentally determined dose rate that does not produce a statistically or biologically significant *effect* of any kind, physical or pathological.
- NOAEL (no-observed-*adverse*-effect level in mg/kgCd) is the highest experimentally determined dose rate that does not produce a statistically or biologically significant *adverse effect* (adverse effects judged to be trivial may be excluded).
- LOEL (lowest-observed-effect level in mg/kgCd) is the lowest experimentally determined dose rate that produces a statistically or biologically significant *effect*.

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- LOAEL (lowest-observed-*adverse*-effect level in mg/kg/d) is the lowest experimentally determined dose rate that produces a statistically or biologically significant *adverse effect.*

The quantitative relationship among these four terms is usually as follows: NOEL < LOEL < NOAEL < LOAEL. The magnitude of a NOEL, NOAEL, LOEL, or LOAEL is a function of species, type of pathology, sample size, route of exposure, age at first exposure, duration of exposure, and observation time from first and last exposure. When human data are not available, it is recommended that the NOEL, NOAEL, LOEL, or LOAEL be selected from a study of the most sensitive animal species. This is necessary because, as in the case of thalidomide, even the most sensitive animal species tested may be less sensitive than humans.

The safety (uncertainty) factor method for calculating acceptable concentrations utilizes the NOAEL. There are an infinite number of possible values of NOEL and NOAEL up to the LOEL and LOAEL. Within a species and type of pathology, use the highest NOAEL unless it is based on a small sample size. In this case, the next lower NOAEL may be selected. If there are several significant pathologies within a species, use the lowest NOAEL unless it is based on a small sample size. In this case, the next higher NOAEL may be used. If there is not usable NOAEL data, the lowest LOAEL is used (with appropriate modifications).

The risk analysis method utilizes dose data associated with statistically significant responses to develop a dose-response relationship for the experimental dose range. Linear extrapolation may be used to bound the true dose-response relationship in the subexperimental dose range. In this case, a line is drawn between the LOEL or LOAEL and the origin.

Delayed effects of long-term, low-level exposures, usually are of primary concern in risk assessment. Hence, the most relevant type of exposure is lifetime and low-level, and the most relevant observation period is lifetime. Both the safety (uncertainty) factor and risk analysis methods should use human and animal dose-response data generated by the relevant route of exposure and in the following order of decreasing preference:

- Human data: lifetime exposure;
- Human data: less than lifetime exposure with lifetime observation;
- Human data: less than lifetime exposure with less than lifetime observation;
- Animal data: lifetime exposure;
- Animal data: less than lifetime exposure with lifetime;
- Observation; and

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- Animal data: less than lifetime exposure with less than lifetime observation.

In general, animal studies of less than 90 days of exposure and/or less than 18 months of observation from first exposure should not be used if longer term studies are available, or additional safety (uncertainty) factors must be incorporated. Acceptable concentrations derived from human or animal studies of less than lifetime exposure should be referred to as "provisional" acceptable concentrations.

Summary: For risk assessment purposes, an animal study and a risk group should be matched as closely as possible on the following bases:

- Exposure conditions (chemical species, route, dose, dose rate, and fraction of lifetime exposed);
- Biokinetics and mechanism of toxicity;
- Age at first exposure; and
- Sex.

The ideal epidemiology study should have the following characteristics:

- Accurate exposure data with no confounding exposure to other toxicants or with confounders clearly identified and controlled;
- Exposure conditions (chemical species, route, dose, dose rate, and fraction of lifetime exposed) similar to the risk group;
- Statistically significant adverse health effects;
- Lifetime follow-up to detect all cases; and
- Control group composed of individuals from the same or similar industry.

There are several types of toxicity data that can be used in risk assessment. Dose-response data for cancer, developmental effects, and organ/tissue effects can be used quantitatively. DNA alteration data (somatic or germ cell) should be used qualitatively with caution to assess the probability that a genotoxic mechanism underlies cancer or developmental effects.

The following is a summary of the types of information which, ideally, should be derived from an animal or human study in order to carry out a complete risk assessment:

- Age at first exposure;
- Conditions of exposure (chemical species, route, concentration, exposure time, and rate of intake);

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- Body weight;
- Time of observation from first and last exposure;
- Initial number of exposed and control subjects;
- Number of exposed and control subjects surviving at least as long as the minimum latent period start here;
- Number of cases observed in the exposed group;
- Number of cases observed in the control group or expected in the exposed group;
- Type of pathology;
- Characterization of the control group;
- Sex and race or species/strain;
- Biokinetics in animals; and
- Deficiencies in matching among the test, control, and risk groups (e.g., age at first exposure, smoking habits, exposure to other toxicants).

Quantitative Evaluation of Human and Animal Studies

The accuracy of a risk assessment increases with the degree of matching between the experimental (animal and epidemiology) and risk (workers or general population) groups. Whenever possible, the experimental and risk groups should be matched for the following: chemical species, route of exposure, age at first exposure, sex, biokinetics, toxic mechanism, dose rate, dose, and fraction of lifetime exposed. Qualitative evaluation of human and animal studies would determine the degree of matching on the bases of the first six factors.

Calculation of the human dose rate from experimental studies: NOEL, NOAEL, LOEL, and LOAELs are special types of dose rates. They are calculated from animal and human studies as follows:

(NOEL, NOAEL, LOEL, LOAEL) = (C x I)/(W x F) (Eq. 4-1)
where

NOEL, NOAEL, LOEL, and LOAEL are in units of mg/(kg/day)

C = concentration in mg per unit of mass or volume of *contaminated* media (air, water, or food)

I = intake in units of mass or volume of *contaminated* media per day.

W = adult body weight in kg.

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= scaling factor for computing interspecies dose rate

$F = F_1 \times F_2 \times F_3$

The ideal experimental study for risk assessment would be matched to the risk group on the following bases: chemical species, route of exposure, age at first exposure, sex, biokinetics, toxic mechanism, dose, dose rate, and fraction of lifetime exposed. Experimental studies usually do not match risk groups on all nine bases. When there is uncertainty in matching, the NOEL, NOAEL, LOEL, or LOAEL is usually adjusted using arbitrary safety (uncertainty) factors. All of the following safety (uncertainty) factors may not be required. The value of each safety factor is arbitrary and may range from 1 to 10. The following are frequently used safety factors:

F_1 is used to account for potential *interspecies* variation in response sensitivity. $F_1 = 1$ for human data. Values of F_1 may range from 1 to 10 for animal data depending on the match of biokinetics and mechanism of toxicity. If these match, $F_1 = 1$ for an animal study. Default value =10.

F_2 is used to account for potential *intraspecies* variation in human sensitivity. Values of F_2 may range from one to 10. If there are no data regarding human variation in sensitivity, the risk assessor must choose between $F_2 = 1$ or 10. Use F=1 if evidence indicates no variability in susceptibility or F=10 when susceptible subgroups are believed to exist. Pharmaceutical companies are using F=3 as a compromise value.

$F_3 = 10$ is used when a lifetime NOAEL is desired and only short-term NOEL or NOAEL or long-term LOAEL data are available. An additional safety factor of 10 would be applied if the LOEL or LOAEL is derived from a short-term study. Thus, the maximum F_3 is 100.

Calculation of the Equivalent Human Dose from Experimental Studies: The equivalent human dose can be calculated from an animal study as follows:

$$D = (C \times I \times 70 \times T \times 75 \times 365)/(W \times F \times L) \quad \text{(Eq. 4-2)}$$

$$= (1.92 \times 10^6) \times [(C \times I)/(W \times F)] \times f$$

where

D = equivalent human dose in mg

$[(C \times I)/(W \times F)]$ = adjusted dose rate in mg/ kg/day

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70 = adult human body weight in kg

T = median time of exposure in days

L = lifetime of experimental species in days

I = scaling factor for computing interspecies time

F = T/L = fraction of lifetime exposed

75 = human lifetime in years

365 = days per year

$1.92 \times 10^6 = 70 \times 75 \times 365$

The above equation can be simplified for data derived from a human study where W = 70 kg and L = 75 years:

$$D = C \times I \times T \quad \text{(Eq. 4-3)}$$

where D = dose for each exposure subgroup in an epidemiology study.

Quantitation of Response: The frequencies of response in the test and control groups in animal studies are computed as follows:

$$P_t = X_t/N_t \quad \text{(Eq. 4-4)}$$

$$P_c = X_c/N_c \quad \text{(Eq. 4-5)}$$

where

T = test group data

C = control group data

P = proportion responding adversely

N_t and N_c = number of animals surviving for at least the minimum latent period from first exposure. When a response is delayed and there is evidence of premature deaths in the test or control groups, N must be adjusted downward.

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An animal is considered to be at risk only if it survived from the time of first exposure for a period at least as long as the minimum latent period.

X = number of cases of (a) a type of pathology (e.g., a specific tumor type) or (b) any type within a class of pathology (e.g., all tumor-bearing animals = TBA). These two definitions obviate multiple counting of animals with multiple types of pathology (e.g., multiple tumor types).

Overall tumor frequency is best characterized by TBA data. The hypothetical data in Table 4-3 can be used to assess errors caused by the occurrence of multiple tumor types in the same animal. Multiple tumor types could result from multiple primary and/or secondary (metastasized) tumors. Total tumor frequency in the test or control groups cannot be calculated by simply adding four tumor frequencies in Table 4-3. Clearly, the total would exceed 100 percent in the test group. The TBA data indicate that: (a) 25 animals had tumors in the test group, (b) three animals had tumors in the control group, and (c) there were multiple tumor types in test and control animals. Whenever TBA data are not reported, the highest *individual* tumor frequency should be used in risk assessment in order to avoid multiple counting of the same animal. The same type of analysis would be used for multiple non-cancer pathologies.

When TBA response in the test group is not statistically greater than that in the control group, further data analysis may be necessary. Frequently, one or more individual tumor types will be statistically significant. Risk assessment can then proceed on the basis of individual tumor types rather than on TBA data.

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Table 4-3. Hypothetical Tumor Response Data for Rats

Tumor Response	**Tumor Incidence (X/N)**	
	Control Group 0 ppm, $N_c = 50$	**Test Group 100 ppm, $N_t = 50$**
Lung	2/50	20/50
Stomach	1/50	22/50
Brain	0/50	14/50
Liver	3/50	10/50
Any tumor type = TBA	3/50	25/50

The results of epidemiology studies are frequently reported in terms of SMRs:

SMR = standard mortality ratio

= ratio of observed to expected number of deaths

= O/E

O = observed number of cases in the exposed group; same as X_t in an animal study.

E = expected number of cases in the exposed group; analogous to X_c in an animal study. The value of E is usually based on the health experience of a large control (unexposed) or reference group such as the general population.

The number of observed and expected cases can be used to calculate P_t and P_c as follows:

$P_t = O/N_t$ = proportion responding adversely (response frequency) in the exposed group; same as P_t in an animal study.

$P_c = E/N_t$ = proportion expected to respond adversely in the exposed group; analogous to P_c in an animal study.

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N_t = number at risk in the exposed group

Tests of Significance: Tests of significance involve the statistical treatment of a dichotomous response variable (i.e., the proportion of subjects responding in the exposed and control groups). There are three ways to test statistical significance of the difference between two proportions. One is the Fisher's exact test based on the binomial distribution. This test usually requires a computer solution. The normal and Poisson approximations to the binomial distribution can be used whenever certain criteria are satisfied. If these criteria are satisfied, all three probability distributions will yield about the same result. The two approximate methods do not require computer solutions.

Calculation of Excess Risk: There are few, if any, types of responses caused by a toxicant that do not also appear in a control or unexposed group (often called a background rate). The mechanism of toxicant-induced response may or may not be the same as the one causing the response in the control group. In order to obtain the response frequency due to the toxicant alone, it is necessary to adjust the test group response downward using the control group response. This is accomplished by assuming that the mechanism of the control response is completely different from (i.e., independent of) that of the test dose response. Excess risk, P_e is calculated as follows:

$$P_e = (P_t - P_c)/(1 - P_c) \quad \text{(Eq. 4-6)}$$

RISK ANALYSIS

Risk analysis has been used primarily to evaluate nonthreshold toxicants. Most applications of risk analysis have concerned carcinogens (genotoxic and nongenotoxic). It is likely that risk analysis will be extended to developmental toxicants (especially genotoxic types) and hereditary disease toxicants in the future. Risk analysis involves the calculation of excess risk for a risk group. The procedures are straightforward for risk group doses which fall *within* the range of experimental doses. In this case, one or more of the following models are used to fit experimental dose-response data:

Tolerance distribution models: probit, logit, Weibull
Mechanistic models: one-hit, multi-hit, multistage
Linear-quadratic-exponential model

Some of these models will fit experimental data equally well. Hence, it can be a matter of personal preference as to which model is used to fit experimental dose-response data. When a risk group dose falls within the experimental dose

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range, excess risk and number of excess cases expected are calculated using one or more of the above models.

Usually, the dose for an individual or group at risk is well below the range of experimental doses. Any of the models discussed above could be used to extrapolate experimental dose-response data into the subexperimental range. For the reasons discussed in the Introduction, linear interpolation is recommended between the response observed at the lowest experimental dose and the origin (at zero dose and zero response) for toxicants which are known or assumed to have no threshold. Hence, excess risk in the subexperimental dose range can be calculated as follows:

P_e = [(experimental excess risk)/(lowest experimental dose)] x D

$= R \times D = R \times C \times I \times T$ (Eq. 4-7)

where

P_e = excess risk for an individual or group at risk

R = risk factor (in mg^{-1}) = excess risk per unit of dose
(derived from the lowest available experimental dose-response point)

D = C x I x T = individual or risk group dose in mg

An important part of risk analysis is the estimation of the number of cases which may be generated by a certain scenario of exposure. Risk groups of primary concern are the general population and subsets of the general population such as worker groups. Scenarios of exposure can involve changes in the concentration and number of toxicants over time, changes in the number of exposed individuals over time, and migration of individuals into and out of the risk group. Usually, the risk group dose is well below the range of experimental doses. In this case, linear extrapolation is recommended between the response at the lowest experimental dose and the origin (at zero dose and zero response) for toxicants which are known or assumed to have no thresholds (e.g., carcinogens). The number of excess cases can be calculated as follows:

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(Eq. 4-8)

I=1 J=1

$$EC = \sum^{nk} EE\,(R \times D \times N)_{ij}$$

$$= \sum^{nk} EE\,(R \times C \times I \times N)_{ij}$$

i=1 j=1

where

EC = excess cases generated over some exposure period
k = number of toxicants
n = number of distinct doses of a toxicant
N_{ij} = number of individuals exposed to a specific dose of a specific toxicant
D = C x I x T = dose in mg

Acceptable Concentration

The method of calculating an acceptable concentration depends on whether a toxicant has a threshold or nonthreshold dose-response relationship. If the toxicant has a *nonthreshold* dose-response relationship, acceptable concentrations can be calculated for the general population and workers on the basis of acceptable excess risk or acceptable number of excess cases. If the toxicant has a *threshold* dose-response relationship, acceptable concentration can be calculated for the general population or workers on the basis of a NOAEL or LOAEL. There are several important concepts associated with the calculation and evaluation of an acceptable concentration:

- Most acceptable concentrations are established to protect against health effects generated from long-term exposure. When acceptable concentration is based on a human or animal study involving less-than-lifetime exposure and/or observation time, the acceptable concentration should be considered to be provisional.
- The risk analysis method is used to calculate acceptable concentrations only for those toxicants that are known or assumed to have no threshold of

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response (e.g. carcinogens). LOEL, LOAEL, and higher dose rate data points are used in the risk analysis method of calculating acceptable concentrations.

- The safety factor (uncertainty factor) method is used to calculate acceptable concentrations only for those toxicants which are known or assumed to have a threshold of response (e.g. organ/tissue toxicants). NOEL and NOAEL data from human or animal studies are used in the safety factor (uncertainty factor) method of calculating acceptable concentrations.

Sometimes a toxicant will produce multiple types of health effects. Whenever both threshold and nonthreshold dose-response models apply to the same toxicant, accceptable concentration can be calculated from either the safety factor or risk analysis method. It is recommended that the lowest acceptable concentration be adopted for regulatory purposes.

Risk Analysis Method for Calculating Acceptable Concentrations for Nonthreshold Toxicants: Nonthreshold toxicants include hereditary disease toxicants, some carcinogens, and some developmental toxicants. The following equation can be used to calculate an acceptable 8-hour time-weighted average workplace concentration:

(Eq. 4-9).

PEL = (acceptable working lifetime risk)/(11,250 x R x I)

where

acceptable risk = 10^{-3} for OSHA
PEL = acceptable air concentration
11,250 days = 250 working days/year x 45 years of work
R = risk factor in units of risk/mg
I = intake in m^3 of contaminated air/day

It is important to insure that a worker's lifetime risk due to all toxicants does not exceed some acceptable level of risk. Consider the scenario where there are several airborne toxicants, and each toxicant has an acceptable concentration based on the same acceptable lifetime risk of, for example, 10^{-3}. In this case, the following equation can be used to assess compliance with a total risk of 10^{-3}:

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(Eq. 4-10)

$$\sum_{i=1}^{n} ECi / PELi \#1$$

where n is the number of airborne toxicants in a class toxicants. The class could be, for example, all carcinogens.

Safety Factor (Uncertainty Factor) Method for Calculating Acceptable Concentrations for Threshold Toxicants: Threshold delayed effects can result from short-term and long-term exposure to organ/tissue toxicants, some carcinogens, and some developmental toxicants. "Delayed effects" refer to health effects that occur weeks, months, or years after first exposure to a toxicant. "Short-term" delayed effects generally refer to health effects which occur within weeks or months of first exposure. "Long-term" delayed effects generally refer to health effects which occur years after first exposure; exposure could be short-term or long-term. Acceptable concentrations to prevent delayed effects can be calculated from the appropriate short-term or long-term $NOEL_a$ or $NOAEL_a$ as follows:

(Eq. 4-11)
PEL = [($NOEL_a$ or $NOAEL_a$) x 70 x f 365 x 75]/(I x T)
where
PEL = Permissible Exposure Limit

$NOEL_a$ = adjusted no-observed-effect level in mg/kg/Cd. The fraction of lifetime of exposure (f) of the experimental group should be closely matched to that of the risk group.

$NOAEL_a$ = adjusted no-observed-adverse-effect level in mg/kgCd. The fraction of lifetime of exposure (f) of the experimental group should be closely matched to that of the risk group.

70 = adult human body weight in kg
f = fraction of lifetime of exposure in the experimental study
365 = days per year
75 = human lifetime in years
T = exposure time of risk group in days
I = intake in m^3 of contaminated air/day

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It is important to insure that exposure to multiple threshold toxicants in a class (e.g., all toxicants which can cause liver damage) does not exceed a combined threshold and produce toxicity. Eq. 4-10 can be used to assess compliance with the prevention of a type of delayed health effect:

Organ/tissue threshold toxicants can cause immediate effects. By definition, T = 0 for immediate effects. Hence, acceptable concentration is based on a short-term $NOEL_a$ or $NOAEL_a$ only:

$$PEL = [(NOEL_a \text{ or } NOAEL_a) \times 70]/I \quad \text{(Eq. 4-12)}$$

The value of the PEL should be interpreted as a maximum acceptable concentration.

It is important to ensure that exposure to multiple threshold toxicants in a class (e.g., all toxicants which can cause liver damage) does not exceed a combined threshold and produce immediate toxicity. Eq. 4-10 can be used to assess compliance with the prevention of a type of immediate health effect.

Figure 4-3 [ACGIH, 1997]. *The prediction of the concentration in air that will induce narcosis based on solubility in olive oil. The graph allows ready comparison between the ability of a material to form an atmosphere which might be narcosis inducing, explosive or oxygen deficient. For example, propane has an oil solubility of 5.9, a lower explosive limit of 21,000 ppm, it is predicted to cause overt narcotic effects at 47,000 ppm, and at 140,000 ppm has displaced oxygen to 18 percent.*

courtesy of APPL. OCCUP. ENVIRON. HYG.

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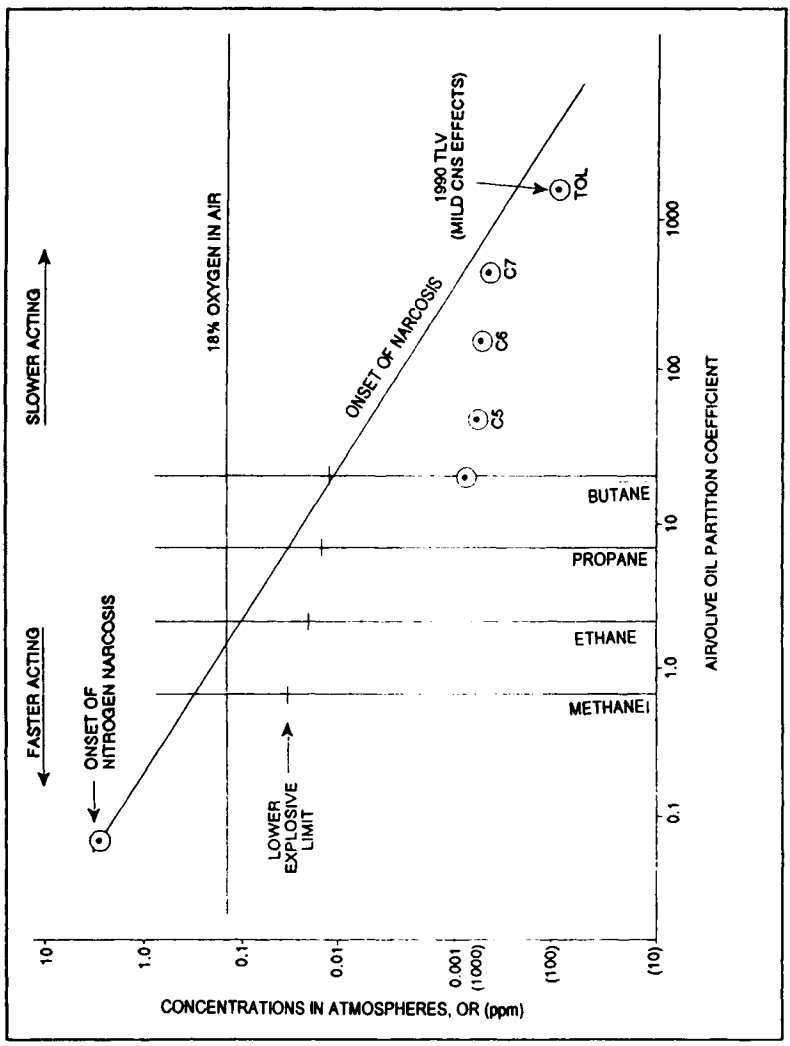


Figure 4-3 demonstrates a good relationship between hydrocarbon gases in the atmosphere and the development of nitrogen narcosis.

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AIR MONITORING AT HAZARDOUS WASTE SITES

Edward Bishop, Ph.D., C.I.H.

INTRODUCTION

This chapter discusses strategies for assessing inhalation exposure to chemicals at hazardous waste sites; monitoring strategies, PPE upgrade level selection, commonly used methods for measuring exposures, operating principles and limitations of common direct-reading instruments, instrument selection considerations, and hazardous atmosphere classification.

Reliable measurements of airborne contaminants are necessary

1. To select appropriate protective equipment based on the potential health effects of the exposure;
2. To differentiate between areas where protection is needed and areas where it is not needed;
3. To determine when operations must be halted for safety or health reasons (e.g., well drilling in potentially explosive atmospheres); and
4. To determine medical surveillance requirements.

Industrial hygiene measurements at hazardous waste sites are similar to other workplaces. However, development of sampling protocols and interpretation of the measurements made at hazardous waste sites are more difficult because many complicating factors are present. The factors peculiar to hazardous waste sites include:

1. Workers may receive multiple exposures due to the large number of (often unidentified) bulk chemicals present and the complexity of the mixtures. Compared to hazardous wastes, the composition of industrial chemicals is well known based upon material safety data sheet information. Wastes are at best unknown mixtures of known constituents and more likely mixtures of unknown constituents. Since most hazardous waste site work involves pre Resource Conservation and Recovery Act (RCRA) wastes, drums, etc.,

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are rarely labeled.

2. The variability of exposure with location without a corresponding change of process or unit operation. Traditionally, industrial hygienists have categorized exposures in terms of their location in the production of a product. For example, production line station 1 is associated with particulate heavy metal exposures, while station 2 is associated with acutely toxic vapors. Workers from station 1 would not ordinarily be assigned to station 2, and so the exposure populations are mutually exclusive. At waste sites, the composition and concentration of chemical substances in a worker's breathing zone varies substantially from point to point on the site. This is due to the different processes or types of operation at various site locations and to the variable composition of the waste from point to point. Differences in exposure with site location have been demonstrated for individuals who work full shifts in and around trenches in contaminated soils and workers who handle contaminated materials directly [Costello, 1983].
3. Hazardous waste cleanup usually occurs in an outdoor environment. In-plant exposures are ordinarily confined to the immediate vicinity of their source. Given a localized source, contaminants are not usually transported from one part of the plant to another. In outdoor environments, airborne contaminants are readily transported from one part of the site to another. Workers are not only exposed to the materials that they handle directly, they are also exposed to materials handled elsewhere on the site.
4. The quality of the waste containers is poor. Commercial products are packaged in containers that do not leak under ordinary circumstances. However, deteriorated containers at waste sites routinely rupture and release their contents.
5. The lack of containment vessel integrity and the incomplete identification of contaminants increase the possibility that waste mixing will occur, resulting in dangerous reaction products.
6. Dusts, including both finely divided hazardous solids and other hazardous materials coated onto soil particles, are highly sensitive to a number of factors that can vary significantly with location and time, especially soil moisture content. Vapor emissions can be produced by mechanical displacement of saturated vapors, which can produce relatively high short-term concentrations; direct evaporations, which can produce moderate short-term concentrations; or diffusion mechanisms, which can produce relatively low short-term concentrations. Direct evaporation and diffusion can also be important long-term phenomena since they may continue for long periods of time and involve large areas.
7. Weather is an important factor. Seasonal temperature changes may greatly influence conditions. An increase in soil temperature will markedly

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increase the vapor pressure of volatile materials. Rain or other moisture can cap or plug vapor emission routes and greatly reduce airborne emissions.

MONITORING TECHNIQUES

Industrial hygiene has three primary methods for quantification of airborne contaminants at hazardous waste sites: direct-reading instruments, chemical detector tubes, and traditional personal/area sampling methods.

Direct-Reading Instruments

Direct-reading instruments provide instantaneous indications of the level of contaminants in the work area. These instruments are commonly used to monitor the work site to indicate if the personal protective equipment should be upgraded. The site specific health and safety plan (HASP) required by 29 CFR 1910.120 [U.S. Dept. of Labor, 1989] should specify predetermined trigger levels for upgrading PPE or leaving the area depending upon the contaminants likely to be found and readily measured. The HASP often specifies entry level PPE based on the direct-reading instrument.

Generally these instruments detect properties common to a class or classes of chemicals. As such, these instruments are often nonspecific and may be subject to interferences. That is, they usually indicate total concentrations of components with similar measurement properties. For example, a typical photoionization detector (PID) will provide a readout of the concentration of benzene, toluene, ethyl benzene, and xylenes (BTEX) and other hydrocarbons in the area. While this is useful information, the instrument is unable to distinguish and isolate the more toxic benzene from other the other contaminants. Without additional sampling, a higher level of PPE is required based on the higher PPE levels required to protect against benzene exposure.

Chemical Detector Tubes

Chemical detector tubes are generally more specific than direct-reading instruments. While these chemical detector tubes may also be subject to interferences, the interferents, direction (positive or negative) of interference is usually documented. For example, in the situation above, a benzene chemical detector tube could be used to verify the level of benzene present. Documentation from one manufacturer as an example, indicates toluene, xylene, and ethyl benzene are positive interferents. In addition, the degree of interference may also be reported.

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Personal/Area Sampling

Personal/area sampling uses personal dosimeters or sample pumps and adsorption media tubes or filters with subsequent analysis by a full scale analytical laboratory. As such, results require additional time for analysis, often several days, if not several weeks. While this is of little use for determining PPE levels, personal sampling should be used to supplement direct-reading instruments. These samples can be used to verify direct-reading instrumentation and the selection of PPE after the fact. This monitoring is also essential for medical surveillance purposes.

HEALTH AND SAFETY PLAN

Hazardous Waste Operations and Emergency Response, 29 CFR 1910.120 [U.S. Dept. of Labor, 1989], requires a written health and safety plan (HASP) for all hazardous waste operations. From an air monitoring standpoint, the key requirements of the HASP are the scope of work to be accomplished, identification of potential chemical hazards, and personal protection equipment (PPE) trigger levels. The air monitoring program will vary depending on the length of the operation, the suspected or known hazards, and the potential concentrations.

Scope of Operations

The scope of hazardous waste operations varies from preliminary assessment/site investigation, through remedial investigation/feasibility study, interim removal action, remedial design and remedial action, and emergency response. The primary air-monitoring considerations for different scopes of operations are the duration of the operation and the number of workers potentially exposed. For example, remedial investigation activities such as well installation, hydropunching, or soil gas surveys, are generally characterized by short durations, few workers (two to three), small and localized exposure sources (e.g., well bore hole), and relatively large geographical separations. In contrast, a remedial action or interim removal action at a drum disposal location could involve many workers and the potential for large releases of hazardous materials.

Initial Entry and Emergency Response

Initial entry should only be made by properly protected personnel with

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appropriate direct-reading instrumentation to determine contaminant levels. In the case of an emergency response to a spill, Level A PPE is probably required.

At undefined hazardous waste sites, Level B PPE is the minimum recommended for initial entry. If contaminants are known and are low hazards, a lower PPE level can be used. The initial entry team should make an sweep using a broad spectrum of instrumentation. This should include an oxygen meter, combustible gas indicator, detector tubes for contaminants known to be present, and a radiation survey meter if applicable. Once contaminant levels are identified, the exclusion zone or hot area is defined, appropriate PPE levels are determined, and other teams can enter the area.

IDLH Locations

All confined spaces are potential IDLH locations. These include sumps, silos, cargo holds, storage tanks, and mine shafts. Bermed areas around storage tanks may also be considered confined spaces. IDLH conditions are less likely in open areas because toxic materials emitted into the atmosphere tend to be transported away from the source and simultaneously diluted. Unless there is a very large (and hence readily identifiable) source, such as an overturned tankcar, IDLH conditions in the open atmosphere are likely to be localized and last for only brief periods. An example is the immediate vicinity of a leaking gas cylinder. The initial entry team must identify all potential IDLH locations. This information must be briefed to other personnel working on the site and should be included in the HASP.

Routine Hazardous Waste Site Operations

Since direct-reading instrumentation is the primary air monitoring process, the site HASP should identify direct-reading instrument trigger levels for all known or suspected contaminants. Since direct-reading instruments generally respond to a range of components, chemical detector tubes can be used to further define the atmosphere. In addition, personal sampling may also be used to support the direct-reading results. Charcoal tube or charcoal passive dosimeter samples submitted for off-site analysis will verify the presence of benzene or other contaminants. This can be used to refine the HASP based on the more detailed information. For the long-duration remedial action, more elaborate air-monitoring programs may be required. These could include scheduled personal sampling for different contaminants of concern, real-time and adsorption media fenceline sampling, etc.

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Potential Contaminants

Whether the site is an emergency response to a spill, the first visit to a known hazardous waste site, or a long-term remedial action, accurate identification of the potential contaminants is essential. Similar to workplace evaluations, a presurvey is required to identify potential contaminants to determine the proper sampling method.

At emergency response sites, identification of potential contaminants should be determined from tank/vessel placards or bill of laden prior to initial site entry whenever possible. At hazardous waste sites, identification is complicated by complex mixtures of contaminants, the potential for unknown contaminants, and reactions of wastes resulting in other contaminants. There can be a large number of potential airborne contaminants coexisting in the workplace atmosphere even at small sites (see Tables 5-1 and 5-2). However, a thorough document review, record search, and personal interviews should narrow the list of potential hazardous materials.

Potential Hazardous Effects

The HASP and air monitoring plan at hazardous waste sites must address acute and chronic health effect levels and the explosive ranges for flammable materials.

Acute Effects. Acute effects are adverse health changes which occur after a short period of time (in the order of magnitude of a few seconds or minutes) following exposure. In hazardous waste operations, an important consideration is the immediately dangerous to life or health (IDLH) concentration level. This is the maximum concentration from which, in the event of respirator failure, one could escape within 30 minutes without a respirator and without experiencing any escape-impairing (e.g., severe eye irritation or irreversible health effects) [NIOSH, 1990]. Because immediate decisions concerning protection are usually required, direct-reading instruments are ordinarily used to evaluate exposures likely to result in acute effects.

The short-term exposure level, or STEL, and ceiling levels are other considerations. The STEL is the level at which the average worker can be exposed for 15 minutes without adverse effect [ACGIH, 1992]. Ceiling levels are concentrations which should not be exceeded. The potential harmful effects of short duration exposures above the STEL or ceiling value dictate the use of direct-reading instruments or chemical detector tubes.

Chronic Effects. Chronic effects reflect the cumulative bodily damage resulting from repetitive exposures that do not produce immediately irreversible consequences. The exposures occur again and again during long periods of time (on the order of magnitude of years). The applicable standards at

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hazardous waste sites include the OSHA permissible exposure levels (PELs), NIOSH recommended exposure levels (RELs), and ACGIH threshold limit values (TLVs). Unlike typical industrial workplaces, the latter guidelines are given legally enforceable status for hazardous waste operations per 29 CFR 1910.120 [Levine, et al.1994].

The techniques for measuring the lower levels of exposure that typically produce chronic health effects frequently differ from those used to measure exposures which may result in acute effects. Full-shift personal air samples, analyzed in an off-site laboratory, are ordinarily used to assess these exposures.

Explosive Limits. Flash fires may occur in the explosive range defined as the concentration range between the lower explosive limit (LEL) and the upper explosive limit (UEL). These levels are typically in the percent by volume range for common flammable materials. The *NIOSH Pocket Guide to Chemical Hazards* [NIOSH, 1990] provides the LEL for chemicals likely to be encountered in hazardous waste operations. In industrial operations, health based concentration standards are normally the limiting concentrations. However, hazardous waste operations present unique situations. For example, since properly selected Level A protection should be suitable for all concentrations, there may be a tendency to not perform air monitoring since the highest level of protection is already used. Workers could be in a potentially explosive atmosphere without instrumentation warning of the dangers. Note also the OSHA Confined Space Entry Regulation, 29 CFR 1910.146 [U.S. Dept. of Labor, 1993] defines hazardous atmospheres as greater than 10 percent of the LEL. Direct-reading combustible gas indicators which read in percent LEL are the instruments of choice. However, other instrumentation may be used if the LEL is presented in ppm is the range of the instrument.

Personal Protection Equipment Trigger Levels

Selecting the proper level of PPE for each task is a critical part of the HASP and requires detailed knowledge of the likely contaminants and the work to be performed. Selection of proper PPE is crucial to safe and healthful hazardous waste operations. Too low a level and workers are unnecessarily exposed. However, over protection increases the risk of heat stress, may introduce additional safety hazards from air lines and reduced visibility, reduces productivity, and is more costly in terms of equipment and training [Levine et al., 1994]. In the absence of knowledge of the components, Level B is the minimum protection that can be used [U.S. Dept. of Labor, 1989].

PPE trigger levels to downgrade or upgrade PPE levels must be based on the most components known or suspected to be present in sufficient quantity to

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present a hazard. This can produce a dilemma when more hazardous components have similar analytical properties as other less hazardous and potentially more prevalent components. A common example is benzene present with other hydrocarbons such as might occur at a leaking underground storage tank site. The upgrade from Level D to Level C occurs when the benzene concentration exceeds the 1.0 ppm benzene PEL or gasoline vapor exceed the 300 ppm gasoline TLV. Since a PID or FID responds to most if not all gasoline components (i.e., it cannot distinguish benzene from the other gasoline components), the upgrade may be ordered unnecessarily.

This situation is further confused when the instrument is calibrated to benzene. Inexperienced users may assume the instrument is reading benzene because it is calibrated to benzene. In the absence of other contaminants, the instrument will correctly respond to benzene. However, when other contaminants are present, it will respond to those contaminants also, although not in a predictable manner. To prove this, calibrate an instrument to benzene (or hexane, etc.) and expose the instrument to a permanent marker (alcohol based) or nail polish remover (acetone based) and note the effect.

Calculations of maximum concentrations are valuable in predicting which contaminants may result in greatest potential hazard. Contaminants which cannot be present in potentially hazardous concentrations can be eliminated from consideration.

There are two common equations for estimating the partial pressure of a particular contaminant. These are Raoult's law and Henry's law

Raoult's law: $p_i = x_i P_i^{sat}$

where: p_i = the partial pressure of the *i*th component
x_i = the mole fraction of the *i*th component
P_i^{sat} = the saturated vapor pressure of the *i*th component

Henry's law for dilute aqueous solutions: $p_i = k_i m_i$

where: p_i = the partial pressure of the *i*th component
k_i = Henry's Law constant of the *i*th component
m_i = molality of the *i*th component = moles per 1000 grams solvent (approx moles/L for water)

Raoult's law is exact as the mole fraction approaches one and Henry's Law is exact as the mole fraction approaches zero [Smith and Van Ness, 1975].

Raoult's law will provide sufficiently reliable estimates of vapor pressures

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of components in drums or similar high concentration mixtures, especially if the components are from the same chemical family (e.g., alkanes) and not mixtures of families. Henry's law will provide reliable estimates of equilibrium vapor pressures for dilute sources such as contaminated groundwater sources such as might occur during well drilling, aquifer pump tests, etc. Henry's law constants are specific for the component. A good source of these constants is Tomes [TOMES, 1993]

Two cautions when using these equations. First, ensure the units are compatible. Unit conversions may be necessary to convert the Henry's law constant to yield the partial pressure in units of mm Hg. Second, these equations predict equilibrium vapor pressures - the saturated vapor pressure at the liquid surface (e.g., the concentrated liquid [Raoult's law] or water [Henry's law]). Additional dilution will occur and should be estimated. Outdoors, a conservative estimate is a threefold dilution based upon the general dilution equation for liquids evaporating into an enclosed room and assuming maximum mixing [AIHA, 1982] - a valid assumption outdoors without major wind obstructions.

To convert to parts per million:

$$(p_i \text{ [in mm Hg]}/760) * 10^6 = \text{ppm}$$

The PPE upgrade occurs whenever a trigger level is exceed. As examples:

Raoult's Law

Conservatively, gasoline contains 5 percent benzene by volume. Table 5-1 shows the results of the mole fraction calculations assuming gasoline can be described as a mixture of benzene, hexane, and octane.

Table 5-1
Calculation of Mole Fraction of Benzene in Gasoline

	MW, gm/mole	Density, gm/cm^3	Mole Fraction, Liquid [1]	P_i^{sat}, mm Hg	p_i, mm Hg	Mole Fraction, Vapor
Benzene, 5 cm^3	78.1	0.88	0.08	80.1	6.4	0.07
Hexane, 50 cm^3	86.2	0.66	0.54	68.7	37.1	0.41
Octane, 45 cm^3	114.2	0.70	0.38	125.6	47.7	0.52

[1] (Vol, cm^3)(Density, gm/cm^3)/(MW, gm/mole) = Moles.

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At this composition, what concentration of gasoline vapors contains 1 ppm benzene?

1 ppm benzene = 0.07(gasoline vapor concentration)

At 14 ppm total gasoline vapor, the estimated benzene concentration is 1 ppm. Therefore, the HASP should specify upgrade to PPE Level C when the PID or FID exceeds 14 ppm. To refine the trigger procedures, the HASP could specify using a benzene specific chemical detector tube at the same trigger point to verify the presence of benzene. Air monitoring continues and PPE is upgraded to Level C whenever the benzene concentration exceed 1 ppm by chemical detector tube or gasoline vapors exceed 300 by PID or FID.

Henry's Law

Well drilling and well sampling operations may also present hazards to workers. Many contaminants may be present in the water at the part per billion range. Again, different trigger levels are common for components have similar analytical properties. Use of Henry's law predicts the maximum concentration of dilute contaminants at the air-water interface. This is demonstrated as follows for 1,2,3 trichloropropane in water at 5mg/L:

$k = 3.44 \times 10^{-4}$ atm m^3/mole in water
MW = 147.5 gm/mole

$p = (3.44 \times 10^{-4}$ atm m^3/mole)(5 mg/10^{-3} m^3)/(147.5 gm/mole)

$p = (1.2 \times 10^{-5}$ atm)

$(1.2 \times 10^{-5}$ atm)(10^6 ppm/atm) = 12 ppm

A threefold dilution yields a maximum estimated concentration of 4 ppm which is safely below the PEL of 10 ppm. An appropriate trigger level is based on the next most restrictive component which could be present in greater concentration.

Summary

Development of appropriate trigger levels requires knowledge of the contaminants and their toxicological and physical properties, and knowledge of the available instrumentation and it's strengths and weaknesses. Continual or frequent direct-reading air monitoring is performed during the entire operation.

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PPE is upgraded whenever a trigger level for any contaminant is exceeded. An additional consideration for upgrading to higher PPE levels for highly flammable materials is to ensure 10 percent of the LEL is not exceeded. For example, 10 percent of the LEL for gasoline (1.1 volume %) is 1,100 ppm. This is 3.7 times the PEL of 300 ppm. Since even a half face organic vapor respirator provides a protection factor of 10, the limiting condition is explosivity.

Air-Monitoring Plan

The air-monitoring plan is developed to address PPE trigger levels, LEL, fenceline monitoring, and medical monitoring requirements using available instrumentation. The plan must include direct-reading instruments and chemical detector tubes to determine the proper PPE levels and when to cease operations such as drilling in the event potentially explosive atmospheres occur as described above. The plan should also address the use of direct-reading instruments and chemical detector tubes for fenceline monitoring to protect the public. In these cases, appropriate public exposure criteria must be identified. These will generally be significantly lower than the IDLH or PEL criteria for on-site personnel.

The following discusses air monitoring considerations for personal or area sampling with pump flow or passive monitors with the appropriate adsorption media to verify instrument results.

Sample protocols are designed within laboratory workload and financial restraints. This approach favors selection of materials present in large quantities. It discriminates against substances present in relatively small quantities, unless the health hazard of even infrequent exposure is deemed overriding.

Personal samples should be taken, even in the absence of direct instrument readings indicating contaminants. This sampling will verify the lack of contamination or provide additional information on the nature of the contamination undetected by the direct-reading instruments. The *NIOSH Occupational Exposure Sampling Strategy Manual* [Leidel, 1977] suggests selective monitoring of high-risk workers; specifically, monitoring those workers who are closest to the source of contaminant generation. The rationale for this procedure is that the possibility of a significant exposure varies directly with distance from the source. If the high-risk workers are not exposed significantly, then monitoring high-risk workers conserves resources that would otherwise be necessary to monitor workers further removed from the contaminant source.

In multisubstance environments, where simultaneous exposures are anticipated and where the contaminants must be collected on a number of

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different media, it may be necessary to sample more than one worker in each operation. Because it is not usually possible to draw air through different sampling media using a single portable battery-operated pump, it requires several days to measure the exposure of a specific individual using each of the media [Costello et al., 1983]. Repetitive sampling of more than one worker in each operation is recommended. One way to overcome this problem is to collect multiple area samples on pieces of heavy equipment. While technically not a personal sample, heavy equipment operators remain at the vehicle operators position throughout most of the workshift and usually are employed in the active materials handling part of the site. Samples collected very close to the breathing zone are reasonably representative of personal exposure and these multi-media samples yield as much information as several personal samples [Costello and Melius, 1981].

Sampling should continue throughout the cleanup, unless it can be demonstrated that the site contaminants are homogeneously distributed and that consistent exposures would be anticipated.

Air monitoring at cleanups is not subject to the uncertainties inherent in emergency response actions because background information is usually available to identify prospective contaminants. For planned sampling visits to evaluate suspected chronic hazards examine the available background data to select the site contaminants to be measured. Information sources include the site assessment and remedial investigation reports. These reports provide information on drum samples, contaminant volumes, and the degree and extent of groundwater and soil contamination.

From this information determine the class of contaminants (e.g., pesticides, petroleum hydrocarbons, etc.) and the quantities and concentrations of each. This allows ranking of contaminants by hazard potential and grouping by sample media (e.g., general hydrocarbons on charcoal, amines on silica gel, etc.).

The physical state of a contaminant must also be considered. Many contaminants such as PCBs, PNAs, or pesticides should be measured as both particulate-bound contaminants and as vapors. The volatile component is collected on a solid adsorbent and the non volatile component is collected on a filter. More than two dozen methods have been developed by NIOSH [Hill and Arnold, 1979] which make use of a dual media sampling system to efficiently collect both the particulate and vapor portion of a single contaminant, (e.g., MOCA). Measurement techniques that analyze only the vapor phase of a substance may fail to identify significant exposure to toxic contaminants if the substance is primarily particulate or particulate bound. Some of the sampling media and analytical techniques that have been used during NIOSH studies at hazardous waste sites are listed in Table 5-3.

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Table 5-2
Estimated Volume of Chemicals [Costello et al., 1983] Triangle Chemical Site Bridge City, TX

Number of Drums	Contents	Volume (gallons)
260	Solvents	10,400
60	Acids	3,600
90	Bases	3,600
175	Alcohols	7,000
85	Ether	3,400
250	Empty	0
		28,000

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Table 5-3
Estimated Frequency of Chemicals
[Costello et al., 1983]
Triangle Chemical Site Bridge City, TX

Category	Compounds	Relative Abundance
Solvents	Dichlorobenzene Toluene Trichlorethylene Xylenes Methylethylketone Orthodichlorobenzene	37%
Acids	Cresylic Acid Hydrochloric Acid Hydrofluoric Acid Surfactant (pH 1) Nitric Acid Phosphoric Acid	13%
Bases	Ammonium Hydroxide Caustic (pH 12) Diethanolamine Methylethylamine	13g
Alcohols	Butanol p-Decyl-phenol Ethanol Glycols Rust tem 200 Methanol p-Nonylphenol	25%
Ethers	Ether	12%
		100%

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Table 5-4 Sample Collection and Analytical Methods

Substance	Collection Device	Analytical Method	Typical Limit of Detection (μg)
Anions: Chloride Nitrate Bromide Flouride Sulfate Phosphate	Prewashed Silica Gel Tube	Ion Chromatography	 5 10 10 5 10 20
Aliphatic Amines	Silica Gel	GC/NPD	10
Asbestos Metals Organics I Nitrosamine s Particle Size PCBs	AA Filter AA Filter Charcoal Tube Thermosorb/N Personal Cascade Impactor GF Filter and Florisil Tube	PCM ICP-AES CG/MS GC-TEA Gravimetric GC/HECD/ECD	4500* 0.5 10 0.01 0.05
Pesticides	13mm GF and Chromosorb 102 Tube	GC/MS	0.05

NOTES:

1.ICP-AES means inductively coupled plasma atomic emission spectrometry; GC/MS means gas chromatography and mass spectrometry; IC means ion chromatography; NPD means nitrogen/phosphorus detector; FID means flame ionization detector; HECD means Hall Electrolytic Conductivity Detector; TEA means thermoelectron detector; PCM means phase contrast microscopy.

2.GF means that a glass fiber filter was used for sample collection.

3.*Units in fibers per filter.

DIRECT-READING INSTRUMENTS

Underground miners were among the first to become aware of the need for a device to detect the presence of hazardous gas concentrations. In their environment, the gases could include methane, carbon dioxide, carbon monoxide, oxygen deficiency, and others. Of these gases, methane has often been present in mines in sufficient quantities to explode. Since it is not a

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systemic toxicant and has no warning odor, explosive levels can accumulate before a worker realizes the potential risk. With high methane concentrations, any source of ignition, including those in the original miner's lamps, could readily set off an explosion. It is in this setting that the use of the first "combustible gas indicator," the Davie's lamp, provided a significant step forward in mine safety. The visible characteristics of the flame of the Davie's lamp could inform the experienced user of much more than just the presence of methane. Refinements of the Davie's lamp are still in use today.

A variety of instruments for measuring combustible gases and vapors are currently marketed. However, most are based on one of five common sensor systems: catalytic combustion, photoionization, flame ionization, solid state, and infrared. These are described below and include descriptions of the general operating principles, performance characteristics, and sensor limitations.

Catalytic Combustion

This sensor type literally measures the contaminant by combustion. Air containing the contaminating gases flows over a sensor heated above the ignition temperature of the gas. The gas is ignited and oxidized to carbon dioxide and water. Higher temperatures in the sensor chamber develop as higher concentrations of contaminant gas are ignited. The increase in temperature is measured by a platinum resistance thermometer. As the temperature increases, the resistance of the thermometer increases resulting in a imbalance in the Wheatstone bridge circuitry.

The encapsulation of a platinum resistance thermometer in a ceramic bead coated with a palladium oxide catalyst results in combustion reactions occurring at the significantly lower temperature of 500°C compared to the original hot wire combustible gas indicator. This results in a much more stable zero condition and the encapsulation provides a degree of protection against shock such as accidentally dropping the probe. If the sensor is properly designed, oxidation on the catalytic surface will be diffusion controlled (this will occur even if the sample is drawn past the sensor by pump or aspirated flow) and all flammable gases will be oxidized regardless of other reaction kinetics [Cullis and Firton,]

The signal produced is generally a linear function of the concentration of the combustible gas or vapor present up to 80 percent LEL. When expressed as a percentage of the lower explosive limit, instrument response is relatively independent of the specific contaminant for most hydrocarbons [Industrial cientific Co., 1993]. This is because the product of the heat of oxidation and the lower explosive level is a constant for the commonly encountered hydrocarbons [Cullis and Firth].

As the concentration approaches the lower explosive limit, the instrument

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will reach a maximum level (peg-out). It will stay at this level until the concentration reaches the upper explosive level (UEL). As the concentration rises above the UEL, the response will decrease due to the lack of oxygen to support combustion. This is shown in Figure 5-1.

These instruments should be relatively unaffected by changes in humidity, however, several users have reported humidity effects. These effects are generally in a positive direction (meter reading is greater than known concentration).

Although these instruments will respond to chlorinated hydrocarbons, a product of combustion is hydrochloric acid which corrodes the sensor and greatly reduces sensor lifetime. Organic lead compounds such as found in leaded gasoline may poison the sensor.

Strengths

- General purpose detector for most combustible hydrocarbons.
- Linear response to 80 percent LEL.
- Indicates total combustibles present.
- Relatively unaffected by temperature and humidity changes.

Weaknesses

- Nonspecific.
- Requires oxygen (air) for operation.
- Not recommended for chlorinated hydrocarbons or tetraethyl lead containing compounds.

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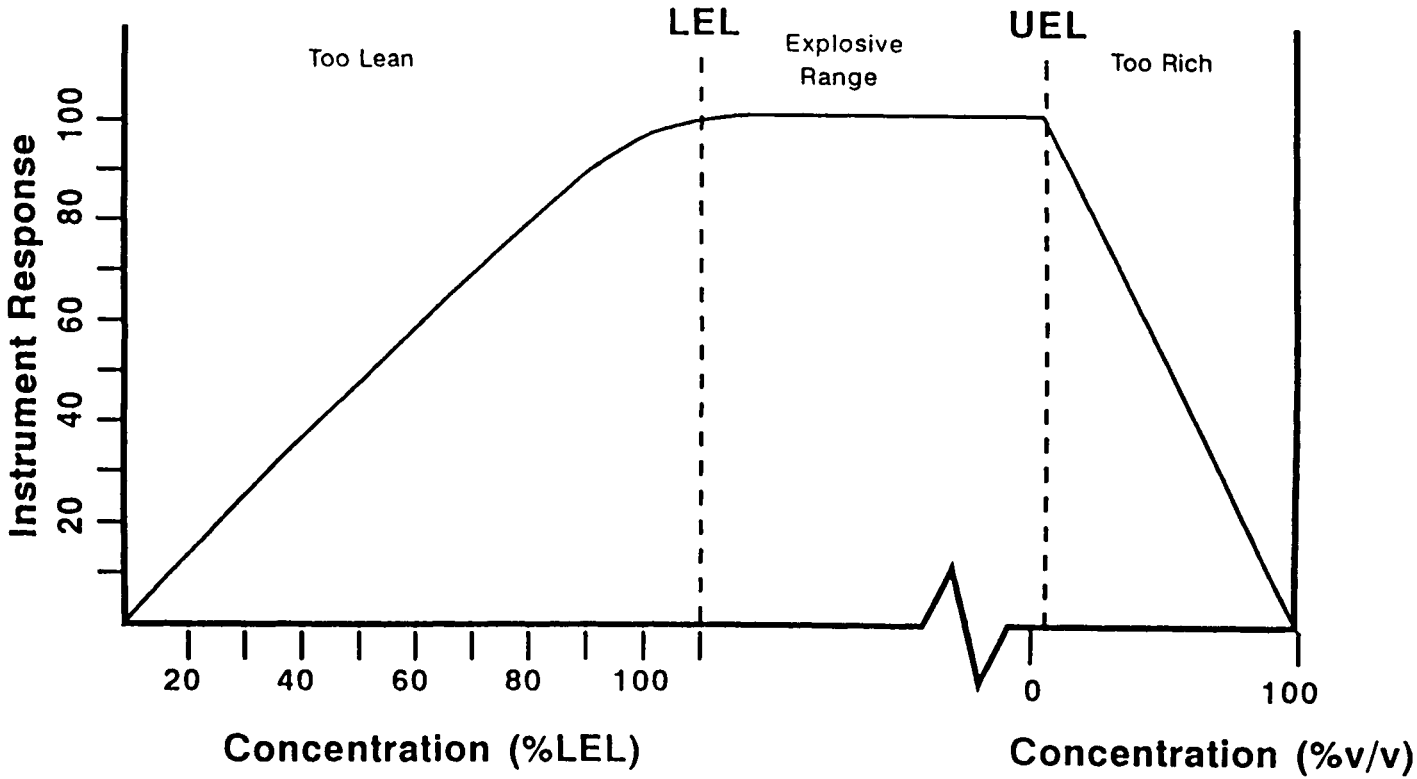


Figure 5-1 Catalytic combustion detector response.

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Photoionization Detector

The PID ionizes contaminants in the air stream with ultraviolet light. The ionized molecules are collected at the negatively charged electrode. The ion current is measured, electronically processed, and presented as a meter readout. The PID ionizes molecules with ionization potentials near the electron voltage of the bulb. The IP range ionized and ionization efficiency depends on the bulb (see Figure 5-2). Typical bulb voltages are 10.2 electron volts (eV), 10.6 eV, and 11.7 eV.

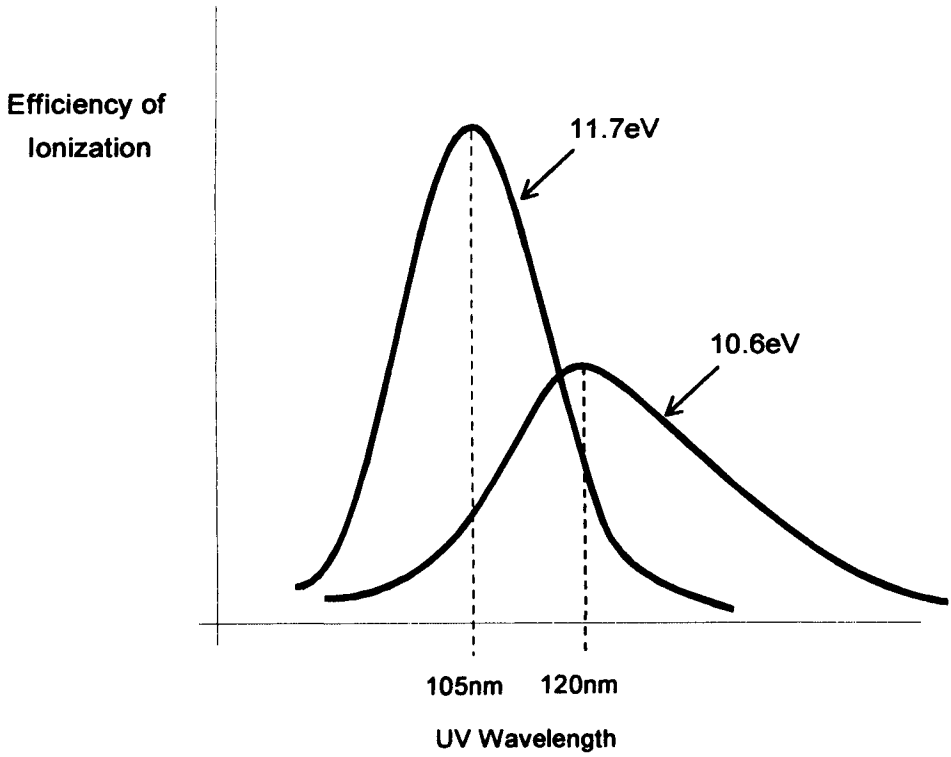


Figure 5-2 Example ionization efficiencies.

The signal produced varies with contaminant and is not necessarily linear with concentration and tends to flatten out at higher concentrations. This is shown in Figure 5-3. It is most sensitive for molecules with a large number of pi electrons in the electron shell. This includes benzene and other benzene ring compounds such as toluene and xylene.

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High humidity decreases the PID sensitivity. Since the magnitude of this effect varies with the instrument, consult the manufacturer. UV energy does not ionize oxygen but oxygen does absorb some UV energy. As a result, the PID will indicate a greater contaminant concentration at lower oxygen levels. This is unlikely to present a problem except under extreme oxygen deficient atmospheres. This effect can be minimized by calibrating the PID with an oxygen concentration similar to the atmosphere to be measured. A more likely error is during the calibration of the PID. The PID calibrated with a nitrogen based (i.e., no oxygen) calibration standard will indicate erroneously low contaminant concentrations in the atmosphere to be measured.

A similar signal decrease effect was reported in the presence of biogenic methane. Signal decreases of 30 percent at 0.5 percent methane and 90 percent at 5 percent methane were observed [Nyquist et al., 1990]. Significantly higher readings with an FID or catalytic combustion instrument compared to PID readings is indicative of a methane interference.

Strengths

- Good general purpose detector.
- Durable and reliable.
- Wide common use.

Common contaminant ionization potentials are readily available in the *NIOSH Guide to Hazardous Chemicals* [NIOSH, 1990].

Weaknesses

- Nonspecific. Response varies with contaminant.
- Affected by humidity.
- Affected by methane.
- Higher bulb voltages (<10.6 eV) are associated with greater instability and greater baseline drift.

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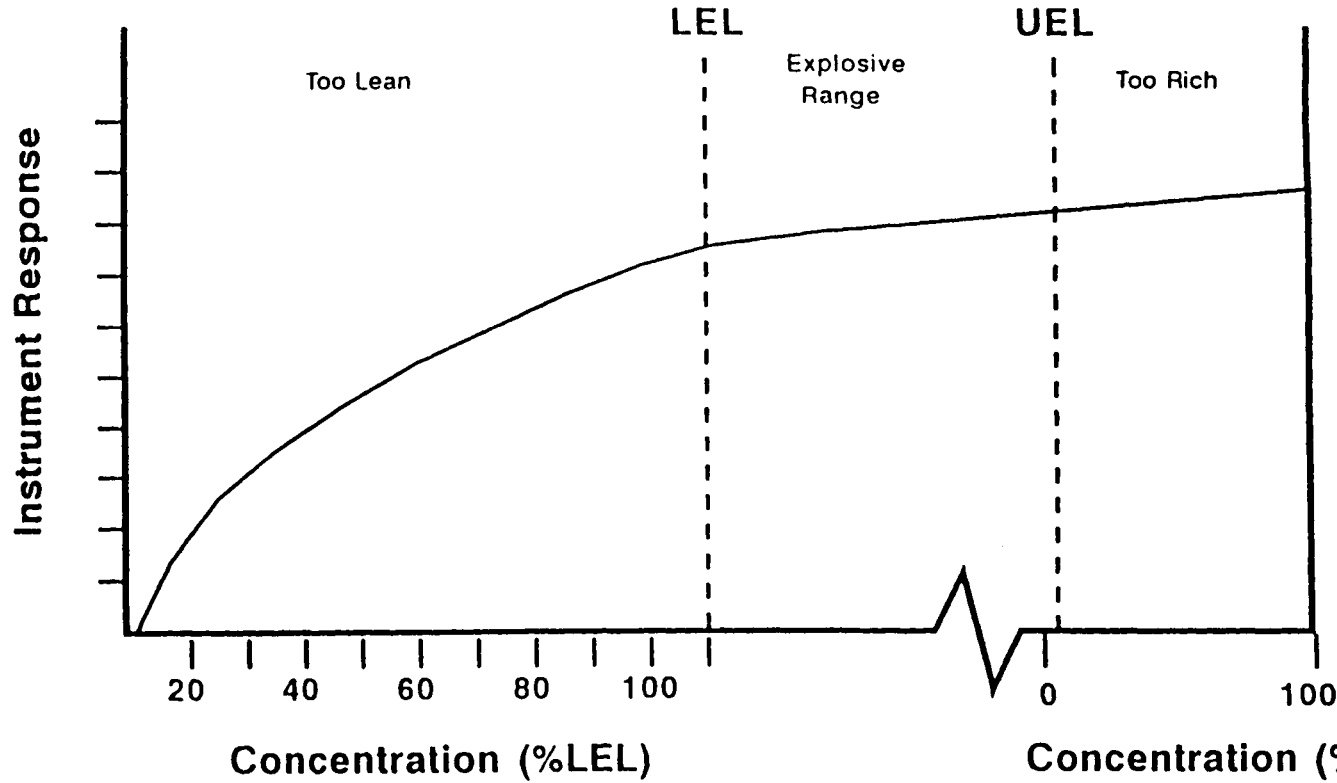


Figure 5-3 Photoionization detector response

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Flame Ionization Detector

A hydrogen flame ionizes contaminants in the airstream. The ions are collected at one electrode resulting in an ion current. This current is electronically processed producing a signal proportional to the level of contaminant present. The signal produced is generally a linear function of the concentration of the combustible gas or vapor present up to 80 percent LEL. FID sensitivity increases with increasing carbon number.

Since the FID is a combustion process it does require oxygen to operate. However, if calibrated for anticipated oxygen levels, it should function properly at levels above the oxygen based IDLH level. At lower oxygen levels, a separate air source can be used.

As the concentration approaches the lower explosive limit, the instrument will reach a maximum level (peg-out). It will stay at this level until the concentration reaches the upper explosive level (UEL). As the concentration rises above the UEL, the instrument flames out due to the lack of oxygen necessary to support combustion in the hydrogen flame. This is shown in Figure 5-4. These instruments are relatively unaffected by changes in humidity.

Although these instruments will respond to chlorinated hydrocarbons, a product of combustion is hydrochloric acid which corrodes the sensor and greatly reduces sensor lifetime.

Strengths

- General purpose detector for most combustible hydrocarbons.
- Linear response to 80 percent LEL.
- Indicates total combustibles present.
- Relatively unaffected by temperature and humidity changes.

Weaknesses

- Nonspecific.
- Requires oxygen (air) for operation.
- Not recommended for chlorinated hydrocarbons.

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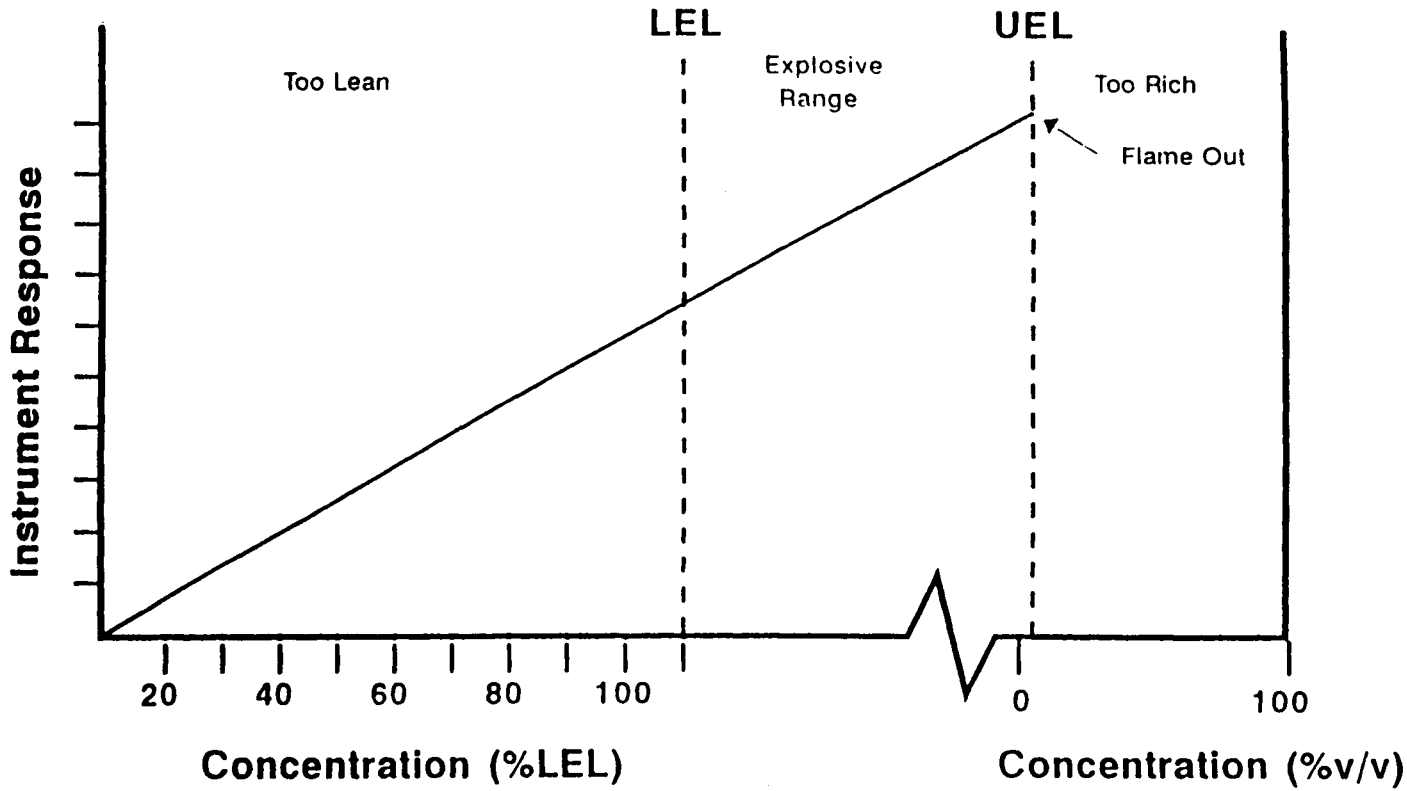


Figure 5-4 Flame Ionization Detector Response.

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Infrared Detector

Infrared (IR) energy is absorbed by molecules in the contaminated airstream. The absorbed energy is measured by a detector, electronically processed, and presented on a meter readout. The IR source is usually a nichrome wire. The IR energy is focused through an IR transparent window, and bounced between mirrors to the IR detector. By focusing the mirrors, paths from 0.75 meters to 20.25 meters are possible. However, the longer the pathlength, the greater the energy dissipation.

Specifically, IR energy is absorbed by the bending and stretching of molecular bonds. This produces a very compound specific IR fingerprint. However, most detectors limit the detection to a single wavelength which is common to many compounds within a class of compounds. For example, the detector could measure the bending or stretching of the carbon-hydrogen double bond in a benzene ring. This wavelength will detect all benzene ring containing compounds.

The signal produced is compound dependent and likewise dependent on all interferences. It is relatively unaffected by contaminant concentration. While the response should be theoretically linear with concentration in accordance with Beer's Law, in practice the response tends to drop off as shown in Figure 5-5. Lower concentrations are measured by increasing the pathlength between the IR source and the detector. The longer the path, the more likely the energy will interact with the molecules.

The IR detector is affected by humidity in two ways. First, the most common IR transparent windows are made of sodium chloride (glass absorbs IR energy), which is very hygroscopic. High humidity can fog the windows requiring expensive replacement. Silver bromide windows are relatively immune to humidity effects. However, these windows are much more expensive than the sodium chloride windows. Silver bromide is strongly affected by ammonia vapors which cause fogging requiring replacement.

In addition to equipment effects, water vapor absorbs IR energy. This absorption can be in the same region as the contaminant of interest. The effect of this interference depends on the contaminant and concentration of interest. However, since water vapor present in relatively high concentrations, it is best to select a wavelength which is not affected by water vapor.

Strengths

- Can be used in oxygen deficient atmospheres.
- Can be tuned to respond to specific components.

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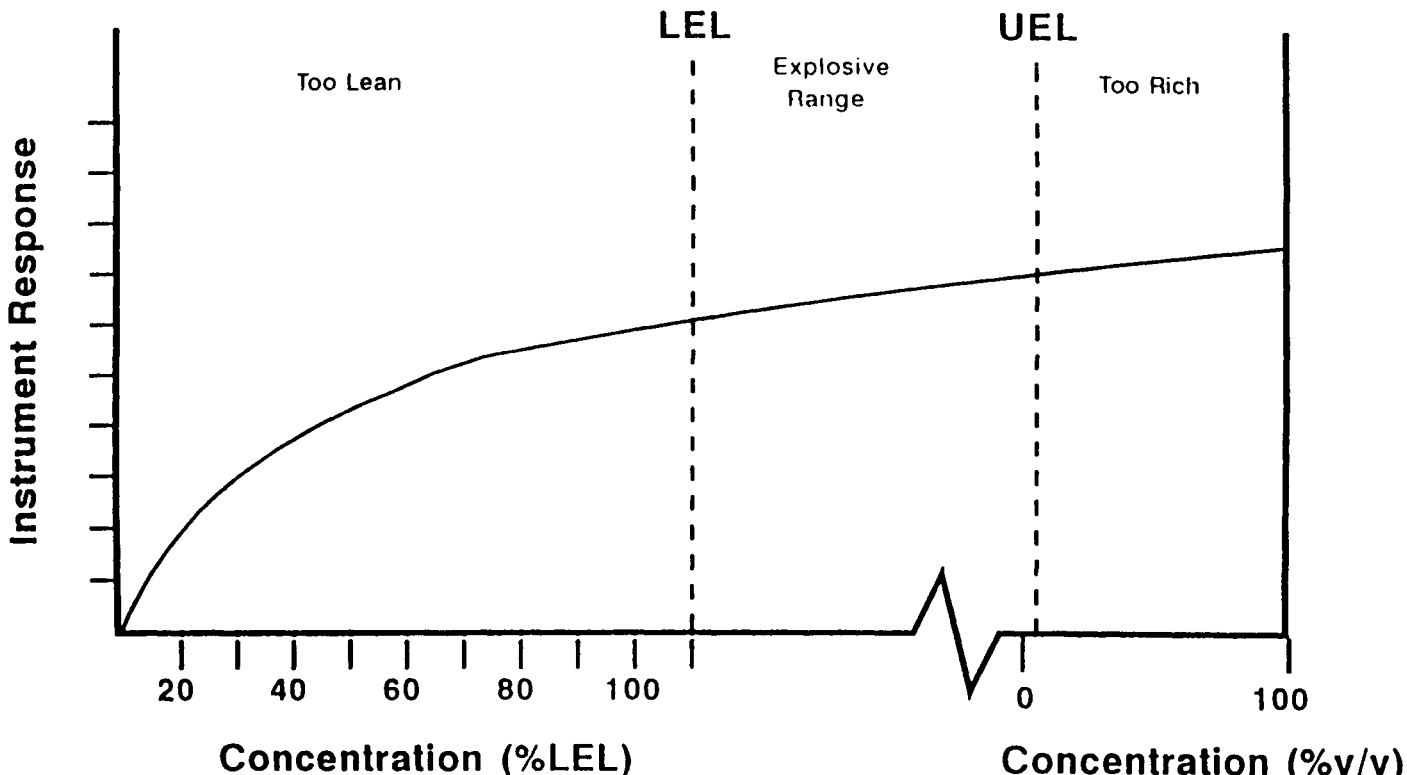


Figure 5-5 Infrared detector response.

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Weaknesses

- Relatively nonspecific in multicomponent atmospheres. This weakness can be overcome to a large extent by Fourier transform infrared (FTIR) [Levine et al., 1989]. However, at this time these instruments are considerably more expensive than the more common filtered IR systems.
- Influenced by high humidity.

Solid State

Solid state semiconductors can be used to detect combustible gases and other compounds. The contaminant gas reacts on the surface of the sensor bead, producing a change in conductivity of the semiconductor that is measured electronically. The change in conductivity is the result of changes in electron distribution in the semiconductor and not due to thermal effects such as occur in catalytic and hot wire detectors.

For n-type sintered tin oxide semiconductors, the contaminant gas is adsorbed and reacts on the detector surface with previously adsorbed oxygen ions producing typical oxidation products such as carbon dioxide and water. The removal of the oxygen ions from the sensor surface releases electrons to the semiconductor metal resulting in a measurable increase in conductivity. The output is then read as a function of the electronic concentration of the contaminant gas that is present. To increase the surface reaction rate, the sensor is heated, usually using a platinum coil. This temperature (e.g., 200°C) is generally less than the temperature of catalytic or hot wire devices [Cullis and Firth]. This lower temperature provides long-term zero stability and prevents the sensor from poisoning by compounds which decompose at higher temperatures. However, at these temperatures, the following reactions can proceed in addition to the surface adsorption reactions,

- Direct burning: The direct burning process is similar to that of the catalytic sensors. It requires oxygen to proceed and heats the sensor. The response increases the conductivity providing a positive response. Since combustion is involved, a flashback arrestor is required to isolate the hot sensor from the explosive atmosphere when high concentrations are measured.
- Oxidation: This reaction is similar to burning, but has been limited here to that occurring at temperatures below the ignition temperatures. This process is also exothermic.

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- Reduction: This term is applied to the reduction of the semiconductor material to the metallic state. Such a change also reduces resistance since the metals are more conductive than their oxides.
- Absorption: The physical absorption of the contaminants by the bead results in some release of heat and therefore some instrument response.
- Absorption: This molecular process is parallel to absorption.
- Thermal effects: The high thermal conductivity of some hydrocarbon gases tends to cool the sensor which results in a decrease in conductivity. This is normally negligible, but can be observed. This action can typically show up during a search for gas leaks. First there is a gradual rise in response until a momentary dip is observed where a sudden surge of the combustible gas is met. For survey type work the transient observed can be evidence for the source of the leak, and the change in instrument sensitivity does not affect the evaluation.

Hydrocarbons, halogenated hydrocarbons, alcohols, ethers, ketones, esters, nitro and amine compounds produce a measurable change in conductivity. Several inorganic gases including ammonia, carbon monoxide, hydrogen, hydrogen cyanide, hydrogen sulfide, nitrogen oxide, and water can also be detected. The sensitivity to water can be a problem in high humidity atmospheres. Water vapor is required for operation as the instrument will not operate in "bone dry" environments. As the humidity increases, instrument sensitivity and response also increase.

This sensor type measures all contaminants that react on the surface and is very sensitive to small concentration changes. However, the response produced may vary greatly among contaminants and is a function of the contaminant, the sensor, and the surface reactions. A meter indication is an indication of contamination, not necessarily explosivity; unlike the catalytic combustion sensor which produces a composite signal indicative of the total combustible concentration.

Response to propane was reported at 1000 ppm, less than a twentieth of its LEL of 22,000 ppm (2.2 percent). Carbon monoxide is detectable at 50 ppm (LEL, 12.5 percent). This sensor is also sensitive to hydrogen sulfide at low concentrations. This combination of sensitivities makes it possible to use it as a multiple sensor for the gases that are typically found in sewage treatment processes and related manholes.

At and above the LEL the sensor response is relatively flat. Therefore, it may not be possible to determine if the atmosphere is at the LEL, in the explosive range, or above the UEL. This is shown in Figure 5-6.

When this sensor is poisoned, the sensor must be replaced. Poisoning is indicated when the sensor does not respond to known combustibles.

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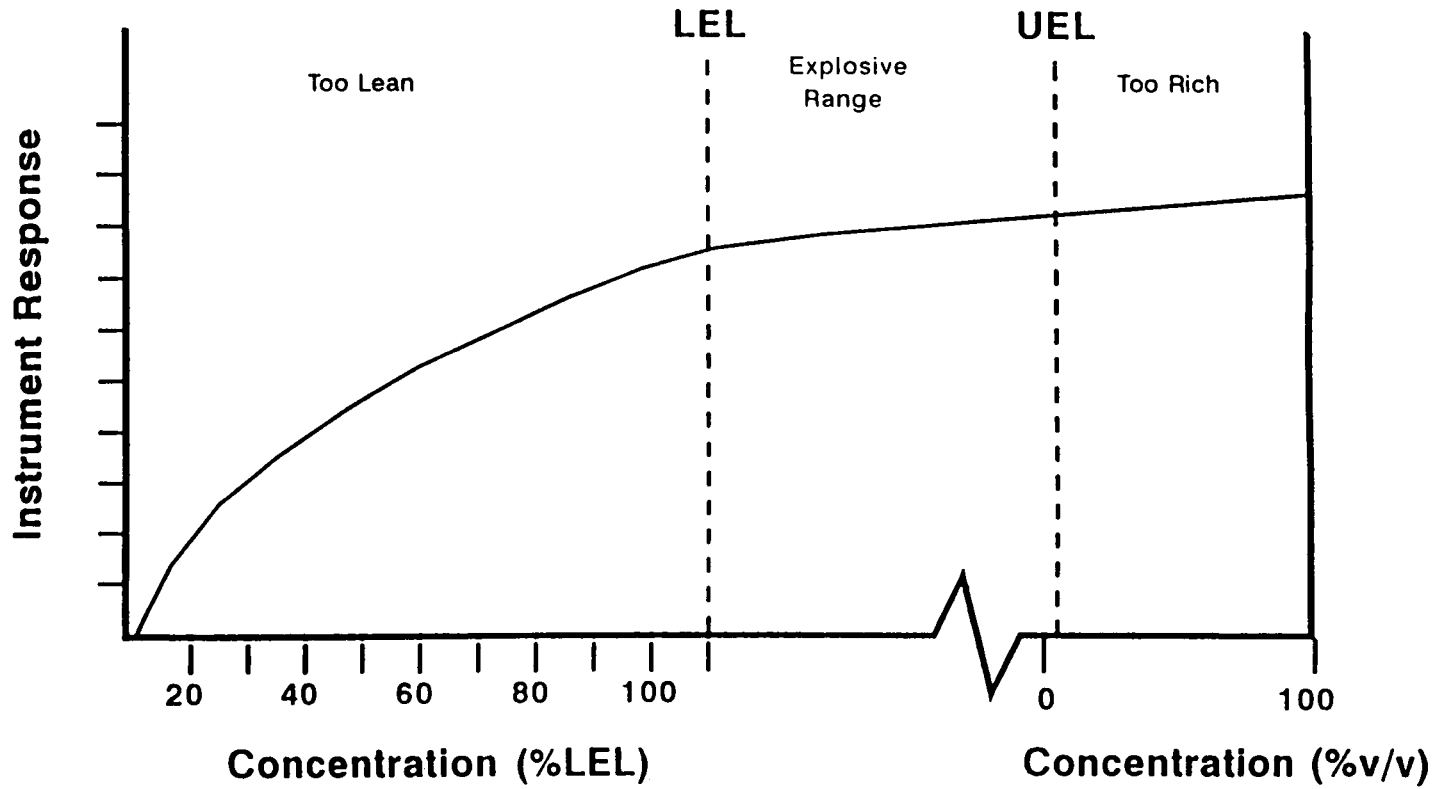


Figure 5-6 Solid state detector response.

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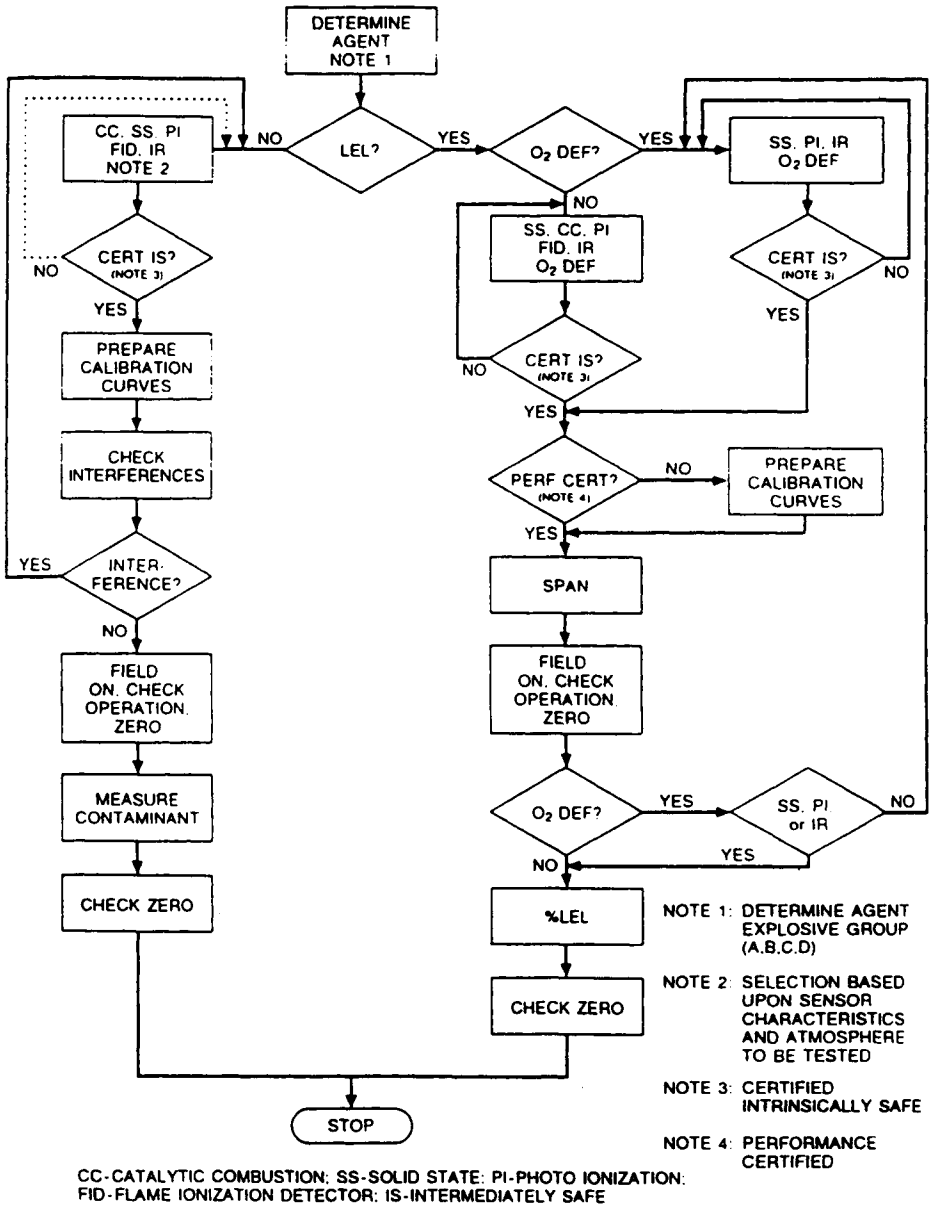


Figure 5-7 Instrument selection flowchart.

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Strengths

- Can be tailored for use for a variety of contaminants, including inorganics.
- Can be used in oxygen deficient atmospheres (except totally inert).

Weaknesses

- Response near and above the lower explosive limit is relatively flat.
- Not recommended in high humidity atmospheres (> 70 percent).

Response is unpredictable (although generally positive) in multicomponent mixtures due to the variety of reactions that can occur.

INSTRUMENT SELECTION AND USE

Considerations for Instrument Selection

A flowchart outlining the steps in selecting and using combustible gas or health survey meters is shown in Figure 5-7. The first and most important step in selecting and using a combustible gas or health survey meter is to determine the agent to be sampled and the identification of any possible interferences, including water from high humidity. Next, determine if the atmosphere to be sampled is likely to be at or above 10 percent of the LEL. The following discussions depend on the initial assessment.

Lower Explosive Limit Measurements

Oxygen should always be measured prior to confined space entries or anytime high vapor or low oxygen concentrations are expected. Instruments based on combustion principles require oxygen to properly quantify the sampled atmosphere.

If the atmosphere is, or is suspected to be, potentially oxygen deficient (e.g., inerting operations), select an instrument based on solid state, photoionization, or infrared operating principles, or supply an outside source of air (oxygen) to support the combustion process. These instruments are not strongly affected by a lack of oxygen.

Any instrument selected for use in potentially hazardous atmospheres must be certified by an independent laboratory as intrinsically safe for the highest category atmosphere to be tested.

If an instrument is selected based on a combustion principle, oxygen concentrations can be used to correct combustible gas readings using

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information supplied by the manufacturer or developed by the user.

Is the instrument performance certified by an independent laboratory such as CSA or FM? In addition to testing for intrinsic safety, some independent laboratories also check to ensure the instrument meets certain performance criteria including accuracy, linearity of response, etc. If it is not performance certified by an independent laboratory, validate the manufacturer's calibration curves. It is also important to calibrate the instrument to the vapors to be sampled at the conditions of sampling to include temperature, humidity, and potential interferences present. A simple way to determine if potential interferences are unimportant is to add the interference vapors and observe the instrument response. If no effect is observed, the potential interferences are not important. If interferences are determined to be important, efforts must be taken to eliminate the interferences with filters, or to use instrumentation either not affected by the interferences or capable of separating the components.

Health Survey Measurements

Select the instrument with the best operating characteristics for the atmosphere to be measured. This selection should consider optimum instrument response for the contaminant of interest and minimum response from potential interferences. Although intrinsic safety certification is not a requirement for health survey instruments due to the lower concentrations expected, a certified instrument is recommended if there is any possibility of encountering potentially hazardous atmospheres. In addition, certain certifications (e.g., CSA, FM) ensure instruments meet certain accuracy and other operating criteria.

Prepare calibration curves for the compounds to be measured, for the concentrations expected, and for similar environmental conditions (primarily temperature and humidity) for the atmosphere to be measured. Users of one combustible gas indicator found the instrument calibration had to be performed in humid air (greater than 50 percent RH) to achieve agreement with the manufacturer's calibration data. Lower humidity resulted in decreased instrument response. In addition, because it is not unusual to obtain different instrument readings on different scales, ensure calibration readings are obtained for the same atmosphere on different instrument scales.

Check for possible interferences from other chemicals likely to be in the atmosphere to be sampled. Simply inject into the test chamber or sampling bag quantities of other chemicals likely to be encountered. Note any instrument response. Care and judgment must be exercised to determine if any observed effect is sufficient to negate the instrument's use. If the interference is great, alternative instruments using different operating principles should be investigated. If other instrumentation is either not available or determined to be

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ineffective, knowledge of the degree and direction of the interference may still allow use of the instrument. However, care must be exercised in interpreting the readings and documenting the results. In all cases, follow-up sampling with an approved method is recommended.

A properly calibrated infrared instrument was used to monitor ethylene oxide from a hospital sterilizer. During the sterilization cycle, a period when no ethylene oxide was expected, a sudden increase in instrument was observed. This response was traced to the use of a bactericidal cleaning compound used to mop the floor. Additional investigation of the same operation, revealed that water vapor absorbs near, and interferes with, the ethylene oxide peak chosen to eliminate the known freon-12 interference, also present in the sterilization operation. Since no other peak was available in the infrared region, a portable gas chromatograph was selected to perform the evaluation.

Instrument Use

Prior to using any combustible gas or health survey instrument, ensure the instrument is in proper operating condition. As a minimum the following should be checked:

1. Ensure the batteries are functioning by using the battery selection position on the meter. Refer to the manufacturer's instructions.
2. Ensure the sampling lines are in good condition, free of leaks and visual damage to include cracking or nicks. Also check the fittings to ensure a proper airtight connection through the sampling train.
3. Visually inspect all in-line filters and driers. Ensure manufacturer's recommended preventive maintenance is performed.
4. Set the instrument to read the proper concentration using the manufacturer's recommended span gas [OIML D, 1991].
5. In the field, turn the instrument on and allow sufficient warm up time as noted by a stable zero baseline. Ensure the instrument is zeroed in a contaminant free atmosphere or use zero gas. Care must be used to ensure the zero gas is the same as the atmosphere to be sampled with only the contaminant(s) removed. For example, zero gas may be pure nitrogen or may be extremely low in humidity. Use of the zero gases can result in improper instrument zero and cause instrument reading error. An appropriate filter can also be used. However, ensure through laboratory experiments the filter use does not alter instrument response either due to pressure differentials or possible water (humidity) removal. Once zeroed, check instrument operation using a known flammable or contaminant source. A permanent marker (alcohol based) is a suitable source.
6. For all confined space entries or any atmosphere in which oxygen

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deficiency cannot be ruled out, the oxygen concentration must be measured. This may be accomplished using the oxygen sensor of the combustible gas meter if so equipped, (Figure 5-7), or a separate oxygen meter. If an oxygen concentration is less than 19.5 percent or greater than 21.5 percent oxygen by volume, care must be taken in interpreting readings from instruments based on combustion principles. These instruments will read low in oxygen deficient atmospheres and high in oxygen enriched atmospheres. Corrections may be made based upon calibration curves prepared at different oxygen concentrations. Although instruments based upon solid state, photoionization, and infrared are generally unaffected by oxygen content, oxygen concentration must be determined prior to any entry into the sampled atmosphere.

7. Measure the concentration starting with the highest (least sensitive) instrument scale. Increase the instrument sensitivity by selecting a lower scale until a reading is obtained. Correct the instrument reading using the manufacturer's or user developed calibration curves.
8. At the completion of measurements, and periodically throughout the measurement period, the instrument should be re-zeroed using zero gas, and the span checked and readjusted if necessary. In addition, periodically check the instrument with a known flammable source (e.g., alcohol-based permanent marker) to ensure the instrument is operating.

Limitations

The following are common limitations the user should recognize and consider while operating a combustible gas indicator.

Combustible gas indicators are used to detect the presence and concentration of a combustible gas or vapor or a composite of the gases present. They generally cannot differentiate between various substances. If calibrated for a single gas or vapor, it can be relied on for accurate determinations of that substance in the environment, provided there are no other combustible or interfering gases or vapors present in that environment.

Catalytic or hot wire combustible gas indicators should not be used for, or in presence of halogenated hydrocarbon gases or vapors. These thermal decomposition products generated by these substances will corrode the sensor and alter its sensitivity and integrity.

A combustible gas indicator or hydrocarbon detector must be selected for the purposes intended. If it is to evaluate health exposure to toxic gases or vapors which are combustible, the sensitivity of the instrument must be greater than if the instrument is to be used for the determination of potential fire hazard levels.

If a potential exists for a hazardous atmosphere (10 percent LEL), ensure

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the instrument selected is certified by an independent laboratory as intrinsically safe for the atmosphere to be tested. This will ensure the instrument will not ignite the sampled atmosphere.

The sensitivity and accuracy of combustible gas indicators are affected by a wide range of conditions. These include the presence of dust, humidity, and temperature extremes. For these reasons the instrument should be calibrated under conditions similar to conditions expected in the environment to be sampled.

Do not interchange parts between two instruments of different manufacturers or different models. If parts of two identical instruments (model and manufacturer) are interchanged, the instrument must be recalibrated before it is used.

Any instrument that requires repair work that replaces the flame arrestor or that breaches the intrinsic safety of the device, should be sent to the manufacturer for testing and recertification of its safe use for the purpose intended.

A combustible gas indicator or hydrocarbon indicator should be tested and field calibrated with a known gas or vapor concentration (e.g., with span gas) before each use. The instrumentation should be calibrated in conditions similar to that expected in the field (e.g., similar temperature and humidity). In addition, if a long sampling line is needed in the field, the same length of line should be used during the calibration check. The instrument should also be tested for operation at the sample location. A permanent marker (alcohol based) or butane lighter can be used for this purpose.

Instruments may exhibit "zero drift." It is important to check and reset the "zero" reading in a clean environment on a frequent basis. If the instrument is taken into a mine or other environment where vapors are always present, a sample of clean or zero air should be carried with the instrument to facilitate frequent zeroing adjustment. This clean or zero air must be contaminant free but similar to the sample environment in all other aspects. For example, pure nitrogen zero air may result in a different reading when exposed to normal air which includes oxygen. A zero air filter that removes the contaminant may also be used.

DETECTOR TUBE SELECTION AND USE

The selection of detector tubes follows the same general logic as the selection of direct-reading instruments. Select a detector tube that will measure the specific contaminant of interest. The manufacturer's literature will identify known interferences and whether the interferences are positive or negative. Usually these interferences will be positive and will be similar in chemical structure (e.g., benzene, toluene, and xylene) and will also be likely found in

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conjunction with the chemical of interest at the hazardous waste site. While this will tend towards the conservative application of PPE, it is more specific than the direct-reading instrument. Detector tubes are used in accordance with the manufacturer's directions. One note of caution, do not mix detector tubes from one manufacturer with a detector tube pump from another. Detector tubes are matched with the pump with specific flow rates, often unique to the manufacturer's pump.

PERSONAL SAMPLING

Personal sampling methodologies are similar to general industrial hygiene sampling. Once the contaminants of interest are identified, use the OSHA *Field Operations Manual* [U.S. Dept. of Labor, 1990] to determine the proper sampling media and flow rates.

HAZARDOUS ATMOSPHERE CLASSIFICATION

Locations containing, or potentially containing, explosive concentrations of vapors, gases, or dusts, are classified according to the degree of hazard. This classification scheme is defined in Article 500 of the National Electric Code [National Electrical Code] which is found in the National Fire Protection Agency (NFPA) publications.

Class

There are three hazardous atmosphere classes, Class I, Class II, and Class III. Class I includes all atmospheres containing or potentially containing explosive gases or vapors. Class II includes those atmospheres containing or potentially containing explosive dusts. Class III includes those atmospheres containing or potentially containing explosive fibers.

Division

Within each class, there are two divisions, Division 1 and Division 2. In Division 1, a flammable material is continuously or usually present. In Division 2 locations, flammables are only present under accident conditions.

Group

Hazardous locations are further classified by group. The groups are A

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through D for vapors and gases, and E through G for dusts and particulates. Group designations for specific materials are given in NFPA publication 497M, "Classification of Gases, Vapors and Dusts for Electrical Equipment in Hazardous (Classified) Locations'' [NFPA].

Gases and Vapors: Group A is the most hazardous (most flammable or explosive) while Group D is the least hazardous. Representative chemicals in each of the groups are:

Group A: Acetylene.

Group B: Hydrogen, ethylene oxide.

Group C: Ethylene, carbon monoxide.

Group D: Methane and most common hydrocarbons.

Dusts and Particulates: The groups for dusts and particulate are specified for particular dusts and particulate as follows:

Group E: Combustible metal dusts regardless of resistivity, or other combustible dusts having a resistivity of less than ohm-centimeters or greater. Examples include aluminum, tin, and iron.

Group F: Carbon black, charcoal, coal, or coke dust having more than 8 percent total volatile material or atmospheres having a resistivity greater that ohm-centimeters but equal to or less than ohm-centimeters.

Group G: Combustible dusts having a resistivity equal to or greater than ohm-centimeters. Examples include corn, rice, and other agricultural dusts.

Use of Hazardous Location Classifications

Instrumentation must be selected on the basis of the most hazardous atmosphere classification. For example, in measuring a potentially explosive atmosphere of ethylene oxide, one would select an instrument which was certified intrinsically safe for Class I, Division 1, Group B. In practice, instruments certified for use in gas and vapor hazardous atmospheres are certified for the most hazardous atmosphere and include all the lower classifications. For example, an instrument certified for use in Class I, Division 1, Group A, would be labeled for use in Class I, Division 1, Groups

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A, B, C, and D.

Although Group D contains methane, this certification is not the same as the Mine Safety and Health Administration 2G certification. The 2G certification is for use in methane atmospheres only. Methane requires a much greater ignition energy than the other members of Group D. Therefore, although methane is in Group D, instrumentation certified safe for use in methane atmospheres, may not be safe for use in atmospheres containing other Group D chemicals.

INSTRUMENT CERTIFICATION

Intrinsic Safety

Instruments selected for use in potentially hazardous atmospheres must be certified by an independent testing laboratory to ensure the instrument is intrinsically safe. As defined by the NFPA in Article 500 of the NEC:

> Intrinsically safe equipment and wiring shall not be capable of leasing sufficient electrical or thermal energy under normal or abnormal conditions to cause ignition of a specific flammable or combustible atmospheric mixture in its most easily ignitible concentration. [National Electrical Code]

In other words, the equipment shall not be capable of igniting an explosive mixture under normal or fault conditions.

There are two basic testing programs. One tests only for intrinsic safety. A user can be assured the instrument is safe to operate in the atmosphere for which it is certified. The second program includes testing for performance also. The user is then assured the instrument is not only safe to use but that it will perform to documented performance criteria as well.

Intrinsic Safety Testing

The basic testing standard for intrinsic safety is ANSI/UL 913-1988 [UL/ANSI ,1988]. This standard was written by Underwriters Laboratories and adopted by the American National Standards Institute. It specifies the conditions for testing equipment for intrinsic safety. These conditions include evaluation of circuits for sources of spark ignition, maximum temperature, possible fault conditions, and testing under normal and fault conditions in hazardous atmospheres. The test atmospheres are representative gases at concentrations within the explosive range. The representative gases are

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Groups A and B: Hydrogen
Group C: Ethylene
Group D: Propane

Performance Testing

In addition to intrinsic safety testing, instruments may also be tested by independent laboratories for performance. The primary performance standard is ANSI/ISA-S12.13, Part 1-1986 [NFPA]. This standard was written by the Instrument Society of America and adopted by the American National Standards Institute. It specifies the conditions for testing instrument performance. Areas tested include:

Accuracy: The instrument must indicate the true test concentration within + 3 percent of full scale gas concentration or +10 percent of the applied gas concentration, whichever is greater.

Temperature Variation: The instrument sensing element will be subjected to temperatures of 0°C and 50°C and the meter indication should be vary from the test concentration by more than +5 percent of the full-scale gas concentration.

Concentration Step Change: When exposed to a test atmosphere of 100 percent of full-scale concentration, the instrument must respond to 60 percent of full scale within 12 seconds. When removed from this concentration, the instrument response should decline below 50 percent of full scale within 20 seconds and below 10 percent within 45 seconds.

Humidity Variation: Instruments are tested at 10 and 90 percent relative humidity after calibration at 50 percent relative humidity. The meter output should not vary more than + 10 percent of full-scale concentration from the 50 percent relative humidity concentration indication.

Air Velocity Variation: The instrument response should be within +10 percent or 5 percent of the static concentration indication when exposed to a velocity of 5 + 0.5 meters per second.

Additional Tests: Instruments are also tested for vibration, electromagnetic interference, and long-term storage.

Certification Programs

Factory Mutual Research (FM): FM considers all combustible gas instruments as life support equipment requiring certification for performance in addition to intrinsic safety. Their performance tests are published in FM publication "Approval Standard, Combustible Gas Detectors" and are similar

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to ANSI/ISA S12-13, Part 1- 1986 [UL/ANSI ,1988]. Their intrinsic safety tests are similar to ANSI/UL 913-1988 [ANSI/ISA, 1986]. Instrumentation successfully passing both the intrinsic safety and performance tests are approved by FM for use in the specified hazardous locations. This approval is indicated by the marking shown in Figure 5-8.

Canadian Safety Association (CSA): CSA approval is essentially the same as FM. Their approval marking is shown in Figure 5-9.

Underwriters Laboratories (UL): UL has two different testing approvals listing and classification.

Classification: Instruments are checked to ensure they operate according to the manufacturer's instructions and are tested for intrinsic safety using the ANSI/UL 913-1988 protocol. Instruments that successfully pass these tests are listed as safe for use in specified hazardous locations.

Listed: In addition to intrinsic safety testing, UL also performs instrument performance testing. This testing is may be to ANSI/ISA 12-13, Part 1-1986 or other criteria as specified by UL. The approval marking is the same as for the classified approval but the words will specify "Listed for Use In'' performance testing criteria. The user must contact the manufacturer or UL to determine the exact performance criteria [Factory Mutual Research, 1989]. The approval marking is shown in Figure 5-10.

National Recognized Testing Laboratories (NRTL): Since UL and FM were the only laboratories providing intrinsic safety testing services when OSHA first wrote standards, OSHA regulations required certification by FM and UL. As a result of additional laboratories with testing capabilities, OSHA has developed the NRTL program. OSHA reviews the capabilities of laboratories to perform intrinsic safety testing (or other specific testing). OSHA requires intrinsic safety testing to an appropriate standard. Although not specified most testing laboratories use ANSI/UL 913-1988. Laboratories successfully passing this review are recognized by OSHA as NRTLs [Factory Mutual Research, 1988]. This recognition is published in the *Federal Register* and laboratories are authorized to use NRTL in advertisements. As of June 1990, ETL, FM, MET, and UL are the only NRTLs for intrinsic safety.

MET Electrical Testing Laboratories: MET performs intrinsic safety testing in accordance with ANSI/UL 913-1988. Their approval marking is shown in Figure 5-11.

ETL: ETL performs intrinsic safety testing in accordance with ANSI/UL 913-1988. Their approval marking is shown in Figure 5-12.

LABELS

Instruments meeting the approval standards for intrinsic safety are marked

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with the independent testing laboratory's approval marking. This marking also includes the specific hazardous locations applicable to the approval (e.g., Class I, Division 1, Groups B, C, and D). Instrument users must ensure the instrument is approved for use in hazardous atmosphere to be measured.

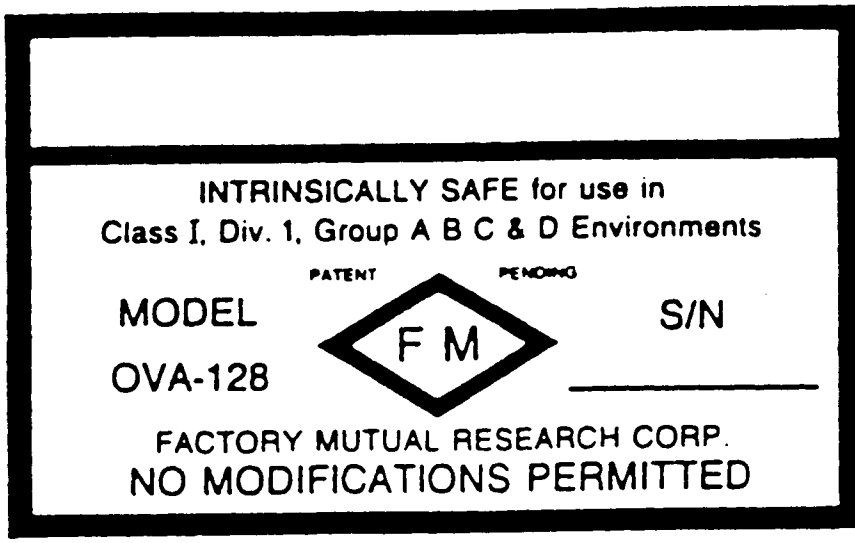


Figure 5-8 Factory Mutual approval markings.

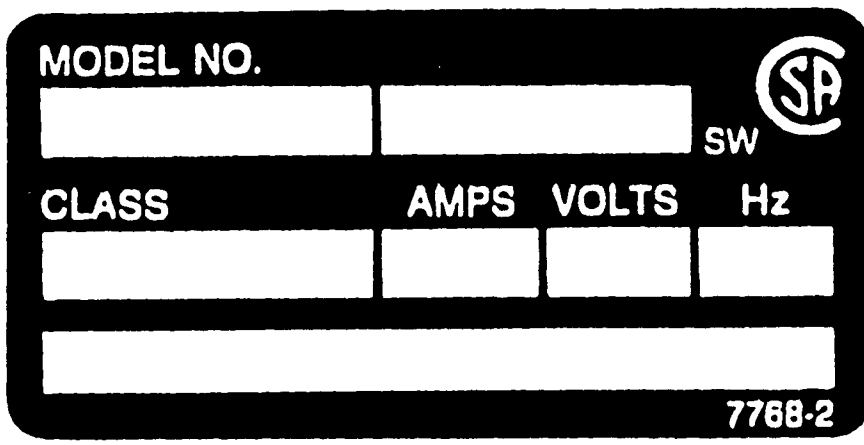


Figure 5-9 Canadian Safety Association approval marking

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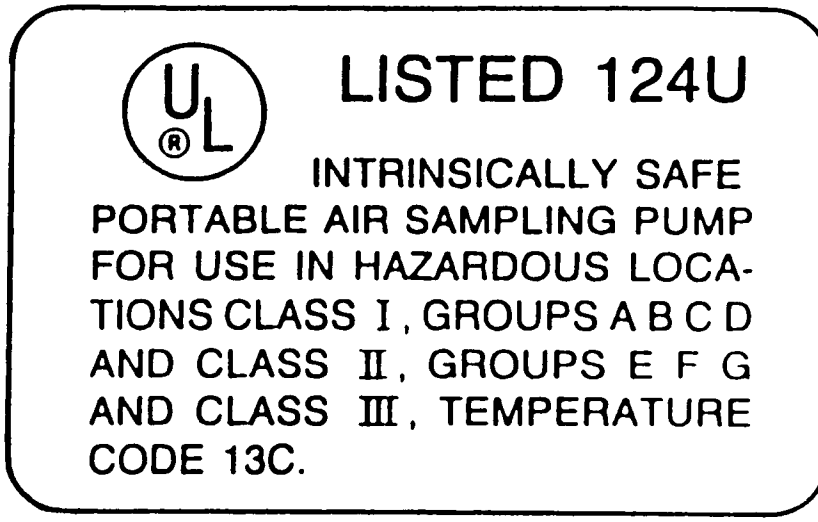


Figure 5-10 Underwriters Laboratory listed approval marking.

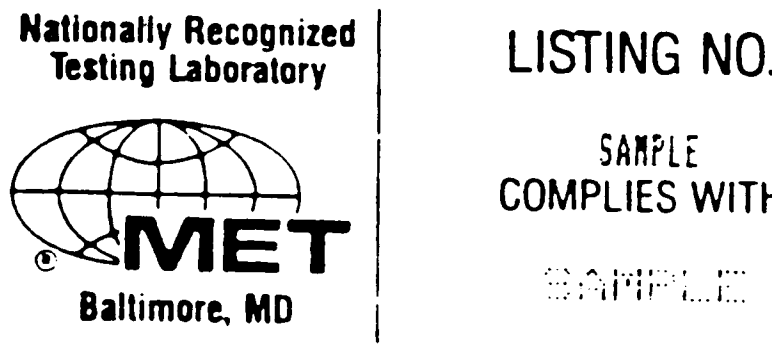


Figure 5-11 MET approval marking.

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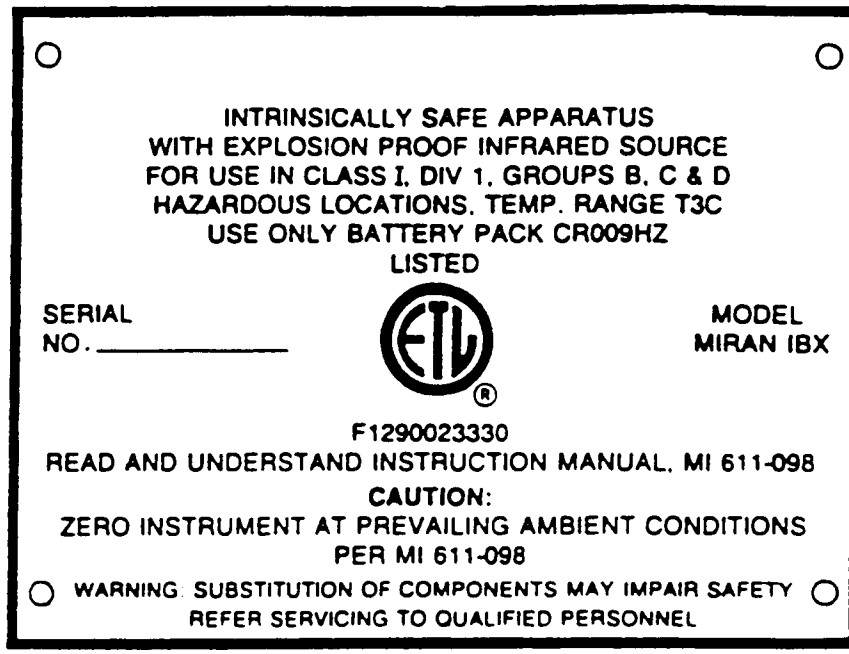


Figure 5-12 ETL approval marking

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6

COMPATIBILITY TESTING

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The stockpiling or dumping of waste chemicals in drums has been a widespread practice throughout the United States. One-quarter of all abandoned waste sites had major drum-related problems, including handling, integrity, characterization, and disposal [Wetzel, et al., 1982]. Bulk recontainerization (bulking) of hazardous materials located in drums, labpacks, tanks, and holding ponds has become the most time- and cost-effective solution to handling the waste. The potentially hazardous incompatibilities must be known for worker safety before comingling wastes. Potential hazards that can result from improper mixing of chemicals include fire, explosion, violent splashing or reaction, polymerization, and corrosive or toxic gas generation.

Bulking involves removing the hazardous materials from the drums, labpacks, tanks, and holding ponds and combining compatible wastes into larger transportable containers. When mixed together, many chemicals can produce potentially hazardous effects such as fires; explosions; violent reactions; and the release of toxic dusts, mists, fumes, and gases. Therefore, chemical wastes must first be tested for compatibility before they are bulked and incompatible chemicals must be segregated [40 CFR, Part 260].

Chemical compatibility testing is not as extensive as the complete characterization of each individual drum of waste by standard laboratory testing procedures (e.g., RCRA Series, GC/MS, Emission Spectrography). There are several useful guidelines for developing field testing protocols. The American Society for Testing and Materials (ASTM) has several useful standards. Several textbooks on qualitative spot tests are useful for developing field testing protocols. The government has developed some guidelines concerning chemical compatibilities. These guideline "references" are listed at the end of this chapter [40 CFR]. Complete chemical characterization would be far too costly and time consuming for the purposes of hazardous waste cleanup. Compatibility testing, followed by bulking compatible drum contents into large containers appears to be the most cost- and time-effective method of preparing the waste for transportation to an approved disposal facility. Therefore, the second goal of compatibility testing is to generate enough knowledge of the characteristics of the waste to develop a hazardous

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waste classification for the shipping manifest which will be acceptable to the site manager, state or federal agency, transporter, and receiver of the waste.

This chapter discusses the importance of compatibility testing, the general steps involved, and the limitations of compatibility testing. In general, compatibility testing involves performing a group of simple chemical tests (e.g., water solubility, pH, flammability) following a flowchart scheme that ultimately classifies the material into general categories. A comprehensive field compatibility protocol will include tests for several potential hazards including: flammability tests, pH, tests for oxidizers, water and air reactivity tests, gas generation, heat generation, and polymerization potential. Even a comprehensive field testing protocol will have limitations. One example is the reaction rate. Oxidation/reduction reactions may be slow in generating sufficient heat for ignition; an example is the combination of motor oil and certain kitty litter brands. Field conditions, including drafts and temperature, also interfere with test performance. Therefore, because of potential interferences with field compatibility tests, field cleanup personnel must be alert to chemical reactions during cleanup operations [U.S. EPA, 1992].

IMPORTANCE OF COMPATIBILITY TESTING

The importance of compatibility testing is evident after examining situations where proper compatibility testing was not performed prior to handling of potentially hazardous waste.

On April 21, 1980, a massive explosion and fire occurred in Elizabeth, New Jersey, at a hazardous waste site owned by the Chemical Control Corporation. Of the 45,000 drums present at the site, more than 20,000 were consumed. During the initial site investigation, which had been underway for 12 months prior to the fire, no compatibility testing and drum segregation had been performed. The post fire cleanup cost millions more than the prefire estimates [Finkel and Golob, 1981].

In January 1982, workers were unloading chemical wastes from a tank truck at the Liquid Disposal Incineration, Inc., in Utica, Michigan. Deadly hydrogen sulfide gas was generated when a mislabeled sulfide waste from the tank truck mixed with acid in the receiving vessel. Two workers died and six others required hospitalization. Compatibility testing had not been performed on the incoming waste [Univ. of Michigan, 1982].

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Field Analyses Plan (FAP)

A meticulous plan of action must be developed before testing chemicals in the field. The field analyses plan must be in writing, and prepared by a qualified and experienced chemist after careful consideration of

- The site conditions, including availability of field laboratory, temperature control, safety fume hoods, protection from explosive/flammable vapors, and the like;
- Known and suspected waste types and hazards; and
- How the wastes are "packaged;" for example, are the wastes in drums, lagoons, tanks, or are all wastes diluted or mixed into environmental media such as water or soil?

A field analyses plan emphasizing known and suspected site hazards must also include potential, yet unsuspected, hazards. For example, when planning field tests for an abandoned metal working plant site, hazardous polymerization screening must still be included despite metal working plants, such as tube mills and welding shops, not typically working with polymerizable compounds. Composite samples of similar or identical characteristics can be screened for polymerization instead of testing each sample. Table 6-1 offers suggestions for an FAP.

Table 6.1 Example Contents of an Field Analysis Plan	
1	Purpose of plan, objectives, and safety precautions and protocols
2	List of known and suspected hazards/wastes
3	Testing procedure for compatibility of mixing wastes
4	Fire/explosion potential testing procedures
5	Air/water reactivity testing procedures
6	Tests for potential to generate toxic gases
7	Solubility, flame tests and physical screening for characterization of wastes
8	Oxidizer testing
9	pH testing
10	Special tests as needed for treatment or disposal of wastes
11	Procedures to inform workers about results of tests

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Field analyses must be done by qualified chemists following standard laboratory safety protocols. Detailed discussions of laboratory safety practices are beyond the scope of this chapter.

The chemist must be familiar with, and closely follow, standard laboratory safety practices and laboratory hygiene plans. The analyst must use appropriate personal protective equipment including, but not limited to, protective gloves, goggles, face shield, heavy rubber laboratory apron, and arm protectors. A protective fume hood should be used. All tests must be done in a safe (nonflammable and nontoxic) atmosphere.

COMMON CHARACTERISTICS OF COMPATIBILITY METHODS

Although the incidents referenced exemplify the importance of compatibility testing, a universally accepted compatibility testing procedure does not exist. The contractor that is awarded the site cleanup contract is given a suggested scheme to follow. The only requirements are that these proposed protocols provide analytical data, compatibility testing results and are environmentally sensitive during removal and disposal of hazardous waste from the site [U.S. Corps of Engineers, 1983]. The scheme chosen for a specific remedial action site is based on the following factors:

1. The general kinds of waste materials suspected to be present on-site as determined by the initial site screening;
2. The criteria chosen by the governmental agency supervising the cleanup;
3. The preferences of the prime contractor and their experience with compatibility testing; and
4. The criteria of the disposal facility to which the waste will ultimately be sent.

The groups listed below have all developed compatibility schemes. These schemes separate the waste into as few as 10 categories [Hina, et al., 1983] and as many as 41:

1. USEPA, Office of Research and Development, Municipal Environmental Research Laboratory (MERL)
2. Samsel Services Company, Cleveland, Ohio [Hina et al., 1983]
3. Environmental Response Team, USEPA [Turpin et al., 1981]
4. H. Materials Co., Findley, Ohio
5. Army Corps of Engineers
6. ASTM, scheme developed by committee D-34
7. Chemical Manufacturers Association, Inc. [Turpin et al., 1981]
8. NIOSH, Occupational Safety and Health Guidance Manual

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9. USEPA, HAZCAT
10. The basic *procedure* in compatibility testing involves subdividing the liquids into general disposal categories, given the following assumptions:
    - A large number of drums exist on-site, and simple overpacking with complete laboratory analysis (GC-MS) is not time- or cost-effective.
    - An on-site facility is available with proper room, equipment, and experienced personnel to perform the analytical tests.
    - The waste contains a complex mixture of solids and liquids.

Compatibility testing is only one step in the handling of drum wastes on a remedial action site. Figure 6-1 diagrams the role that compatibility testing plays during drum handling.

Although each compatibility scheme is unique, most follow a similar flowchart. Figure 6-2 is the flowchart of the scheme used by O. H. Materials Co. Note that incompatible wastes such as radioactive, air and water reactive, PCB, sulfide, and cyanide wastes are identified by compatibility testing but are usually not bulked prior to disposal. These highly hazardous wastes are repacked or overpacked, depending on the condition and size of their original container, and disposed separately.

The basic steps in compatibility testing occur in three stages of drum handling: (1) testing performed prior to drum opening; (2) testing performed during drum handling; and (3) testing performed on collected samples. The tests generally performed in each of these stages are discussed in Figure 6-1.

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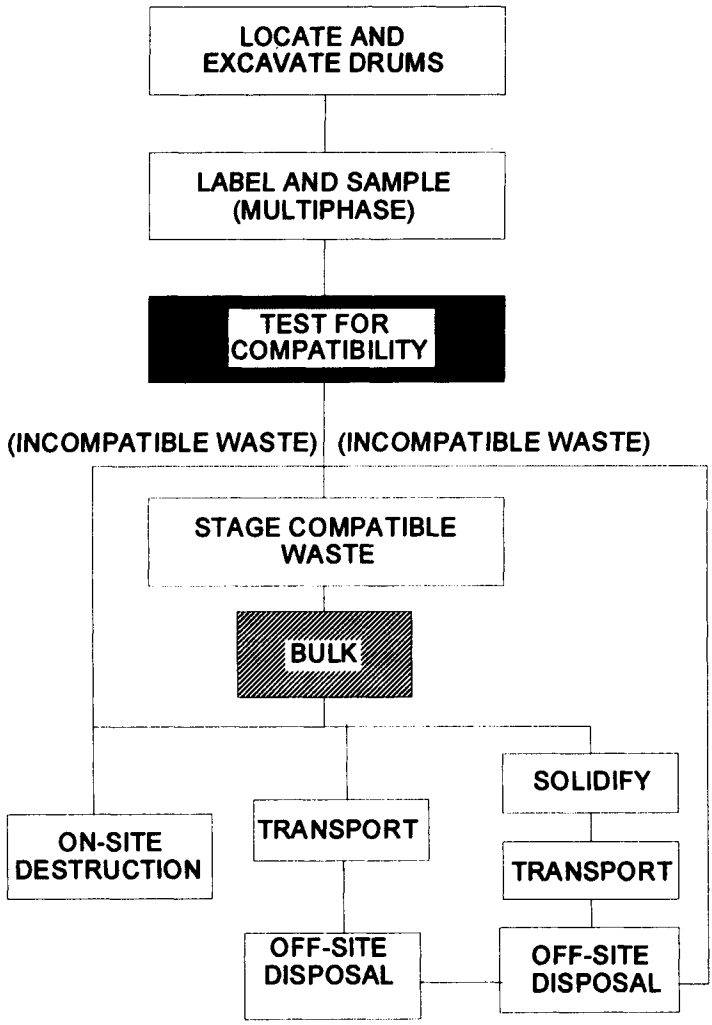


Figure 6-1 Flow diagram of drum handling operations during site remedial action

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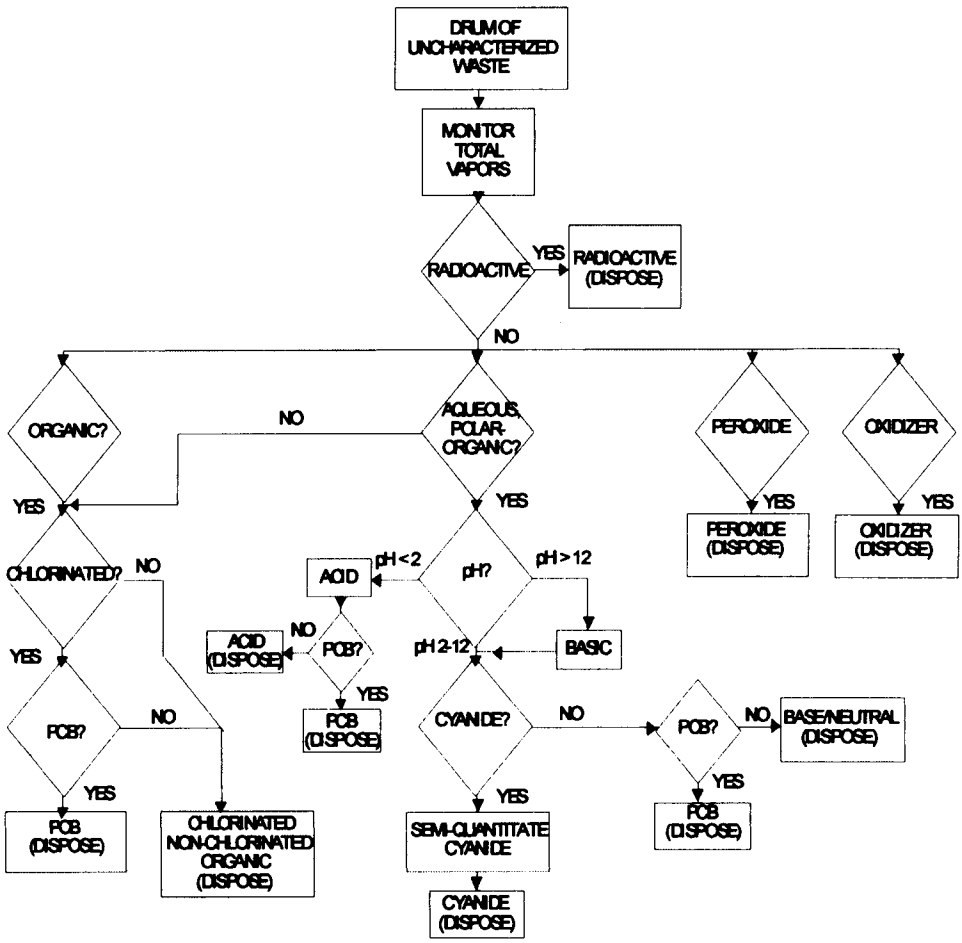


Figure 6-2 Compatibility testing for characterization of hazardous wastes.

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TESTING PERFORMED PRIOR TO DRUM OPENING

Radioactive Wastes

The sampling team should identify radioactive wastes during the initial stage of site evaluation, using a halogen quenched uncompensated Geiger-Mueller tube with a thin mica end window. Following this procedure and performing the initial air monitoring will help ensure the safety of site personnel. Radioactivity levels are checked by scanning the closed drums initially. The OSC (on-site coordinator) should be notified immediately of all drums found having radiation levels above the local background. The OSC should then determine the appropriate handling and disposal steps for radioactive drums with the state or federal agency having responsibility for radioactive wastes.

All workers performing radioactive drum handling, sampling, or analysis should be monitored by documented radiation dosimetry techniques. Since normal environmental gamma radiation background is approximately 0.01 to 0.02 milliroentgen per hour (mR/hr), routine employee exposure should not be more than two to three times this background level. At no time should routine employee exposures be at or above 10 mR/hr without the advice of a qualified health physicist [Turpin, et al., 1981].

The absence of instrument readings above background should not be interpreted as the complete absence of radioactivity. Radioactive materials emitting low-level gamma, alpha, or beta radiation may be present, but for a number of reasons may not cause a response on the portable instrument. However, unless they are airborne, these radioactive materials should present minimal hazard. Reanalysis for radioactivity during sample compatibility testing is recommended. See Chapter 14, Radiation Safety, for more details.

TESTING PERFORMED DURING DRUM SAMPLING

Physical Screening

At abandoned waste sites, unknown wastes can be organized into streams through a combination of physical screening, compatibility testing, and laboratory analyses. Wastes with identical physical characteristics can be grouped for compatibility screening because they are likely candidates for bulking or mixing. Table 6-2 gives example physical parameters to use for characterizing unknown wastes.

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Table 6-2 Physical Characterizations of Wastes	
Color	Describe color(s) of waste in decreasing order of prominence
Turbidity	Clear (transparent), cloudy (translucent), or opaque
Viscosity	Estimate in terms of common products, examples: Low (water); medium (motor oil); high (honey or molasses); solid
Physical State	Liquid, semi-solid, solid, powder, granular, mixed phasing, sorbents, free liquid
Layering	How many layers and physical characteristics of each
Odors	Note *only* obvious incidental odors. Intentional smelling is not to be performed under any circumstance.

Explosives/Air Reactives

After radioactivity testing has been performed and all radioactive drums have been separated, the remaining drums are staged and opened for sampling. Drum opening, sampling, and staging protocols are shown in the process flow diagram in Figure 6-1, and detailed in the literature [Mayhew et al., 1982] and must be *strictly* followed.

The objective of taking total vapor concentrations values just inside the bung hole is to assist in determining whether or not the headspace has a potentially explosive atmosphere. The limitations and operating characteristics of the monitoring instrument must be recognized and understood. Instruments such as the photoionization detectors (PID) and the organic vapor analyzer (OVA-FID) have unique sensitivities and specificities to identical substances, and proper calibration when dealing with "unknowns" is impossible. Also, dangerous gases/vapors undetectable by photo and flame ionization detectors may be present. Such gases would include phosgene, hydrogen cyanide, chlorine gas, and liquid/solid particulates.

The next compatibility test performed on opened drums is air reactivity. This is performed by visual observation during sampling. Any sample taken from a drum containing a solid which ignites or emits fumes or gases is considered air reactive and is immediately resealed and separated [Hina et al., 1983]. Also, any drum found containing metal submerged in liquid should be immediately segregated and considered air reactive. Additional sampling should be done to identify the type of metal. The most common elements

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found disposed in this manner are phosphorus (air reactive) and sodium (water reactive).

TESTING PERFORMED ON COLLECTED SAMPLES

Water Reactivity/Solubility

Radioactive, air reactive, and explosive testing are performed prior to and during sampling. One of the first compatibility tests performed on the collected samples should be water reactivity/solubility. This simple test can generate a host of information on the uncharacterized waste.

The characteristics of reactivity, as defined in the RCRA regulations (40 CFR 261.23), are exhibited if a representative sample of the waste has any of several properties, including

1. It reacts violently with water,
2. It forms potentially explosive mixtures with water,
3. When mixed with water, it generates toxic gases, vapors, or fumes in a quantity sufficient to present a danger to human health or the environment.

The compatibility methods call for a small volume (1 mL for highly reactives to 10 mL for nonreactives) of liquid waste to be added to water and the mixture observed for water miscibility, temperature exotherm, precipitation, and/or gas formation. If any of these occur, the waste is classified water reactive. Following this definition, acids and bases are initially classified as water reactive. They will later be separated by pH measurements. A major interference of this test is that certain water reactive materials may require a reaction time, catalyst, or heat before reactions occur. While potentially dangerous, this test can be relatively safe if precautions against explosions and toxic vapors hazards are taken. Unknown organic vapors, hydrogen cyanide, hydrogen sulfide, chlorine, ammonia, and hydrogen gases could be generated in small amounts.

Another scheme [Hina et al.,1983] classifies only materials that evolve gases, fumes, or ignite as water reactive. Materials that produce a temperature change are not considered to be water reactive unless the water approached boiling temperature. Following this definition, acids and bases are initially separated from water reactives. Water reactive drums should be isolated and sheltered from the elements. However, because of the danger of explosion and fire, indoor storage is not recommended. Table 6-3 presents solubility characteristics of selected organic compounds [Feigl and Anger, 1966].

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Table 6-3 Solubility Characteristics of Selected Organic Compounds

Compound	Water	Ether	HCL 10%	NaOH 10%
Salts of Acids, Bases	Soluble	Insoluble		
Alcohols, Esters, Ethers	Soluble	Soluble		
Hydrocarbons, Aliphatic or Aromatic	Insoluble	Soluble		
Amines, Amino Acids	Insoluble		Soluble	
Acids, Anhydrides	Insoluble			Soluble
Phenols	Insoluble			Soluble
Nitriles	Insoluble	Insoluble	Insoluble	Insoluble

Organics/Inorganics

When a liquid sample from an uncharacterized waste drum is placed in water and is nonreactive, it will either be soluble or insoluble in the water. If it is insoluble, it will either sink or float (becomes the top or bottom phase).

Samples that are soluble in water are strong suspects for inorganic classification. The solubility of these samples is determined in hexane, and if they are soluble in the hexane they are classified as nonhalogenated organics (polar). If they are insoluble in the hexane, they are classified as inorganic liquids.

Organics/Halogenated Organics

Samples that are insoluble in water and are the top phase are classified as organic liquids. Two schemes [Mayhew et al., 1982] check the vapor concentration above the sample at this point with either a PID or an OVA-FID to determine if the organic liquid should be classified as volatile or not. A value of 12,000 ppm is recommended to classify an organic sample as volatile.

Samples that are insoluble in water and are the bottom phase are classified as halogenated organics. This procedure for determining halogenated organics is essentially a procedure designed to determine gross halogen content, not parts per million as required by law for PCBs. Further tests to confirm the

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presence of halogens using either a copper loop flame test [O.H. Materials Co., 1983], halogenated organic GC-ECD scan [U.S. EPA, 1983], potentiometric titration [Mayhew et al., 1982], and total organic halogen (TOX) have been suggested.

Analysis of all drums classified as organic for PCBs [U.S. Corps of Engineers, 1983] must be conducted to determine if ultimate disposal is possible in a non-PCB approved incinerator (for liquids) or landfill (solids and soil). This testing procedure, semiquantitative from a hexane extraction by gas chromatography [Mayhew et al., 1982], should be conducted prior to drum bulking so isolation of PCB-contaminated containers and/or a change in bulking sequence can be inserted to avoid further PCB contamination. The PCB analysis can be conducted on composited samples, to save time and money; however, it would be pratical to not composite more than ten drums per sample. Any drums determined to be > 50 ppm PCB are classified as PCB-contaminated wastes.

Flammability

Although a standard flashpoint test would furnish helpful information about the unidentified waste, this analytical method becomes impractical when dealing with large numbers of drums on a remedial action site. For example, if a test could be performed every 20 minutes, it would take approximately three man-years to analyze 20,000 monophasic drums. Thus, simple flammability techniques have been developed to separate flammables from nonflammables.

For solid unknowns, a small sample (20 to 50 mg) is transferred on a steel spatula into an open flame. If the material is a liquid, a stainless steel loop holding a drop of the unknown is employed [Hina et al., 1983]. If the sample ignites violently at some point in the heating, it is classified as an explosive. If the material burns with the flame, it is considered flammable and organic. Exceptions to this guideline are inorganics such as phosphorus and sulfur; however, their characteristics during burning may be used to distinguish them from organics. Also, clear halogenated organics, such as chloroform or carbon tetrachloride, test as inorganics in the flame test. If the material does not burn, it is considered inorganic. The first screen test requires only one drop of a representative sample on a spatula or forceps. As that drop is brought close to a flame, observe whether the flame seems to "jump" out at the drop. That happens because sample vapors are ignited; the sample is flammable. If the sample will ignite only when the drop is at the flame, then there has been no formation of flammable vapors, but the sample is combustible. When the drop must be heated by the flame before igniting, the waste is combustible with a high flash point. If the drop of sample is flammable, or "pops" or explodes, do

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not test with larger sample amounts. Table 6-4 provides some interpretations of the flame type that might be observed with this test [40 CFR, Part 260].

Table 6.4 Flame Tests

Flame Type	Interpretation
Almost smokeless	Low chain organics
Bluish flame	Compounds with lots of oxygen
Dark smoke	Halogenated
Sooty smoke	Aromatic
Boils without igniting	Aqueous
Chars without igniting	Inorganic

The preceding test may have false negative results because of the small amount of sample used, the susceptibility to air drafts, or the difficulty in seeing the flame. A larger amount may be tested after the initial test indicates that there are no undue hazards in further testing. Place between 1 to 5 g or mL of sample in a nonflammable container such as a metal weighing dish or a crucible cover. Holding the dish with long forceps, bring the dish to a blue, bunsen burner flame slowly. Alternately, the dish may be held in place by a laboratory apparatus stand while the burner is moved slowly to the dish. Observe the actions of the flame and sample. A sample that ignites before or when the burner flame touches the dish is considered to have positive flammability potential. A sample that does not ignite after 15 seconds in the burner flame is considered to have negative flammability potential [ASTM-D 4982-95, 1997].

Another scheme [Turpin et al., 1981] suggests placing a 2 to 5 mL representative sample in a disposable beaker. The beaker is placed in a large sandbox and a propane torch is slowly passed over the unidentified waste. If a flame is observed, the waste is classified as flammable. A nonflammable classification is assigned to the waste after the torch has passed over the waste several times. Certain disposal facilities may require confirmation flashpoint testing to be conducted on all spot-tested samples that were classified positive.

Most observers will be able to make a distinction between organics, inorganics, and free metals using a flame test. Because of the dangers of explosions or fires with these types of flammability testing, safety requirements must be strictly followed. Indoor flammability testing should be performed in explosion-proof high-flow hoods. Fire extinguishers and safety showers must be immediately available. A field quality control program would be useful to verify field observations. Several compounds of known

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flash points can provide the field analyst with points of reference for his or her observations. The quality control program is especially important when interpretations of the flame and smoke types are desired.

pH

To guard against explosive exothermic reactions and evolution of deadly gases (cyanide, sulfide) caused by the commingling of caustic and acidic wastes, pH measurements are taken to separate potentially dangerous drums. The pH of each sample, previously classified as water soluble, is determined using either an electronic pH meter with temperature compensation adjustment and appropriate electrodes, or indicator strips (pH paper) covering the pH range of interest. Both have disadvantages when used on "dirty" samples containing organic layers, sludge, or concentrated solutions. For instance, standard pH electrodes are easily fouled and require constant cleaning, recalibration, and regular replacement. Most colorimetric indicators and papers are easily obscured by grease, sludge, or opaque solutions.

A pH meter can determine the pH of a representative sample to within 0.1 of a pH unit. The pH meter must be calibrated using at least two standard buffer solutions. Clean the pH electrode gently before and after each use. Dip the electrode into sufficient sample to immerse the electrode's sensing element. Record the pH. Clean the electrode. Repeat the process on several samples of the same material until the readings differ by 0.1 pH unit with indicator strips [ASTM-D 4980-89, 1997].

Interfering chemicals may even cause false color changes. These interferences are limited by the use of multiband pH paper, which contains reaction zones and a series of indicator colors fixed for reference. After the strip has been exposed to the waste, the color comparison of the reaction zone and the indicator color is made "assuming" that both have been affected in the same way by the waste.

The greatest concern with the commingling of acids and bases is the generation of deadly cyanide and sulfide gases. Cyanide and sulfide wastes are usually buffered at a pH of 10 in order to remain in aqueous solution. This important fact has been used to define acids and bases for compatibility purposes. Caustic wastes are defined as those with a pH above 10, and acidic wastes are defined as those with a pH below 10 [Turpin et al., 1981]. Following this definition, the accidental release of sulfide or cyanide gas during drum bulking is greatly reduced.

Other schemes separate the wastes into three or four categories depending on the pH value. Wastes with pH values less than 2 are classified as acids; between 2 and 7 are classified as acidic aqueous solutions; between 7 and 12

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are classified as basic aqueous wastes; and greater than 12 are classified as bases.

Wet methods [Mayhew et al., 1982], and the use of ion-selective electrodes [O.H. Materials Co., 1983] are used to determine the presence and concentration of cyanide and sulfide in bases. All drums tested positive are separated from the bases. Additional staging safeguards, including barriers, are recommended to reduce the risk of accidental mixing of cyanide/sulfide bases with acids.

The method of defining acids and bases and selecting analytical methods should be based on the future analytical tests required to meet the criteria set by the approved disposal facility accepting the waste. Many disposal facilities require base and acid reactivity testing prior to acceptance. This method can be found in the *Federal Register*, 40 CFR 261, Subpart C. The hazardous wastes regulations under RCRA (40 CFR 261) regulate as hazardously corrosive those acidic compounds with pH from 0 to 2, and those basic compounds with pH from 12.5 to 14 [40 CFR Part 261].

Strong acids and (sulfide- and cyanide-free) bases identified can be blended on-site for neutralization. These reactions will be highly exothermic and should not be attempted without adequate safeguards [Mayhew et al., 1982] including real-time sulfide/cyanide air monitoring systems and bulking chamber temperature monitors. On-site neutralization may significantly lower disposal costs of waste acids and bases.

Screening for Sulfides or Cyanides

Acidify a small amount of a representative sample in a test tube to screen for sulfides or cyanides in a material. Then test the gases evolved for the presence of the toxic gases. Please note that proper safety precautions must be taken to avoid exposure to the toxic gases.

Testing for sulfide may be done by acidifying 5 to 10 g of wet sample in a large test tube or small beaker with hydrochloric acid. A wet strip of lead acetate paper over the top of the tube or beaker will react with hydrogen sulfide to change the paper color to brown or black. An alternative test method for sulfides is to acidify the sample with a phosphoric acid buffer solution in a beaker. The air above the test solution, inside the beaker, is pumped through a gas detector tube selected for its sulfide sensitivity. A color change in the gas detector tube is an indication of the presence of sulfides in the sample [ASTM-D 4978-95, 1997].

Four field tests for cyanide are published by ASTM. As with the tests for sulfides, cyanide in wastes can be tested by acidifying a sample and testing for cyanide in the evolved gases. Cyantesmo test paper or gas detector tubes can be used to detect cyanide in the gases over the acidified samples. A

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distinct color change is considered a positive test result. Two other test methods involve using specific reagents to produce color changes in the test solutions. One solution will detect cyanides amenable to chlorination; the other is an indicator of free cyanide and many complex cyanides [ASTM-D 5049-90, 1997]. The fourth method is a gas detector tube method similar in procedure to the test for sulfide.

Oxidizers/Reducers

Compatibility testing procedures have been developed for analyzing and classifying drums containing oxidizing or reducing agents, including wet methods, test papers, and portable instrumentation methods.

The wet methods [Hina et al., 1983] include a colorimetric determination of organic peroxides in solid organic unknowns using titanium sulfate as a yellow color indicator and a colorimetric determination of inorganic oxidizers in solids or liquids using manganous chloride as a black or brown indicator. Test papers have had the widest acceptance due to their quickness and simplicity; however, the authors are unaware of any documentation of their ability to determine oxidizers and reducers in complex waste samples.

A potentiometric determination of the redox potential of drum samples through the use of a portable battery-operated instrument has been developed and tested [Turpin et al., 1981]. The unique features of this method is its ability to perform redox measurements not only in aqueous but also organic matrices, such as are found on hazardous waste sites. The entire procedure requires only a few minutes and can be performed by inexperienced operators in the drum staging area. The test is very sensitive and a reaction with only a small portion of an oxidizing agent will give a positive test.

The method involves using an electrolyte solution to generate a known redox potential and then measuring the change in the potential when an unknown waste is added to the electrolyte. Ferrous ammonium sulfate, as a standard electrolyte, is used for oxidation readings. Potassium chromate is substituted for reduction measurements.

Two minor problems have been encountered with this field procedure: electrode probe clogging and electrolyte freezing at sub-zero ^{0}C temperatures. The clogging problem is identical to the pH electrode clogging problem and can be resolved by proper cleaning of the probe between samples. The cold weather, however, causes the probe electrolyte to freeze. This problem is resolved by conducting the tests inside an on-site laboratory.

Another oxidizer screening test is relatively simple. A small sample is placed on a piece of potassium iodide starch paper. A positive test result is indicated by the appearance of a blue color change in the paper. Obviously, dark and opaque samples might mask the color change and give false negative

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results. A drop of liquid sample on the starch paper is enough for this test. To test solid and semisolid samples, mix a small amount of sample into a similar amount of water. Apply a drop of the water to the starch paper.

Use known oxidizing compounds for the quality control program. Compounds selected on the basis of their widely different oxidizer potentials will acquaint the analyst with the sensitivity of the test.

Labpacks

Labpacks are 55-gallon drums that contain small volume containers of waste chemicals. Most are chemical reagents discarded by laboratories. Proper disposal of this type of container presents a unique and hazardous cleanup problem. The chemicals stored in many of these small containers are incompatible. Usually, these containers were not packed in absorbent material prior to original disposal, so breakage and chemical mixing during drum handling is common. For this reason, these drums are considered primary ignition sources for fires during remedial action.

Compatibility testing is performed by chemists conducting visual inspection of the individual containers, without opening and attempting to classify them. If crystalline material is observed in the neck of any bottle, it is handled as shock sensitive, due to the potential presence of picric acid or similar materials. Shock-sensitive containers are repacked in absorbent material, not more than five to a drum, and shipped to a disposal facility; or detonated on-site. The containers with markings that can be identified and trusted (a purely subjective judgement) are segregated into similar compatibility categories and repacked in absorbent material [Wyeth, 1981].

The repacking protocol for unidentifiable containers is set by the facility accepting them for final disposal. This usually involves separating the unknowns into solids and liquids, and the liquids into single- and multiphased.

A compatibility scheme for labpacks has been tested that identifies expected chemicals among unlabeled materials, segregates the remaining unlabeled materials into one of six disposal groups and destroys or neutralizes the excepted materials sufficiently to permit landfill disposal. This method [Hina et al., 1983] involves opening, sampling, and performing classic compatibility testing on each container.

Another suggested scheme for the disposal of labpacks calls for opening each container with a high velocity, low mass projectile (a 0.22 caliber bullet) [O.H. Materials Co., 1983]. This safely accomplishes two things: the containers (almost exclusively glass bottles) are remotely opened by fracture from the bullet impact, and the contents are collected and rendered stable in an absorbent material. Advantages to this method include simplicity over remote control detonation, minimal set-up, low-technical procedure, low

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visibility compared to detonation, and low cost. In highly populated locations, this scheme has been adapted by opening each container by running it over with a bulldozer, and then performing RCRA testing on the contaminated soil.

Compatibility Screening Prior to Mixing Wastes

Before mixing wastes for shipment or disposal, those wastes must be screened for mutually compatibility. Typical mixing hazards include fire, explosion, violent reaction, splashing, heat or toxic gases generation and violent polymerization [40 CFR Part 264].

Representative samples of the wastes are mixed under controlled conditions. The test mixture is carefully monitored for any adverse reaction [ASTM-D 5058-90, 1997].

Compatibility screening requires determination of which wastes will be mixed, what volume of each, and in what order will they be combined. Mix 150 mL (warning: perform a pretest with 1 to 2 mL of each sample to reduce the risk when mixing potentially high reactive waste) of representative samples of the wastes into a beaker which is thermometrically monitored. Mix those samples in the same sequence in which the wastes will be mixed. A common laboratory safety guideline illustrates the importance of performing the compatibility screen test by mixing the samples in identical order as the wastes. The laboratory safety guideline notes that acid must always be added acid to water for safety sake; violent reactions may occur when water is added to acid. Potentially hazardous reactions might be missed if the samples are not mixed in the same order as the wastes. Carefully note any heat generation, or other adverse reactions. Stop testing immediately when any adverse reaction is noticed [ASTM-D 5058-90, 1997].

Once the screen test is completed without adverse reactions, the testing can continue using larger amounts of samples. The resulting amount of the tested representative samples should be about 150 mL. Again, stop the test when any reaction is observed. Mixing the samples in represented amounts increases the sensitivity of the test.

Another approach to compatibility screening involves testing samples of unknown wastes against known chemicals. Table 6-5, from 40 CFR 264, Appendix V, shows potentially incompatible waste types. An unknown material can be characterized into a compatibility scheme by mixing very small samples of unknown wastes with similar amounts of known materials.

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Table 6-5 Potentially Incompatible Wastes

Group 1-A	Group 1-B
Acetylene sludge Alkaline caustic liquids Alkaline cleaner Alkaline corrosive liquids Alkaline corrosive battery fluid Caustic wastewater Lime sludge and other corrosive alkalies Lime wastewater Lime and water Spent caustic	Acid sludge Acid and water Battery acid Chemical cleaners Electrolyte, acid Etching acid liquid or solvent Pickling liquor and other corrosive acids Spent acid Spent mixed acid Spent sulfuric acid
Potential consequences of mixing Groups 1-A and 1-B: Heat generation; violent reaction.	
Group 2-A	Group 2-B
Aluminum Beryllium Calcium Lithium Magnesium Potassium Sodium Zinc powder Other reactive metals and metal hydrides	Any waste in Group 1-A or 1-B
Potential consequences of mixing Groups 2-A and 2-B: Fire or explosion; generation of flammable hydrogen gas.	
Group 3-A	Group 3-B
Alcohols Water	Any concentrated waste in Groups 1-A or 1-B Calcium Lithium Metal hydrides Potassium SO_2 Cl_2g Pcl_3, CH_3 Si Cl_3 Other water-reactive waste
Potential consequences of mixing Groups 3-A and 3-B: Fire, explosion, or heat generation; generation of flammable or toxic gases.	
Group 4-A	Group 4-B
Alcohols Aldehydes Halogenated hydrocarbons Nitrated hydrocarbons Unsaturated hydrocarbons Other reactive organic compounds and solvents	Concentrated Group 1-A or 1-B wastes Group 2-A wastes
Potential consequences of mixing Groups 4-A and 4-B: Fire, explosion, or violent reaction.	
Group 5-A	Group 5-B
Spent cyanide and sulfide solutions	Group 1-B wastes
Potential consequences of mixing Groups 5-A and 5-B: Generation of toxic hydrogen cyanide or hydrogen sulfide gas.	

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Group 6-A	Group 6-B
Chlorates Chlorine Chlorites Chromic acid Hypochlorite Nitrates Nitric Acid, fumming Perchlorates Permanganates Peroxides Other strong oxidizers	Acetic acid and other organic acids Concentrated mineral acids Group2-A Group 4-A wates Other flammable and combustible wastes
Potential consequences of mixing Groups 6-A and 6-B: Fire, explosion, or violent reaction.	

Instead of preparing a test with all six groups listed, other tests in this chapter are more appropriate in classifying some reactivity groups in Table 6-5. For example, pH is a fast and easy method to classify wastes in groups 1-A, 1-B, 2-B, part of group 3-B, 4-B, 5-B, and parts of groups 6-A and 6-B. Wastes that fall into other reactivity groups from Table 6-5 can be identified by tests discussed in this chapter.

To determine the polymerization potential of a waste, mix a small (1 mL) sample of the waste into a similar amount of triethylamine on a ceramic spotplate. Please note the potential for violent reaction and take appropriate safety precautions. Observe any reaction including gelling, fuming, gas evolution, burning or charring. Only if no reaction was observed, should larger amounts be used in a test tube, about 5 mL each of sample and reagent. Do not hold the test tube. Again, observe for any chemical reaction. Any chemical reaction is a positive indication of incompatibility [ASTM-D 4981-95, 1997].

A field quality control program can be established by periodically testing compounds of known composition and compatibility. Demonstrations of incompatible reactions under controlled conditions are commonplace in chemistry classes. For example, the reaction of a small piece of sodium in water is commonly used for safety lectures.

Limitations of Compatibility Testing Procedures

It should be understood that the compatibility methods discussed are designed to detect acute incompatibility only. Reactions that require heat or other catalyzing effects for initiation will not be detected by these tests [U.S. Corps of Engineers, 1983].

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Mixtures are only identified as far as it is necessary to place them into one of the disposal groups. Since these procedures are not designed to identify specific compounds, there are a number of types of materials for which these procedures are not applicable. The identification of highly toxic or carcinogenic materials, such as dioxin, which should not be landfilled is beyond the scope of these procedures. Although these procedures may be employed to segregate total unknowns into disposal groups, additional specific tests must be performed to determine the presence and concentration of materials that cannot be landfilled [Hina et al., 1983]. This problem may be controlled for by incinerating all nonsoil wastes in a Class B facility; however, this solution is not cost-effective.

The need to test-mix the wastes on a small scale, prior to drum bulking, is emphasized even if the compatibility tests indicate compatibility. A major problem with the test mixing, and thus compatibility testing, is obtaining a homogeneous sample from each uncharacterized drum, especially when working with multiphased drums containing both liquids and solids or more lithic solids. Even after the unknown drums are mixed, the cleanup personnel are unable to estimate the short-term (minutes to hours) or long-term (days to weeks) effects of mixing and recontainerizing unknown materials.

Very little data exists that document the effectiveness of compatibility schemes in separating unknown wastes. The data that does exist details major classes that cannot be identified, including isocyanates, epoxides, nitriles, and polymerizable materials. In addition, a need exists for a sound quality-control criteria for compatibility testing.

No methods have been proposed for the screening of pathogenic or infectious materials. These may be present in the uncharacterized drums, especially labpacks.

Although compatibility testing is generally detailed enough for disposal purposes, its use from an industrial/environmental hygiene standpoint is limited. Since no other assays are performed (unless expensive GC-MS is ordered for legal purposes), very little information exists, particularly on drum content, that is useful from a toxicological standpoint. For example, when a drum is categorized nonhalogenated organic, no other data is generated to determine if the drum contains a slightly toxic compound toluene (TLV 100 ppm, 8.7 g/kg LD50), a moderately toxic chemical benzaldehyde (TLV None, lg/kg LD50), a highly toxic chemical parathion (TLV 0.0lmg/m3, 2mg/kg LD50), or a mixture of all three.

A greater knowledge of drum material composition would permit the tailoring of worker and community protection strategies to those specific materials. To meet these needs, however, classic compatibility test procedures (spot tests) have become more and more complex. Consequently, they have lost their time- and cost-effectiveness and become prone to positive and negative interferences.

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A need exists for an analysis procedure that can potentially fill the gap between existing compatibility testing methods and expensive GC-MS. This procedure should

1. Furnish chemical information beyond that which is obtainable via compatibility testing, (i.e., identification of the primary constituents of uncharacterized drum samples);
2. Be rapid enough to complete 100 to 200 samples with a 24-hour turnaround;
3. Be cost effective with respect to compatibility ($30/sample) and simple GC-MS ($750/sample) testing.

Research continues in the development of new compatibility testing procedures, that attempt to meet the preceding criteria; however, until a new method is developed and tested following proper peer review, the classical spot-test methods are recommended as the only alternatives.

SUMMARY

This chapter addressed the role that compatibility testing plays during the waste characterization and bulking phase of a remedial action. The classical spot-test methods were discussed in depth, and proposed unique methods were outlined. Major safety problems encountered and proposed safety protocols were detailed.

The limitations of compatibility testing was addressed, pointing out the need for a quality-control protocol. A criteria based on the need for fast, cheap, but high-quality compatibility testing was given against which to judge future proposed methods.

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MEDICAL SURVEILLANCE FOR HAZARDOUS WASTE WORKERS

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Medical surveillance has two main and two subsidiary objectives. The main objectives are (1) the early recognition of adverse medical conditions or physiologic or biochemical changes in workers due to hazardous substances or conditions at work and (2) the identification of excessive exposures to a workforce by detecting changes in one or more workers. The subsidiary objectives concern (3) fitness determinations and (4) health maintenance. The medical encounter frequently serves for evaluating the fitness of workers to tolerate protective equipment and perform their jobs. The OSHA Hazardous Waste Worker and Emergency Response Standard (HAZWOPER 29 CFR 1910.120) identifies a variety of steps including medical surveillance and fitness determination, which is covered under paragraph (f) [29 CFR Part 1910.120, OSHA, 1987]. The standard tries to incorporate fitness determinations into a nominally medical surveillance approach, and its objectives are therefore somewhat cloudy. In addition, large employers with relatively permanent workforces, particularly those with a heavy personnel investment in engineers and scientists, may provide additional tests as part of a health maintenance program. These four objectives should not be confused, but it should be recognized that the same medical tests may address more than one objective.

Unlike engineering controls, industrial hygiene assessment of the environment, or worker education and training, which are all primary preventive strategies, medical surveillance is only secondary prevention [Gochfeld, 1992]. To be effective it must be integrated into a comprehensive system of hazard recognition and control. Fitness determination and health promotion can be considered primary prevention as well.

Designing a medical surveillance program for any category of workers is a difficult task [Melius and Halperin, 1982]; for hazardous waste workers, it is particularly challenging. While available industrial hygiene data indicate that these

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workers usually have very low levels of exposures to the multiple chemicals commonly present at a hazardous waste site, there is a significant potential for these workers to be exposed for short periods of time to high levels during waste cleanup activities. These short-term exposures, usually the results of accidents or unforeseen encounters with materials and damaged containers, are unlikely to be identified or quantified by industrial hygiene monitoring at waste sites. These potential exposure situations provide the rationale for much of the protective equipment and work practice programs described elsewhere in this book.

The other obvious difficulty with designing medical surveillance programs for workers at hazardous waste sites is the potential for exposure to multiple toxic substances, many of which may not be identified prior to or even during the cleanup process. The potential lack of adequate information must always be considered in developing protective programs and in the design and operation of the medical surveillance program.

Finally, the design of a medical surveillance program for hazardous waste workers also differs from many other situations in another important aspect. Most medical surveillance is predicated on the occurrence of a significant degree of exposure to specific toxic substances, with a significant likelihood of adverse outcome to be averted by early detection. The medical testing is aimed at detecting health effects that could occur from that level of exposure to that specific toxic substance. Combining the usual medical screening recommendations for each of the dozens of chemicals to which the hazardous waste worker could be exposed would produce a costly, unwieldy list of screening recommendations that would be of doubtful effectiveness.

Hazardous waste work entails a great variety of activities with variable likelihood of exposure. At hazardous waste sites, there are many workers involved in infrastructure activities----building or repairing access roads, erecting fences or temporary powerlines, constructing coffer dams. Usually these construction workers do not consider themselves hazardous waste workers, and work at hazardous waste sites may be only a small, though significant, part of their overall employment. More typical of full-time or career hazardous waste work are workers involved in site characterization such as soil sampling or well drilling. Usually the most hazardous tasks involve material handling such as moving drums or draining tanks.

The following recommendations for a medical program for workers are based on the established health hazard for those workers, a review of the available data on their exposures, current OSHA standards [29 CFR Part 1910.120, 1987], and available information on medical programs for these workers.

In the last five years both the Department of Energy and the Department of Defense have embarked on major hazardous waste cleanup or environmental management operations on huge federal facilities, several exceeding 300 square miles (see Appendix G). Although the federal agencies generally abide by OSHA-

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like standards, OSHA does not currently have jurisdiction over work on these sites (even work by private sector employees). This is currently under negotiation between DoE and OSHA, and OSHA is likely to assume some enforcement responsibility on DoE sites in the future. Much of the hazardous waste work at these facilities involves the decommissioning and demolition of buildings or other structures, including nuclear reactors and chemical separation facilities [U.S. DoE, 1994]. Physical hazards such as building collapses or explosions are prominent. In addition to chemical hazards, radiation and biologic hazards may be encountered by hazardous waste workers.

This chapter is not intended to provide a generic program applicable to all hazardous waste site programs, nor specific details applicable to particular exposures, but rather to show the basic steps in designing medical programs for hazardous waste cleanup operations (see Exhibit 7-1). The medical recommendations are intended for a program under the direction of a physician trained in occupational health or with considerable experience in conducting occupational health programs. This is particularly important since the OSHA Hazardous Waste Worker Standard (CFR 1910.120) requires substantial medical judgment. There are conflicting tendencies when it comes to medical examinations: (a) broad-based, "shot-gun" protocols involving many tests at high costs, and (b) cost-savings, minimalist programs often performed by inadequately trained individuals. Ideally a medical program should achieve a balance, performing those tests deemed useful, and necessary, and avoiding those done just "to be complete" [Hardison, 1979].

These recommendations also are based on the assumption that workers will be adequately protected by the use of engineering controls, personal protection, and work practices as delineated elsewhere in this book. The recommendations are presented under the headings of: preemployment screening, periodic screening, provisions for episodic and emergency medical care, recordkeeping, and program evaluation.

A CONTEXT FOR MEDICAL ASSESSMENT OF HAZARDOUS WASTE WORKERS

To be effective, the medical role in protecting workers has to be integrated with other health and safety activities. The Hazardous Waste Standard (29 CFR 1910.120 [29 CFR Part 1910.120, OSHA, 1987]) includes sections on the development of site specific Health and Safety Plans (HASPS) [NAPA, 1997], on hazard recognition, on personal protection as well as paragraph (f) on medical surveillance [29 CFR Part 1910.120, OSHA, 1987].

This chapter is not intended to be all inclusive, for important medical functions such as accident treatment and investigation, return-to-work, mental fitness, and health promotion, are mentioned only in passing.

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Not all employees require medical fitness or surveillance examinations. One set of criteria are provided by the OSHA 1910.120 standard (see below). Other criteria may be established by individual employers, and individuals assigned to various surveillance programs on the basis of Employee Job Task Analysis (EJTA, see below).

Based on multiple sources of information and various criteria, workers will be assigned to medical surveillance programs. This includes core activities such as history, physical examination, and laboratory tests as well as activities specific to particular kinds of exposure (lymphocyte testing for those exposed to beryllium, B-reading of chest X-rays for those exposed to asbestos, blood lead testing for lead exposure, and even psychologic histories for public safety employees or those in extremely stressful jobs). Selection of tests for each protocol is the responsibility of the occupational physician; assignment of workers to particular test protocols is a cooperative venture between physician and industrial hygienist.

PREEMPLOYMENT SCREENING

Preemployment or preplacement screening can play several roles for hazardous waste workers. The OSHA standard emphasizes fitness determinations, but medical examinations also provide a baseline for ongoing surveillance.

The Occupational Safety and Health Administration has promulgated its final regulations covering hazardous waste operations [29 CFR Part 1910.120, OSHA, 1987]. These regulations require medical screening for all employees engaged in hazardous waste operations who (a) are or may be exposed above permissible exposure limits for 30 days or more a year, (b) wear a respirator for 30 days or more a year, c) are injured due to over-exposure from an emergency incident involving hazardous substances or health hazards, and (d)members of hazardous materials response teams. The Occupational Safety and Health Administration (OSHA) respirator standard has been revised and will be full effective by October 1998. Thus 29 CFR 1910.137 replaces 1910.134 except for tuberculosis. It states that no employee may be assigned to a task that requires the use of a respirator unless it has been determined that the person is physically able to perform under such conditions. It also provides details on fit testing requirements and methodology. Formerly, this standard required a medical clearance examination. The revised standard uses a detailed screening questionnaire, on the basis of which a licensed health professional (not necessarily a physician, nurse practitioner, or physicians' assistant) can decide whether or not to refer the employee for further testing.

Some companies require preemployment or preplacement examinations for all employees, even those who do not or will not meet the above-listed criteria. Some companies offer levels of examinations--more superficial for those with little

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potential hazardous exposure and more detailed for those with regular work on hazardous waste sites.

The major focus of preemployment examinations is whether the worker is physically fit to perform the assigned work [Hoffman and Jones, 1990]. This work often involves physically strenuous activity (moving 55-gallon drums that weigh in excess of 200 pounds, etc.) and, in addition, requires the worker to wear personal protective equipment (respirators, protective suits, etc.). Wearing this equipment poses an added physiological burden on the worker, particularly when working in high ambient temperatures [Favata et. al, 1990], since evaporative heat loss is effectively blocked, resulting in a significant risk of heat stress. Unfortunately, there is no accurate method of quantitatively measuring this added physiological burden at the present time, nor of determining ability to tolerate heat stress. Therefore prevention of heat stress should rely on engineering and work practices rather than medical screening (see Chapter 10). However, further evaluation is required for persons who have a history of heat related syndromes, heat exhaustion or heat stroke, or syncope. In many cases these workers would not be cleared for working at level C or higher.

The preemployment screening should therefore include a medical and past-exposure history and physical examination to determine if the worker will be able to handle strenuous work while wearing personal protective equipment. The medical history should ascertain information on past illnesses and chronic diseases (particularly asthma, pulmonary disease, and cardiovascular disease) and include a review of symptoms (especially dyspnea on exertion, other chronic respiratory symptoms, chest pain, and heat or exercise intolerance, or heat-related syndromes). Other characteristics that may make an individual more susceptible to heat stroke, such as obesity and lack of physical exercise, should also be ascertained.

Hazardous waste workers frequently move from job to job and even company to company. Many are construction workers who are employed by one firm for a finite period of days to years to complete one job, and then move on to new employment. Although not unique, this employment pattern is characteristic of hazardous waste work. Consequently, the preemployment history should carefully document past exposures to hazardous materials, as well as protective strategies employed, and any illnesses or injuries sustained. The medical history also affords the opportunity to verify that the worker has received the appropriate hazardous waste training and refresher courses.

The physical examination should focus on the pulmonary and cardiovascular system. Depending on the results of the medical history and physical examination, and on the worker's age, further medical testing, such as a chest X-ray, pulmonary function testing, and an electrocardiogram may be useful in ascertaining the person's ability to perform strenuous work while wearing a respirator and other protective equipment. These additional tests, however, need not be done for every-one. Little information on fitness would be gained from these additional tests for a

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young, healthy, nonsmoking worker. On the other hand, pulmonary function testing and an electrocardiogram may prove quite useful in evaluating an older worker with a long history of cigarette smoking. There is no medical basis for routine stress testing, although this may be performed when medically indicated by multiple risk factors (age > 45, angina or significant exercise intolerance, family history of early cardiovascular disease, elevated cholesterol, hypertension, obesity, smoking).

Much hazardous waste work involves noisy equipment, and baseline audiometry is recommended.

Based on the medical history, physical examination, and appropriate further tests, the examining physician must then make a decision on the worker's ability to perform the required work while wearing protective equipment (see Exhibit 7-2). Unfortunately, there is very little sound guidance in the literature on which to base this decision [Hoffman and Jones, 1990]. Prospective employees with severe lung or heart disease should obviously be excluded; however, there are no clear-cut guidelines for an asymptomatic worker with modest reduction in pulmonary function. Usually in these instances the medical assessment must be based on an overall assessment of the person's medical examination. Current research on the physiological burden involved in wearing respirators and protective clothing, and on the effects of reduction in pulmonary function and respirator tolerance, should help provide better guidance for these assessments in the future.

Many companies have developed programs in which physicians in one clinic provide the hands-on data gathering, but are not trained to make decisions. The chart is then forwarded to a corporate occupational physician who must make a fitness determination on a work applicant who has not been seen. Although this approach may be necessary for remote locations, the quality and reliability of such determinations may be diminished by problems with communicating medical findings and with the inability for the physician of record to question the applicant.

Another major purpose of preemployment testing is to ascertain the worker's ability to work in hazardous environments (i.e., is the worker unusually susceptible to specific chemical exposures?). Since exposures at hazardous waste sites are multiple and often unpredictable, other than serious medical conditions that would disqualify a worker by the above criteria or a history of severe asthmatic reaction to a specific chemical, specific medical testing would not be effective for this purpose.

The final purpose of preemployment medical screening is to establish baseline data to better evaluate the effects of subsequent toxic exposures. This baseline testing may include both medical screening tests and biological monitoring tests. The latter (e.g., blood lead level) may be useful for ascertaining preexposure body burdens of specific substances to which the worker may be exposed and for which reliable tests are available. Given the problem in predicting significant exposures for these workers, there are no clear guidelines for prescribing certain tests. Alternative approaches range from doing no testing to conducting an extensive battery of biochemical and biological monitoring. A more rational approach would include

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baseline testing selected according to the past history of the workers (previous medical and occupational history) and on some assessment of the predominant and significant exposures which the worker may experience.

The most common potential chemical exposures for workers at a hazardous waste site are solvents, followed by heavy metals and pesticides. Although some solvents have specific toxicity (e.g., benzene causes leukemia), the most common medical effects from solvent exposure are neurotoxic and hepatotoxic. Other than history and physical examination, routine preemployment screening tests for neurotoxic effects are not readily available. Liver enzyme tests are commonly used in testing for hepatotoxic effects, but their sensitivity and specificity for detecting the effects from low-level exposures to multiple solvents are probably low [Hodgson et al., 1990]. Their utility in preemployment or periodic screening is questionable, and there is a high rate of "false positive" tests. Upfal and Burtan [1992] caution that programs must be well-designed so that data are useful in prevention. They emphasize the important distinction between medical tests used for clinical diagnosis and those used in a screening mode for exposed workers.

An alternative approach to baseline testing would involve a situation where a specific significant exposure for the hazardous waste worker is known and biological or biochemical monitoring of that exposure is well established. For example, long-term cleanup of a polychlorinated biphenyl (PCB) waste facility could be monitored with preemployment and periodic serum PCB testing [Chase and Shields, 1990]. Lead, cadmium, mercury, arsenic, and organophosphate pesticides are additional examples of substances for which this approach could be appropriate. Given the common use of respirators and protective clothing for workers at hazardous waste sites, typical industrial hygiene monitoring will not provide an accurate indication of the worker's potential for exposure (i.e., through the respirator and protective clothing). Therefore, in situations where a hazardous waste worker may be exposed over a sufficient period of time to a substance that can be monitored by available biological monitoring techniques, preexposure, and periodic biological monitoring for that substance may provide very useful information on the actual exposure for that worker or group of workers. Exposure is more likely to arise during unanticipated incidents when some workers are not wearing protective gear.

Studies have shown that routine biomonitoring tests (blood tests for heavy metals or pesticides) are usually not useful and greatly increase costs. An alternative approach involves drawing preemployment blood specimens and freezing them for later testing if environmental monitoring indicates significant exposures to an agent amenable to such monitoring (e.g., PCB, some pesticides) or if an accident (fire, explosion, spill) occurs.

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PERIODIC SCREENING

The frequency and content of periodic screening, sometimes called medical surveillance [Gochfeld, 1992] of hazardous waste workers will depend on the nature of their work. In general, these examinations should take place at least yearly. The OSHA regulations allow the physician to extend this to two years but not longer. Termination examinations are required unless the employee has been examined within the previous six months. The screening should include an interval history and physical examination. The medical history should focus on changes in health status, illnesses, and possible work-related symptoms occurring since the last screening examination. The examining physician should have some knowledge of the worker's exposure during that period of time. This information should include any exposure monitoring done at the worker's job site. This could be supplemented by self-reported exposure histories or more general information on the potential exposures at the hazardous waste sites where the employee has worked. Any unusual incidents or suspected exposures should be sought. Additional medical testing would depend on the available exposure information and on the medical history and examination results. This additional testing should be specific for the possible medical effects of the worker's exposure. The application of a large batch of medical tests in an attempt to cover all possible consequences of the multitude of potential exposures facing the worker is not very useful. Such testing may only lead to problems due to the occurrence of elevated values due to other factors or to chance (i.e., false positives).

More frequent monitoring may be appropriate where there are significant exposures at a site (e.g., PCB, lead, etc.) as described in the preceding section. The schedule for this monitoring would depend on the degree and type of exposure and the duration of work at the job site. Periodic review of the screening results can help determine the appropriate frequency.

The requirement for periodic examinations is triggered by the same criteria that trigger preemployment examinations, and some companies elect to offer or require such examinations even when the OSHA criteria are not met. Consultations with a trained occupational physician can help determine whether such programs are warranted.

ACUTE OR EPISODIC MEDICAL CARE

As part of an HASP, provisions for acute medical care need to be developed for each hazardous waste site. This should include provisions for emergency first aid at the site. Key employees at the site should have some formal first aid training, particularly in dealing with explosion and burn injuries, with heat stress, and with acute chemical toxicity. Appropriate first aid equipment also needs to be available at the site. Companies that specialize in work at hazardous waste sites, often train

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several field personnel in first aid courses, or even as emergency medical technicians (EMTs).

At any hazardous waste site, arrangements for evacuating injured or ill personnel need to be formalized, and all site personnel should be familiar with them. These include how to arrange transportation to a nearby hospital. The emergency department of the hospital should be notified in advance of hazardous waste remediation. Where site work is protracted (e.g., more than two weeks) a formal arrangement should be made to provide more detailed information to the hospital emergency department, and even training of hospital personnel to prepare for medical emergencies from the site. Advance preparation can avoid unnecessary delays in treating injured or ill workers due to lack of information or inappropriate concerns about chemical contamination of the hospital (this has actually occurred after a fire at a hazardous waste facility). Medical staffs may delay treatment or even deny treatment if they have unwarranted fears about contaminating hospital rooms or personnel.

The medical care facility should be informed about the nature of potential exposures at the site, the specific details on the incident involving the ill or injured worker, and about the worker's medical history. These arrangements are particularly important when specific medical treatment is required for a toxic exposure (e.g., cyanide, organophosphate pesticides).

In addition to the provisions for a medical emergency, a mechanism to provide episodic medical care for hazardous waste workers needs to be arranged. This may be difficult, particularly if the worker is not close to the home office of the employer or is working in a rural area. Nevertheless, it is important to ensure that any possible symptoms or illnesses, either related to exposures or due to unrelated medical conditions, are properly evaluated in the context of the worker's exposures at the site and that other illnesses do not put the worker at greater risk due to the requirements of working with hazardous waste. Arrangements need to be made for the treating physician to have access to the worker's medical records. Depending on the situation, this can be done by keeping the medical records (or a copy) at the hazardous waste site (with appropriate provisions for security; e.g., locked file cabinet) or at a nearby hospital.

Another important group of workers who may be exposed at hazardous waste sites is emergency response personnel, including police, fire fighters, emergency medical technicians, and members of local hazardous materials (HAZMAT) teams. These workers may encounter significant acute exposures in responding to fires, explosions, spills, or other emergencies. Proper preparation can help prevent serious consequences in these situations. Prior to the hazardous waste site cleanup, the fire department and other emergency response personnel need to be informed about potential hazards from incidents at the site. Procedures to limit these exposures and to ensure the availability of appropriate protective equipment can be made. Arrangements also need to be made for decontamination or disposal and

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replacement of fire fighting equipment used at the site. In the event of significant exposure for any of these workers, arrangements need to be made for appropriate medical or emergency care, including informing the medical care provider of possible exposures at the site.

RECORDKEEPING

Recordkeeping is an important part of any medical surveillance program. For hazardous waste workers, this is difficult due to the multiple employers for whom they work, and the multiple sites they visit. Current OSHA regulations require that medical records of all employees be retained for 30 years after they leave employment (45 CFR 35212). Who keeps and retains these records is sometimes controversial. Medical records must be treated as confidential, and usually they are retained under lock and key in a medical department under the control of a doctor or nurse. Current practice has made this more difficult, since employers (who are the ones legally responsible for record retention) increasingly contract medical services to outside providers. In principle, these providers should be responsible for the records, but often the providers simply perform tests and turn the records over to the personnel office of the employer. Although this is contrary to ethical principles of occupational medicine, it is a widespread practice. The OSHA Hazardous Waste standard actually encourages this practice by failing to assign this responsibility to a health care professional trained in maintaining confidential medical records. Thus the standard specifies that the clearance letter must maintain confidentiality, but then makes the employer responsible for custody of the records.

The results of medical testing and full medical records must also be available to the workers, their union representatives, and OSHA inspection staff. Informing workers about their exposures and medical testing results is particularly important in helping them to take appropriate precautions and form informing their other or subsequent medical providers of their exposures as hazardous waste workers. Too often when medical records are turned over to personnel officers, there is no one to provide information or test results to the workers. A sound practice would be for every hazardous waste worker to receive and retain a complete copy of all their medical examination and test results and to provide copies of this to subsequent examiners. This is especially important in a workforce that is as highly mobile as hazardous waste workers. Occupational accident and illness records must also be maintained and reported yearly to OSHA. Each accident or injury should be promptly evaluated to determine the cause of the incident and to implement appropriate changes in the health and safety procedures for the site.

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PROGRAM EVALUATION

A successful health and safety program should include periodic reassessment of its own effectiveness. This will involve reviewing medical records; therefore, these documents should be well maintained. The occupational physician should review these at least annually, looking for patterns of exposure or test abnormalities that might indicate unexpected exposures. This activity is particularly important in conducting a program for hazardous waste sites where the nature of the work and the variety of potential occupational exposures require good compliance with work procedures to maintain an effective health and safety program. This is especially important for large hazardous waste companies who utilize many providers around the nation, for a particular worker may be seen at one clinic in year one and at different clinics in subsequent years. Moreover, each provider may differ in the quality and experience of their personnel and the rigorousness of their testing and recordkeeping. The occupational physician with overall responsibility should periodically audit the records from all outside providers [Udasin et al., 1992].

The review should critically evaluate the efficiency of specific medical testing, particularly in the context of information on the potential or actual exposures at a site. Industrial hygiene and environmental data may suggest the need for adding specific medical tests or deleting current tests. The director of the medical surveillance program should also review the potential exposures at all new hazardous waste sites to determine the specific medical testing required for workers at that site.

Once individual workers are assigned to a medical surveillance program, it is desirable to periodically reassess the validity of this assignment by reviewing their exposure histories and any industrial hygiene data, including personal monitoring. It is likely that some workers are in programs which are no longer appropriate for them, while others may be excluded from medical programs that would protect them.

UNIQUE MEDICAL SURVEILLANCE CHALLENGES AT FEDERAL SITES

The common image of a hazardous waste worker generally involves the digging and moving of contaminated soil, unearthing leaking underground tanks, pumping ground water, or lifting and hauling of 55-gallon drums. At DoE sites, many other tasks are required as well. High level radioactive waste gets converted to dry form; boxes and barrels filled with plutonium must be shifted by remote control, before workers can even enter certain building. Ash basins and lagoons containing radionuclides must be sampled and contained [U.S. DoE, 1995]. Both the tasks and hazards are familiar to only a relatively small number of DoE site workers and the medical, safety, and radiation specialists on those sites [U.S. DoE, 1995]. And the

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DoE sites have traditionally not taken account of the large amounts of hazardous chemicals, much less the interactions between chemicals and radionuclides.

Until recently the large federal sites owned by the DoE and were operated by single contractors or military services with large health and safety organizations and sweeping responsibility for huge numbers of workers, including those exposed to hazardous materials. DoE orders (5480.8A, and 440.1) provide criteria for the occupational medical programs of its contractors to follow [U.S. DoE, 1995]. Recently, as a cost-saving measure, the DoE has looked toward "privatization" as a way of having more work done by smaller, and presumably less costly, contractors [NAPA, 1997]. Inevitably these contractors have fewer trained health, safety, and medical personnel. Although difficult to document, studies indicate that outside contract employees are more likely to experience exposure to contaminants than operators [Hery et al., 1996]. Even though large occupational medical departments persist at many DoE sites, at many sites they no longer have responsibility for, nor provide services to, workers engaged in cleaning up hazardous wastes. This increases the "regulatory complexity of the sites" and frames "a challenge for OSHA" [NAPA, 1997]. It also increases the challenge of providing medical surveillance for the huge number of workers who will be employed in managing hazardous waste on the federal facilities in the coming decades [Hery et al., 1996].

ENHANCED WORK PLANNING AND HAZARD RECOGNITION

Traditionally, the medical surveillance process is informed by industrial hygiene and process data. Recently, attempts have been made to formalize a process called enhanced work planning, by which managers, in conjunction with industrial hygiene and safety personnel, are required to define more precisely the hazardous substances and circumstances which workers may encounter. This begins with an employee job task analysis (EJTA) which supersedes mere job descriptions, providing at least semiquantitative data about hazards. To be sure, this is easier to complete for industrial workers, than for hazardous waste workers, because of the intrinsic unpredictability of the latter, but it at least requires careful consideration and anticipation of hazards, as well as definition of the personal protection and other strategies used to avert them. Industrial hygienists thus indicate whether employees may be expected to exceed certain exposure criteria. The EJTA even covers psychosocial stress and stressors, and lists the key functions the employee must perform, as well as the physical demands [Takaro et al., 1997]. It includes such key features as a formalized algorithm for respirator use, including the kinds and frequency of use.

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RESPIRATOR CLEARANCE

This is a rapidly changing area, and OSHA has recently revised its RESPIRATOR STANDARD (1910.134). Nonetheless some basic principles apply. A person may be unable to wear or tolerate a respirator because of physical or psychological limitations. The former may be physiological (cardiovascular or pulmonary or upper airway disease), or physical (discomfort or deformity which interfere with use or fit). Psychological factors include claustrophobia or anxiety, either because of the mask or of what its use implies.

The clinician should know the level of protection required (air purifying, self-contained, etc.) and whether such protection will be used regularly or only for emergency escape. In the former case, will the equipment be used for a full-shift or only for short-term (15 to 30 min) tasks. What level of protective clothing will accompany respirator use (see Chapter 9)? What level of physical activity will accompany it? Will the work be outdoors in sunshine, outdoors shielded, or indoors?

Workers should be asked what kinds of respirators they have used in the past year and with what frequency. Any problems encountered using respirators should be documented including shortness of breath, wheezing, exercise intolerance, fainting. Medical conditions, including those newly diagnoses, should be documented as well.

Spirometry was not explicitly required for clearance, but is usually performed for this purpose. There is no automatic cut-off below which an otherwise asymptomatic person will be denied clearance. However, values of FVC or FEV1/FVC ratio below 80 percent of predicted arouse suspicion. Clearance may sometimes be denied because of other indications, even in the face of normal spirometry.

The new standard relies on a screening questionnaire reviewed by a health professional. Depending on the answers, a worker may be referred for additional evaluation prior to clearance. Thus in the future it is likely that many hazardous waste workers will not even have a clinical examination or spirometry prior to respirator clearance.

SPECIFIC RISKS AT HAZARDOUS WASTE SITES

Although hazardous waste work is characterized by the general and often unpredictable nature of the agents encountered, there are some remediation projects that target one or a few hazards. Asbestos waste in old buildings, elemental mercury in abandoned vapor lamp factories, beryllium at DoE facilities. Surveillance protocols should be tailored to emphasize these potential exposures. Some hazardous waste workers specialize in particular kinds of jobs such as asbestos

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management, whereas others are "generalists" whose exposures may change from week to week or year to year.

RCRA WASTE MANAGEMENT

Although our traditional view of hazardous waste work focuses on abandoned waste sites, much and perhaps most hazardous waste management, is an ongoing process in industry, managed under the Resource Conservation and Recovery Act. On some industrial sites, one or a few workers may have long-term responsibility for managing wastes that are currently generated. This may include sampling, treatment, storage, and transportation. The training, industrial hygiene and medical monitoring requirements of such workers are more similar to those of chemical operators on their sites, than to hazardous waste workers on abandoned sites.

CONCLUSION

The design and conduct of a medical program for hazardous waste workers is a difficult task. These workers are potentially exposed to thousands of chemicals, often in unknown combinations, where identification or quantification is not possible. The medical program for these workers must provide baseline information, fitness information, and detect changes on subsequent periodic examinations. The program must remain adaptable to exposures at specific sites. Most important, this program must be integrated with the industrial hygiene, personal protection, and safety programs for the site. Together these programs can provide a safe and healthful workplace in what initially appears to be an unsafe workplace—a hazardous waste site.

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Exhibit 7-1 Medical Program for Hazardous Waste Workers

PREEMPLOYMENT SCREENING

A. Recommended
   1. Medical history and physical examination with selective medical testing **where required by an occupational physician** (e.g., chest X-rays, pulmonary function testing, EKG) to determine worker's fitness to work while wearing protective equipment.
   2. Preemployment or (preexposure) baseline biological monitoring for specific exposure at a hazardous waste site (e.g., PCB).

B. Optional
   1. Freezing a preemployment serum and whole blood specimen for later testing, in the event an exposure is suspected.
   2. Other routine baseline tests, blood count, liver enzyme tests, and so on.

PERIODIC SCREENING

A. Recommended
   1. At least yearly medical history and physical examination with appropriate medical testing selected on the basis of this examination and on the worker's exposure history, and on site specific characteristics.
   2. More frequent screening based on exposure to specific hazards (e.g., organophosphate pesticides, PCBS) or individual health factors.

B. Optional
   1. Yearly testing using routine medical tests (e.g., blood count, liver function tests, etc.).

ACUTE MEDICAL CARE

A. Recommended
   1. Provisions for emergency first aid at the site (adequate equipment and basic training for all personnel).
   2. Provisions for transportation to hospital, and for informing the hospital about exposures at the site, particularly if specific medical treatment is available for a toxic exposure (e.g., cyanides).

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3. Mechanism for episodic health care with evaluation of possible site-related illness.

RECORDKEEPING AND PROGRAM EVALUATION

A. Recommended
   1. Maintenance and access to medical records in compliance with OSHA regulations.
   2. Recording and reporting of occupational injuries and illnesses.
   3. Periodic review of the medical surveillance program including integration with available exposure information about the hazardous waste sites where the workers are employed.
   4. Review of specific site safety plans to determine if special testing is required for the workers at that site.

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Exhibit 7-2 Guidelines for Determining Respirator Fitness

These guidelines will help determine if a person is fit to wear self-contained breathing apparatus. It applies to fire fighters, emergency responders, and others who may have to enter environments with high inhalation hazard, where other powered air-supply respirators will not work. The following guidelines have been modified from the *Guidelines for Determining if a Firefighter is Medically Able to Wear a Self Contained Breathing Apparatus*, prepared for the New Jersey Public Employees Occupational Safety and Health service by M. Gochfeld.

1. The assessment must take into account:
   a) Weight of the SCBA may exceed 35 pounds
   b) Concomitant use of heavy chemical protective or heat-protective clothing.
   c) Potentially intense physical activity.

Medical History should emphasize cardiopulmonary system and identify:

1. Previously diagnosed disease
   a) Cardiopulmonary: emphysema, bronchitis, asthma, chronic cough, shortness of breath, heart trouble, hypertension, chest pain on exertion, palpitations.
   b) Other: diabetes, epilepsy, chronic skin condition, hernias, history of heat exhaustion, sinus condition, ruptured ear drum, claustrophobia
   c) Physical: arthritis, back injury or pain
   d) vision: use of corrective lenses
   e) smoking history
2. Respiratory problems during normal work.
3. Past problems with respirator use.
4. Psychological problems such as claustrophobia, anxiety, or other respirator intolerance.
5. Current and recent use of medications (may identify underlying chronic illness, or impaired alertness)
6. Surgical history
7. Allergies
8. History of heat stress or exertion-related medical events
9. Musculoskeletal problems including back or extremity pain or limitation of motion.
10. Family history of cardiovascular disease

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PHYSICAL EXAMINATION

1. Height, weight, body mass index, and change in weight.
2. Blood pressure and pulse for one minute to detect irregularities.
3. General appearance, affect, and gait.
4. Skin for evidence of dermatologic conditions.
5. Basic neurologic examination including cranial nerves, cerebellar function, deep tendon reflexes, motor strength, and sensation in extremities.
6. Range of motion of extremities and trunk.
7. Auscultation of heart and lungs.
8. Abdominal examination.
9. Optional rectal examination and occult blood.

SPIROMETRY: Although not required, probably perform on all persons who require clearance for respirator use under OSHA 1910.134.

STRESS TEST: Not recommended for asymptomatic, healthy adults unless they have 3 or more risk factors.

INTERPRETATION AND CLEARANCE

Experience shows that as a result of self-selection, the vast majority of persons reaching the stage of medical examination, will be cleared for unrestricted respirator use. The most common exception are older employees who may suddenly find themselves assigned to fieldwork as a result of job changes. This is the domain of the experienced occupational physician who must exercise considerable judgment and sometimes investigate extensively, those cases where clearance is in question either because of medical history or physical examination or testing abnormalities. All results have to be considered together and in the context of the employee's work requirements.

Age itself is not a contraindication for respirator use. However, as workers age the likelihood of cardiopulmonary impairment increases and should be evaluated. Age alone is not an indication for a stress test, but for persons with multiple risk factors, the examining physician may require a stress test prior to issuing clearance. Persons with a history of angina, for example, will most likely not be cleared for SCBA use, but may be cleared for level C (air-filtered respirator) if physical activity demands are limited.

A history of asthma alone is not a contraindication to clearance, but frequent asthmatic attacks, or asthmatic attacks while wearing respirators, may be grounds for denying or restricting clearance. For persons who are deemed unfit for regular respirator use, it may still be possible to clear them, if their only use is for emergency egress. If both supervisor and worker agree that intense exercise or

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physical demand is not required, clearance may be granted to a person who would not be cleared for physically demanding effort.

Abnormal spirometry results are one of the most frequent flags, and some clinicians treat them (for example FVC below 75 percent or 80 percent of expected) as absolute criteria for denying respirator clearance. Spirometry is not designed for that purpose, however. Some proportion of perfectly normal individuals, must fall below these percentiles. Abnormal spirometry may serve as a flag, or may confirm a clinical impression.

PHYSICIAN REPORT: The physician should maintain the confidentiality of the information received from the employee, and should provide to the employer only the following information. A standardized report would include the following statements:

In accordance with the Occupational Safety and Health Respirator Clearance Standard 29 CFR 1910.134:

John Doe is medically fit to wear a self-contained breathing apparatus. The next recertification examination should be performed on _____.

or John Doe is not medically cleared to wear a self-contained breathing apparatus, but is cleared to use an air-filtering respirator (level C) protection, in conjunction with light physical activity.

or John Doe is not medically cleared to wear a self-contained breathing apparatus, except for emergency egress use.

or John Doe is not medically cleared to perform any work that will require the use of respiratory protective equipment.

There are other possibilities, but these are the most common. In no case should the diagnoses be provided.

AGE AND FREQUENCY OF EXAMINATIONS: No fixed schedule has been agreed on. A commonly recommended protocol is age-related: every three years below age 35; every two years between 35 and 45, and annually over age 45. However, since OSHA 1910:120 requires annual examinations or at most an examination every other year, this supercedes the three year recommendation for those who meet the criteria of 1910.120(f).

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8

ENGINEERING CONTROLS: SITE LAYOUT

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INTRODUCTION

Hazardous waste site management will directly affect the health and safety of not only personnel who work at the site, but also those in surrounding environments. Knowledge of the contaminants, their mode of action, and fate and transport in the environmental media at the site is also important. First and foremost is the establishment of physical barriers to isolate contaminants such as fencing or clearly marked designated areas and the appropriate personal protective equipment in clothing and respiratory equipment. Also, proper safety procedures for equipment use must be followed.

The following discussion is provided to detail procedures and practices which have proven to provide prudent and necessary to effect safe and secure methods for such activity.

This chapter discusses site management as it relates to (1) *site layout* through the establishment of work zones and (2) *engineered controls*.

SITE LAYOUT

The site must be physically arranged and laid-out to accomplish the remedial objectives. The establishment of *controlled* work zones at hazardous waste sites provides the basis of good site layout (see Figure 8-1).

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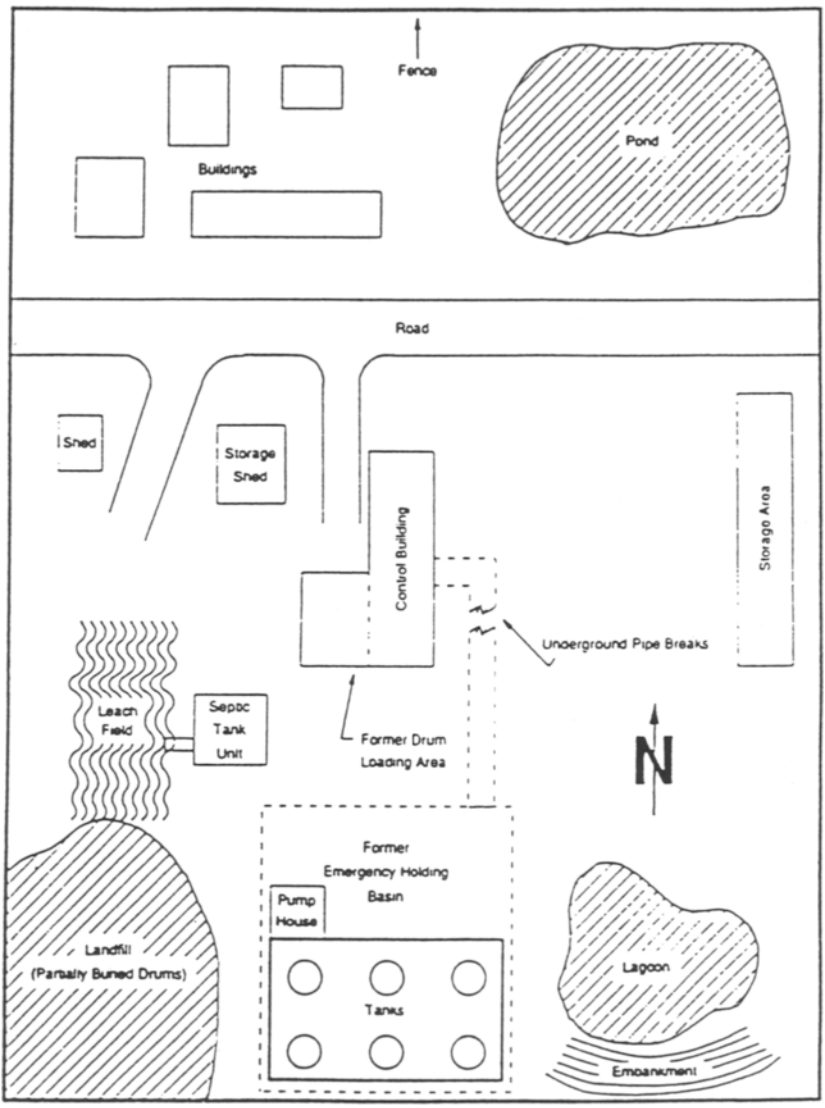


Figure 8-1 Sample site map.

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A properly laid out and managed site will have excellent materials handling operations and control over all entry and exit of personnel, equipment, and materials. Such control is necessary to ensure the safety of personnel on-site and decrease the migration of contaminants from the site. The EPA Standard Operating Guide (SOG) for Establishing Work Zones [U.S. EPA, PB9285.2-04A, 1992] offers the following:

One of the basic elements of an effective site control program is the delineation of work zones at the site. This delineation specifies the type of operations that will occur in each zone, the degree of hazard at different locations within the site, and the areas at the site that should be avoided by unauthorized or unprotected employees. Specifically, the purpose of establishing work zones is to

- Reduce the likelihood that workers or equipment will accidentally spread hazardous substances from the contaminated areas to the clean areas;
- Confine work activities to the appropriate areas, thereby minimizing the likelihood of accidental exposure; and
- Facilitate the location and evacuation of personnel in the event of an emergency.

The shape and topography of the site and its existing physical facilities; that is, buildings, pits, tanks, stacks of barrels, fences, roads, overhead power lines, ponds, and so on, that are located on or adjacent to the site will influence and control the establishment of work zones. All such physical facilities must be identified, located and mapped as part of the initial site investigation.

Since no two sites are the same, this information is vital for planning the best physical arrangement for activities and functions at each site. Similarly, information on the types and locations of existing and potential hazards must be known so that a safe and functional layout can be accomplished. All such information should be included on a site map and must be used in developing the master control plan.

In addition to identifying the location of all waste piles, physical barriers, hazards, and special problems on the site map, working areas must be identified. Specific areas are needed for sampling, staging, detoxifying, processing, bulking, treating, loading, transporting, storing, decontaminating, and numerous support functions. Some of these activities, like detoxification and staging can take place in areas that are not free of contamination. Other activities, such as storing containers of decontaminated materials or most support functions, must take place in areas that are clean and free from contamination. All such areas must be identified and considered in the site layout plan and located on the site map.

The site map is a very important tool to be used both in planning and in executing the control plan. It is a visual tool to complement written plans or orders

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and must be updated as changes occur. Clear plastic overlays can be used to easily make changes and show current information on all posted maps.

The site map must be easily understood by all personnel and visitors. Every effort should be made to ensure that the information contained on the map is both current and accurate.

One key to a successful site operation is total control of the ingress and egress of all materials, equipment, and personnel. The site plan must, therefore, consider the location of existing and potential routes for entering and leaving the site. Special attention must be given for emergency access and egress routes. Separate routes for personnel and equipment must sometimes be provided. All such routes and locations should be clearly marked on the site map.

CONTROL ZONES

The recommended method to prevent or reduce the transfer of contaminants and maintain control is to delineate zones or specific areas on each site where prescribed operations occur. The site must then be operated to ensure that only those operations which are prescribed occur within the designated zone. Control of access and exit points to each of the zones or specific areas is key to site control. Movement of personnel and equipment between zones and onto the site itself are then limited to the access points. This will assist in keeping contaminants within specified areas on-site and reduce the potential for spreading contamination.

A site may be divided into as many zones as necessary to minimize exposure to hazardous substances. The three zones or control areas most frequently identified and designated at hazardous waste sites [U.S. EPA, PB92-963414, 1992] are (see Figure 8-2):

- Zone 1: Exclusion Zone (or "hot zone")
- Zone 2: Contamination Reduction Zone (CRZ)
- Zone 3: Support Zone (or "clean zone")

The use of a three-zone system, access control points, and exacting contamination reduction procedures, provides reasonable assurance against the translocation of contamination. A description of the purpose and layout of each zone follows.

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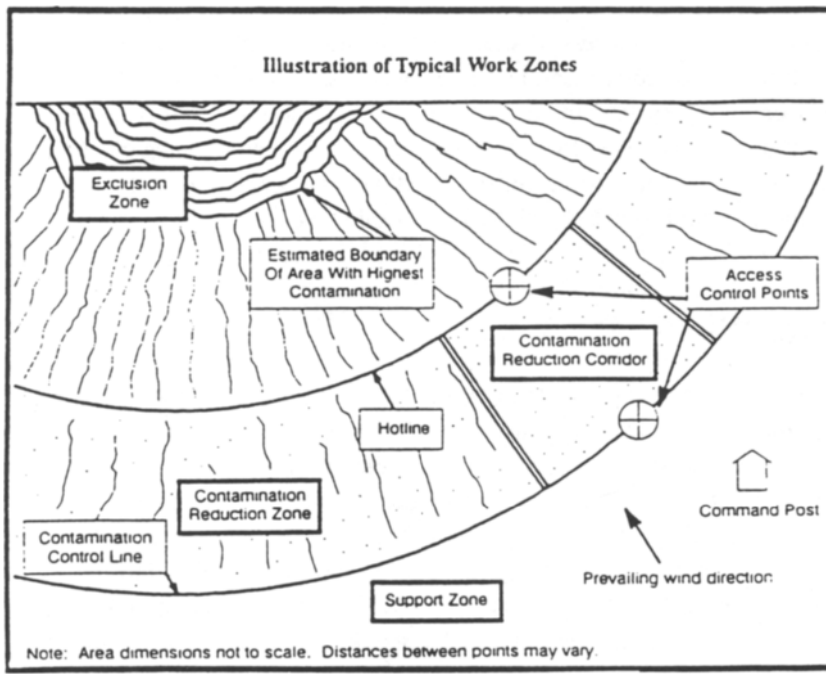


Figure 8-2 Illustration of typical work zones.

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Zone 1: Exclusion Zone

The exclusion zone is laid out to include all of the areas on-site where contamination is known or suspected to occur and all of the areas where the processing of hazardous wastes is planned. The boundaries are initially established from information obtained during preliminary site investigations (see Chapter 2, Information Gathering, Site Characterization and Information Resources). Such information should include site records, visual observations, and instrument readings indicating the presence of contaminants. Analyses for vapors or gases, harmful particulates in air, combustible gases, radiation, and the results of water and soil samples are used as indicators of the presence of possible contaminants. Other factors to consider when locating exclusion zone boundaries include the distance needed to prevent fire or explosion from affecting personnel and equipment outside the zone, the physical area necessary to conduct the various operations which directly involve the hazardous materials, and the potential for contaminants to be windblown or otherwise transported from the area. (For hazardous materials incidents, the boundary of the exclusion zone is established by surveying the immediate environs of the incident to determine where the hazardous substances are located, noting where leaching or discoloration are visible, and determining drainage patterns.)

In order to separate the exclusion zone from the rest of the site, the outer boundary of the exclusion zone must be clearly marked. This outer boundary is known as the "hotline" and is physically marked on-site and clearly shown on the site map.

The "hotline" should be established up-wind of operations and separated from exclusion zone operations by sufficient distance to allow for unexpected venting of materials that may occur during a fire or explosion and to protect entering personnel.

Access to and egress from the exclusion zone should be restricted to designated control points at the "hotline." Such points are used to regulate the flow of personnel and equipment into and out of the contaminated area and to verify that site control procedures are followed. Separate points should be established for entrance and egress. It is important to separate personnel and equipment movement into and out of the exclusion zone.

Once the boundaries and entrance and egress points of the exclusion zone have been determined, they should be physically secured and well defined by visible landmarks. It is recommended that physical barriers such as chains, fences, earth-berms, ditches, or barricades be erected around this zone to designate its location and to control access. Signs must be posted and the use of bright-colored flagging or other visual material to draw attention to its location are very helpful and will probably be required.

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The exclusion zone may be subdivided into different areas of contamination based on the known or expected type and degree of hazard or the incompatibility of waste materials. If the exclusion zone is subdivided in this manner, additional demarcation and access control points may be necessary.

Hazardous wastes are either treated and disposed of on-site or are prepared for safe shipment to an approved disposal site. In either case, the work of opening, sampling, emptying, bulking, mixing, detoxifying, treating, solidifying, filling, staging, and associated handling of hazardous materials, is managed within the exclusion zone. Liquid and solid residues from the decontamination processes located in the contamination reduction zone, and any other contaminated material from the site, are brought to the exclusion zone for treatment and disposal. In order for the wastes to be properly confined so as not to spread contaminants, all such functions must be controlled and contained within this zone.

The exclusion zone must be laid out to allow multiple operations. Some remedial functions will occur simultaneously and others will occur sequentially. For example, there may be drum sampling, drum moving, drum staging, and monitor-well drilling all going on simultaneously, while bulking, solidifying, and loading would all be preceded by other operations. Site layout must be planned to assist in accomplishing the goals and sequences of the remedial actions that will be required at each particular site.

During remedial actions in the exclusion zone, adequate space must be provided for: (This is not intended to be an all inclusive list.)

- Sampling and identifying wastes, including remote drum opening operations.
- Moving wastes. There must be room to maneuver waste handling equipment without bumping or spilling other wastes.
- Storing wastes. Wastes must be stored only with other wastes which are compatible. This may require several separate storage areas. Wastes are stored until they are treated and/or removed.
- Bulking wastes. Emptying the contents of drums or small containers into tanks or other large containers for processing or removal. There may be several bulking areas depending on waste compatibility and the volume of operations.
- Treating wastes. There must be room for each of the treatment processes which are to be used on-site. Some processes may have much larger space requirements than others, such as ponds, mixing basins, incinerators, reactor vessels, explosion pits, and so on.
- A space buffer in case of fire or explosion.
- Storing and treating contaminated run-off or surface water.
- Entrance and exit corridors for both equipment and personnel.
- Demolition of structures, tanks, or equipment and storage of the residue until their treatment and/or removal.

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- Excavation of buried wastes, including room for the excavation to take place and storing both the excavated soil and wastes.
- Equipment storage for loaders, backhoes, drum grapplers, trucks, pumps, hoses, and the like.
- Fire fighting or other emergency equipment to operate.
- Well drilling equipment to drill monitoring wells or test holes.

During operations, the location of zone boundaries may be moved or modified as required to meet program, operational, or environmental changes. Zone boundaries must be made to serve the purposes of the remedial actions taking place on-site.

All personnel and equipment are to be excluded from this zone unless they have specific permission of the on-site coordinator or site manager *and* are properly protected by the prescribed level of personal protective equipment (PPE). Prescribed levels are based on site-specific conditions which include the type of work to be done, the hazards that might be encountered, the physical condition of the worker, and environmental conditions such as weather (see Chapter 9, Personal Protective Equipment).

Because many different activities can occur at the same time within the exclusion zone, different levels of protection are often justified. For example, the task of collecting samples from open containers might require one level of protection, while a walk-through air monitoring task or an observer task may require a different level of protection. The level of protection is determined by the measured concentration of substances in the work area, the potential for contamination while performing the task, or the known or suspected presence of toxic substances, and perceived hazards, chemical and physical, at the site.

It is important that levels of protection be established commensurate with the actual or perceived hazards and not based on worst case scenarios that may not pertain to that particular site or site conditions. It may seem easier to designate one level of protection for everyone rather than worry about controlling several different levels in one zone. However, the assignment, of different levels of protection within the exclusion zone generally makes for a more flexible, effective, and less costly operation, while still maintaining a high degree of safety.

Where different levels are permitted, areas within the zone must be conspicuously marked to identify each area and clearly labeled as to the levels of personal protective equipment required for each area. This is not only important for the workers within the zone, but it is vital for any emergency response personnel who may be required to enter the exclusion zone.

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Zone 2: Contamination Reduction Zone

The contamination reduction zone is laid out to surround the exclusion zone and provide a buffer or isolation area to separate contaminated areas from uncontaminated or clean areas. This zone provides a transition area to assure that the contamination of personnel and equipment does not occur, or is limited to acceptable levels.

Contamination reduction is accomplished by a combination of factors including control of access, decontamination procedures, work functions, and zone restrictions. If on-site contamination is physically contained within the exclusion zone boundaries, then the contamination reduction zone will begin as a noncontaminated area, and remain so except where decontamination activities occur.

Contamination reduction corridors, which are movement control points between the exclusion zone and the support zone, will need to be established (see Figure 8-2). These corridors for both personnel and equipment should consist of an appropriate number of decontamination stations necessary to address the contaminants at the site.

As operations proceed, the contamination reduction zone will remain an effective transition area only if it is properly maintained and managed. Some minor contamination may occur, but the amount of contaminants should decrease from the "hotline" and not be detected at the support zone boundary. Any contamination that does occur should be removed and returned to the exclusion zone for treatment.

The decontamination stations serve as control points to contain the contamination within the exclusion zone. Such stations must be located at the boundary between the exclusion zone and the contamination reduction zone, and along the contamination reduction corridors, as required. Chapter 11, Decontamination, outlines requirements and procedures and gives necessary details on setting up and operating decontamination stations.

Access to the contamination reduction zone from the support zone must also be controlled. The contamination control line marks the boundary between the contamination reduction zone and the support zone. Personnel and equipment must be allowed to enter only through designated control points and only when authorized. Personnel entering the contamination reduction zone from the support zone must wear the personal protective equipment prescribed for this zone. The decontamination area always requires some level of protection.

Personnel should leave any contaminated protective equipment at the decontamination station when leaving the contamination reduction zone. Personnel and equipment entering this zone from the exclusion zone will go through the decontamination stations and will leave all contaminated equipment and clothing at the stations. They must still maintain the specified level of protection required for this zone while passing to the support zone.

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The control or safety plan must address all activities and functions that take place at a remedial site and prescribe the personal protective equipment that will be used for each activity or function. The planning and execution of the plan to ensure compliance are important steps to insure that the operation will be conducted safely commensurate with the actual problems of each function or activity.

Zone 3: Support Zone

To establish a proper support zone, the specific hazards and the degree of potential personnel exposure at the site must be considered. Site characterization is the basis for developing the site health and safety plan (HASP), and provides needed information to identify site hazards, select proper personal protective equipment, and implement safe work practices.

The support zone must be located in clean or noncontaminated areas outside of the contamination reduction zone, usually in the outermost portions of the site and sometimes in areas separated from the site. *It is important to remember that the absence of sampling results should not be considered evidence that an area is clean* [U.S. EPA, PB92-963414, 1992].

The support zone is generally located within an established site security perimeter, however some support activities such as personal vehicle storage and some emergency care facilities may be located outside of the security perimeter. Since support functions may be located in several different parts of the site, security must be maintained at required areas of the support zone. Contaminated personal clothing, equipment, and samples are not permitted in this zone, but are left in or taken to the decontamination stations in the contamination reduction zone.

Support functions such as the command post, medical station, equipment and supply center, laboratory facilities, equipment storage, training or briefing rooms, observation tower, and administrative functions, are normally located within this zone. This does not mean that observation facilities, laboratory facilities, equipment storage, or first aid facilities cannot or are not located elsewhere, but only indicates that the support zone is set up to provide support functions in a clean area.

Care must be exercised in locating every facility on-site. Site inspections have revealed that the level of contamination, based on air monitoring results, was greater in one support laboratory than was measured in the exclusion zone [Costello, et al., 1983]. This, of course, may not always be the case, but it points out that planning and control are necessary in locating *all* activities on-site if a safe and efficient operation is to be maintained. Laboratories and other facilities that handle grossly contaminated samples or conduct tests that could release airborne contaminants, should be located within the contamination reduction zone or the exclusion zone.

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Personal protective equipment is not usually required within this zone. Normal work clothes are appropriate. Emergency respiratory protective equipment should be available in case of an explosion, fire, or unexpected occurrence, but this would be for an emergency action and not for normal operations. All personnel working in the support zone should receive instruction in the use of such emergency equipment and in proper evacuation procedures in case of a hazardous substance emergency.

The location of the command post and other support facilities in the support zone depends on a number of factors. They include

- Accessibility, topography, open space available, location of highways and railroad tracks, location of available emergency routes, or other limitations.
- Wind direction, preferably the support facilities should be located up-wind of the exclusion zone. Shifts in wind direction and other conditions may dictate that the initial selection of certain support functions was not correct and they may have to be moved to a greater distance from work areas than was originally anticipated.
- Resources such as telephone and power lines, water, adequate roads for moving materials and equipment, and shelter.

Other functions that may be located in the support zone include the communications area, the staging area for supplies and equipment, a wind direction indicator visible to all, a visitor briefing area or facility traffic control and site security control headquarters, medical center, and other auxiliary functions that support a complex operation.

Some operations such as those provided by local police and fire departments may not be housed within the support zone, but still must be considered in site layout. For example, sufficient room must be provided for access and maneuverability of special equipment (fire engines), and water sources must be identified for fire fighting operations. Access routes must be provided and kept unobstructed for ambulances or emergency vehicles.

The location and operation of all functions at hazardous waste sites is dictated largely by what the function does or is supposed to do. If the operation is clean or must be kept clean, it should be located in the support zone. If it is an operation that involves sampling or handling of contaminated materials it should be located in either the exclusion zone or contamination reduction zone.

It is conceivable that the support zone may inadvertently become contaminated after site remediation begins. For example, changes in the wind speed and direction, temperature, and rainfall may result in exposures different from those experienced during initial on-site surveys. It is important that the integrity of the support zone be maintained throughout response operations. The support zone *must remain clean*! This may require periodic monitoring of the support zone. Proper zone siting and

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strict use of site controls will help minimize the transfer of contamination into this clean area. In the event that contamination has occurred, the boundaries of the work zones should be reevaluated and, if appropriate, realigned [U.S. EPA PB92-63414, 1992]

AREA DIMENSIONS

The distance between various on-site functions must, of necessity be site-specific. The size of each zone or work area must also be based on the conditions at each site and not on some standard formula. Considerable judgment is required to ensure that the distances between zone boundaries and distances between activities within zones are adequate for operations. The distances must also be great enough to prevent the spread of contaminants and eliminate or significantly reduce the possibility of injury due to explosion or fire.

The following criteria should be considered in establishing area dimensions and boundary distances:

- Physical and topographical features of the site, including the exterior dimensions of the site itself;
- Weather conditions;
- Field and laboratory measurements of air contaminants and environmental samples;
- Air dispersion calculations;
- Potential for explosion and flying debris;
- Physical, chemical, toxicological, and other characteristics of the substances;
- Cleanup activities required;
- Potential for fire both on-site and to surrounding areas;
- Area needed to conduct operations;
- Decontamination procedures;
- Dimensions of actual contaminated areas;
- Potential for exposure;
- Accessibility to support services (e.g., power lines, roads, telephones, shelter, and water); and
- Duration of cleanup activities.

Boundaries should not be considered permanent but should be flexible and moveable as the demands of the site change.

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CONTAMINATION CONTROL

Contamination will only be contained if control measures are planned and implemented. A site will only be as safe as those who are in control make it. The project manager, team leader, or on-site coordinator is responsible for control of all on-site activities. The safety officer only assists, but should have the authority to stop an operation if it is found to be life-threatening.

An elevated observation tower and/or strategically located video cameras provide useful methods to observe safety procedures, work progress, and work procedures. During an emergency, having visual observation capabilities can be very helpful, and be used to observe ways to improve existing procedures.

To verify that site control procedures and existing boundary locations are preventing the spread of contamination, a monitoring and sampling program should be established. Zones should be regularly monitored to provide data from which to make management decisions. Operations should involve reasonable methods to determine if contaminated material is being transferred between zones, to assist in modifying zone or site boundaries, and to modify site safety or control plans as required. All such monitoring must be kept within the capacity of the analytical support functions available or it will be of limited or no value in making rapid decisions. Where applicable, direct reading instruments can be used to monitor vapor, gases, and particulates in the air. Some data on contaminants in water can be obtained rapidly but normally most analyses for water and soil take several days to obtain results.

The use of a three-zone system, access control points and corridors, effective cleanup, and exacting decontamination procedures provide reasonable assurance that contaminating substances can be controlled.

Less stringent site control and decontamination procedures may be utilized than here described if more definitive information is available on the types of substances involved and the hazards present. The necessary information can be obtained through air monitoring, and technical data concerning the characteristics and behavior of the material that must be handled. Experience gained from previous remedial work is very valuable in assessing the conditions and dangers associated with this type of work. Most decisions are judgmental and rely on the ability and experience of the decision-maker in cooperation with the monitoring or enforcement authority.

The site layout procedures given in this chapter may need to be adapted to the unique situation at each individual site.

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ENGINEERED CONTROLS

Occupational safety and health professionals consider the use of engineered safeguards that contain, isolate, or remove the hazard from the worker to be superior to the use of personal protective equipment that attempts to isolate the worker from the hazard. This approach works well in industrial settings where ventilation systems and physical barriers are employed to isolate or remove the hazard and leave the worker in a safe environment. This approach is considerably more difficult to accomplish at hazardous waste sites because of the conditions that normally exist at such sites and because the operations are usually of much shorter duration than in industrial settings. Nevertheless, it is still a better policy to control the hazard by isolation, processing, containment, and removal in conjunction with proper worker protection than to rely solely on personel protective equipment. When the hazards are controlled, all personnel are protected.

Many hazardous or potentially hazardous conditions on-site can be eliminated or significantly reduced by employing engineered controls. Unsafe conditions, such as rutted or bumpy roads for forklifts carrying hazardous chemicals, sharp objects that could rip protective clothing, inadequate warning devices (backup alarms) fire and explosion hazards, inadequate illumination in closed areas or at night, excessive noise levels, confined space entry proper ventilation, and buried or overhead electrical cables are all examples of potential causes of accidents or injuries at hazardous waste sites. Effective engineering can help prevent such accidents.

Remote or robot-controlled drum handling or drum opening devices, protective berms or embankments, sparkless tools, vacuum pumps and tanks, overpack drums, and controlled drainage areas are examples of engineered controls that can be used to isolate or control hazardous materials handling activities and thus reduce human exposure to hazardous substances.

Selection of alternate processes or activities can also provide an engineered safeguard for personnel. If the suggested treatment procedure for a particular waste was incineration and there was a danger of explosion of a waste stored nearby, an alternate process of treatment such as solidifying or containerizing might provide a solution with less risk to personnel. All such alternate approaches should be considered during planning and operation to ensure that the best possible alternative is used commensurate with the problem.

A lock-out, tag-out system should always be considered and implemented during operations. All equiment and processes should be evaluated and lock-out, tag-out procedures developed and enforced.

Engineered safeguards, alternate processes, special equipment, and engineered construction techniques can and should be used whenever possible at a hazardous waste site.

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SITE PREPARATION

Prior to undertaking response activities, time and effort must be spent in preparing a site for cleanup activities to ensure that response operations are efficient and that personnel safety is effective. Because of the real and potential hazards involved in site preparation, personnel should place high priority on safety measures during all site preparation activities.

Before on-site response or remediation activities begin, the following site preparation activities should be performed [US EPA, PB92-963414, 1992]:

- Construct roadways to provide a sound roadbed for heavy equipment and vehicles and arrange traffic patterns to provide ease of access and to ensure safe and efficient operations;
- Eliminate physical hazards from the site to the greatest extent possible, including;
  - Ignition sources in flammable areas;
  - Exposed underground wiring and low overhead wiring that may entangle equipment;
  - Sharp or protruding edges (e.g., glass, nails, torn metal, etc.) that may puncture protective clothing and equipment or inflict puncture wounds;
  - Debris, holes, loose steps or flooring, slippery surfaces, or unsecured railings, that can cause falls, slips, or trips or obstruct visibility;
  - Unsecured objects, (i.e., bricks and gas cylinders) may dislodge and fall;
- Install skid-resistant strips and other antiskid devices on slippery surfaces;
- Construct operation pads for mobile facilities and temporary structures, loading docks, processing and staging areas, and decontamination pads;
- Provide adequate illumination for work activities. Equip temporary lights with protective guards to prevent accidental contact; and
- Install wiring and electrical equipment in accordance with the National Fire Code.

ISOLATION AND CONTAINMENT BARRIERS

Containment of materials can often be achieved by the construction of berms or dikes of suitable on-site soils. In rare cases, imported soils may be used. Synthetic liners may be required to contain liquids if porous soils are used. Liners can also help to reduce the amount of contaminated soil that may require disposal. Trenches can be constructed to collect or divert spills and releases of liquids or contaminated water for later treatment and disposal; for example, leachate and contaminated runoff.

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Access to contaminated areas or potential areas of contamination can be controlled by exclusion barriers such as chains, fences, trenches, or earth-berms to keep personel and equipment out, thereby preventing inadvertent entry into hazardous areas. Streamers, flags, ribbons, or other visual warning can alert persons to hazard areas and reduce accidental entry into such areas. Signage as required by law must be posted at hazardous waste facilities.

SPECIAL EQUIPMENT

Equipment must be selected, developed, or modified to reduce direct contact of workers with wastes and containers during handling and transport of materials. Remote or robot operated equipment has been developed for hazardous waste operations. Surveys at hazardous waste sites have identified the frequency of occurrence of various material such as metals, sludge, paper, asbestos, etc. [U.S. EPA, PB91-921283, 1991] (see Figure 8-3). This type of characterization should be made and will aid in the selection of needed specialized equipment.

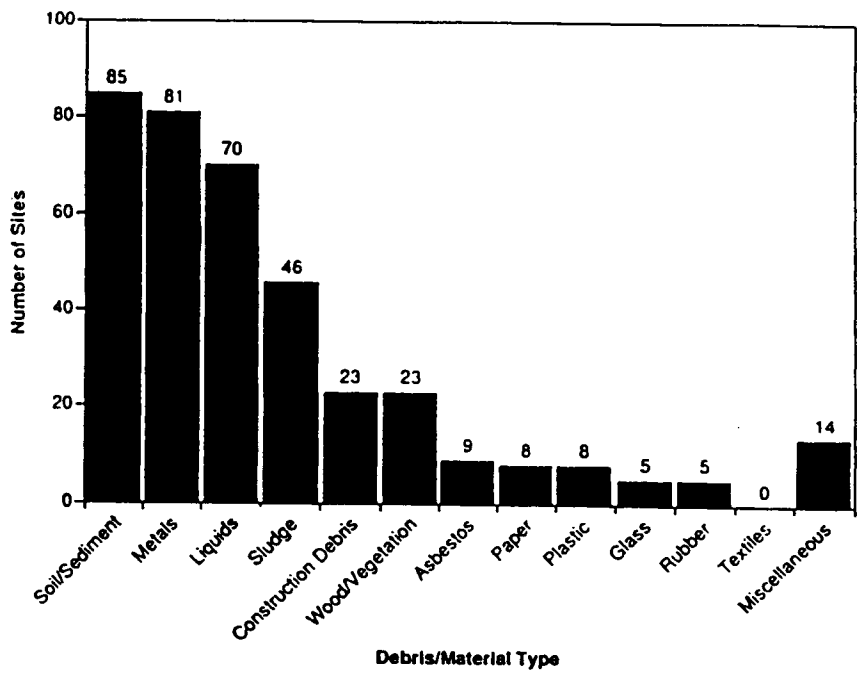


Figure 8-3 Frequency of occurrence for types of debris/materials found on 100 hazardous waste sites.

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Containers can be moved by machines such as Bobcats, forklifts, drum grapplers, backhoes, and cranes. Moving and loading of containers, bulk solids and small spills can be achieved by front-end loaders, backhoes, draglines, Bobcats, and the like.

Splash plates or shields and cab enclosures can prevent or reduce worker exposure to spills, splashes, and releases under force; for example, liquids and solids released under pressure, explosions, and so on. In extreme cases, total cab enclosures with temperature controls and self-contained air supplies could be necessary to provide total protection from vapors, solids, and liquids while operating in hazardous areas. Some contractors are routinely using HEPA filter to provide full air filtration systems for sealed cabs.

Special equipment such as reactor vessels for on-site chemical treatment, tanks or ponds for wastewater treatment, vacuum pumps and vessels, pneumatic pumps, bulking and handling equipment, and similar items should be reviewed by qualified engineers and safety and health personnel for technical suitability and safety. Workers using the equipment and other personnel performing activities in the same area must be protected from improperly designed or constructed special equipment.

WARNING ALARMS AND DEVICES

Emergency alarms should be provided to alert personnel of emergency conditions such as fire, dangerous weather conditions, accidents, material releases, etc. All personnel should be familiar with the alarms, signals, and warnings established for different types of emergencies.

For operations where vehicles or equipment must back up, and for loaders carrying containers in front that partially block visibility, the use of warning devices is advisable and in most cases required. Flashing lights and audible warning devices such as beepers or horns are necessary to alert workers who may not be watching or whose vision and hearing may be reduced because of their personal protective equipment or other obstruction.

Certain hazardous conditions such as vapor and oxygen concentrations can be monitored by devices that will give an audible alarm when concentrations reach a preset level. Use of these devices in enclosed spaces is required. Heat and smoke detectors can be used to alert workers and off-site response groups to fires and potential fire conditions. Such devices should be used whenever workers are involved in activities adjacent to the potential hazardous conditions. Heat and smoke detectors can signal fire departments and trigger alarms when personnel are not working such as evenings and weekends. For further discussion of emergencies, see Chapter 13, Health Safety Plans and Contingency Plans.

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AIR POLLUTION CONTROL

Control or minimization of the concentrations of air contaminants such as mists, vapors, and particulates can be achieved several ways. Using devices to collect or draw off the contaminants from the work area, application of water or other appropriate liquids, encapsulation of the wastes, dispersion and dilution of contaminants, proper handling of wastes and debris, permissible controlled releases at specified intervals or under controlled conditions, and selection of alternative treatment methods that reduce generation of air contaminants.

Gas collection systems such as passive gas trenches, passive trench barriers, and active gas extraction wells [Walsh and Gillespie, 1982] are designed to control gas migration through soils and subsequent releases to the air. If necessary, filters, flares, or other methods can be used to treat gases vented from these systems.

Ventilation systems consist of air moving devices, hoods or vents, ductwork, and air cleaning devices. Such systems can either collect the contaminants at the source using canopy hoods or enclosures, or dilute the level of contaminants by exhausting the air through appropriately placed vents. The airflow is usually supplied for these systems by safe fans selected by careful consideration of the required fire code considerations. Fans can be located to either draw air into the system by negative pressure or force air into the system by positive pressure. General ventilation basically reduces or dilutes contaminants while local ventilation is designed to prevent or ameliorate exposures to workers.

Mobile on-site laboratories are equipped with hoods to prevent exposure to lab workers. Most sites are not conducive to the application of large ventilation systems. If ventilation systems are required, they should be designed by qualified safety engineers or industrial hygienists.

Exhausts from ventilation systems can either be released (based on proper dispersion models) or treated by applicable pollution control devices such as electrostatic precipitators, bag house systems as approved by the appropriate regulatory authority. This decision should be based on the concentration of contaminants in the exhaust stream and the potential hazards of each pollutant. Treatment residues must be disposed of in accordance with applicable regulations. Any major use of ventilation systems for contaminant control should carefully consider the safety, effectiveness, practicality, and costs of such systems.

The use of general ventilation by forced air to aid in the dispersion of contaminants in the working area, to aid in worker comfort in hot weather, or to add warmth during cold weather should be carefully monitored and controlled so as not to disperse contaminants to other locations on- or off-site. Properly located exhaust stacks can make good use of normal dispersion for dilution of contaminants providing exhaust levels do not exceed acceptable limits ["Documentation of Threshold Limit Values," 1982].

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Wetting down road surfaces serves to reduce the amount of dust generated and assists in compaction of the road surfaces [Church, 1981]. Dust controls should be employed using water sprays or other suitable liquids. Contaminated road dusts can be reduced by prudent and application of water dust suppression agents.

Liquid sprays and curtains can be used to reduce dust during transfer, handling, and packaging of bulk wastes and wastes with particle sizes capable of air dispersion such as powders and finely ground compounds. For some wastes, this may require the use of special wetting agents to aid in adherence or adsorption to the particles. The wetted materials must be collected, contained, and disposed of in accordance with applicable regulations to prevent redispersion [NSC, 1971]. Similar wetting of waste piles, working areas, and containers can serve to reduce dust during materials handling operations and cleanup activities. Care must be excised to determine that the wetting agents are compatible with the wastes. Care must also be taken to avoid using too much water and spreading pollutants by the runoff.

Reduction of airborne contaminants can also be achieved by the cleanup of debris and containment of wastes. This can be accomplished by using appropriate cover materials such as tarps, caps, or sealants and containers such as drums, overpacks, covered tanks, and dumpsters with closable lids. This normally involves the selection of appropriate materials for caps and sealants common sense and good housekeeping practices.

Short-term or temporary controls such as the use of tarps and containers mentioned above, are more applicable to cleanup operations involving off-site disposal. Contaminated tarps must be disposed of by incineration or burial if they cannot be decontaminated.

The cost of providing control of air pollutants and protecting worker health and safety should be a major consideration in the selection of acceptable alternative remedial actions. Efforts should be made to select methods and procedures for tasks at remedial action sites that reduce exposures by minimizing generation of dusts, vapors, and mists.

CONTAMINATED SURFACE WATER CONTROL

Exposure of workers to contaminated water and migration of contaminated water to clean work areas or off-site areas can be prevented or minimized by diverting rain run-on and runoff away from wastes, and collecting storing and treating any contaminated water that is generated. Good use of engineered dikes, berms, drainage pipes, ditches, and contour grading are used to keep surface water from hazardous waste locations. Similar engineered controls are used to direct contaminated runoff water coming from the site to collection basins and ponds for pretreatment and/or transfer to on-site or off-site treatment and disposal facilities

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[Rogeshewski et al., 1982]. Surface water control/containment must be addressed in original work plans. Use of packaged filtration units to meet preestablished action levels for discharge can be a very cost-effective site management device. In areas of insufficient water for fire protection, surface water that is kept from entering the site and collected is a possible source for this purpose. Runoff water from contaminated areas or leachate should not be used for fire control.

DEBRIS/MATERIALS CONTROL

Debris is defined as any unused, unwanted, or discarded solid or liquid that requires staging, loading, transporting, pretreating, treatment, and/or disposal on a hazardous waste site. The largest quantities of materials requiring handling and engineered controls are soil/sediments followed by metals, liquids, and sludges [U.S. EPA, PB91-921283, 1991] (see Figure 8-3).

The wide variety of chemicals found on hazardous waste sites may lead to handling problems because of factors such as high corrosivity, shields on heavy machinery, or highly toxic or combustible compounds, which require special handling or personal protective equipment. Additional handling problems may arise from incompatibility reactions occurring because of the complex mixtures of chemicals found on-site. In addition to debris, other materials (e.g., soil, sludge, asbestos, and various liquids) must be handled [U.S. EPA, PB91-921283, 1991].

The selection and use of engineered controls needed to handle the large quantities and varieties of debris/materials resulting from hazardous waste remedial actions requires considerable judgment and may require equipment usage/ modification/fabrication for site specific activity.

Most of the equipment used for excavation and removal work at hazardous waste sites is standard heavy duty construction equipment. Selection of excavation equipment depends on the quantity and physical properties of the debris and materials present. Valuable performance data on such equipment at hazardous waste sites are available in an EPA publication, "Survey of Materials-Handling Technologies used at Hazardous Waste Sites" [U.S. EPA, PB91-921283, 1991]. This book is a valuable resource for understanding what has worked at previous sites to avoid making mistakes that could be avoided when considering engineered controls for a large majority of debris and materials handling at such sites.

Despite the site-specific nature of hazardous waste remediation, similar conditions are found at many sites. This results in similar techniques and standard operating procedures (SOP) being used at different sites for materials handling. The following are site-specific solutions to problems found at hazardous waste sites. [U.S. EPA, PB91-921283, 1991].

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- Hydraulic systems may have to be modified to adapt a backhoe for drum handling (grappler).
- Rubber or foam tires may be required instead of pneumatic tires at sites with large quantities of sharp metal/glass objects.
- Splash shields will be required and must be installed on heavy equipment.
- Large bulldozers may be required to winch smaller dozers up and down the steep grades of asbestos or other tailing piles.
- Propane-powered instead of diesel-powered loaders may be required to reduce fumes, especially in enclosed areas.
- Heavy equipment may require special attention to avoid failure due to weather (e.g., cracked hydraulic lines from cold, tractability during icy conditions, metal fatigue from digging frozen soil).
- A drum crusher may be required instead of a backhoe to crush drums.
- Rolloff boxes may be converted into treatment chambers for wastes such as cyanide-contaminated film chips. These units can be very effective containment devices for drum piercing activities and provide considerable explosive protection.

Engineers and operators involved in selecting, designing, and operating engineered controls to increase efficiencies and the effectiveness of materials handling operations are expected to be innovative and creative in accomplishing their tasks. The more we can learn from past efforts and the more we understand the nature of the material that must be handled, the better we can get the job done in a safe manner.

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PERSONAL PROTECTIVE EQUIPMENT

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A variety of known and unknown chemical and physical health hazards are potentially present on a hazardous waste site. Remedial action personnel must be properly protected to prevent short- and long-term disabilities related to these hazards. Engineering controls, administrative controls, good work practices, and personnel protective equipment (PPE) are the routes to such protection. The focus of this chapter is protection from chemicals, rather than physical hazards. Consequently, respirators and chemical protective clothing are the principal topics of discussion.

HAZARDS

A virtually infinite number of chemicals and chemical mixtures are potentially present on hazardous waste sites. These chemicals and chemical mixtures may be in the form of solids, liquids, and gases, and they can range from benign to extremely toxic poisons and carcinogens (see Chapter 4, Toxicology and Risk Assessment; and 6, Compatibility Testing). Furthermore, may be corrosive, explosive, flammable, or radioactive. Oxygen-deficient confined spaces may also be present. Although less common but of growing concern, potentially hazardous biologically active materials such as bacteria and pathogens may also be present. Physical stresses on-site may include high noise (e.g., excavation machinery, drum crushing), rough surfaces, and cut and puncture threats. In addition, the climate, workload, and PPE may introduce heat or cold stresses (see Chapter 10, Heat Stress in Industrial Protective Encapsulating Garments).

Such hazards can produce a multitude of different health effects, including

- Temporary or permanent damage to the eyes, ears, skin, internal organs, or the nervous or circulatory systems;
- Carcinogenicity, mutagenicity, or teratogenicity; and

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- Loss of limbs, organs, or death.

This chapter is focuses on PPE as a means for minimizing or eliminating deleterious health effects due to contact with chemicals. These health effects are dependent principally on the route of exposure, the duration of the exposure, and the toxicity of the chemical. The routes of exposure may be ingestion, inhalation, and skin contact. Upon skin contact, there may be damage to the skin itself as well as absorption into the body where other effects may occur. For any given exposure, the effects may also vary from individual to individual [Clayton and Clayton].

TYPES OF PPE

At a typical site, personal protective equipment is an essential component of a sound worker protection program [Mansdorf, 1993]. Chemical protective equipment (CPE), which is a subset of PPE, includes respirators, gloves, boots, aprons, goggles, faceshields, hoods, and coveralls. In extreme situations, a self-contained breathing apparatus and a full-encapsulating, gas-tight ensemble compose the CPE needed. Virtually all types of chemical protective equipment is fabricated from synthetic materials (i.e., plastic and rubber). Such materials have been developed to resist degradation by and absorption of chemicals. As will be discussed later, chemical protective clothing (CPC) from a wide variety of such materials of construction is available. The challenge to those persons responsible for worker safety and health is to select the most appropriate clothing material(s) for the hazards involved. For example, leather gloves and boots are to be avoided where there are potential chemical hazards since leather readily absorbs many chemicals, posing a health hazard to the wearer. Leather is also very difficult to decontaminate. Hard hats and safety footwear should be worn in conjunction with chemical protective clothing.

Eye, ear, and face PPE can include safety glasses or goggles, ear muffs, ear plugs, and faceshields. Tinted safety glasses and goggles are available for welding and burning applications. Goggles can be gas-tight to prevent gases and vapors from contacting the eyes or vented to allow for good ventilation, depending on the application. Faceshields protect the entire face and in some cases the neck region from liquids and solid objects. Good-fitting eye, ear, and face protection is critical to providing protection, as well as not introducing additional hazards. Equipment from several manufacturers may be required in order to assure that every worker has a good fit for each item. Poorly fitting ear plugs will not attenuate the noise, and loosely fitting safety glasses or goggles may create an additional hazard during strenuous fast-paced work. The

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advantages and limitations of these protective devices should be fully defined and understood by the individual user [Stull, 1998].

Hoods used in combination with hard hat, goggles, and respirators will adequately cover the back of the neck and head from spills and splashes of chemicals. Aprons and sleeves may be utilized, bearing in mind the limitations of their coverage.

Coverage of the body can be by one-piece (coverall-type) suits, two-piece ensembles (pants and shirt/jacket), and encapsulating ensembles. Each of these types of garments is available in both reusable, single-use (i.e., disposable) and limited-use forms.

Encapsulating suits provide a self-contained internal environment for the wearer. All parts of the body, including head, hands, and feet are enclosed. These suits must be equipped with a supplied-air system to provide the user with a fresh air source. Fully encapsulating suits can be chemical resistant, as well as heat-resistant, thus permitting personnel to work in dual-hazard environments.

In addition to protecting the body, single- and multicomponent suits prevent contamination of the individual's street and underclothing. This reduces the potential for spreading the hazard to lunch and smoking areas, offices, automobiles, and homes.

On waste sites, gloves and respirators are considered the key items of personal protective equipment. Gloves should permit an individual to handle equipment and materials while providing a highly resistant barrier between hazardous chemicals and the skin. The effectiveness of gloves as a barrier has been well studied during the past 10 to 15 years. Chemical resistance and permeability of glove materials and other clothing materials such as butyl rubber, neoprene, natural rubber, plastic film laminates, and the like are discussed later in this chapter.

In selecting and using PPE, one should seek to balance the needs of

- Protection;
- Worker productivity;
- Worker comfort;
- Worker acceptance of and compliance with PPE requirements; and
- Cost.

Briefly, the goal is to provide just the right amount of protection—no more and no less than is warranted by the hazard. By so doing, one minimizes the negative effects on worker productivity and comfort typically associated with protective equipment as well as the cost. The cost of PPE extends far beyond its purchase price and includes the costs associated with training the worker in

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the use of the PPE, lost productivity due to don and doff time as well as hindered mobility, dexterity, communications, vision; decontamination, maintenance and storage, and disposal [Schwope, 1997].

The remainder of this chapter focusses on respirators and chemical protective clothing.

RESPIRATORS

A respirator is any device designed to provide the wearer with respiratory protection against inhalation of a hazardous atmosphere [Code of Federal Regulations, 1996]. Respirators are often used on hazardous waste sites to prevent the inhalation of hazardous gases, vapors, or particles by the wearer. Since the type of respirator needed for each class of respiratory hazard may differ in both design and function, the selection of the correct respirator must be made on the basis of the specific hazard against which protection is needed. This requires that a hazard characterization be performed to determine the identity and concentration of hazardous agent(s) present at the work site.

Two federal agencies have specific responsibilities for the respirators used on hazardous waste sites. The National Institute for Occupational Safety and Health (NIOSH) establishes performance criteria for each type of respirator, tests products against these criteria, and issues approvals to devices that conform. With rare exceptions, only "NIOSH approved" respirators should be considered for use on hazardous waste sites. The Occupational Safety and Health Administration (OSHA) governs respirator use. OSHA's *Respiratory Protection* regulation 29 CFR 1910.134 applies to hazardous waste sites, and requires an organized respiratory protection program that addresses all aspects of respirator selection, use, and maintenance [*Federal Register*, 1998].

All respirator designs include a respiratory inlet covering to form a barrier between the contaminated atmosphere and the user's respiratory system. Respiratory inlet coverings also provide a point of attachment for the portion of the respirator that provides respirable air to the user (breathing tubes, filters, etc.). They can be classified as either tight-fitting or loose-fitting. Tight-fitting respiratory inlet coverings require that a seal be formed between the device and the user. The quarter facepiece, half facepiece, and full facepiece are examples of tight-fitting inlet coverings that rely on a facepiece to face seal. The quarter facepiece covers only the nose and mouth, resting on the bridge of the nose and the front of the chin. The half facepiece extends from the bridge of the nose to the area below the chin. The full facepiece fits around the entire perimeter of the face, and provides protection from eye irritation as well as respiratory protection. A special type of tight-fitting inlet covering is the filtering facepiece. This is most often a half facepiece particulate respirator in which

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the filter is an integral part of the facepiece or with entire facepiece composed of the filtering medium. The final tight-fitting respiratory inlet covering is known as the mouthpiece or mouth bit. This design requires a seal to be formed between the mouth bit and the user's lips, and also requires a nose clip to pinch the nostrils closed. All respirators that use a mouthpiece are intended for emergency escape only.

Loose-fitting respiratory inlet coverings do not form a tight seal between the device and the user's breathing zone. Therefore, all loose fitting inlet coverings require that respirable air be supplied continuously to the breathing zone at a flow rate greater than the expected inhalation rate of the user. Specific loose-fitting respiratory inlet coverings include the hood, helmet, loose-fitting facepiece, and supplied-air suit. The hood is defined as a flexible covering for the head, neck, and sometimes the shoulders of the wearer. The helmet covers the same areas as the hood, but uses a rigid shell to provide head protection. The loose-fitting facepiece consists of a rigid faceshield with a flexible material around the perimeter to form a partial seal with the face. The headgear may or may not include head protection, and the neck and shoulders are not covered. Supplied-air suits cover the entire body, and are designed to simultaneously provide air to the trunk and extremities as well as the breathing zone. This feature distinguishes them from traditional chemical protective suits, which in themselves provide no respiratory protection.

Respirators are commonly divided into two groups according to the method by which protection is provided. *Air-purifying respirators* refer to those devices which provide protection by removing contaminants from the air inhaled by the worker. *Atmosphere-supplying respirators* protect the worker by providing a source of respirable air that is independent from the work environment.

Another commonly used system for categorizing respirators classifies the devices according to the pressure in the respiratory inlet covering (facepiece, hood, or helmet) relative to atmospheric pressure. *Negative pressure respirators* are those in which the facepiece pressure drops below atmospheric at some point during the inhalation-exhalation cycle. Conversely, *positive pressure respirators* are designed so that a positive pressure is normally maintained inside inlet covering throughout the entire breathing cycle. This minimizes the likelihood of inward leakage of contaminated air.

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Air-Purifying Respirators

Air-purifying respirators use air-purifying elements referred to as cartridges, canisters, and filters to remove specific contaminants present in the work area. The use of air-purifying respirators is limited to situations in which

1. Concentrations are measured or reasonably estimated;
2. The contaminants present in the atmosphere have been identified and the contaminant concentrations are not immediately dangerous to life or health (IDLH); and
3. The atmosphere is known to contain at least 19.5 percent oxygen.

The types of air-purifying elements are discussed briefly in the following paragraphs.

Filters remove solid and liquid particles using the mechanical filtration processes of impaction, interception, and diffusion. Many modern filters also use electrostatic charges to enhance filtration efficiency for small particles. Filters for negative pressure respirators are currently approved by NIOSH in three series, identified as N, R, and P. Within each series, three minimum levels of efficiency may be certified: 95 percent, 99 percent, and 99.97 percent. The resulting nine types of filters are identified by their series and efficiency as follows:

N95, R95, P95
N99, R99, P99
N100, R100, P100

N-series filters may be used only for solid and liquid aerosols that do not contain oil. R- or P-series filters may be used for all aerosols, and must be used when oils are or may be present in the atmosphere. In general, R-series filters are limited to 8 hours of use or a 200 milligram aerosol loading (100 milligrams per filter for dual filter respirators) when oils are present [NIOSH, 1996]. P-series filters must be changed in accordance with the individual manufacturer's instructions in the presence of oil aerosols [NIOSH, 1997]. In addition, any filter must be changed when breathing resistance increases due to aerosol loading, the filter is damaged, or for hygiene reasons.

Because the NIOSH certified efficiency levels represent minimum performance under worst case conditions, filter efficiency in the workplace will always exceed the certified efficiency. It follows that the class 95 filters will be appropriate in nearly every situation, although specific regulations may require class 100 filters.

Chemical cartridges and *canisters* are used to remove gases and vapors.

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Canisters are distinguished from cartridges in two ways:

1. Their larger volume, which can provide longer service time at a given contaminant concentration; or
2. Their approval, which allows escape only from IDLH atmospheres that contain at least 19.5 percent oxygen. Neither cartridges nor canisters are approved for routine use in IDLH atmospheres.

Both cartridges and canisters use sorbents such as activated charcoal to remove gases and vapors via the physical process of adsorption. In some cases, the sorbent is treated with a chemical that will react with and thereby remove specific gaseous contaminants. This removal process is referred to as chemisorption. In rare cases, a catalyst is used to convert a gaseous contaminant into a less toxic substance, e.g., the catalytic conversion of carbon monoxide into carbon dioxide. These removal processes are essentially 100 percent efficient until the sorbent is saturated or the catalyst is poisoned [Colton and Nelson, 1997]. Continued exposure to the contaminant beyond this point results in breakthrough: that is, passing through the sorbent and, during use, into the user's breathing zone.

Cartridges and canisters can be approved to remove specific gases, (e.g., ammonia), an entire class of gaseous contaminant (e.g., organic vapors), or combinations of up to 10 gases and vapors. It is critical that these air-purifying elements only be used for the contaminants for which they are approved.

NIOSH requires that air-purifying cartridges and canisters be color-coded in accordance with American National Standard K13.1-1973, as shown in Table 9-1 [ANSI, 1992]. In addition to this requirement, P100 particulate filters must be magenta in color [42 CFR Part 84, 1996].

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Table 9-1 Cartridge and Canister Color Coding

ATMOSPHERIC CONTAMINANT TO BE PROTECTED AGAINST	COLOR ASSIGNED
Acid gases	White
Organic vapors	Black
Ammonia gas	Green
Carbon monoxide	Blue
Acid gases and organic vapors	Yellow
Acid gases, ammonia, and organic vapors	Brown
Acid gases, ammonia, carbon monoxide, and organic vapors	Red
Other vapors and gases not listed above	Olive
Radioactive materials (except tritium and noble gases)	Purple
Dusts, fumes, and mists (other than radioactive materials)	Orange

NOTES:

1. A purple stripe shall be used to identify radioactive materials in combination with any vapor or gas.
2. An orange stripe shall be used to identify dusts, fumes, and mists in combination with any vapor or gas.
3. Where labels only are colored to conform with this table, the canister or cartridge body shall be gray, or a metal canister or cartridge body may be left in its natural metallic color.
4. The user shall refer to the wording of the label to determine the type and degree of protection the canister of cartridge will afford.

For many years, the use of cartridges and canisters was limited to protection against contaminants with adequate warning properties; that is, odor, taste, or irritation that are detectable and persistent at concentrations at or below the contaminant's exposure limit [ANSI, 1992]. This was the case because detection of the warning property was the user's indication that the sorbent was no longer effective and that it was time to replace the cartridge or canister. A recent change to OSHA's *Respiratory Protection* regulation has ended this reliance on warning properties as the primary signal for cartridge or

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canister change. Instead, employers who want to use air-purifying respirators for gas or vapor exposures are required to either:

1. Use cartridges or canisters with end of service life indicators (ESLI) that warn the user via color change or other means when the sorbent is reaching its capacity; or
2. Implement a change schedule based on objective information or data that will ensure that cartridges or canisters are changed before the end of their service life [*Federal Register*, 1998].

Since ESLI are currently available for only a few contaminants, considerable effort is being directed toward developing methods to predict service life. Methods that have been suggested include [Colton and Nelson, 1997]:

1. Estimating service life based on general guidelines, if the contaminant has adequate warning properties. These estimates may not always be accurate, but the warning properties will alert the user if the actual service time is shorter than the estimate and allow the change schedule to be adjusted.
2. Laboratory testing of cartridges or canisters to measure breakthrough times for specific contaminants. This is generally done for a single contaminant under limited conditions of concentration, humidity, and air flow. The results are often difficult to extrapolate to the workplace, where exposure conditions are significantly different from the test conditions.
3. Using breakthrough equations. These can be useful for single contaminants, but can be extremely complicated or inapplicable for mixed atmospheres.
4. Field testing in the specific work environment where the cartridge or canister will be used. This may involve drawing air through the actual cartridge or canister with a high volume air pump. Another field test method known as the respirator carbon tube (RCT) uses a small amount of sorbent from a respirator cartridge or canister packed into a glass tube. A relationship is established between measured breakthrough time with the RCT and the actual cartridge or canister. Since both of these methods test performance under specific workplace conditions, they may provide the most useful information on service time. However, both methods require sampling equipment and expertise that may not be readily available to many employers.

It is likely that additional, simpler methods for estimating service time will evolve. For example, it may be possible to estimate service time based on the increase in weight of the purifying element [Tanaka et al., 1990]. It may also

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be feasible to sample cartridge discharge air with direct-reading instruments or detector tubes to measure breakthrough in the workplace [Tanaka et al., 1998]. This method has the potential for use with a sampling adapter located between the cartridge or canister and the respirator facepiece. Sampling adapters currently used for quantitative respirator fit testing (discussed later in this chapter) may be suitable for this purpose.

Negative pressure respirators require the user to inhale to draw air through the air-purifying elements discussed in the preceding paragraphs. The powered air-purifying respirator (PAPR) is a respirator that uses a fan to draw air through the air-purifying elements and blow the purified air into the respiratory inlet covering. NIOSH requires a minimum air flow rate of 4 cubic feet per minute (cfm) for PAPR used with tight-fitting respiratory inlet coverings and 6 cfm if loose-fitting inlet coverings are used. This air flow eliminates breathing resistance, reduces fatigue, and increases user comfort. Inward contaminant leakage is also minimized because the pressure within the respiratory inlet covering is greater than atmospheric pressure at most work rates.

Atmosphere-Supplying Respirators

Atmosphere-supplying respirators provide the user a source of respirable air that is independent from the work environment. These respirators fall into three subcategories: supplied-air respirators (SAR), self-contained breathing apparatus (SCBA), and combination SAR/SCBA.

Type C supplied-air respirators, commonly known as airline respirators, provide respirable air to the user through a compressed air hose connected to a cylinder(s) or air compressor. The NIOSH approval for airline respirators includes the respiratory inlet covering, breathing tube, air control device, and the air supply hose and its connectors (including "passthrough" connectors used with encapsulating suits). Supply hose lengths up to 300 feet and operating pressures up to 125 pounds per square inch (psi) may be approved. The breathing air *source* is not a part of the NIOSH approval. However, both NIOSH and OSHA have minimum requirements for the *quality* of breathing air used in approved respirators [*Federal Register*, 1998]. OSHA's breathing air quality requirements for all atmosphere supplying respirators are the more stringent, and can be found in Table 9-2.

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Table 9-2 OSHA Breathing Air Quality Requirements for Atmosphere-Supplying Respirators	
Characteristic	**Requirement**
Oxygen	19.5 - 23.5%
Carbon monoxide	≤ 10 ppm
Carbon dioxide	≤ 1000 ppm
Condensed hydrocarbon (oil mist)	≤ 5 mg/m^3
Dew point (compressor air)	≥ 10° F below ambient temperature at atmospheric pressure
Dew point (cylinder air)	≤ - 50° F at atmospheric pressure

Airline respirators are limited to use in situations in which the contaminants are known and are present in concentrations that are not IDLH, and some oxygen deficient atmospheres.

Airline respirators operate in one of three modes: demand, pressure demand, and continuous flow. *Demand* supplied-air respirators always include a half or full facepiece and a demand air flow regulator. Air flow is triggered when the facepiece pressure falls below atmospheric pressure as the user inhales. When the user exhales, the flow of air is stopped, and the exhalation valve on the facepiece opens to allow exhaled air to escape to the environment. Since the facepiece pressure is negative during inhalation, inward leakage of contaminated air is possible if the facepiece to face seal is compromised. It is for this reason that demand type respirators should not be used.

Pressure-demand supplied-air respirators also use tight-fitting respiratory inlet coverings and an air flow regulator. However, the regulator and the exhalation valve are designed such that a slight positive pressure is always maintained in the facepiece. This is typically accomplished by spring-loading the regulator to initiate air flow when the resistance on the regulator outlet is below a specified value. A spring-loaded exhalation valve is used to create enough resistance to overcome the spring in the regulator and stop the flow of air: *air does not flow continuously in a pressure demand system!* When the user inhales, air flow is reinitiated by the spring in the regulator *before* the pressure in the facepiece becomes negative. Because the pressure within the facepiece of a pressure demand system is above atmospheric pressure during both exhalation and inhalation, any compromise in the facepiece to face seal results in outward leakage of air. Therefore, pressure demand systems provide much higher levels of protection than do demand systems.

Continuous flow supplied-air respirators can be configured with either tight-fitting or loose-fitting respiratory inlet coverings. As the name implies,

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air flows continuously from the source into the user's breathing zone. Continuous flow respirators commonly include an adjustable belt-mounted valve that allows the user to control air flow within the range required by NIOSH approval. Approvals for some continuous flow airline respirators permit the control valve to be replaced with a vortex tube, which can provide significant cooling or heating to the air delivered to the user as it regulates flow rate. The required air flow ranges of 4 to 15 cfm for tight-fitting and 6 to 15 cfm for loose-fitting inlet coverings minimize inward contaminant leakage by maintaining the pressure within the respiratory inlet covering above atmospheric pressure at most work rates. The disadvantage of these flow requirements is that the use of continuous flow respirators is generally not practical unless a compressor is available as the air source.

The second subcategory of atmosphere supplying respirator is the *SCBA*. These respirators permit the user to carry the respirable gas source on his person and thus allow freedom of movement. The disadvantages of SCBA include their weight, which can be up to 40 pounds, and their relatively short service time of 4 hours or less. Their NIOSH approvals allow them to be used in all hazardous atmospheres, including those that are IDLH. Some SCBA are limited to use for escape only from these atmospheres.

Open circuit SCBA use compressed air as the respirable gas. The air is subject to the air quality specifications shown in Table 9-2. The cylinders most commonly used are rated for either 30 or 60 minutes service time, but actual service time is often substantially less. In open circuit systems, air from the cylinder is inhaled by the user and exhaled to the atmosphere. Demand type regulators may be found on older open circuit SCBA. However, because of the negative pressure during inhalation in a demand system, these systems should be replaced with pressure demand systems to maximize protection.

A special type of open circuit SCBA is the escape only, continuous flow system, often referred to as an ESCBA. These devices typically include a hood for quick donning and a cylinder of air rated for 5 or 10 minutes duration. They are small enough to be carried by the worker, so they are available for immediate donning and escape in the event of a large contaminant release. They must never be used to enter a contaminated atmosphere.

Closed circuit SCBA recirculate the user's exhaled air. These systems contain a carbon dioxide scrubber and a cylinder of compressed or liquid oxygen to replenish the airstream before it is sent back to the facepiece. This recirculation of air allows closed circuit systems to have rated service times up to 4 hours and stay below the 40 pound weight limit. Its disadvantage is the tendency to retain heat, which can contribute to the heat burden of the user. As is the case with open circuit systems, only positive pressure closed circuit SCBA should be used.

Combination SAR/SCBA are the final category of atmosphere supplying

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respirator. These devices typically include a pressure demand airline respirator and an integral cylinder of compressed air. The airline mode gives the user the ability to work for extended periods of time, and the cylinder provides at least enough air to escape the hazardous environment should the airline or its source fail. Because both modes of protection are available, these respirators can be used in any hazardous atmosphere, including those that are IDLH. The NIOSH approval restricts use of the cylinder portion to escape only when the rated service time is less than 15 minutes. Cylinders rated for 15 through 60 minutes may also be used for entry, provided that entry consumes no more than 20 percent of the air.

Assigned Protection Factors

The assigned protection factor (APF) is the minimum expected workplace level of respiratory protection that would be provided by a properly functioning respirator or class of respirators, to properly fitted and trained users. It represents an estimate of the amount of reduction in exposure that class of respirator can provide. For example, a respirator with an APF of 10 is expected to reduce the contaminant concentration by a factor of 10 when properly used. APFs are used in the respirator selection process as follows:

1. The contaminant concentration is measured or estimated
2. The contaminant concentration is divided by an appropriate exposure limit (the OSHA permissible exposure limit [PEL] represents the legally enforceable exposure limit). The resulting value is known as the *hazard ratio.*
3. A table of APFs is consulted. A respirator that is appropriate for the hazard and which has an APF equal to or greater than the hazard ratio is chosen.

There is currently no table of APFs that is universally applicable. Some of the OSHA substance-specific health standards, e.g., 29 CFR 1910.1028 *Benzene* have their own APF tables, expressing the APFs as multiples of the PEL [29 CFR Part 1910.1028, 1996]. These APFs represent legal requirements for those specific materials. OSHA's *Respiratory Protection* regulation does not have an APF table, but future rulemaking to develop APFs is planned [*Federal Register,* 1998]. Until OSHA's APF table is published, employers must take the best available information into account in selecting respirators [*Federal Register,* 1998].

Two tables of APFs that are widely used today were developed by NIOSH and the American National Standards Institute (ANSI) [NIOSH, 1987]. The

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APF values recommended by these organizations are shown in Table 9-3. The APFs for some respirator types differ for several reasons:

1. The NIOSH values are several years older.
2. Most of the NIOSH values are based on laboratory tests performed on respirators available in the 1970s.
3. Most of the ANSI values are based on workplace performance data, or design analogies to respirators for which this data exists.

For these reasons; the ANSI APFs represent the best estimates of respirator performance today [Colton and Nelson, 1997].

Table 9-3 NIOSH and ANSI Assigned Protection Factors

Type of Respirator	NIOSH Respirator Decision Logic	ANSI Z88.2 - 1992
AIR-PURIFYING		
Single Use or Quarter Facepiece	5	10
Half Facepiece	10[1]	10
Full Facepiece, D/M or D/F/M	10	100
Full Facepiece, all other media	50	100
POWERED AIR-PURIFYING		
Half Facepiece	50	50
Full Facepiece	50	1000[2]
Loose Fitting Facepiece	25	25
Hood or Helmet	25	1000[2]
AIRLINE		
Half Facepiece		
Demand	10	10
Continuous Flow	50	50
Pressure Demand	1000	50
Full Facepiece		
Demand	50	100
Continuous Flow	50	1000
Pressure Demand	2000	1000
Loose Fitting Facepiece	25	25
Hood or Helmet	25	1000
SCBA		
Demand	50	100
Pressure Demand	10,000	10,000[3]

[1] Includes disposable particulate respirators if quantitative fit testing is used.
[2] 100 if dust/mist filters are used.
[3] For emergency planning where concentrations can be estimated.

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Fit

Because tight-fitting respiratory inlet coverings rely on an adequate facepiece to face seal to minimize inward contaminant leakage, it is essential that users be fit tested to determine the size and model of facepiece that provides an acceptable fit. While proper fit is obviously critical to the performance of negative pressure respirators, it is also important for optimal performance of positive pressure tight-fitting respirators. For example, outward air leakage from the facepiece of a pressure demand SCBA can significantly shorten its service time. There is also evidence that positive pressure respirators may be "overbreathed", that is, drawn into negative pressure at very high work rates [Wilson et al., 1989]. For these reasons, fit testing requirements are now applied to all tight-fitting respirators. Fit tests for positive pressure respirators are conducted using a negative pressure configuration of the facepiece to be used on the positive pressure device.

Respirator fit can be assessed using either qualitative or quantitative methods. Either type of fit test may be used for half and full facepiece respirators when worker exposures do not exceed 10 times the exposure limit. Quantitative fit tests are required for fit testing full facepiece respirators when worker exposures are between 10 and 50 times the exposure limit. Either method is acceptable for fit testing positive pressure respirators.

Qualitative fit tests are relatively inexpensive and simple to perform. They are subjective in that the indicator of unacceptable fit is the test subject's sensory response to a challenge agent. Reliable qualitative fit tests include procedures to verify the subject's sensitivity to the challenge agent. They also use reproducible procedures to generate and contain the test atmosphere, so the approximate challenge agent concentration is known. In addition, the respirator must be free of defects and equipped with the correct air-purifying element to remove the challenge agent. It can then be assumed that any challenge agent detected by the user during the test entered the facepiece through face seal leakage. If the challenge agent is not detected by the subject, the respirator fit is considered to be acceptable. Commonly used qualitative fit tests are summarized in Table 9-4.

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Table 9-4 Qualitative Fit Tests		
Fit Test Agent	**Sensory Response**	**Required Air-purifying Element**
Isoamyl Acetate	Odor of bananas	Organic Vapor Cartridge/Canister
Saccharin Solution	Sweet Taste	Any Particulate Filter
Bitrex™ Solution	Bitter Taste	Any Particulate Filter
Irritant Smoke	Irritation/Cough	Class 100 Particulate Filter

Quantitative fit tests use instruments to objectively measure face seal leakage. Quantitative fit testing instruments can also facilitate record keeping by directing fit test records into computerized databases. The costs of purchasing and maintaining the instruments are among the disadvantages of quantitative fit testing. In addition, quantitative fit testing requires the use of probed respirators or special adapters.

The most widely used quantitative fit testing methods use an aerosol as the challenge agent. The instruments measure the concentration of the aerosol both outside (C_o) and inside (C_i) the respirator facepiece during the test. The resulting ratio of C_o to C_i is referred to as a fit factor. Another commercially available instrument measures air leakage into a sealed respirator facepiece to compute an equivalent fit factor. In general, the minimum fit factor required to "pass" a quantitative fit test is 10 times the assigned protection factor for the type of negative pressure facepiece being tested. For example, to use a half facepiece with an assigned protection factor of 10, a fit factor of 100 or greater must be measured when quantitative fit testing is used.

OSHA's *Respiratory Protection* standard includes specific, detailed procedures for conducting both qualitative and quantitative fit tests. These protocols are mandatory for OSHA compliance, and should be followed completely.

In addition to being fit tested, users of tight-fitting facepieces must be instructed to perform a user seal check (also referred to as a fit check) each time they don the respirator. User seal checks are done to confirm that the respirator is properly donned. They are not substitutes for qualitative or quantitative fit tests.

User seal checks for elastomeric half and full facepieces are generally performed using the positive pressure or negative pressure checks. The positive pressure check is conducted by blocking the exhalation valve with the hand and exhaling gently. The user should be able to maintain slight positive pressure without air leakage. The negative pressure check is conducted by closing off the inhalation opening(s) inhaling. The facepiece should collapse slightly, and a negative pressure maintained without inward leakage for about 10 seconds.

Manufacturer's instructions should be followed for performing user seal checks on filtering facepieces. While these user seal check procedures often

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differ from the traditional positive and negative pressure checks, their performance has been reported to be equivalent [Myers, 1995].

Respiratory Protection Programs

As mentioned earlier in this chapter, the OSHA *Respiratory Protection* regulation requires an organized respiratory protection program to ensure that respirators provide the level of protection for which they are designed. The following are the program elements that must be addressed with written procedures to ensure effective respirator use:

- Proper selection;
- Medical evaluation;
- Fit testing;
- Respirator use;
- Cleaning, storing, inspection, and repair;
- Air quality, quantity, and flow (for atmosphere supplying respirators);
- Training (regarding respiratory hazards to which workers are exposed and proper respirator use); and
- Program evaluation.

OSHA requires that a respirator program administrator be appointed to coordinate and oversee these activities. This person must be qualified by training and experience for this responsibility.

The written procedures should describe in detail how the employer will address each of the elements of respirator use listed above. The program should specify, for example, how fit testing and medical qualification will be done and by whom. The content and administration of respirator training programs should be fully described. The program administrator and other individuals with responsibility for carrying out specific portions of the program should be designated by name. The procedures should identify the specific respirator required for each situation, and the basis of how that selection was made. Further, if air purifying respirators without ESLI are used for gas or vapor exposures, the data and rationale used to establish the cartridge change schedule must be included in the program.

A complete program will ensure that each of the important activities associated with the use of respirators is addressed. It will also serve as a reference for employees (and, importantly, regulators) who are interested in how the program works. Most importantly, though, the written program serves as a record of the tasks and responsibilities to be undertaken by all members of the work team to ensure that the protection that is intended and required is

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actually provided.

CHEMICAL PROTECTIVE CLOTHING

Chemical protective clothing serves two principal purposes at waste sites. First and foremost, it prevents or minimizes contact of potentially hazardous chemicals with the skin, which is the largest organ of the human body. Second, if doffed and decontaminated properly, it prevents or minimizes the transfer of potentially hazardous chemicals from the site.

As mentioned earlier, the goal is to select and use just the right amount of protective clothing to minimize negative effects on worker productivity and comfort and to control costs. The late 1980s and 1990s have seen major advancements in chemical protective clothing. New, more chemically resistant fabrics have become available along with testing methods and test data to support claims of resistance. Attention is being given to worker productivity by means of clothing designs. Better characterization and understanding of hazards has enabled the selection of clothing that addresses workers' needs for comfort. Finally, the health and safety community is developing a better understanding of the complete cost of using clothing for protection from chemicals. This latter development is enabling more informed trade-offs with engineering controls and other approaches to protecting workers.

Most importantly these advancements are being summarized in readily available and usable documents. These include

- *Chemical Protective Clothing*, a two-volume textbook published by the American Industrial Hygiene Association [Johnson and Anderson, 1990].
- *Guidelines for the Selection of Chemical Protective Clothing*, a two-volume field/reference manual published by the American Conference of Governmental Industrial Hygienists [Schwope, 1987].
- *Quick Selection Guide to Chemical Protective Clothing*, a pocket-sized, paper-backed summary of chemical resistance information [Forsberg and Mansdorf, 1997].
- The proceedings of the six international conferences on protective clothing sponsored by the American Society for Testing and Materials [Barker and Colletta, 1986; Mansdorf and et al., 1988; Perkins and Stull, 1989; McBriarty and Henry, 1992; Johnson and Mansdorf, 1996; Stull and Schwope, 1997].
- *Chemical Protective Clothing Performance Book*, a tabulation of chemical toxicity and chemical resistance information [Forsberg and Keith, 1997].

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- *Guidelance Manual for Selecting Protective Clothing for Agricultural Applications*, extensive discussion and compilation of CPC use, performance data and descriptions and availability [U.S. EPA, 1993].

These documents along with significantly more informative product brochures from the CPC manufacturers have greatly increased the opportunity for finding, selecting, and correctly using protective clothing on waste sites. These tasks are the subject of the remainder of this chapter. The discussion begins with a brief review of the challenge represented by the various forms in which the chemical may be present.

Chemical Hazards

The proper selection and use of CPC begins with a characterization of the potential hazard, as addressed in several other chapters of this book. In summary pertinent to CPC, chemical hazards may be present in the form of solids, liquids, and vapors. Each represents one or more challenges to PPE. Solids are of special concern when particulates are involved. Respirators, of course, provide protection from the inhalation of particulates. Also important is to limit the transport of hazardous particulates from the workplace due to its accumulation in street clothing. Such particulates represent a hazard to those who associate with the worker and are not equipped with respirators. This is exemplified by the relatively higher incidence of asbestosis among the families of asbestos workers [Peters and Peters, 1980]. Similar concerns apply to lead and arsenic dusts, pesticide powders, and radioactive particulates. The most widely used approach for countering such challenges is the use of porous, low air permeability fabrics that provide protection while allowing some loss of body heat generated by working. Alternatively, non- or microporous, moisture vapor transport (i.e., "breathable") fabrics are also used.

Liquid and vapor challenges require a different level protection than that for the solids. Clothing containing a continuous (i.e., non-porous) layer of a plastic or rubber is necessary to isolate the worker from these hazards. Porous fabrics are unacceptable, although some situations lend themselves to fabrics that include a moisture vapor transport layer. Examples include challenges such as aqueous solutions (e.g., acids, bases, and liquids containing pathogens) or when the likelihood for chemical contact is remote or infrequent (e.g., a splash) and, should it occur, can be addressed by rapid, safe removal of the clothing.

Useful forms of the plastic or rubber (i.e., polymeric) materials for liquid and vapor protective clothing are thin, flexible films, sheets, laminates, and coatings. Many of these materials are inexpensive and in many cases can be

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reused multiple times. Furthermore a wide variety of candidate polymeric materials are available from which one or a select few may be applied to specific requirements. Items ranging from gloves to full-body ensembles can be made virtually air-tight and waterproof. Because of this, such items are often referred to as "impervious" clothing; however, with regard to chemical challenges, as opposed to air and water, such items may be far from impervious. Chemicals and chemical mixtures can absorb into and permeate clothing fabricated from polymers [Nelson et al., 1981; Sansone and Tewari, 1980; Williams, 1980]. In the extreme, the chemicals may actually dissolve the clothing. Because of this, the chemical resistance of the clothing material to the chemicals of concern is a critical issue in the clothing/equipment selection process.

PERMEATION

Theory

The resistance of a clothing material to liquids and vapors is judged largely on effectiveness of the material as a barrier to chemical permeation. Permeation of a chemical through a non-porous, polymeric film or coating is a three-step process involving: (1) the sorption of molecules of the chemical at the surface of the clothing exposed to the chemical, (2) the diffusion of the chemical through the material, and (3) the desorption of the molecules from the opposite or inside surface of the material. In this discussion, steps 1 and 3 will be considered fast relative to step 2; consequently, the diffusion step controls the rate of the permeation process. Classical diffusion theory (Fick's law) states that the permeation rate (mass/time/area) is proportional to the concentration gradient of the chemical across the material [Crank and Park, 1968; Crank, 1975]. The proportionality becomes an equation by the introduction of the diffusion coefficient.

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Equation (1)

Thus,

$$J = -D \int_{x=0}^{x=l} dc / dx$$

where

J = permeation rate, $\mu g/cm^2/min$
D = diffusion coefficient, cm^2/sec
c = the chemical concentration in the material, g/cm^3
x = distance from the contacted surface, cm
l = thickness of material, cm

The minus sign in Eq. (1) accounts for the decrease in c across the thickness of the clothing material.

The diffusion coefficient is an intrinsic property of the chemical/ material pair. It also is a function of temperature and in some cases is dependent on the chemical concentration within the material. With the knowledge of D, one can estimate permeation rates for a range of material thicknesses and concentration gradients. Thus, it is worthwhile to determine diffusion coefficients for permanent/barrier pairs.

Diffusion coefficients are readily determined from the results of permeation testing. ASTM Method F739 is the recognized and practiced standard for conducting such testing, and is described in detail later in this chapter [Henry and Schlatter, 1981]. The test is conducted using a two-chambered cell in which the material of interest forms the partition between the two chambers. The challenge chemical or chemical mixture is charged into one chamber (i.e., the challenge or upstream chamber) and the other chamber (i.e., the collection or downstream chamber) is monitored for the presence and concentration of the chemical that permeates the material. Initially, no chemical is detected. At some time, however, the chemical becomes evident; this is called the breakthrough detection time. Thereafter, the chemical appears at an increasing rate until the so-called steady-state is reached. This process is graphically depicted in Figure 9-1.

Two diffusion coefficients can be estimated from the data: the steady-state D_s and the time-lag D_L. The degree to which the two D's approximate one another is an indication of the "idealness" of the permeation process for a particular chemical/clothing material pair. The steady-state D_s is calculated using the steady-state permeation rate, J, and an integrated form of Eq. (1) and

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the assumption that the chemical concentration in the collection medium, and therefore $C_{x=l} = 0$, is maintained at essentially zero.
Equation (2)

$$J = D_s C_s / l \qquad \text{or} \qquad D_s = Jl / C_s$$

where C_s is the saturation concentration of the challenge chemical in the material and l is the material's thickness. C_s is readily determined by immersion of a separate sample of the material in the chemical until a constant weight is achieved. (Subtleties of immersion testing are described later.)

The time-lag D_L is calculated according to Eq. (3).

Equation (3)

$$D_L = \frac{l^2}{6T_L}$$

where T_L is the time at the intercept of the extension of the steady-state line to the time axis.

Upon inspection of Eqs. (2) and (3), one notes that the steady-state permeation rate, J, is inversely proportional to thickness while the time-lag time, T_L, is proportional to the square of the thickness. Researchers have further shown empirically that measured breakthrough times are approximately proportional to the square of the thickness [Todd et al., 1979]. Thus, doubling the thickness of the polymer layer of an item of protective clothing will theoretically quadruple the measured breakthrough time. This finding has significant implications relative to the selection and specification of chemical protective clothing. The interpretation and use of the permeation test results has been studied extensively [Schwope et al., 1981].

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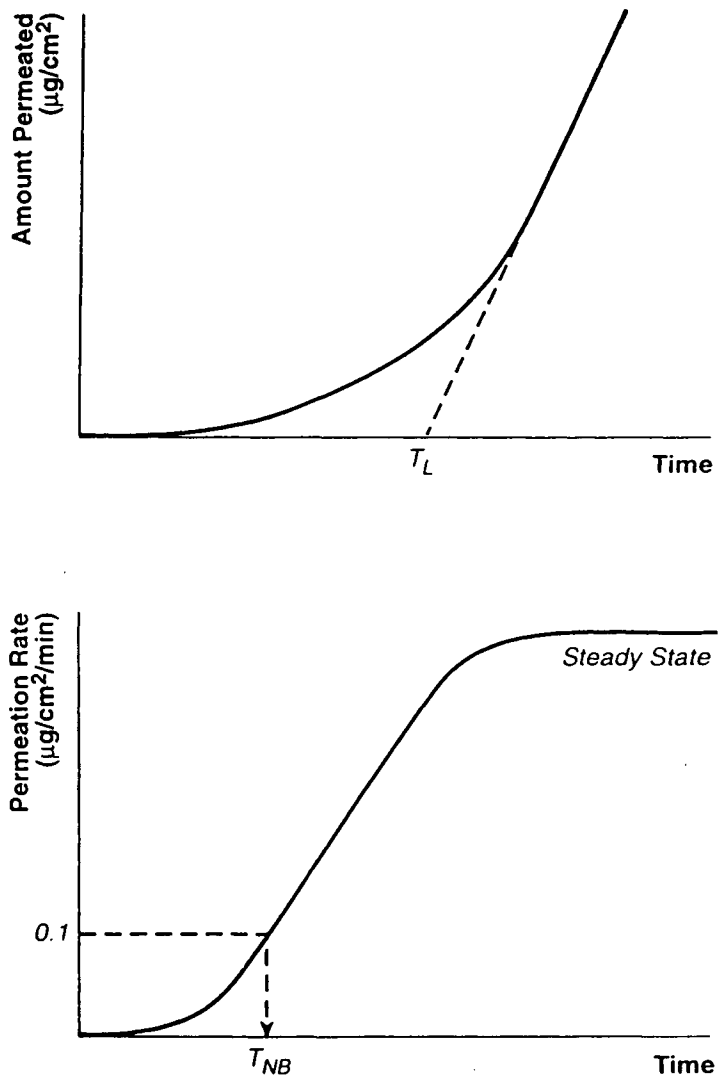


Figure 9-1 Ideal permeation through a polymeric film.
The lower curve is simply the derivative of the upper curve.

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Ideal permeation, as described above, involves a diffusion process in which the breakthrough time is followed by a period of smooth transition to a steady-state situation in which the permeation rate does not change with time. Ideal diffusion is most likely to occur when there is little or no other interaction between the material and the chemical. It should be recognized, however, that deviations (i.e., anomalies) from the ideal may occur [Nelson, 1981]. As the name implies, anomalous permeation is not predictable. There are, however, several conditions under which the probability for non-ideal permeation is increased:

- Where there may be a reaction of the chemical with the plastic/elastomer of the CPC or some other component of the material. In some cases, the reaction will lengthen the breakthrough time and reduce permeation rate by consuming chemical. In other cases the reaction will reduce the barrier effectiveness of the CPC by degrading its properties.
- Where the chemical, merely by its being absorbed, changes the properties of the CPC. Many organic liquids are known to craze (produce surface cracks) in the hard, clear plastics used for lenses and face shields. Many of these same chemicals will soften or plasticize the clothing materials.
- Where the chemical extracts components from the CPC materials. For example, leaching of plasticizer from PVC clothing will significantly affect its barrier as well as functional properties.

Permeation theory can provide significant insight to clothing performance when data from testing are available. It is often necessary, however, to estimate CPC performance without the benefit of test data. This may be especially true where multicomponent solutions are involved. At present, there are no established theories that provide a mechanism for this activity although several investigators have approached this problem from a basis of solubility parameter theory [Zellers and Sulewski, 1993; Goydan et al., 1987]. Furthermore, experience has led to the formulation of some guiding principles relative to the probable chemical resistance of clothing materials. The first is that, in general, chemicals from the same family (e.g., the simple alcohols - ethanol, propanol, etc.) tend to permeate a given CPC material at similar rates and with similar breakthrough times. There are, of course, exceptions. Other generalizations are

- Higher molecular weight members of a homologous series of chemicals permeate at slower rates than lower molecular weight members;

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- Pendant groups (which increase the size of a molecule) tend to slow permeation relative to that of the simple molecule;
- Polar chemicals tend to permeate polar materials more rapidly than non-polar chemicals, and the converse is true;

Furthermore, research on solutions containing relatively high molecular weight pesticides has shown that the lower molecular weight carrier solvents can "carry" or accelerate the permeation of the larger molecular weight active ingredients [Schwope et al., 1992].

Test Methods

The barrier effectiveness of a particular item of clothing to a particular chemical/mixture is dependent on the specific interactions between the clothing material and the chemical/mixture. This, in turn, is determined by the formulation of the clothing material, its method of manufacture, and its thickness. Temperature and other conditions of use also influence clothing barrier properties. Breakthrough times and steady-state permeation rates typically follow an Arrhenius relationship with temperature [Zellers and Zhang, 1993]. Finally, the composition of the chemical/mixture is of major importance since relatively small percentages of a second, third, etc., component can drastically alter the way in which a chemical interacts with a material. While permeation theory helps an understanding these effects, methods for using theory to predict barrier effectiveness (i.e., breakthrough and peremation rate) are not sufficiently developed nor validated for practical use in waste site applications. Consequently, protective clothing selection decisions should be based on the results of testing of the chemical/clothing material pair whenever possible.

Immersion Test

Immersion of a clothing material in a chemical/mixture followed by inspection for changes in appearance, strength, dimensions, and weight is the easiest and perhaps most telling test of a clothing material. Weight change information is of particular interest since in general chemicals which are absorbed at levels of 10 percent or more are likely to rapidly permeate the material. There appears to be a correlation between weight change and breakthrough time [Stampfer, 1984]. Furthermore, C_s of Eq. (2) is directly estimated from the weight change of the material once it has reached a steady level.

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ASTM Method D471-79 and ISO Method 2025 (International Organization for Standards) are standard methods for immersion testing. An important consideration when conducting such tests with multilayer clothing materials is that only the outside layer of the clothing should be exposed to the chemical/mixture. The edges of such materials should not be exposed. Absorption of the chemical layers by sublayers or supporting fabrics that would not normally "see" the chemical would confuse interpretation of the results. The calculation of C_s for a multilayer fabric may not be practical since it is likely to be difficult to determine the amount of chemical in each layer.

Finally, it should be noted that lack of change in an immersion test does not necessarily indicate that the material is a chemical barrier. One can have confidence in the test as a means for eliminating poor barriers but not necessarily identifying good barriers. Effective barriers can only be determined by permeation testing as described in the following paragraph.

Permeation Testing

Breakthrough time and permeation rate are determined by means of a permeation test. In addition to ASTM Method F739, Methods F1383 and F1407 have been specifically developed for the evaluation of protective clothing materials [ASTM F1407]. The Methods F739 and F1383 use a test cell that is divided into two chambers at the midline by the clothing material to be tested. The challenge chemical is placed in one chamber and the other chamber (i.e., the collection chamber) is monitored for the chemical of interest. Of interest are the time the chemical is first detected (T_B), the normalized breakthrough time (T_{NB}), the rate of permeation, and the cumulative amount of chemical permeating the clothing. The collecting medium must not interact with the clothing material; air, nitrogen, helium, or water are preferred collection media.

The detection of breakthrough is dependent on the sensitivity of the test system, including the analytical method, the surface area of the clothing material, the volume or flowrate of the collection medium, and other experimental parameters. Because the sensitivity can vary from test –to -test and laboratory –to -laboratory, ASTM Committee F23 which is responsible for the procedure has defined normalized breakthrough time as the point at which the permeation rate equals 0.1 $\mu g/cm^2/min$. Thus, there is now a common basis for comparison of clothing products. With reference to Figure 9.1, T_{NB} is shown to occur before T_L, but this is not necessarily always the case. The sequence of events is dependent on the chemical/material pair.

Typical, preferred analytical methods for measuring permeation, include gas, liquid and ion chromatography, analysis for total combustible organics,

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ultraviolet and infrared spectrophotometry and radioanalysis. The properties of the chemical, the sensitivity requirements for the test, and cost are the principal factors considered in selecting an analytical method. For relatively volatile chemicals, gas chromatography and infrared spectrophotometry are the preferred methods. Liquid chromatography is used for relatively nonvolatile organic compounds. Ion chromatography is particularly useful for inorganic acids and salts. Finally, radiolabeled compounds may be preferred where high sensitivity and specificity is required. Furthermore, if the compound of interest is readily available in radiolabeled form, radiochemical methods may be significantly less costly than the development and use of the other techniques.

Permeation testing of protective clothing materials has increased significantly during the past decade. The *Journal of the American Industrial Hygiene Association* and the product catalogues of the CPC vendors have become the principal vehicles for dissemination of test findings. As mentioned earlier, most of these test data have been compiled in comprehensive publications that are readily available. Vendor literature is discussed in greater detail later in this chapter.

ASTM F739 involves the continuous contact of the challenge chemical with the clothing material. To guide testing under conditions that may be more representative of actual exposure conditions, ASTM Method F1383 was developed. ASTM F1383 involves intermittent contact of the liquid or gas with the clothing material. The duration of and number of contacts, as well as the time between contacts, are determined by the tester. The same apparatus and analytical procedures are used.

ASTM Methods F739 and F1383 are laboratory tests. To address the frequent need for assessing chemical resistance in the field, the U.S. Environmental Protection Agency (EPA) developed the permeation cup test [Schwope et al., 1988]. This test, which has been standardized as ASTM Method F1407, involves a swallow, lightweight cup and a balance. A small amount of liquid chemical is placed into the cup. A swatch of protective clothing material is secured over the mouth of the cup and the cup weighed. The cup is then inverted so that the liquid is in contact with the clothing material. Periodically, the cup is reweighed. Loss in weight indicates chemical permeation. In order to detect such permeation the chemical must be volatile. The test procedure also enables inspection of the clothing material for swelling, softening, or other signs of poor chemical resistance.

To further facilitate product comparisons, ASTM Guide F1001 defines a battery of 15 liquids and six gasses with which to challenge clothing materials. The battery includes chemicals representative of several chemical families: ketone, aldehyde, amine, linear hydrocarbon, aromatic hydrocarbon, acid, base, chlorinated hydrocarbon, and so forth.

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Penetration, Including Biologically Active Substances

In contrast to permeation, ASTM defines penetration as the movement of solids, liquids, or gases through pores, or other openings in the clothing material, seams, or closures. ASTM Method 903 describes the test, which involves pressurizing a liquid on one side of the clothing material and visually observing the other side for the appearance of liquid. ASTM Method 903 has been adapted to two biohazard applications. ASTM Method F1670 uses as the challenge a liquid that simulates the surface tension of blood. Method F1671 uses the same liquid but with the addition of a bacteriophage (Phi-X 174). Rather than visual observation of penetration, the tester swabs the outside of the clothing material and then cultures the swab. Growth of bacteriophage indicates that the material was penetrated.

Vision

Faceshields and lenses, in addition to being chemical barriers, must provide clear, undistorted vision to the wearer. Hard, inflexible faceshields and lenses fabricated from polymeric material may be subject to crazing (i.e., surface cracking) upon contact with certain chemicals. Crazing renders the surface foggy and can drastically reduce vision. Since chemical contact with the faceshield or lens is more likely to occur in uncontrolled or emergency situations when reduced vision would be an additional severe hazard, shields and lens materials should be tested for resistance to chemical attack. Crazing can also reduce the impact strength of the material.

ANSI/ASTM Method F484-77 describes a procedure for determining stress crazing by chemicals. A second method for determining the effect of chemicals on clear plastics is by measuring the transparency of the plastic before and after exposure to the chemical; ASTM Method D1746 is one such procedure.

Other Factors

Although the focus of this discussion is chemical resistance of clothing materials, the selection and use of protective clothing involves other factors of equal or greater importance. For example, gloves must provide the wearer some minimum level of dexterity, and fabrics must have some level of tear resistance. The relative importance of different performance factors is largely dependent on the work tasks to be carried out.

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At present, there is no standard, overall protocol for evaluating protective clothing or clothing materials for all the performance parameters of importance to workers on hazardous waste sites. The more pertinent, widely used methods have been compiled. [ASTM, 1990]. Since its publication, several of the methods in this compilation have been revised; persons intending to conduct or to specify testing should seek out the most recent versions. A subset of the methods is presented in Table 9-5. For completeness, the chemical resistance methods mentioned above are included in the table.

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TABLE 9-5 Test Methods for Chemical Protective Clothing	
Characteristic	**Test**
A. CHEMICAL RESISTANCE	
1.Permeation Resistance	ASTM F739: Resistance of Protective Clothing Materials to Permeation by Liquids and Gases under Conditions of Continuous Contact ASTM F1383: Resistance of Protective Clothing Materials to Permeation by Liquids and Gases under Conditions of Intermittent Contact ASTM F1407: Resistance of Chemical Protective Clothing Materials to Liquid Permeation - Permeation Cup Method
2.Penetration Resistance	ASTM F903-96: Resistance of Protective Clothing Materials to Penetration by Liquids
3.Swelling and Solubility	ASTM D471: Rubber Property--Effect of Liquids
4.Strength Degradation	ASTM D543: Resistance of Plastics to Chemical Reagents
5.Crazing	ASTM F484: Stress Crazing of Acrylic Plastics in Contact with Liquid or Semi-Liquid Compounds
6.Transparency	ASTM 1746: Transparency of Plastic Sheeting
B. BIOLOGICAL RESISTANCE	
1.Synthetic Blood	ASTMF1670: Resistance of Protective Clothing Materials to Synthetic Blood ASTM F1819: Resistance of Materials Used in Protective Clothing to Penetration by Synthetic Blood Using a Mechanical Pressure Technique
2.Viral Penetration	ASTMF1671: Resistance of Protective Clothing Materials to Penetration by Blood-Borne Pathogens Using Viral Penetration as a Test System
C. STRENGTH	
1.Tear Resistance/Strength	ASTM D751: Testing of Coated Fabrics ASTM D412: Rubber Properties in Tension Fed. 191A-5102 (ASTM D1682): Strength and Elongation, Breaking of Woven Cloth: Cut Strip Method Fed. 191A-5134 (ASTM D2261): Tearing Strength of Woven Fabrics by the Tongue Method
2.Puncture Resistance	ASTM F1342: Protective Clothing Material Resistance to Puncture
3. Cut Resistance	ASTM F1790: Cut Resistance of Materials Used in Protective Clothing

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4.Abrasion Resistance	ASTM D1175: Abrasion Resistance of Textile Fabrics
D. DEXTERITY/FLEXIBILITY	
1.Dexterity (gloves only)	See Reference 62
2.Flexibility	ASTM D1388: Stiffness of, Cantilever Test Methods
E. AGING RESISTANCE	
1.Ozone Resistance	ASTM D3041: Coated Fabrics--Ozone Cracking in a Chamber ASTM D1149: Rubber Deterioration--Dynamic Ozone Cracking in a Chamber
2.UV Resistance	ASTM G27: Operating Xenon-Arc Type Apparatus for Light Exposure of Non-Metallic Materials--Method A--Continuous Exposure to Light
F. WHOLE ITEMS	
1.Gas Tightness	ASTM F1052Pressure Testing Vapor Protective Ensembles
2.Comfort & Fit	ASTM F1154: Qualitative Evaluation of Comfort, Fit, Function, and Integrity of Chemical Protective Suit Ensembles
3.Liquid Tightness	ASTM F1359:Liquid Penetration Resistance of Protective Clothing or Protective Ensembles under a Shower Spray while on a Manikin
4. Sizing	ANSI/ISEA 101: Sizing Standard for Limited-use and Disposable Garments
5.Labelling	ASTM F1301: Labeling Chemical Protective Clothing

There are four specifications for clothing as used by first responders (typically, firefighters and emergency medical technicians) to emergencies involving chemicals or injured persons. These are National Fire Protection Association (NFPA) standards 1991, 1992, 1993, and 1999. The four standards specify the minimum performance characteristics for, respectively:

- Vapor protective suits for hazardous chemical emergencies;
- Liquid splash-protective suits for hazardous chemical emergencies;
- Support function protective garments for hazardous chemical operations; and
- Protective clothing for emergency medical operations.

The specifications are based principally on ASTM test methods. Clothing items are certified to these specifications by independent, third-party testing, and bear an NFPA seal.

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More generally listings of several types of protective equipment that have passed third-party, independent testing are available from the Safety Equipment Institute.

Vendor Literature

The most widely available sources of information on CPC are the product catalogues of the CPC manufacturers and vendors. These product catalogues contain descriptions of the types, sizes, and varieties of CPC produced by each manufacturer. In most cases, the basic materials of construction of the CPC are also included in the product descriptions. Many manufacturers also include information pertinent to the chemical resistance of their products or of the materials from which the products are fabricated. This information is generally in the form of tables of quantitative permeation data or qualitative recommendations for the products/materials and particular chemicals. A few vendors also provide information pertinent to abrasion, tear, and so on, resistance but, in general, most catalogues do not address such application-related issues. The exception is for items which are certified to meet NFPA specifications. For those items details, specific test results and use guidance are available upon request.

The amount, level of detail, and quality of information available from the major manufacturers of chemical protective clothing has increased dramatically during the past five to ten years. Furthermore, vendors are more knowledgeable and anxious to answer questions as to the use, maintenance, decontamination, and disposal of their products. Indeed several of the larger vendors now provide product and product performance information on floppy disks and CD-ROM, and via 800 telephone numbers and the world wide web. Examples include DuPont Nonwovens, Kappler Safety Group, Best Manufacturing, and Ansell-Edmont.

Performance and Purchase Considerations

The performance of CPC as a barrier to chemicals is determined by the materials of construction and the design and quality of the clothing construction. Each application places particular demands on the clothing and, therefore, the performance requirements. For example, a less durable piece of clothing may be more than adequate for a moderate duration, mild activity (e.g., sampling), whereas it would not endure more than five minutes of a vigorous, waste site cleanup activity. Garment strength, durability, and fit, as well as worker comfort, must be addressed. Depending on the application, chemical barrier effectiveness may be more or less important than the physical attributes of the clothing. For example, incorrect fit or sizing can result in torn

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seams due to tightness or baggy clothing that becomes its own source of safety problems due to snagging and other interferences. Sizing standards for disposable and limited-use garments have been promulgated. [*ANSI/ISEA 101*, 1996]. Persons responsible for worker protection must ensure that each worker is fit with the appropriate size. Some clothing manufacturers clothing design and patterning to achieve improved worker mobility and comfort.

When considering chemical resistance, three underlying factors must be taken into account:

- In general, there is no such thing as "impermeable" plastic or rubber clothing.
- No one clothing material will be a barrier to all chemicals.
- For certain chemicals or combinations of chemicals there is no commercially-available glove or clothing that will provide more than an hour's protection following contact.

Other considerations are:

- Stitched seams of clothing may be highly penetrable by chemicals if not overlaid with tape or sealed with a coating. Zippers, other closure, and interfaces (e.g., sleeve-to-glove) are also pathways for chemical ingress.
- Pinholes and areas where the polymer coverage is relatively thin can compromise barrier effectiveness.
- Although the generic names of the clothing material may be the same, there can be significant differences between the performance of the products of several vendors. This may be due to formulation or fabrication differences [Michelson and Hall, 1987].

In response to needs for more effective, less expensive CPC, manufacturers have introduced gloves and garments fabricated from multilayer, plastic films. These films typically exhibit a higher degree of chemical resistance to a broader range of chemicals than rubber materials traditionally used in CPC. The films are used alone or applied to synthetic supporting fabrics for added strength. Gloves of plastic film laminates are bulky, significantly reduce dexterity, and are slippery when wet. These deficiencies are largely addressed by donning a pair of rubber gloves over the laminate gloves (i.e., double gloving). Garments based on such films typically are lighter and less expensive than analogous products based on traditional rubber-coated fabrics. The combination of high chemical resistance with relatively low cost and concerns over the uncertainties surrounding decontamination has spawned a new category of CPC: limited use garments.

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SELECTION OF PPE

When any piece or ensemble of PPE is to be utilized on a hazardous waste site, the advantages and limitations of the equipment should be carefully considered with regard to the potential exposures to chemical and physical hazards, worker productivity, worker comfort, and cost. Consequently, selection of the equipment should be performed by an individual who is familiar with both the equipment and the likely use conditions under which the PPE will be used.

On hazardous waste sites, the solutions and mixtures of chemicals are unknown; often, the visible, physical characteristic of the chemicals (solid, gas, liquid) or the odor are the only available information. Thus, it is difficult to assess the degree of hazard to which workers may be exposed. The state-of-the-art approach for selecting PPE in such cases is to initially assume the worst exposure condition and use the highest level of PPE. Then, as the chemical and physical agents on site are characterized, the PPE can be selected to match specific hazards. A good example of this approach is demonstrated by an EPA advisory protocol for hazardous waste site entry, shown in Table 9-6.

As illustrated on the left side of Table 9-6, if any of the selection criteria listed under Level A were present on site, then Level A protective equipment must be used. As the concentration of contaminants, hazardous substances, potential for splash, and organic vapor levels are reduced, the level of protective equipment is lowered to Level C. It should be noted that Level D PPE is primarily a work uniform and should not be worn where there is potential for contamination of body parts through boots or when inhalation of gases or vapor is possible.

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TABLE 9-6
Environmental Protection Agency Site Entry Protocol *

Level/Selection Criteria **	Eye/Face	Head	Hands	Feet	Full Body	Respirator
LEVEL A						
Chemical concentration known--ABOVE SAFE LEVEL Extremely hazardous substance (dioxin, cyanide) Skin destructive substance Confined spaces	See full-body SCBA	Hard hat	2 pairs gloves	Chem-resistant steel toe, shank, disposable booties	Fully-encapsulated chem-resistant suit w/disposable outer suit, gloves, boots	SCBA (pressure-demand)
LEVEL B						
IDLH and concentrations above PF provided by full mask, air purifying <19.5% 0_2 Skin contact unlikely to head and neck Unidentified vapor suspected	See SCBA	Hard hat	2 pairs gloves	Chem-resistant steel-toe, shank, disposable booties	2-piece suit w/hood or disposable suit	SCBA (pressure-demand)
LEVEL C						
Known air concentration that PF will control in air-purifying mask No IDLH possible No skin destruction No unidentified vapor	See respirator	Hard hat	2 pairs gloves	Steel-toe, w/shank, disposable booties	2-piece suit or disposable suit	Full-face air-purifying mask
LEVEL D						
No measurable concentration No exposure to splashes or inhalation	Safety glasses	Hard hat	1 pair gloves	Steel-toe, shank	Coveralls	None

* "Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities," US DHHS (NIOSH) No. 85-115 (1986).

** Meeting any of listed criteria requires that level of protection.

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The selection of the most appropriate respirators has been discussed earlier. The selection of clothing requires decisions relative to the areas of the body which must be covered and the materials of construction of clothing. The extent of body coverage is a function of the hazard to be faced. Common practice is to use the minimum amount of PPE as necessary to provide protection to the worker. PPE can be burdensome and restrictive; minimizing PPE increases the likelihood that it will be worn and minimizes the loss in worker efficiency that typically accompanies PPE utilization [U.S. EPA, 1993; Ross and Ervin, 1987]. In addition, PPE can be expensive. Furthermore, each time PPE is used, it must be either disposed of or decontaminated and properly maintained; therefore, it is desirable to minimize time and costs directed to these activities. The determination of the amount of clothing which is appropriate for any given job is the purview of the industrial hygienist or safety engineer. These professionals must consider in their decision all aspects of the job to be done, the conditions under which it will be done, and the capabilities of the workers.

PPE USE

In order to obtain maximum performance from any item of PPE, it must be free of defects and in good operating condition, and the wearer must understand the purpose of the item and how to use and care for it. PPE should be unpacked and inspected immediately upon its reception. This initial inspection is to check that the desired items were actually received and that the items are defect-free and operational. This inspection prevents the surprise of finding nonfunctional or inappropriate PPE in emergency situations or losing time while replacement PPE is ordered.

Following inspection, PPE should be stored in a cool, dry place with clear and definitive labels in order to prevent mix-ups that could result in the utilization of the wrong PPE for a given application. For example, gloves made from neoprene, butyl rubber, PVC, and nitrile rubber can be similar in appearance, yet there can be significant differences in the barrier performances of these materials. ASTM Guide F1301 describes information critical to CPC labelling [Myers et al., 1995].

At the time of use, each wearer should inspect the clothing prior to donning it. Again, the objective is to identify tears, punctures, fabrication flaws or functional problems that could compromise the protection anticipated from the PPE. A postdonning inspection is essential for full-body encapsulating suits. This may be best carried out with the assistance of a second individual who is able to check closures and interconnections between, for example, gloves and

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sleeves, and boots and pants. Further reinspections should be performed throughout the work period, especially if the wearer has experienced significant contact with a chemical or suspects the integrity of the PPE has been breached.

Following completion of the work assignment or the work period, PPE is removed (doffed). A primary consideration in doffing is to avoid transfer of chemical that may be on the outside of the PPE to clean areas, skin, and underclothing. It is common practice at waste sites to doff PPE at designated areas, in many cases following a preliminary decontamination of the PPE with soap and water. The EPA has developed comprehensive doffing procedures which address doffing, decontamination, and disposal of contaminated PPE.

Decontamination and re-use of PPE is a matter of considerable interest and concern (see Chapter 11, Decontamination). At issue is any chemical that may have been absorbed by the PPE material. Is the chemical removed by the decontamination process? If not, what happens to this chemical during storage? Does the chemical continue to permeate the clothing such that the next time the PPE is donned, chemical is present on the inside surface? Researchers are only now beginning to address these problems; however, practitioners must deal with the issue every day. Some have opted for the use of inexpensive, single-use disposable clothing whenever possible. Such clothing is not universally applicable, however, and the use of more expensive PPE may be required. Some full ensembles can cost $4,000 or more versus $300-500 for some limited-use garments, while the most expensive gloves are in the range of $40-50/pair versus less than a dollar a pair for the less expensive gloves. Obviously, there is an economic incentive to reusing the more expensive items; the challenge is to ensure that these items are effective and have no intrinsic hazard the second time they are worn.

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SUMMARY

Since engineering controls are not readily implemented at hazardous waste sites, PPE combined with good work practices are the primary means for minimizing the exposure of workers to hazardous chemicals. PPE ranges from respirators to supplied air systems to gloves to full-body encapsulating ensembles. Proper selection of PPE requires careful assessment of the risk hazard. This assessment includes the chemicals involved, the skills of the workers, the tasks, and the duration of potential exposures. PPE must then be selected on the basis of its demonstrated performance under such conditions. With regard to clothing, chemical resistance is a key concern and it must be recognized that there is no universal barrier material. Once PPE has been selected and purchased, it should be inspected for construction flaws and function. Workers must be instructed as to the use and limitations of PPE. Reuse requires special attention to decontamination and storage.

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10

HEAT STRESS IN INDUSTRIAL PROTECTIVE ENCAPSULATING GARMENTS

Ralph F. Goldman, Ph.D.

There are a great many aspects to work: physical, physiological, psychological, sociological, financial, and so on. Our concern for hazardous waste site workers is with the first two, and how imbalances between the physical and physiological *demands* imposed by their tasks, and the worker's *capacities* to meet those demands, affect their health and performance. The ratio of the task demand to the worker's capacity is the critical element in whether a task is "comfortable." Usually, tasks demanding < 20 percent of capacity will be "comfortable." For demand/capacity ratios from 20 to 40 percent, the "mild discomfort" may not seem to degrade performance; indeed this range may be best for task performance if individual's "arousal levels" cause them to focus on the work, making them less apt to relax or doze. When demands are 40 to 60 percent of capacity, performance of complex tasks requiring mental or manual dexterity skills may be noticeably degraded. However, while performance of routine physical work (e.g., digging) may not appear to be altered, the work rate will probably be decreased (i.e., self-paced) to adjust the demand to 45 percent of a worker's capacity. Performance will become tolerance time limited as the ratio increases from 60 percent (tolerable for about a one hour) to 85 percent (tolerable for about 15 minutes). Accident rates appear to increase as demand to capacity ratios exceed 60 percent. At ratios above 80 percent, probability of illness or injury (heat exhaustion, physical exhaustion) increases. Ratios above 100 percent (i.e., D > C) exhaust the body's physical and physiological reserves in minutes.

Heat stress represents an imbalance between the heat produced by an individual and the heat loss allowed to the environment. The latter is more often controlled by the clothing worn than by any combination of environmental conditions; there is no single temperature or combination of temperature and humidity at which heat stress can be said to begin. Heat stress has occurred in men working very hard in the cold and snow, although it is usually not recognized as such but thought to be some mysterious ailment. Typical heavy,

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outdoor winter clothing ensembles, (e.g., clothing insulation of 4 clo), may allow heat loss of only 2.5 kcal/hr per °C difference between the skin of an average size wearer (i.e., with 1.8 m^2 of body surface area) and the ambient environment. Even at -40°C, the maximum heat exchange by radiation and convection (H_{R+C}) through such clothing would be less than 200 kcal/hr; that is, 2.5 kcal/hr °C times the 75°C difference between a warm 35°C skin temperature and the ambient of -40°C. While some additional heat would be lost by respiration, since heat production for sustainable high activity is about 500 W (425 kcal/hr) about half of the total heat production would require sweat evaporative cooling (E_{req}) for it to be eliminated. However, thick (i.e., high insulation) clothing stringently limits a wearer's maximum evaporative cooling (E_{max}).

Using an average value of a 58 kcal increase in body heat storage for each 1°C increase in mean body temperature [i.e., t_b which = 1/3 skin temperature (t_{sk}) + 2/3 deep-body temperature (t_{re})] for a 70 kg man (i.e., specific heat of body = 0.83 kcal/kg °C), it seems clear that accumulation of heat storage (ΔS) which would lead to body temperatures above 39°C could occur within a few hours, even at -40°C.

The question of human heat balance can be analyzed by a well-defined heat balance equation. A major factor that must be considered is the metabolic energy production (M); the heat production required for a given task is a function of the total weight (body plus any load) moved, the efficiency with which this total weight is moved, and the rate of movement. The nature of the terrain over which the weight is moved is also involved. Walking on soft sand may double the energy cost for given speed and weight compared to walking on a smooth surface. Climbing stairs, or any lift (grade) work, is also very demanding in energy cost increases.

Another major factor, the nonevaporative heat exchange (H_{R+C}), is a linear function of the difference between the wearer's skin temperature (t_{sk}) and the ambient air temperature (t_a). Similarly, the maximum possible sweat evaporative cooling (E_{max}) is a linear function of the difference between the vapor pressure of sweat on the skin (P_s) and the ambient vapor pressure ($\phi_a P_a$). It is important to note that it is the relative humidity (ϕ_a) times the saturated vapor pressure of air (P_a) at ambient temperature (t_a) which determines the evaporative cooling capacity, not the relative humidity *per se*; thus sweat evaporative cooling can occur in environments with 100 percent humidity. The heat exchange with the environment depends not only on the skin and ambient environmental conditions but also on the clothing, and the extent to which it limits the heat exchange between the skin and the ambient environment. Hazardous waste site protective clothing, and particularly chemical protective clothing, tends to be quite limiting both because of its insulation (clo) and its

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reduced moisture vapor permeability (i_m). Air motion (WV) also plays a key role in controlling these nonevaporative and evaporative exchanges, primarily by the extent to which it reduces the insulating still air layer (I_a) at the interface between the clothing surface and the ambient environment. The intrinsic insulation of the clothing *per se* (I_{clo}) can also be reduced by wind penetration. A fourth environmental factor (in addition to t_a, $\phi_a P_a$, and WV) which frequently must be considered is the radiant heat load (H_R) produced by the sun, by such high temperature (shortwave, infrared) heat sources as blast furnaces or arc lights, or by such lower temperature "blackbody" sources as radiators, warm pipes, walls or ceilings. The mean radiant temperature (MRT) is an integrated expression of the average radiant temperature. Note that the white color often found in hazardous waste site protective garments reflects > 90 percent of any *solar* radiant heat load; this complicates using some of the standard environmental indices for heat stress.

THE HEAT BALANCE EQUATION

The factors introduced so far, form the key elements in the following heat balance equation for the human body:

Eq. 1 $$(M - W_{ex}) + (H_{R+C}) - E_{req} - \Delta S = O$$

where
- M = energy production (measured by oxygen consumption)
- W_{ex} = external work
- H_{R+C} = the net exchanges by radiation and convection between the body and the environment
- E_{req} = the required evaporative heat loss established by $[(M-W_{ex}) + (H_{R+C})]$
- ΔS = any change in body heat content

Additional terms are sometimes included such as the heat exchanges by respiration, involving both humidification and heating of the inspired air, and diffusional evaporative heat losses from the skin; these respiratory and diffusional losses generally amount to about 25 percent of metabolic heat production at rest, and are most often ignored during work in the heat.

The amount of evaporative cooling (E_{req}) in the heat balance equation would ideally be much less than the maximum evaporative cooling that can be obtained through the clothing (E_{max}); that is : $E_{req} = [(M-W_{ex}) + (H_{R+C})] << E_{max}$.

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As long as the heat losses are less than ($M - W_{ex}$), and all the evaporative cooling required can be obtained, no change in body heat storage (ΔS) is required. If heat loss by radiation and convection is greater than ($M - W_{ex}$), and the difference is greater than E_{max}, a heat debt will be incurred [Hardy,1949]. Changes of ± 25 kcal in body heat content are probably not detectable by an individual, but an accumulation of body heat storage approaching 60-80 kcal generally results in the individual being unwilling to continue working. Thus, satisfaction of the heat balance equation with minimal heat storage is a necessary condition for comfort and continued work. It is not, however, a sufficient condition; discomfort in the heat is largely generated by the sense of skin wettedness or dampness. The sensation of wettedness at the skin can be directly calculated as the ratio E_{req}/E_{max} [Gagge, 1940]; that is, the body will produce enough sweat to meet its evaporative requirements so that the relative humidity at the skin (alternatively defined as the "percent skin wettedness") can be calculated simply as the ratio E_{req}/E_{max}. If E_{req} is 50 W (i.e., $M - W_{ex} + H_{R+C} = 50$) and $E_{max} = 100$ W, then the skin need be only 50 percent sweat-wetted; that is, skin relative humidity will be 50 percent. Expressed more precisely, the average skin vapor pressure (P_s) will be 50 percent of the saturated vapor pressure of water (= sweat) at t_{sk}.

As the maximum evaporative cooling (E_{max}) approaches or is less than the required evaporative cooling (E_{req}), the body cannot obtain the required evaporative cooling. The maximum evaporative cooling may be limited by the clothing, or by a high ambient vapor pressure, or even by very low ambient air motion. A necessary condition for comfort is that the relative humidity at the skin (i.e., percent sweat wettedness) be less than about 20 percent. Note that, as discussed later, this ratio has been used as a heat stress index [HSI; [Belding and Hatch, 1956]]. Increasing levels of sweat wettedness are associated with increasing heat discomfort. One must carefully screen and select workers for physical fitness at conditions requiring 60 percent sweat wettedness; at about that level, sweat will begin dripping off the skin. In general, a 60 percent sweat wettedness (i.e., skin relative humidity of 60 percent as defined by the ratio E_{req}/E_{max}) will be about the highest acceptable level for even a well-motivated, very fit and well-acclimatized workforce.

So far, the heat balance equation has been presented and its importance identified in determining whether or not a given combination of factors results in heat stress. While the reader may be concerned at the rather casual treatment of respiratory and diffusional heat losses, it must be recognized that the heat balance equation itself represents an approximation. Considering the variability in individual size, in physical and physiological states between workers, in the clothing worn and in its fit on a given individual, it is obvious that any human heat balance equation is inherently not a precision statement. Thus, this

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approach clearly falls within a *GEGU—good enough for general use*—category. This *GEGU* acronym will be used to emphasize adequacy, albeit imprecision, at a number of points in the subsequent discussion.

The six key parameters involved in the calculation of the heat balance equation have now been identified. Four are environmental factors: the air temperature (t_a), the ambient air motion (WV), the ambient vapor pressure ($\phi_a P_a$), and the mean radiant heat temperature (MRT). The other two factors, which are subject to behavioral temperature regulation, are the task workload (and the associated heat production of the worker) and the clothing worn by the worker. Each of these factors will be addressed in turn.

THE SIX KEY FACTORS

Ambient Air Temperature (t_a)

Surrounding every physical object is a surface film of trapped air. This "surface still air layer" contributes a very significant part of the insulation surrounding a human body (usually over 50 percent when dressed for indoors). This insulating air film is altered by air movement and this accounts for the perceived difference between the ambient air temperature as sensed by a still hand, and the ambient air temperature sensed when the hand is in motion. If one simply hangs a thermometer in ambient air, any radiant heat in the environment may be absorbed by the thermometer and effectively trapped there by the surface film layer around the thermometer. Accordingly, in order to measure the true psychrometric properties of air the thermometer must be ventilated, to minimize any surface still air film. This is done either by having the thermometer swung on the end of a chain (a sling psychrometer) or by having air pulled across it by a fan (an aspirated psychrometer). If the work site is close to an intense radiant heat source (smelter, glass furnace, etc.) special shielding for the thermometer bulb, or a specially shielded sensor, may also be required.

Ambient Vapor Pressure ($\phi_a P_a$)

The ambient vapor pressure is usually determined from the measurement of a "wet bulb" thermometer temperature. Most psychrometers, sling or ventilating, simply pair two identical thermometers, with one bulb mounted a few centimeters below the other, and equip the lower bulb with a wettable cotton wick; hence the terminology dry bulb ($t_{db} = t_a$) and wet bulb (t_{wb})

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temperature. The wick is saturated with water prior to aspirating or slinging the psychrometer. Because of both the omnipresent potential for convective heat gain from the air by the evaporatively cooled wet bulb thermometer and the potential radiant heat regain, ventilating the wet bulb thermometer to the appropriate air motion [air movement >4.5m/s 900 feet per minute (fpm) past the wet bulb wick] is of critical importance.

Some environmental physiologists have argued, correctly, that use of a psychrometric wet bulb to represent the potential evaporative cooling available to a worker is unreasonable—unless the worker is somehow to be ventilated or slung by the heels to produce a high air velocity across his 100 percent sweat-wetted skin. Accordingly, some of the environmental indices, to be discussed subsequently, incorporate a "natural"—or nonpsychrometric—wet bulb (t_{nwb}). Figure 10-1 presents a standard temperature-vapor pressure (Moliere) diagram for air at sea level, which can be used to convert the measured dry bulb and wet bulb temperatures to a relative humidity; in turn, this can be converted to the ambient vapor pressure which is the key environmental parameter required for calculation of the maximum evaporative cooling capacity. Alternatively, tables of wet bulb depression at a given dry bulb temperature, or a "psychrometric slide rule," can be used to obtain the percentage of relative humidity. Note that, because evaporation is a function of the difference between the skin and the ambient vapor pressures, evaporation of sweat from the skin can occur at 100 percent relative humidity as long as the air temperature is less than the temperature of the skin; thus ambient relative humidity per se is of little interest for heat balance.

The point of intersection of the wet bulb and dry bulb temperature lines on the psychrometric chart (cf. Fig. 10-1) identifies the relative humidity; the uppermost curve on the graph represents the 100 percent relative humidity line. At 100 percent relative humidity, the ambient air is saturated (i.e., cannot take up any more moisture), so the wet bulb and dry bulb tempera tures will, of course, be equal; no evaporation can occur unless air temperature increases. Observation of the psychrometric chart also indicates that the vapor pressure can be determined from this point of intersection of the dry bulb and wet bulb lines; it is simply read from the Y axis in either kilopascals (the SI unit) or, the more familiar, mm Hg units. In the example drawn on the psychrometric chart (Figure 10-1) the ambient vapor pressure is one kilopascal or 7.5 mm Hg. Note that at the indicated dry bulb temperature of 25.5°C, the ambient vapor pressure at 100 percent relative humidity would be about 25 mm Hg; that is, P_a, the saturated vapor pressure would be 25 mm Hg. Multiplying this P_a by the 30 percent relative humidity indicated on Figure 10-1 (by the intercept of the dry bulb and wet bulb lines, ϕa) yields 7.5 mm Hg, the ambient vapor pressure; simply stated, the air is holding 30 percent of the total moisture that it

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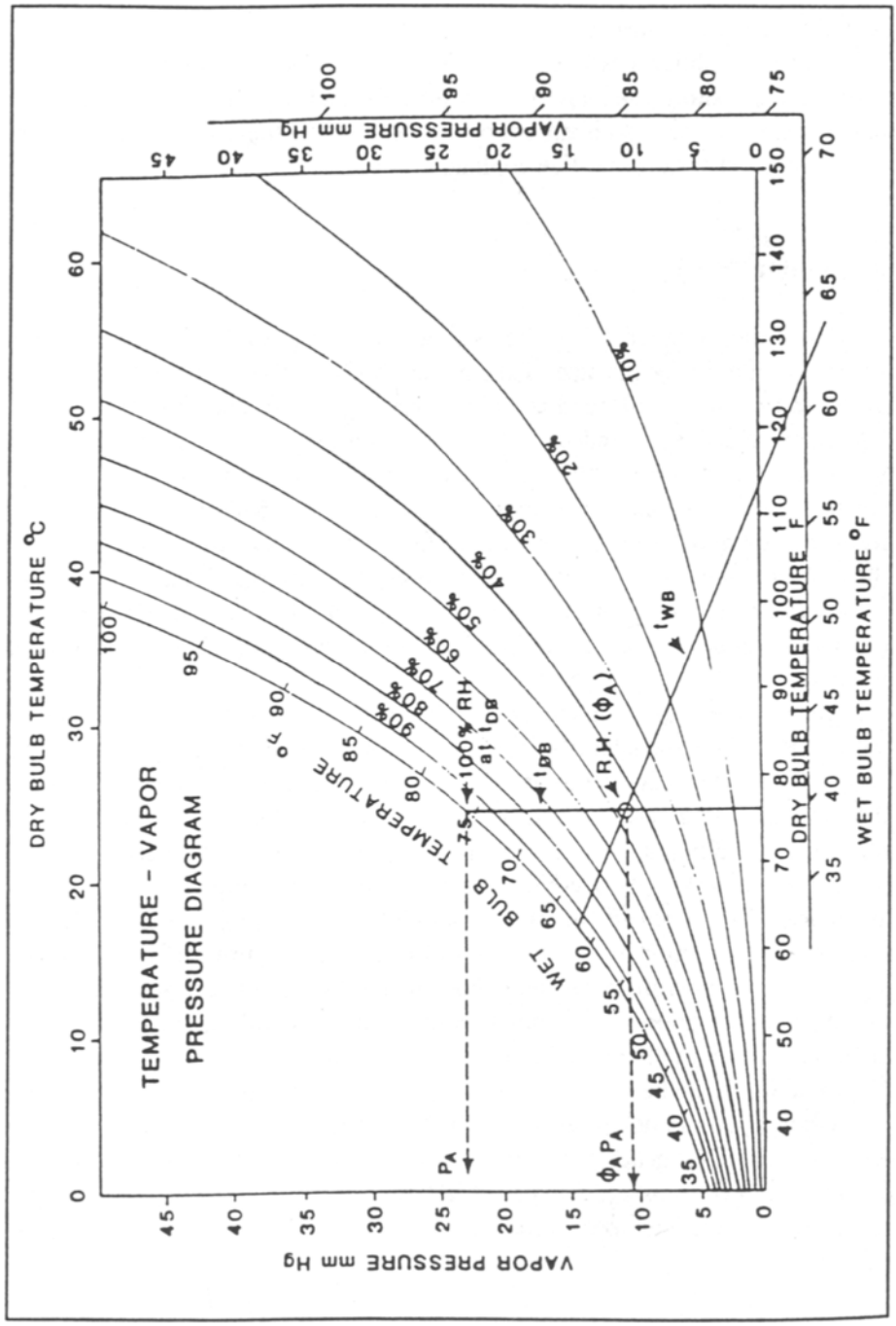


Figure 10-1 Psychrometric chart for air at sea level showing relationships.

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could hold when saturated at t_{db}.

Under conditions where there is little or no requirement for sweat evaporative cooling (i.e., low work with light clothing at comfortably cool to colder temperatures), ambient vapor pressure is of little concern since there is no requirement for evaporative cooling.

Air Motion (WV)

The importance of the surface still air film as insulation has already been noted. For a cylinder the size of the human body, with low air motion the still-air layer film at the surface becomes a very significant contributor to the total insulation of a human. Indeed, when wearing a long-sleeved shirt and trousers under still-air conditions, the contribution of the external air film (I_a; = 0.8 clo) equals or exceeds the intrinsic insulation (I_{cl}; = 0.6 clo) of the shirt and trousers. Air movement then is a major factor in heat transfer from the body to the ambient environment, with or without clothing. Even with an impermeable, encapsulating chemical protective clothing system, the external surface-air film (I_a) is still important unless reduced by air motion caused by wind or body motion.

Measurement of air movement requires sophisticated instrumentation, or sufficiently high but nonturbulent air motion that simpler field devices (e.g., vane anemometers) can be used. Thus, the usual approach for determining air motion indoors and outdoors, is to estimate it. One frequently sees air movement specified as 50 feet per minute (fpm), or as a seemingly more exact 44 fpm, which is simply one-half mile per hour. Such values are simply *GEGU* estimates. With ambient air motion at about 0.13m/s (25 fpm), the natural convective air motion which results from the temperature difference between skin and air temperature becomes the primary factor; thus, lower ambient air motion is meaningless. The insulation of the surface still air layer at that low air motion is about 0.8 clo units for a human body.

In addition, if the worker is moving, body motion generates an "effective" air velocity [Colin and Houdas, 1967]. Newburgh suggested that the effective wind velocity (V_e) generated during activity could be estimated from the heat production of the worker, using the MET unit of metabolism (one MET equals an average, "resting" heat production of 50 kcal/m²hr), he suggested the relationship:

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Eq. 2 $V_e = .07\ (MET-0.85)$

where V_e is effective wind motion generated (in m/s) and the 0.85 represents a "sedentary" MET level.

Fanger suggested that the effective air velocity could be calculated as $0.1 + 0.4\ (MET - 1)^{0.5}$, which gave a heat transfer coefficient (h_c) for average indoor clothing of $12.1\ (V_e)^{0.5}$ (V_e in m/s; hc in W/m² °C). Such refinements are unnecessary for most practical work but should be kept in mind under conditions of very low ambient air movement. The effective air velocity is more important with light clothing and is particularly important with air permeable, chemical protective clothing as will be addressed further in the section on clothing.

Mean Radiant Temperature (MRT)

Indoors, the temperature of the wall, windows, floor and ceiling are usually considered equivalent to the temperature of the air; however, thermal radiation can be a major contributor to discomfort and heat stress when an individual works near a large window or on the top floor of a building with an uninsulated roof. Thermal radiation is a major concern in industrial settings with such large, high-temperature heat sources as ovens, arc furnaces, and the like.

The mean radiant temperature of an environment is an integrated value, representing the uniform surface temperature of a radiantly black enclosure in which an individual would exchange the same amount of radiant heat as he does in the actual, non-uniform, radiant environment. The usual mean radiant temperature measuring device is a hollow, thin-shelled, 15 cm (6-inch) copper sphere, painted flat black; the globe temperature (t_g) is measured at the center of the inside of the sphere. The mean radiant temperature (MRT) is calculated from the globe temperature [Bedford,1934], as a function of the ambient wind velocity (WV), by the equation:

Eq. 3 $MRT = t_g + k\ (WV)^{0.5}\ (t_g - t_a)$

where k is 2.2 for t (°C) and WV (m/s) or k is 0.157 for t (°F) and WV (fpm)

Metabolic Heat Production

As indicated above, the metabolic heat production of an individual is frequently expressed as so many watts (= 1.163 kcal/hr) per square meter of surface area. A typical "standard" male will weigh 70 kg (154 lb), stand 174 cm (5 foot 8-1/2") tall, and therefore have 1.8 square meters (19.5 ft²) of body

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surface area. A "standard" female will weigh about 57 kg (125 lb), stand 164 cm (5 foot 4-1/2") tall and have a body surface area of 1.6 m^2. The resting heat production of a standard adult male will be about 105 W, which can be calculated quite nicely using either 1.5 W/kg of body weight (1.3 kcal/hr kg) times 70kg, or 58 W/m (=1 MET= 50kcal/hr m^2) times 1.8 m^2. Because of the larger amount of body fat (which is relatively inactive) in females, their resting heat production (about 85 W, or 80 percent that of the standard male) cannot be approximated by using the standard, surface area based MET unit; it can, however, be approximated using the 1.5 W/kg of body weight relationship. The heat production requirement for almost all physical work is a function of the weight moved (e.g., kg of body weight + load weight) and workers must move the weight of their fat, the weight-based equation presented below for estimation of energy cost (i.e., heat production) applies equally well for men and women. Since a "standard" female has about 28 percent body fat compared to 18 percent for a "standard" male, a greater thickness of the subcutaneous fat layer in females provides more insulation between the skin and the heat produced in the body. Under cool conditions, females may have cooler skin temperatures; studies suggest that women prefer about 1°C (1.8 °F) higher air temperatures for comfort than men. However, under warm or hotter conditions, the circulation effectively moves heat from the core to the skin past the subcutaneous fat; thus this difference in fat, and cold tolerance, does not affect heat tolerance.

Workers seldom work at anywhere near their maximum work capacity levels during normal work. The metabolic heat production (M) at rest is, like heat loss, a linear function of body surface area. Typical office work ranges from 125 kcal/hr for "light" work to 150 kcal/hr for heavier tasks. However heavier tasks are rarely performed continuously so the energy cost (i.e., heat production) of hard work tasks must be time weight averaged with the intervening periods of resting heat production for example, while football players must have the capacity for very high, peak, heat production, their average heat production from the start of a game to the end of the fourth quarter is much lower. Workers performing tasks requiring heavy physical work that is machine paced, or for which overly high production quotas have been set, or marching with heavy loads, have far higher, time weighted average (TWA), heat productions. Table 10-1 presents a useful technique for estimating the energy cost of work.

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Table 10-1. Estimating Energy Cost by Task Analysis			
		Typical kcal/minute	Average Range
Factor 1. Basic metabolism		1	0.8 to 1.2
Factor 2. Body position & movement			
	Sitting	0.3	
	Standing	0.6	
	Walking	by formula*	2.0 to 3.0
	Walk uphill	by formula* or add	0.8/meter rise
Factor 3. Type of work			
Hand work	-light	0.4	0.2 to 1.2
	-heavy	0.9	
One arm	-light	1.0	0.7 to 1.2
	-heavy	1.8	
Both arms	-light	1.5	1.0 to 3.5
	-heavy	2.5	
Whole body	-light	3.5	2.5 to 9.0
	-moderate	5.0	
	-heavy	7.0	
	-very heavy	9.0	

SAMPLE CALCULATION **Average kcal/minute**

(for "standard worker")

Assembly work with heavy hand tools:

1. Basic metabolism	1.0
2. Standing	0.6
3. Both arms - heavy work	3.5
Estimated TOTAL =	5.1 kcal/min

Metabolic heat production can also be estimated from a worker's heart rate. Heart rate, standing at rest, in a healthy adult male averages about 70 beats per minute (bpm), although very fit individuals may average 50 bpm; females, on average, have 10 bpm higher heart rates than males. An individual's maximum heart rate can be estimated as 220 bpm minus age in

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years. Heart rate during work is one of the most easily measured physiological responses (a count, for a minimum of 20 seconds, of the pulse rate, usually at the wrist). In the absence of heat stress, the rise in heart rate is linear with the rise in the metabolic cost of the work. For a fit, young, male worker, in the absence of heat stress, a simple measurement of heart rate can serve as an indicator of the difficulty of physical work, its energy cost (M), probable deep body (rectal T_{re}) temperature, and the respiration volume (in L/min) since respiratory volume usually increases linearly with M as oxygen extraction rises only slightly during moderate work, as shown in Table 10-2.

Table 10-2 Estimation of Work From Heart Rate

Heart Rate beats/min	Work Level	M kcal/min	Usual T_{re} °C	Respiration 1/min	1/min O_2
<75	Very light	<2.5	≤37.5°	10	0
75-100	Light	2.5- 5.0	≤37.5°	10-20	0.5-1.0
100-120	Moderate	5.0- 7.5	37.5- 38.0	20-35	1.0-1.5
120-140	Hard/heavy	7.5-10.0	38.0- 38.5	35-50	1.5-2.0
140-160	Very heavy	10.0-12.5	38.5- 38.8	50-65	2.0-2.5
160-180	Unduly heavy	12.5-15.0	38.8- 39.0	65-85	2.5-3.0
>180	Exhausting	>15.0	>39.0	>85	>3.0

Linear interpolation can be used to fine-tune such estimation. Note that at higher heart rates, work time becomes limited (see below).

Thus, in the absence of heat stress, heart rate per se is a reasonable indicator of metabolic cost for an average, reasonably healthy worker. Work requiring heart rate to increase by < 30 bpm above the resting level is considered "comfortable;" work requiring a steady state heart rate of >120 bpm is not. Work at 140 bpm should be limited to 4 hours or less for fit, young men, while that requiring 160 bpm has a suggested time limit of about 2 hours. Heart rates >180 bpm should not be allowed for more than 15 minutes, and even then only for fit, young men. Assume that it requires an additional 35 bpm to deliver enough oxygen to meet the needs of a specific task. Given that [220 - 20] = the maximum heart rate of an average 20 year old, and assuming a resting heart rate of 70 bpm, the 20 year old has a "maximum heart rate increase" of 140 b/m (i.e., [200 - 70] b/m). The assumed task requirement of a 35 bpm heart rate increase represents 25 percent of the 20 year old's maximum heart rate increase. Returning to the D/C ratio concept introduced earlier, this task would be just a bit above the comfortable level for the 20 year old. It would represent about 40 percent of the capacity of a 60 year old (i.e., [220 - 60] - 70 = 90

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bpm of maximum heart rate rise for a 60 year old) and fall just at the 40 percent threshold, thus changing this demand from "uncomfortable" to "performance degrading."

Alternatively, if the primary element involved in the activity is walking, the following equation has been developed [Givoni and Goldman, 1971] (and validated across a wide range of studies) to predict the heat production:

Eq. 4 $M = 1.5(W) + 2(W + L)(L/W)^2 + (\mu)(W + L)(1.5V^2 + 0.35\ VG)$

where: W= body weight (kg); L = load carried (kg);
V = walking velocity (m/s); G = grade (percent); and
μ = a non-dimensional "terrain coefficient" ranging between a value of one, for a hard surfaced floor, to a value of two for soft sand.

The first term in the above equation expresses the resting energy cost of 1.5 W/kg of body weight, which works *GEGU* for males and females. The second term simply represents the energy cost of standing with a load on the back. If some portion of the load carried is not borne on the torso, adjustment should be made for the inefficiency of loading; each pound carried by hand costs roughly the equivalent of two pounds on the back, and each pound of footwear worn while walking is equivalent to five pounds carried on the back [Soule and Goldman, 1969]. The importance of keeping the weight of protective footwear at a minimum can be seen from this relationship; for example chemical protective boot covers which weight two pounds have the equivalent effect of an added ten pounds of backpack weigh during walking. The weight of headgear should, in theory, be incremented by about 30 percent to equate it to a back-carried load, but generally this is too small an adjustment to require consideration. However, it should be recognized that the frequent complaints of the weight of protective headwear are apt to stem from too high a center of gravity, and the accompanying torque and momentum changes with body motion which result in a higher perceived weight, rather than from the actual weight of protective headgear per se.

The next term in the equation indicates that energy cost goes up as a function of the square of the walking speed and introduces a coefficient (μ) to adjust for the nature of the terrain being traversed [Haisman and Goldman, 1974]. Any smooth, hard, non-slippery surface, be it a treadmill, floor or blacktop road requires essentially the same energy cost and for these is assigned a multiplier of 1. Terrain coefficients (i.e., relative multipliers) to adjust for the energy costs of walking at a given speed across other terrain surfaces are: 1.1 for a gravel road; 1.2 for light brush; 1.3 for packed snow or ice; 1.5 for heavy brush; 1.8 for swampy terrain; and 2.1 for soft sand.

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Sample Calculation: for a 70 kg man, marching at 1.2 m/s with a 30 kg pack in level, light brush

$$M = 1.5(70) + 2(100)(30/70) + 1.3(100)[1.5(1.2 \times 1.2)]$$

Calculated Heat Production = 456 W or 393 kcal/hr

A task requiring heat production below 5 kcal/min would be considered average work, and would require a heart rate between 75 and 100 bpm. to deliver sufficient oxygen to the working muscles. Moderate to hard work tasks would require up to 7.5 kcal/min (or 523 W) of metabolic energy cost; these would require heart rates in the range of 100 to 125 bpm. Heavy work, sustainable for about one hour by an individual of average fitness, would correspond to an energy cost of about 10 kcal/min. (700 W) and require heart rates between 120 to 140 bpm. Finally, physical work which corresponds to a physiological energy cost of about 15 kcal/min. (or 1,050 W), would present a work level that might be sustained by an average, young individual for only about 10 minutes, and would push heart rates up to 160 to 180 bpm. If the same physical work were done under hot conditions, the metabolic energy costs would be slightly, if at all, increased initially, but the heart rates would increase rapidly and dramatically as the burden of transferring heat from the working muscles to the skin increased. Eventually the heat production would also increase dramatically, as the worker became increasingly uncoordinated, dizzy and, eventually, unsteady and staggering if work continued.

Note that these work rate-time limitations refer to reasonably fit young adult males; they really represent given percentages of such individuals' maximum oxygen uptake (VO_{2max}) or "maximum work capacity." Industrial tasks seldom demand more than 5 kcal/min, or roughly one-third of an average young adult male's (VO_{2max}). A number of studies suggest that the voluntary hard work level adopted by individuals who must sustain such work for at least 3 to 5 hours corresponds to about 45 percent of their capacities (~7 kcal/min for fit young men [Hughes and Goldman, 1970]). An average of about 33 percent of VO_{2max} was sustained throughout one, 5 day, military field study. Although sustained, high physical work demands are rare in industrial work, individuals can sustain work demanding 60 percent of their individual VO_{2max} capacity for about 1 hour, 75 percent of their capacity for about 30 minutes, 85 percent of capacity for about 15 minutes and will be exhausted in about six minutes working at their maximum oxygen uptake, by definition of VO_{2max}. Table 10-3 is the expected VO_2max (in W) for men (wgt = 70 kg), and women (60 kg), as a function of age and fitness rating.

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Table 10-3. Maximum Work Capacity (watts) by Age and Fitness					
Age	**Poor**	**Fair**	**Average**	**Good**	**Excellent**
MEN					
17-19	<924	948-1042	1066-1161	1185-1256	>1279
20-24	<829	853- 924	948-1066	1090-1232	>1256
25-29	<805	829- 900	924-1042	1066-1184	>1208
30-34	<782	805- 877	900-1019	1042-1137	>1161
35-39	<758	782- 829	853- 971	995-1090	>1113
40-44	<711	734- 805	829- 900	924-1042	>1066
45-49	<663	687- 758	782- 829	853-1019	>1042
54-59	<616	640- 711	734- 782	805- 995	>1019
WOMEN					
17-19	<670	690-771	792-853	873-954	>975
20-24	<649	670-731	752-813	832-914	>934
25-29	<609	629-690	711-792	792-873	>893
30-34	<568	589-648	670-752	711-832	>852
35-39	<528	548-609	629-711	731-792	>813
40-44	<495	507-568	589-670	690-752	>771
45-49	<447	467-528	549-629	650-711	>731
54-59	<406	426-488	507-589	609-670	>690

To convert these values from W to kcal/hr multiply by 0.86; convert for other body weights by ratio (e.g., wgt/70 * table).

A 1000 watt level for maximum, short term, 6 minute "peak" work by fit, young men, as shown in the above table, can be used as the capacity term for estimating the effects of work using the D/C format; work requiring <200 W should be comfortable, from 200 to 400 W probably is the most productive range for physical work performance, 400 to 600 W should produce some performance decrements, and work demanding more than 600 W should be tolerance time limited for a 25-year-old-male in "good" physical condition. The values in this table can be substituted for the generalized 1000 W as the capacity (C) term to tailor the D/C ratio for age, sex or weight, and to estimate the effects of a physical fitness training program assuming that the improvement in work capacity will be 15 percent at most. The preceding relationships can be tailored for fitness level, age or sex, by using 45 percent of

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the tabulated value in place of the 500 W which represents 45 percent of VO_{2max} for an average, fit, soldier.

There is little need to initiate new energy cost measurements; extensive tabulations exist for the heat production associated with almost all forms of human activity [Passmore and Durnin, 1967].

Clothing

The clo unit used to express clothing insulation is of relatively recent origin; it was first proposed in 1941 by Dr. A. P. Gagge that the insulation of a typical business man's wool suit of the late 1930s be assigned a value of one clo of insulation. The mathematical value assigned to one clo was derived by calculating the potential difference for nonevaporative heat transfer from the human body to the ambient environment, and dividing it by the desired heat flow to calculate the resistance of the clothing worn which, it was assumed, allowed heat balance to be established for the wearer. This desired heat flow was assumed to be the resting heat production (M), one MET (58 Watt/m^2 or 50 kcal/m^2hr), less the 25 percent of the resting heat production lost from the body by respiration and by evaporation of body moisture, diffusing through the semipermeable skin and evaporating to the air. Using 33°C as a comfortable skin temperature and 21°C as a standard room temperature (in the early 1940s) produced a 12°C driving force for non-evaporative heat transfer. Dividing by the desired heat flow of 38 kcal/m^2hr (i.e., 75% M) provided a total conductance for the clothing plus the external air film at the clothing surface of 0.32°Cm^2hr/kcal In subsequent studies on nude men in still air, the still-air surface film conductance was evaluated at 0.14°Cm^2hr/kcal, which left the intrinsic conductance of the heavy business suit of the early 1940s as 0.18 °Cm^2hr/kcal. Taking the reciprocal of this conductance established the value for one clo unit of insulation (I) as 5.55 kcal/m^2hr °C (or 6.45 W/m^2 °C). Under these conditions, the air temperature and mean radiant temperature were identical and the clo value is, in fact, the combined insulation against radiative and convective heat transfer. For conditions where air and mean radiant temperature are not very closely equal, one can simply substitute the adjusted dry bulb temperature (t_{adjb} = (MRT + t_a)/2). For ease in calculation, one may use the insulation per man rather than per m^2; then, for the average adult male who has a surface area of 1.8m^2, one clo of insulation results in a heat loss of 10 kcal/hr °C (11.63 W/ °C), two clo of insulation requires the transfer of 5.8 W (5 kcal/hr) per °C difference between skin and air temperature, etc. The insulation of a material is almost always a linear function of its thickness, with 1.57 clo of insulation provided by each cm of material thickness (4 clo per inch); in essence, a 6.5 mm (1/4") thick blanket provides one clo unit of

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intrinsic insulation (I_{cl}). This same general approach applies to the insulation used in building construction; the clo unit of clothing insulation is equal to 1.14 of the R units used in building insulation.

Thus, in calculating nonevaporative heat transfer, one simply needs to know the total clo value of the clothing worn and the surface still air film (I_a) trapped at its surface. The total insulation value of an ensemble is measured with a life-sized, heated (and when desired, sweating by means of wetted cotton "skin") manikin whose heating wires are distributed throughout the skin to produce a human skin temperature pattern. Such manikins also have temperature sensors distributed throughout their surface to measure an average skin temperature and a thermostat to demand sufficient heat to maintain the desired constant average skin temperature. When such manikins are run in a controlled temperature environment in steady state, the amount of heat demanded to maintain a constant skin temperature is exactly equal to the amount of heat lost. This allows direct measurement of the total insulation value of any clothing ensemble so tested, using the 6.45 W/m^2 °C (5.55 $kcal/m^2hr$ °C) defining value of one clo of insulation [Sprague and Munson, 1974].

For cold weather conditions, one simply needs to know the heat production of the individual and the clo value of his insulation, in order to calculate whether the heat loss from the body will match the 75 percent of heat production available for nonevaporative losses. If it does not, any excess heat loss demand will be withdrawn from the body, in which case body cooling results; if less heat is lost than is produced, heat storage by the body must ensue unless the body can lose heat by evaporative cooling.

When less heat is lost through the clothing insulation than required to match the heat production at rest or work, then the 25 percent of resting metabolic heat production lost by respiration and diffusion of moisture through the skin, and its evaporation, must be supplemented with actual sweat evaporation; i.e., the normal 6 percent relative humidity of the skin (or 6 percent diffusion "sweat-wetted area," equivalently) must be increased by production of sweat by the body. Note that if sweat cannot be evaporated, no cooling benefit is derived; the individual simply dehydrates at a more rapid rate unless adequate drinking water is taken. This is a frequent problem with chemical protective clothing; for example, a well heat-acclimatized individual will produce more sweat then one who is not acclimatized [Givoni and Goldman, 1973a] but, if the clothing worn is a barrier to sweat evaporation, heat acclimatization is of little benefit and may simply contribute to more rapid dehydration and earlier onset of heat exhaustion [Goldman, 1970].

An approximate value for the clo value of a typical clothing ensemble also can be calculated based on the *GEGU* relation that 1 kg of clothing equals 0.35

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clo (0.16 clo/lb). This includes a surface air layer (I_a) which provides 0.8 clo of insulation in still air, but only 0.2 clo with a 5 m/sec (12 mph) breeze. The value for I_a with other air motions can be calculated by the formula: $I_a = 1/(0.61 + 1.25/WV)$ where 0.61 represents the radiation heat transfer component and WV, the wind velocity in mph, represents the convection component of the surface air layer. Note that the insulation provided by I_a is greater than the insulation provided by any single item of clothing.

Table 10-4 suggests that the total insulation of a clothing ensemble also can be estimated by taking 80 percent of the sum of the individual values of the items worn (to allow for compression at overlaps) and adding 0.8 clo for the still air surface air insulation layer indoors.

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Table 10-4 Calculated Intrinsic Insulation (Clo) Values Based on Individual Clothing Items Worn.

Clothing	Men	Clothing	Women
Underwear		Underwear	
Tank top	0.06	Bra + panties	0.05
T-shirt	0.09	Half slip	0.13
Underpants	0.05	Full slip	0.19
Shirt		Blouse	0.20[1]
Light*: short sleeved	0.14	Light	0.29[1]
long sleeved	0.22	Heavy	
Heavy: short sleeved	0.25	Dress	
long sleeved	0.29	Light	0.22[1, 2]
(+5 percent for turtleneck or tie)		Heavy	0.70[1, 2]
Vest		Skirt	
Light	0.15	Light	0.10[2]
Heavy	0.29	Heavy	0.22[2]
Trousers		Slacks	
Light	0.26	Light	0.26
Heavy	0.32	Heavy	0.44
Sweater		Sweater	
Light	.020[1]	Light	0.17[1]
Heavy	0.37[1]	Heavy	0.37[1]
Jacket		Jacket	
Light	0.22	Light	0.17
Heavy	0.49	Heavy	0.37
Sox		Stockings	
Ankle length	0.04	Any length	0.01
Knee high	0.10	Panty hose	0.01
Shoes		Shoes	
Sandals	0.02	Shoes	0.02
Oxfords	0.04	Pumps	0.04
Boots	0.08	Boots	0.08

* Wearers cannot reliably distinguish more than "light or heavy."

TOTAL clo value = 0.8(Σindividual items) + still air 0.8 clo

[1] Less 10 percent if short sleeved or sleeveless.

[2] Plus 5 percent if below knee length; less 5 percent if above.

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SAMPLE CALCULATION:

Tshirt + shorts + light, long sleeve shirt + light pants + sox + shoes:
(.09 + .05 + .22 + .26 + .04 + .04) = (.70), and 80 percent of (.70) =

.56 clo of intrinsic clothing insulation
+ .80 clo for I_a without wind
1.4 clo of total clothing insulation

Table 10-5 gives representative values for the type of chemical protective clothing ensembles that might be worn by industrial workers. Note that these values are for normally fitted clothing. An example of the inherent variability in insulation values can be obtained by considering that the long-sleeved shirt and trousers value of 1.41 clo might go as low as 1.35 clo for a tight-fitting ensemble, and up to about 1.43 for a fairly loose-fitting shirt and trousers.

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Table 10-5
Insulation (clo) and Permeability (i_m) of Chemical Protective Clothing Ensembles

Clothing Assembly[1]	Insulation[2] (clo)	Permeability (i_m)	Index Ratio (i_m/clo)
Category I-- Everyday Clothing			
Long-Sleeved Shirt + Trousers	1.41	0.37	0.26
Supplemented with:			
a. Safety helmet	1.49	0.37	0.25
b. Safety gloves	1.48	0.36	0.24
c. Mask, hood	1.56	0.29	0.18
d. Air backpack	1.45	0.34	0.23
e. Plastic apron	1.50	0.28	0.18
f. a+b+c+d+e	1.70	0.24	0.14
Category II-- Charcoal-in-foam			
a. Worn alone, open[3]	1.65	0.40	0.24
b. Worn alone, closed[4]	1.92	0.32	0.18
c. Worn over long shirt and trousers, open	1.97	0.42	0.21
c. Worn over long shirt and trousers, closed	2.30	0.35	0.15
Category III-- Impermeable (butyl)			
a. Worn alone, open	1.58	0.12	0.08
b. Worn alone, closed	2.05	0.09	0.04
c. Worn alone, w/wetted terry coverall	2.05	0.27	0.13

[1]Includes underwear (T-shirt, shorts), socks and shoes; values estimated from comparable military assemblies.
[2]All values given at 0.3m/s (0.75 mph) air motion, and include I_a of 0.8 clo.
[3]Open = without mask, hood, gloves; with open collar, etc.
[4]Closed = with mask, hood, gloves; all apertures closed.

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From these changes in insulation value with clothing fit, obviously any values in the table beyond the first decimal place are more indicative than precise. An average man (i.e., surface area of 1.8 m^2) would lose 7.1 kcal/hr. °C difference between skin and ambient air temperature with 1.4 clo of insulation, but only 5 kcal/hr. with 2 clo of insulation. A long-sleeved shirt and trousers provide intrinsic insulation of 0.6 clo and the external air layer about 0.8 clo in still air. The total of 1.4 clo results in a heat transfer, for a standard (1.8 m^2) man of 7.1 kcal/hr°C. Belding [Belding, 1971] suggested a radiant heat transfer of 6.6 kcal/hr°C with such clothing and a convective heat transfer of 7(WV)0.6 kcal/hr°C in still air (e.g., WV = 0.11 m/s or 0.25 mph). This convective exchange would be 1.8 kcal/hr °C, providing a combined transfer of 8.4 kcal/hr°C (i.e., 6.6 + 1.8) by radiation and convection. With a hot skin temperature [36°C (97°F)] and environmental temperatures of concern generally in excess of 20°C (68°F), the 15-20 kcal difference in heat loss per hour resulting from even a 0.5 clo difference in the insulation of an ensemble is clearly of minor importance; however, as discussed below, the effect of insulation is much more substantial in the extent to which it can affect evaporative heat transfer.

The evaporative cooling allowed by the environment, as discussed above, is determined from a psychrometric wet bulb thermometer. Woodcock used this in defining a moisture permeability index (i_m) for materials; Goldman and Breckenridge [1976] subsequently applied this concept to measuring and calculating the maximum evaporative cooling allowed by a clothing ensemble. The permeability index (i_m) is simply the dimensionless ratio of the evaporative cooling allowed by the clothing and its surface air film (i.e., through $I_{cl} + I_a$), to the maximum evaporative cooling obtainable by a psychrometric wet bulb thermometer.

Typical permeability index values for most clothing or materials average about 0.45 (at 0.3 m/s air velocity) unless impermeable layers or water repellent treatments are incorporated within the clothing assemblies, but the measured value depends in part on the insulation of the material or ensemble. Increases in insulation tend to be matched by increases in measured moisture permeability. Since impermeable materials tend to be relatively thin, covering the body surface with these materials may add only slightly to the total insulation, but will directly reduce the permeability in a linear ratio to the area covered by impermeable material [Goldman, 1981]. Adding an impermeable layer, such as a plastic hood or mask to cover an area of previously exposed bare skin [Goldman, 1963], will produce a much more serious reduction in the overall permeability index than covering an equivalent area of the body that is already covered with clothing [Fourt and Hollies, 1970].

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The permeability index is a measure of the evaporative characteristics of the clothing materials and associated trapped air layers, but it does not provide a true measure of the evaporative cooling potential from the skin to the ambient environment. The reason i_m is generally fairly constant, about 0.45 in still air, is that i_m really represents a characteristic moisture diffusion constant through air. The actual effective evaporative cooling obtainable by the clothing wearer is a function of this diffusion constant (i_m) (as modified by unique or water-repellent treatments, very tight weaves, or specifically introduced impermeability), divided by some expression of the length or thickness of the diffusion path; the clo insulation value provides a suitable measure of this thickness. Thus, the net evaporative cooling obtainable by the wearer of a garment system is determined by the permeability index ratio i_m/clo. This form of expression for the insulation and evaporative capacity of clothing can be much more readily interpreted than the use of the resistance terms R_c for radiative and convective heat transfer, and Re for evaporative transfer; adding R_c units requires conversion to $1/R_c$ in order to sum the contributions of multiple layers, while an R_e value, unlike i_m, is inherently dependent on R_c.

Table 10-5 includes estimated values of the permeability index (i_m) and the more critical, permeability index ratio (i_m/clo) for a series of clothing assemblies that might be worn for chemical protection. Using the 2.2°C/mmHg Lewis relationship, to link the evaporative heat transfer to the convective heat transfer, it is clear that, with one clo of insulation, one should obtain 22 kcal/hr (i.e., 10 kcal/hr°C times 2.2°C/mm Hg) of heat transfer per mm Hg difference between skin (P_s) and ambient air vapor pressure ($\phi_a P_a$) for a standard 1.8 m^2 adult male, if he behaved like a psychrometric wet bulb. Multiplying this potential maximum cooling of 22 kcal/hr mm Hg by the i_{r-}/clo ratio determines the actual potential maximum evaporative cooling allowed through a clothing assembly. Therefore, each change of 0.1 i_m/clo produces a change of 2.2 kcal/hr mm Hg difference between skin and air vapor pressures. The vapor pressure of a hot (36°C) sweaty skin is about 44 mm Hg and, at 25°C (77°F), 50 percent relative humidity, the ambient vapor pressure is about 12 mm Hg; under that environmental condition, a change of 0.1 i_m/clo represents a change of approximately 70 kcal/hr in the maximum evaporative cooling allowed by the ensemble [i.e., 22 x (44 - 12) x .1]. This direct role played by increasing insulation in the evaporative cooling obtainable by the wearer of a clothing assembly explains why individuals wearing multiple layers of heavy clothing (i.e., high insulation (clo) values) in the winter can become heat casualties during heavy work despite cool-to-cold and relatively dry ambient environmental conditions; they simply cannot get enough evaporative cooling at the skin, despite the very low ambient vapor pressure, to balance their heat production. Note that although Belding appears to have been unaware of the

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Lewis relationship (2.2°C/mm Hg), the evaporative heat transfer he suggested of 23 $(WV)^{0.6}$ per mm Hg difference between skin and ambient vapor pressure for a long-sleeved shirt and trouser ensemble is 1.9 times the 12 kcal/hr °C he used for its convective exchange.

The role played by wind speed in altering insulation has been described above, as has the role played by body motion in inducing an effective wind [Mitchell, 1974]. Body motion has a direct effect on clothing insulation and, hence, effective evaporative cooling (i_m/clo) by "pumping" (i.e., exchanging) the air trapped within the clothing fabric and between the clothing layers. This increases the evaporative and nonevaporative heat exchange with the ambient air. Belding described a reduction of almost 50 percent in the total insulation of a heavy Arctic ensemble as the wearers went from rest to walking at 3.5 mph on a treadmill. Givoni and Goldman [1972] have developed a family of pumping coefficients to characterize the changes in various clothing ensembles with "effective wind" (WV_{eff}), where WV_{eff} was defined as the sum of the ambient air motion and 4 percent of the increase in M (in W) above the resting heat production; i.e., $WV_{eff} = WV + 0.04\ (M - 105)$. Although, obviously, the appropriate m/s units for air velocity cannot be rationally derived from this totally empiric estimate, this treatment of effective air motion, and the use of a pumping coefficient to characterize the changes in both the clothing insulation and the permeability index ratio, has been demonstrated to be more than adequate (*GEGU*) to characterize the changes in insulation and permeability of clothing during wearer activity. The pumping coefficient (p) for insulation is the slope of the line connecting two measurements of insulation at different windspeeds on a logarithmic plot; since insulation decreases with increasing wind speed, the pumping coefficient for insulation has a negative exponent. Similarly, the pumping coefficient for the permeability index (i_m) is the slope of the line connecting two determinations of i_m at different effective wind velocities; since permeability increases with increasing wind speed or wearer motion, the pumping coefficient for i_m is a positive exponent. Thus, the form of the pumping coefficient for the permeability index ratio is $(i_m/clo)^{2p}$.

A value of 0.25 can be taken as the pumping coefficient for a long-sleeved shirt and trousers, compared with a value of 0.20 for a completely closed, but air-permeable, charcoal-in-foam, chemical-protective ensemble. The pumping coefficient (p) for a heavy butyl garment, normally worn totally closed with mask, hood and gloves, has not yet been measured but could be less than 0.10. In summary, the insulation of chemical protective clothing is largely a function of its thickness, looseness of fit and number of layers, while its permeability is a direct characteristic of the nature of the chemical protection sought.

There are four possible approaches to provide such chemical protection. First, everyday work clothing can be supplemented with specialized gloves,

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aprons, faceshields, and the like, if only partial protection is needed against spatter or skin contact. If respiratory protection is required, this can be provided with a filtered mask [Smith, 1980]. If full-body protection is needed, it can take three forms. Heavy, multilayered ensembles have been impregnated with chemicals which decompose the toxic agents; for example, chlorocarbon impregnated underwear and outerwear. Such ensembles have some ability to sweat-wet through and thus allow some evaporative cooling, but their wear may also produce significant skin irritation. Alternatively, charcoal- in-foam overgarments, worn alone or over normal work clothing, can be used; these garments require liquid-repellent surface finishes to minimize the potential of a local, surface concentration build-up to overwhelm the adsorbent properties of the charcoal in the garment. The charcoal-in-foam systems have been adopted by the military since they appear to be the most comfortable of the available chemical protective garments, but they may fail when they are soaked through or overwhelmed by massive surface contamination; also, while they are most comfortable when worn in a high wind because they are air permeable, the rate of air movement across the charcoal could be too rapid to insure adsorption of all the toxic chemicals. The fourth, and most frequent industrial choice, is a totally impermeable clothing system. The major drawback to the totally impermeable systems is the high potential of heat stress associated with totally blocking evaporative cooling from the human body.

Fourteen clothing materials have been evaluated for approximately three hundred chemicals, and recommendations for selection among them have been published in "Guidelines for the Selection of Chemical Protective Clothing." (See references in Chapter 9, Personal Protective Equipment.) Chemical protective clothing, considered as a subcategory of personal protective clothing, has been divided into five classifications in these guidelines:

a. Head, face, and eye protection, which encompasses hoods, faceshields and goggles;
b. Hand and arm protection as provided by gloves and sleeves;
c. Footwear protection includes specialized boots and shoe covers;
d. Partial torso protection, provided by an apron, jacket, pants, coat or bib overalls; and
e. Complete torso protection, including simple coveralls and full-body encapsulating suits.

A number of approaches to alleviate the heat stress associated with chemical protective clothing are commercially available or under development. These include ice vests and wettable covers, both of which can be extremely effective and simple solutions for the industrial workforce, and range to

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microclimate cooling systems where filtered ambient air, conditioned ambient air, or liquid cooling is supplied within the impermeable ensemble using Vortex tubes, prefrozen (e.g., ice) block heat exchangers, mechanical air conditioners and the like. The potential cooling provided by such systems has been extensively explored in a number of reports [Shvartz and Benor, 1972]. Those available commercially to date appear to require trade-offs between weight carried by the user and limited cooling duration, or require external power and umbilical connections which limit mobility.

ENVIRONMENTAL HEAT STRESS INDICES

It is difficult to consider simultaneously the six separate factors that must be measured to assess the heat stress of individuals at rest or work in a given clothing ensemble in any environment. Accordingly, over the years a series of environmental indices have been developed to express the interaction of two or more of these six factors. It must be recognized that an environmental index is not a precision statement. Instead, it is a ranging term and, as such, falls in the *GEGU* category. Extensive reviews of the indices for heat and cold are available in the published literature [Dukes-Dobos and Henschel, 1971].

Direct Indices

Of the four environmental factors cited above as essential to measure in order to determine comfort and/or heat stress, air movement and black globe temperature have little meaning *per se* as environmental indices. The other two, air temperature and wet bulb temperature, can serve as direct indices, the former for thermal comfort and the latter for heat stress, under a proper set of constraints as to clothing and activity level.

Air Temperature and Thermal Comfort

The simplest index of cold and warm conditions in conventional clothing in a conventional workplace is obtained from the air temperature (t_{db}) itself. Given conventional indoor clothing (1.4 clo), air motion (<0.2 m/s [40 fpm]) and humidity (40 percent), and air temperature equal to mean radiant temperature, the range of dry bulb temperatures from about 22°C to 25.5°C (72 to 78°F) is generally comfortable for sedentary workers (M = 120 W $\pm$ 10 percent) [Fanger, 1973]. Note that, having specified commonly occurring values for five of the six factors, a modest range of values can be assigned to the sixth to delineate a zone of thermal comfort; this "passband" for air temperature for

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comfort is about 3.5°C (6°F) wide [Goldman, 1981]. Of course, increasing heat production moves the comfort air temperature band substantially lower, with each increment of 30 W (25 kcal/hr) in heat production requiring a lowering of the comfort band by about 1.7°C (3↓F); indeed, as pointed out earlier, heat stress can occur at air temperatures below 0°C, given a high enough metabolic heat production and sufficient insulation.

Wet Bulb Temperature and Heat Stress

Tolerance times and temperature sensations can be plotted directly on a temperature vapor pressure diagram. For *cold* conditions, at low work levels, the dry bulb temperature *per se* appears to control discomfort with little or no adjustment for wet bulb temperature (i.e., humidity); this seems logical because there is no need for sweat evaporation. However, for normally clothed or unclad individuals working at moderate or higher levels, the wet bulb temperature *per se* can serve as a satisfactory index of heat stress. The upper limit for unimpaired performance of most cognitive tasks can be taken as a wet bulb temperature of 30°C (86°F) for both normally clothed and unclothed subjects with air movement ranging from 0.1 to 0.5 m/s (20-100 fpm). Note, however, that for individuals wearing chemical protective clothing, where the limitation on evaporative cooling is imposed by the clothing per se rather than by the ambient vapor pressure, wet bulb temperature is not an appropriate index. In such a case, the ambient dry bulb temperature (t_a) or, making a correction for radiation, the adjusted dry bulb temperature (t_{adjb}) is a better index.

Rational Indices

In unusual work situations, for example, performing under high intensity arc lights on a movie set, MRT *per se* could serve as a rational index of heat stress, but it appears not to have been used as such.

Operative Temperature (t_o)

Mean radiant temperature represents the uniform surface temperature of an imaginary black enclosure. Operative temperature represents the uniform overall temperature of the same enclosure, and encompasses an exchange of heat between the man and his environment, by both radiation and convection, to the same degree as in the actual environment. Operative temperature can be derived from the heat balance equation where one defines a combined (i.e., radiation and convection) heat transfer coefficient (h) as the weighted sum of

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the heat transfer coefficient by radiation (hr) and the average heat transfer coefficient by convection (h_c). The operative temperature (t_o) [Gagge, 1940] is then derived as:

Eq. 5 $$t_o = (h_r t_r + h_c t_a)/(h_r + h_c)$$

The operative temperature represents a more precise form of the adjusted dry bulb temperature [$t_{adjb} = (t_a + MRT)/2$]; the latter should not really be used when extreme radiant temperatures are involved but, in general, is *GEGU*. The operative temperature can be used directly in the heat balance equation to calculate the heat exchange by radiation and convection (H_{R+C}) as:

Eq. 6 $$(H_{R+C}) = h(t_o - t_{surf}) = h(t_o - t_{sk})\, F_{cl}$$

where: t_{surf} = mean surface temperature of the clothing
t_{sk} = mean skin temperature

and F_{cl} is an intrinsic thermal efficiency of the clothing [Nishi and Gagge, 1970]. Note that use of the F_{cl} form of expressing intrinsic clothing thermal efficiency, as used in the *ASHRAE Handbook of Fundamentals* requires an adjustment for the relative increase in the area of the clothed body surface over that of the unclothed body surface. It also requires the addition of an adjusted insulating surface air film. In general, it seems preferable to express the total insulation of a clothing ensemble as directly measured from a copper man [Breckenridge and Goldman, 1977] in clo units and substitute t_o for t_a to account for the combined convective and radiative heat exchanges.

Heat Stress Index (HSI)

The HIS is one of the most useful indices for evaluation of heat stress, in part because Belding and Hatch provided a table of the physiological and hygienic implications of 8-hr exposures at various HSI (cf. Table 10-6). The Heat Stress Index itself is simply an application of the heat balance equation. It is the ratio of the evaporative heat loss required (E_{req}) for thermal equilibrium, to the maximum evaporation (E_{max}) allowed through the clothing that can be taken up by the environment, as discussed previously. An adjustment is required for the maximum rate of sweating which, for an average man approaches 2-3 L/hr, but this sweat rate cannot be sustained. Indeed, under such maximum strain, heat exhaustion usually occurs in less than an hour. The generally accepted value for a sustainable maximum sweat rate is 1 L/hr, which represents a potential cooling power of some 700 W if all the sweat can

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be evaporated; i.e., each mL (1 mL = 1 g) of sweat evaporated produces 0.58 kcal of cooling, but unevaporated sweat provides no cooling, uselessly increasing body dehydration. Figure 10-2 presents a series of monograms for a graphic solution of HSI which, as developed, assumes a 35°C skin temperature, and a conventional long-sleeved shirt and trousers (I = 1.4 clo; that is, I_{cl} = 0.6 clo + I_A = 0.8 clo) clothing ensemble; note also (cf. Block C of Fig. 2) that E_{max} is limited to 700 W. Although informative, it should not be used for clothing other than ordinary, indoor work clothing (i.e., long sleeved shirt and trousers).

Skin Wettedness (% SWA)

Percent skin-wettedness, as defined by Gagge [Gagge, 1940], is essentially identical to HSI except that, in theory, the percent SWA uses the observed skin humidity or wettedness, rather than the required evaporative cooling as the numerator in taking the ratio to the maximum evaporative cooling power of the environment. Skin wettedness (alternatively, skin relative humidity or the percent of skin surface that is sweat-wetted) appears to be what the body uses to sense its thermal discomfort. There seems to be little, if any, sensory input from deep-body temperature or from skin temperature, although both deep-body temperature and local skin temperature provide the control inputs for regulation of sweating. A worker will generally not continue work which results in skin-wettedness much above a 60 percent level [% SWA=HSI = 60 or, equivalently, a relative humidity of the skin (ϕ_s) $\geq$ 60 percent P_s]. At this 60 percent level, sweat begins to drip from the skin and, thus be wasted, except under conditions of low ambient vapor pressure, minimal clothing and/or reasonably high air movement.

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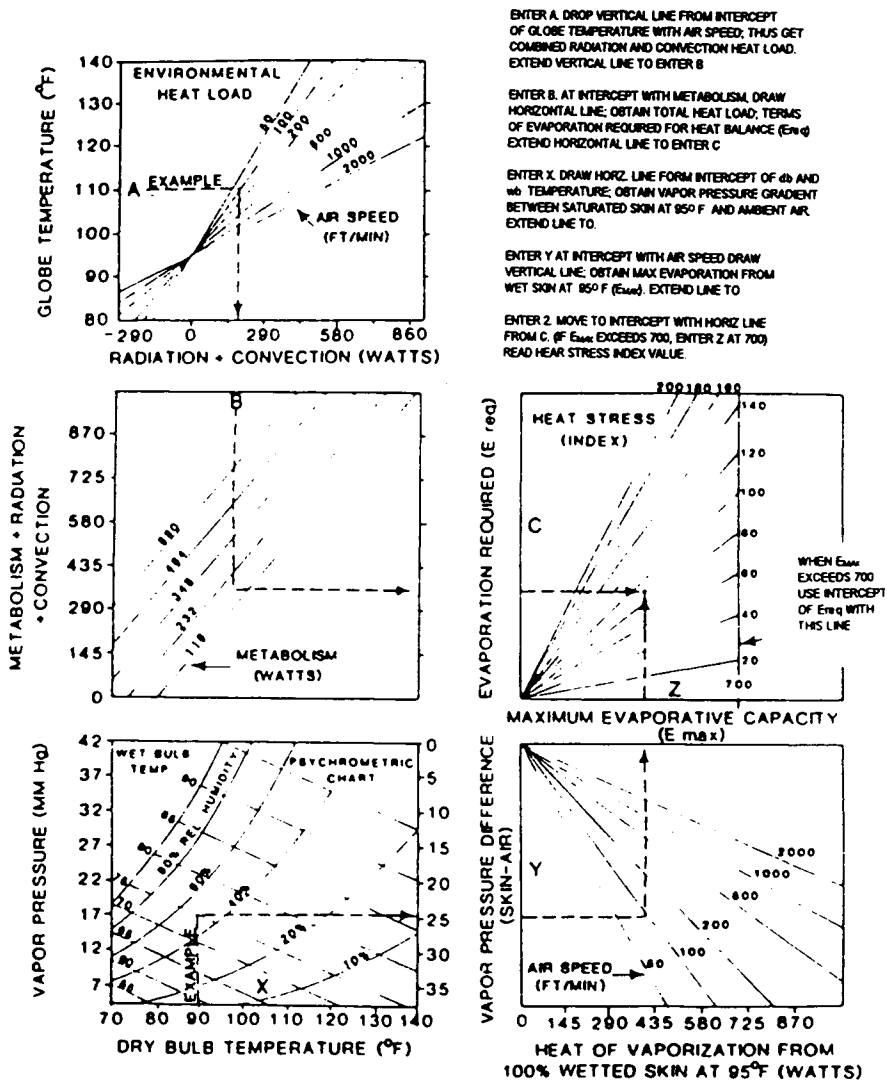


Figure 10-2 Nomograms for graphic solution of the heat balance equation.

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Table 10-6
Physiological and Hygienic Implications of 8-hour Exposures to Various Heat Stresses

Index of Heat Stress (HSI)	Heat Stresses
-20 -10	Mild cold strain. This condition frequently exists in areas where men recover from exposure to heat.
00	No thermal strain.
+10 20 30	Mild to moderate heat strain. Where a job involves higher intellectual functions, dexterity, or alertness, subtle to sub stantial decrements in performance may be expected. In per formance of heavy physical work, little decrement expected unless ability of individuals to perform such work under no thermal stress is marginal.
40 50	Severe heat strain, involving a threat to health unless men are physically fit.
60	Break-in period required for men not previously acclimatized. Some decrement in performance of physical work is to be expected. Medical selection of personnel desirable because these conditions are unsuitable for those with cardiovascular or respiratory impairment or with chronic dermatitis. These working conditions are also unsuitable for activities requiring sustained mental effort.
70 80 90	Very severe heat strain. Only a small percentage of the popu lation may be expected to qualify for this work. Personnel should be selected (a) by medical examination, and (b) by trial on the job (after acclimatization). Special measures are needed to assure adequate water and salt intake. Amelioration of working conditions by any feasible means is desired, and may be expected to decrease the health hazard while increasing efficiency on the job. Slight "indisposition" which in most jobs would be insufficient to affect performance may render workers unfit for this exposure.
100	The maximum strain tolerated daily by fit, acclimatized young men.

Adapted from H. S. Belding and T. F. Hatch, "Index for Evaluating Heat Stress in Terms of Resulting Physiologic Strains," *Heating, Piping, and Air Conditioning* 27:129-136, 1955.

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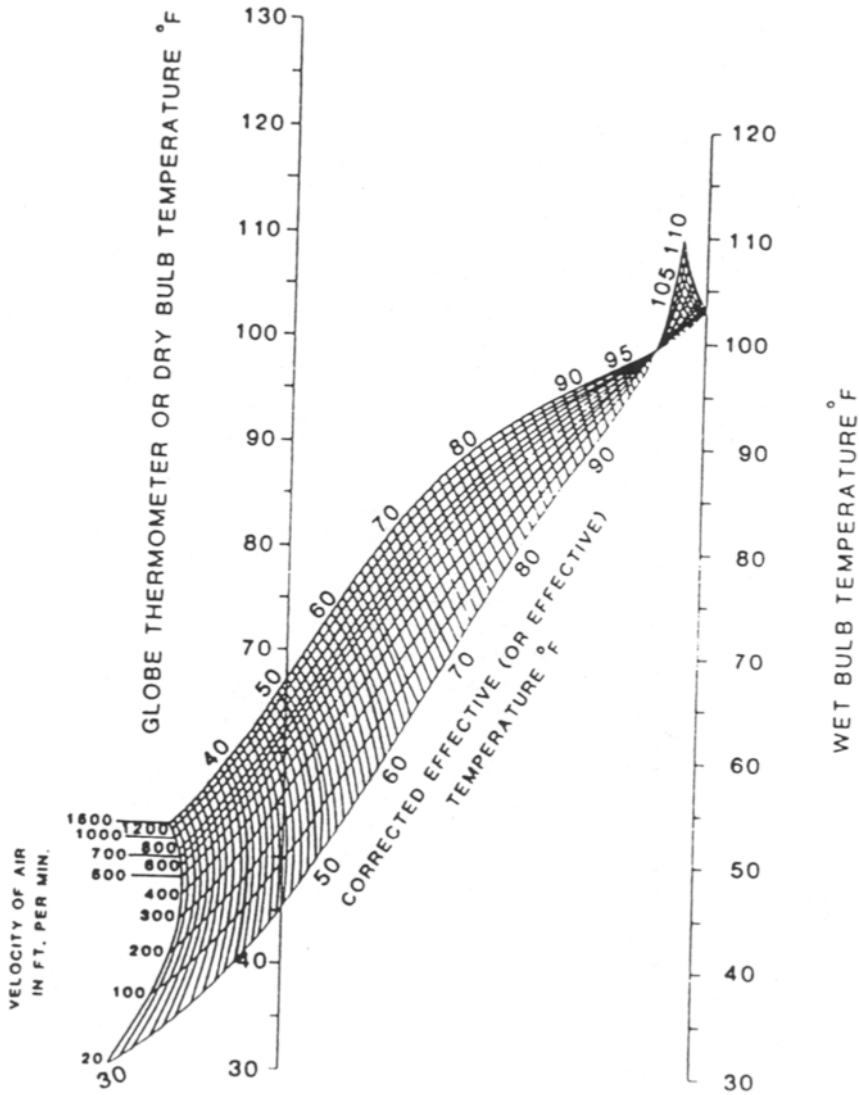


Figure 10-3 Chart showing normal scale of corrected effective temperature.

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Empirical Indices

Effective Temperature (ET, CET and ET*):

The best known and most widely used of the environmental indices is the effective temperature (ET) index originally derived in 1923 for ASHRAE (35). It is generally calculated from the nomogram given in Figure 10-3, and combines the effects of dry bulb and wet bulb temperatures and air movement. Substituting the black globe temperature (t_g) directly in place of the air temperature produces a corrected effective temperature (CET) thereby accounting for radiation. Thus, the CET index combines all four of the key environmental factors into a single number. ET and CET were derived using subjective judgments of equivalence by a limited number of subjects. Gagge developed a new effective temperature, ET* which uses a 50 percent relative humidity, as the reference humidity. The ET* corresponds more closely to familiar sensations at a t_a = ET* than it does to the 100 r.h. referenced ET.

Effective temperature has been used most extensively for studies of psychological tolerance limiting conditions. It serves as the most useful guideline to the efficiency of a workforce. An ET (CET) greater than 30↓C (86↓F) generally is considered unacceptable and usually decreases productivity in an industrial workforce. A World Health Organization scientific group has proposed tolerance limits to heat stress in terms of ET/CET [World Health Organization Scientific Group, 1969]. The suggested limit for unacclimatized individuals doing sedentary to light work (<215 W) was 30°C (86°F); for moderate work (to 360 W) the suggested ET/CET limit was 28°C (82.5°F), and for heavy work (to 500 W) a limit of 26.5°C (80°F). Fully heat-acclimated individuals (i.e., after 7 days of work in the heat for 2 or more hours each day) were supposed to tolerate 2°C higher ET (CET) levels for an 8-hr daily work shift. These proposed values are generally consistent with thermal environmental conditions in deep mining which resulted in stable rectal temperatures (equilibrium rectal temperatures at "safe" levels) in groups of highly acclimatized South African miners. With very large groups of workers, however, some heatstroke still occurred, probably because of the large individual variability in response to heat stress. Individuals of low maximum oxygen uptake (i.e., small body stature or poor physical condition) appear to be particularly susceptible to heat illness [Wyndham, 1973]. In addition, there was a slight reduction in productivity of these gold mine workers (5 percent) beginning at about ET 82°F (27.7°C), which is also the threshold reported for onset of fatal heatstroke during "hard" work.

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Wet Bulb Globe Temperature (WBGT)

The WBGT index uses the naturally convected (i.e., ventilated only by ambient air motion) wet bulb as a measure of the environmental stress, rather than the psychrometric wet bulb used in all other indices presented thus far. This natural wet bulb temperature (t_{nwb}) value is used as 70 percent of the WBGT; another 20 percent is contributed by the black globe thermometer temperature (t_g) directly, and 10 percent by the dry bulb temperature (t_{db}):

Eq. 7 $$WBGT = 0.7\ t_{nwb} + 0.2\ t_g + 0.1\ t_{db})$$

The WBGT index thus combines the effects of humidity and air movement (in t_{nwb}), low temperature radiant heat and solar radiation (in t_g), and air temperature (t_{db}). WBGT instruments are commercially available from a number of manufacturers, but some misrepresent the WBGT, using a psychrometric rather than the natural wet bulb; others use smaller globes or unusual radiant heat sensors, with little validation that the adjustment (if any) made in calculating their WBGT is acceptable. Most, being battery operated and requiring calibration, can fail or be easily miscalibrated and the commercial instruments for WBGT, therefore, seem better suited for laboratory than field use. The military still use WBGT guidance for prevention of heat illness during training but it is being supplemented by a new wet globe thermometer (WGT, see below) for operational use.

As pointed out above, for individuals wearing impermeable or reduced permeability clothing, the WBGT is probably not as good an index as the adjusted dry bulb temperature alone. However, for individual workers wearing conventional clothing, WGBT remains the index of choice for expressing physiological tolerance limits at work or rest. The WBGT index was developed by Yaglou [Yaglou and Minard, 1957] to help reduce the number of heat casualties incurred during Marine training in southern U.S. military bases. Its introduction was followed by a dramatic reduction in the incidence of heat casualties when the following guidelines were mandated:

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At WBGT Of:	Procedure:
82°F 85°F	Unseasoned personnel only do limited heavy exercise. Strenuous exercise such as marching at stan dard rate, should be suspended during the first 3 weeks of unacclimatized troop training; outdoor classes in the sun should be avoided.
88°F	Strenuous exercise should be curtailed for all recruits and trainees with less than 12 weeks of training in hot weather.
88-90°F	Thoroughly conditioned troops, after acclimatization each season, could carry on limited activities for up to 6 hours per day.

The successful reduction of heat casualties in the military community by adherence to these WBGT guidelines was not lost upon the civilian community. Brief and Confer [1971] proposed WBGT limits of 32.2°C (90°F) for light work, 30°C (86°F) for moderate work, and 26.7°C (80°F) for heavy work under indoor situations in 1971.

In 1974, an Advisory Committee on Heat Stress sponsored by NIOSH developed the following table (Table 10-7) on threshold WBGT at which work should be suspended [DHHS, 1980]. Note that the Committee split WBGT levels into two categories as a function of air velocity, with threshold WBGT levels at air velocities of less than 1.5 m/s (300 fpm or 3.3 mph) some 2 to 3°C below the corresponding thresholds for air velocities greater than 1.5 m/s. These WBGT threshold values are not strikingly different from those proposed by Brief and Confer for light and moderate work, if one uses the values for air velocities greater than 1.5 m/s, but are rather different for the heavy work situation. In many areas of the United States, such high WBGT's occur sufficiently often that shutting down would make a factory unprofitable, but infrequently enough that air conditioning was not seen as cost-effective. As a result, to date no heat stress standard has been promulgated. Perhaps the next national heat stress standard proposal [ISO, 1981] should follow the WBGT guidelines recommended by the American Commission of Government Industrial Hygienists for permissible heat exposure threshold limit values, given in Table 10-8 [ACGIH, 1980]. Such recommendations for work-rest cycle alteration should be much more acceptable to both management and labor. Essential work could be continued under quite severe WBGT conditions, albeit for only a limited period during each hour; for example, at a WBGT of 30°C, heavy work could be performed for 15 minutes of each hour, with the

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rest of the hour spent at rest. This would cater to those factories or regions where the occurrence of high WBGT's is infrequent, or of only a few hours duration each afternoon. No investment in major air treatment programs would be required, but there would not be a total loss of productivity, or cessation of all essential activities [Goldman, 1979]. Industry would also have a more rational decision basis for recognizing the trade-offs between productivity losses and the economic costs of providing increased ventilation, dehumidification or frank air conditioning for indoor situations. Outdoors, fewer options are available; shading the working area is frequently the most feasible option.

Table 10-7
Threshold WBGT Values Proposed by the Standards Advisory Committee on Heat Stress, 1974

Work Load	WBGT in °C Air Velocity 1.5m/s	1.5m/s
> 300 kcal/hr (>200 W/m²)	26	29
201 - 300 kcal/hr (135 W/m² - 200 W/m²)	27	31
200 kcal/hr (135 W/m²)	30	32

Table 10-8
ACGIH Permissible Heat Exposure Threshold Limit Values in °C WBGT

Work-Rest Regimen	Work Load Light	Moderate	Heavy
Continuous work	30	27	25
75 percent work- 25 percent rest, each hour	31	28	26
50 percent work- 50 percent rest, each hour	31	29	28
25 percent work- 75 percent rest, each hour	32	31	30

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Wet Globe Temperature (WGT)

In addition to the problem of reading and mathematically manipulating three temperatures, the WBGT apparatus usually is set up at a fixed location and is frequently quite remote from the working environment. Botsford developed a simpler device, the "wet globe thermometer" (WGT or "Botsball") for use in the aluminum industry. This device is simply a 3-in. globe with a black, wettable cover; a standard metallic stem thermometer is inserted into the globe through an extended neck, which contains a small water reservoir to maintain the black cover at 100 percent wettedness.

The device is simple, portable, and easy to read. A single number value is directly provided, rather than the three separate values provided by the WBGT. Goldman modified the WGT by color-coding the critical zones [Onkaram et al., 1980] to provide operational guidance during actual field operations. The WBGT is still in use; however, the simpler, color-coded WGT has been used in the field with remarkable success. Table 10-9 suggests Doctrine on Adjustment of Work-Rest Cycles and Increasing Water Intake. Note the guidance that the Botsball WGT's are equivalent to 2°F higher WBGT's; this 2°F offset value was obtained in several laboratory and field evaluations [Goldman and Staff, 1982], but will not be correct in all cases. Furthermore, it may be difficult to maintain the WGT surface wet enough in a hot day environment and the offset from WBGT may be much greater than 2°F. Note also that, under "GREEN" conditions (i.e., WGT between 80 and 83°F) water intake of between one-half and one quart per hour is recommended for 50-min work/10-min break cycles. With increasing heat stress, recommended water intake is further increased and work-rest cycles are decreased.

Table 10-9
Water Intake, Work/Rest Cycles for Essential Field Operations (which cannot be curtailed) for Heat Acclimated Fit Workers

Heat Condition	Botsball WGT (°F)*	Water Intake (qt/hr)	Work/Rest Cycles (Min)
Green	80°-83°	0.5-1.0	50/10
Yellow	83°-86°	1.0-1.5	45/15
Red	86°-90°	1.5-2.0	30/30
Black	90° & above	2	20/40**

*To convert WGT to WBGT add 2°F. Below 80° drink up to 0.5 qt/hr, 50/10 work/rest cycles.
**Depending on condition of the worker.

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To maintain physical performance:

1. Drink 1 qt. of water in the A.M., at each meal, and before any hard work.
2. Take frequent drinks, since they are more effective than all at once. Larger workers need more water.
3. Replace salt loss by eating three meals per day.
4. As the WGT increases, rest periods must be more frequent, work rate lowered, and loads reduced.
5. Use water as a key element to maintain top efficiency by drinking each hour.

HEAT STRESS AND PRODUCTIVITY

There have been a great many studies [MacPherson and Ellis, 1960] attempting to relate the productivity of a workforce to the environmental heat stress. Most of these have used the effective temperature as an expression of the environmental heat stress, but very few have adequately controlled such key factors as motivation, need or expectancy. Thus, the results of studies on the effects of heat stress on productivity have varied widely. Some actually suggest improved performance under conditions of heat stress when men are in total chemical protective encapsulation. In other studies, very mild heat stress has been shown to decrement performance in men wearing normal work clothing. In response to a report by Fox et al. [Colquhoun and Goldman,1972] that increasing heat stress actually improved target detection, Colquhoun and Goldman [Colquhoun and Goldman,1972] evaluated the ability to detect a target as a function of increasing body heat storage. Performance in their study involved not only detection of a target, but also a judgment on the certainty with which the target was detected. The results showed that while total target detection did improve, as Fox et al. [Colquhoun and Goldman,1972] had stated, the identification and decision-making skills of the subjects decreased. While more targets were being detected, more nontargets were erroneously identified, with increasing certainty that they were targets as body heat storage increased. One of the most massive studies on the effects of mild heat (and cold) stress on performance was conducted by Wyon et al. [1982]. The interaction between environmental discomfort and performance is far from clear, with some tasks decremented and others enhanced in the various subpopulations (males and females, native and caucasian workers) studied. Wyon has recently focused on the role of discomfort in increasing "arousal"; this appears to be very helpful in understanding the relationship between heat stress and productivity.

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Decrements in performance are clearly task-dependent, as well as highly dependent on the motivation of the workforce. Tasks involving decision making, judgment and complex mental functions appear to decrement at much greater rates than rote tasks such as addition. Physical task performance is relatively insensitive until the workers are affected by incipient heat exhaustion. The ability of two journeymen electricians to install duplex outlets was essentially unimpaired as effective temperature was increased from 21 to 27°C (70 to 80°F) across a full spectrum of relative humidities, but was reduced by 10 percent at 32.2°C (90°F) ET with the greatest reductions at the highest relative humidities. At 38°C (100°F) ET, productivity ranged from a low of 57 percent at 90 percent r.h., to 84 percent for r.h. < 40 percent, while at 43°C (110°F) ET, productivity was negligible above 80 percent r.h., and ranged from 50-60 percent at relative humidities between 20-70 percent. This limited data base on a few highly trained and extremely well-motivated workers indicates that the decrements for such rote tasks can be relatively small under most heat stress conditions. In contrast, the National Association of Building Contractors suggests, as guidelines for cost estimating, that productivity for tasks involving gross motor skills will be decremented by about 30 percent at 27°C (80°F) ET, 40 percent at 32.2°C (90°F) ET, and 60 percent at 38°C (100°F) ET. Since these figures are used in estimating costs (and no cost estimator intends to lose money on contract bids), these estimates probably overstate the losses in productivity. Again this data base applies to normally dressed individuals, and not to individuals wearing chemical protective garments.

GUIDELINES FOR HEAT STRESS IN PROTECTIVE CLOTHING

Inadequacy of WBGT and WGT

Both WBGT and WGT depend primarily (>70 percent) on the natural evaporation allowed by the environment. This would suggest that WBGT and WGT, while perhaps the best heat stress indices for individuals wearing normal clothing (even, perhaps, with some partial, chemical protective, impermeable coverage such as aprons, masks or gloves) become increasingly inappropriate guides as one moves to the reduced permeability charcoal-in-foam overgarments, unless a very stiff breeze is blowing. WBGT and WGT values are probably quite inappropriate to use as guidance for workers encapsulated in totally impermeable chemical-protective clothing. It is important to note, however, that at upper levels of environmental heat stress [except in desert

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(hot-dry) environments] all these environmental indices give somewhat similar values; that is, C.E.T., WBGT and WGT all tend to have similar values.

Variability in Heat Tolerance Between Groups

Most of the well-known environmental heat stress data base was generated on physically fit, highly motivated young men in military studies, or the select population of fit young mine workers, prescreened to eliminate individuals with lower heat tolerance, in South Africa [Wyndham, 1973]. Witherspoon and Goldman have reviewed work rate and ET interactions from large number of military and civilian data bases and produced Figure 10-4, which includes one line for significant discomfort or change in deep-body temperature for a mixed population and another line for maximum equilibrium (i.e., acceptable, steady state) values representing tolerance for at least 4 hours without collapse in a highly fit, young population. The data points are plotted as a function of work rate across a range of ET (or CET) values and include data from Africa, India, Germany, Unitied Kingdom, and United States, and include clothed and unacclimatized populations as well as unclothed, usually acclimatized, populations. The consistency of the findings is perhaps the most remarkable thing about this diverse data base. The same authors point out the relative uniformity in heat tolerance between individuals of comparable age and fitness, as shown in Figure 10-5, where the data from seven studies between 1923 and 1967 are presented for fit, young men, wearing minimal clothing (usually shorts and boots), at work (280-350 kcal/hr) or at rest, in a range of very hot environments; the environmental heat stress is expressed as the Oxford index WD (= 0.85 t_{wb} + 0.15 t_{db}), using the psychrometric wet bulb and tolerance time is expressed in minutes. Note that even under the most severe conditions, average tolerance time is twenty minutes; as long as the pain threshold at the skin surface is not reached [a skin temperature of about 45°C (113°F)], some 20 minutes of time was provided simply by "mass damping" before body temperatures or heart rates reached critical levels [in these studies, 39.2°C (102.5°F) and 180 bpm, respectively [Goldman et al., 1965]. As shown by the inset, when one compiles all the data from these seven studies on a log-log plot (adjusted to a base of 75°F for the 300 kcal/hr exercise data, and to a base of 81°F for rest data) the correlation coefficient is extremely high ($r \sim 0.96$). This implies that about 92 percent (i.e., r^2) of the tolerance time can be explained simply by the environmental heat stress as expressed by this WD index. Under conditions of severe heat stress, individual variability appears to be minimal within populations of comparable fitness. In an industrial population, however, individuals vary substantially with respect to their state of heat acclimatization, body size and fitness, degree of hydration, congenital sweat gland distribution,

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etc. Thus, although Figure 10-4 suggests remarkable agreement in heat stress response across quite divergent populations, appropriate screening is suggested if generalized guidelines are to be used for an industrial workforce required to wear complete chemical protective clothing ensembles. Wear of totally impermeable clothing will, of course, further homogenize the responses of a population by wiping out any differences in effective sweating and differences in heat acclimatization status, other than perhaps those associated with more rapid dehydration in well heat-acclimated individuals. Thus, given an equivalently screened population, it seems safe to conclude that conditions which are sufficiently heat stressful to produce problems for one or two workers are not far from being unreasonably stressful for the total population.

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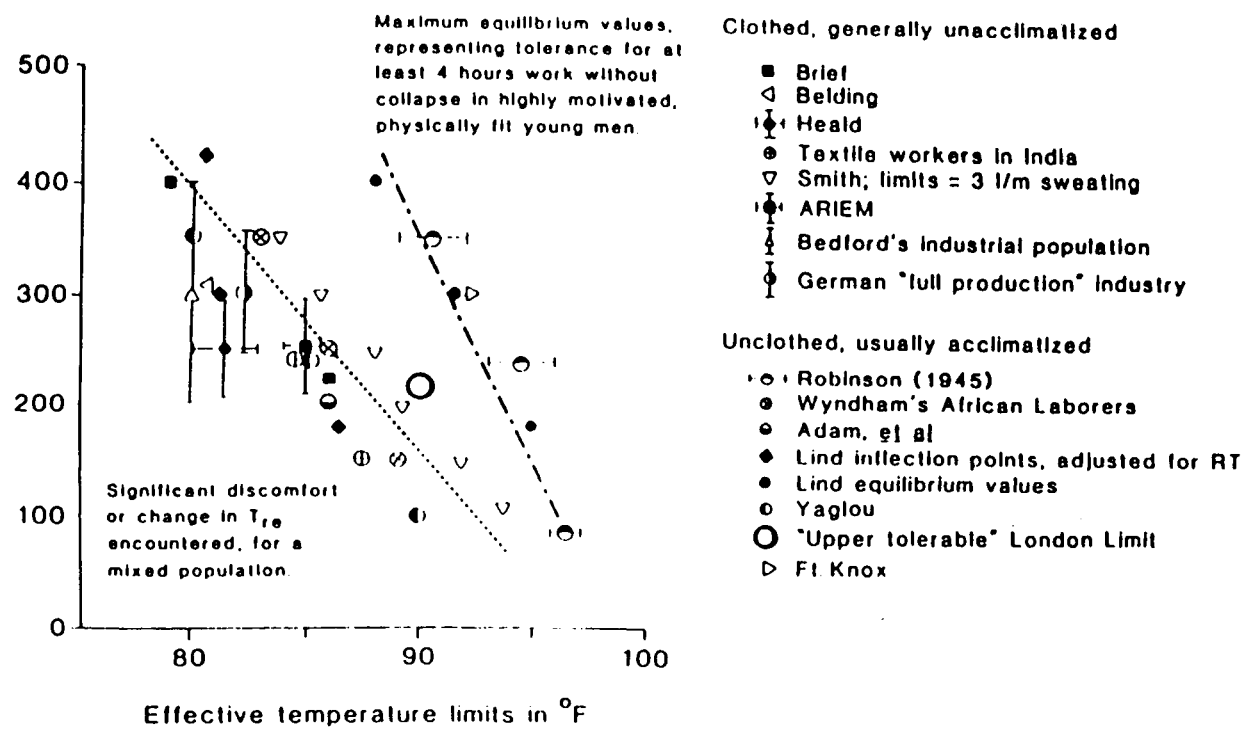


Figure 10-4 Work rate limits as a function of effective temperature

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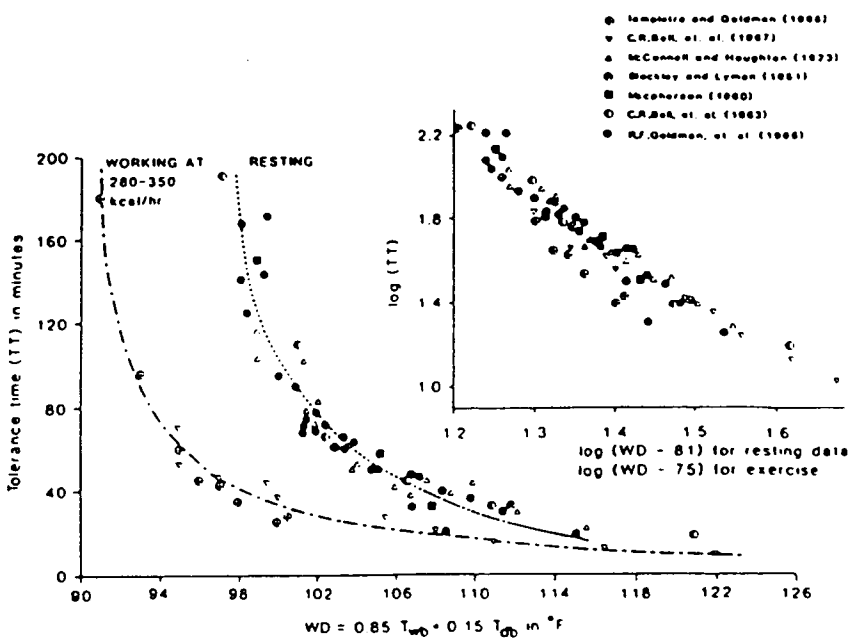


Figure 10-5 Tolerance time limits (TT).

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Impermeable Protective Clothing Guidelines

By now, it should be obvious that almost all the indices discussed have limited applicability to men in totally impermeable clothing [Mihal, 1981]. The ambient vapor pressure is a meaningless measure of the environmental heat stress for individuals wearing impermeable clothing, as are all indices in which ambient wet bulb temperature (psychrometric or nonpsychrometric) is a major factor. The dry bulb (air) temperature, adjusted for solar heat load by using either the adjusted dry bulb temperature, or by an increment for solar radiation of 7°C (13°F) times the percent cloud cover might seem the most appropriate index for totally impermeable garments, but has not proven to be an improvement. Custance has collated data (Table 10-10) for safe "closed" impermeable suit times for moderate work (250 kcal/hr) from six U.S., Canadian, and Russian studies, as a function of air temperature. As indicated below, predictive modeling has reached the stage where quite valid predictions and extrapolations can be made [Goldman, 1970]. For specific cases, predictive modeling should provide the best guidelines for comfort, discomfort, performance or tolerance limits, and risk.

Table 10-10
Safe "Closed" Suit Times for Moderate Work (300 W; 250 kcal/hr)

Ambient Air (Ta) Temperature (°F)	Wearing Time (Closed)
30° or less	8 hours
30° - 50°	5 hours
50° - 60°	3 hours
60° - 70°	2 hours
70° - 80°	90 minutes
80° - 85°	60 minutes
85° - 90°	30 minutes
90° or above	15 minutes

AGE, GENDER, AND HEAT STRESS

The effects of age in predisposing to heat stress appear to be primarily associated with the cardiovascular system, although older individuals start to

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sweat later, and produce less sweat during comparable work in the heat than younger individuals. While older individuals appear to have a higher peripheral blood flow during work in the heat, their maximal work capacity (i.e., VO_{2max}) is reduced (see Table 10-3 and discussion), based on the reduction in maximum heart rate with age (220 bpm - age in years). Thus, even healthy, older individuals tend to have reduced heat tolerance to work, exhibit higher heart rates and slightly higher deep-body temperatures, and take longer to return to normal body temperatures. The effects of heat stress on individuals with specific medical problems (e.g., cardiorespiratory difficulties) can, of course, be devastating [Ellis, 1972].

The original proposed guidelines for an OSHA Heat Standard [NIOSH, 1972] postulated differences between male and female workers with respect to their tolerance to heat. Such recommendations were based on the limited research data base available prior to 1974 [Goldman, 1979], which suggested that females, as a group, were less tolerant than males to heat stress. Based on newer studies, however, it appears that gender-free standards can be established; brought to equivalent levels of fitness and heat acclimatization, the remaining difference between males and females of any real significance in respect to heat resistance, is body size. A smaller, less fit male is at no less or greater risk to heat stress than an equivalent-sized, less fit female while, with increasing fitness or greater opportunities for heat acclimatization, females and males appear to perform equally well in the heat. Havenith, in his Ph.D. thesis, recently presented a relative weighting of the factors that are associated with individual differences in heat stress tolerance; maximum cardiac output, which is the maximum heart rate (a function of age) times the maximum stroke volume (a function of heart size) appears to be the most important factor, quite logically. It seems that the availability of sufficient circulating blood volume (effected by level of hydration, vasovagal and activity dependent blood pressure regulation, and perhaps alcohol ingestion) should also be critically relevant but has not yet been as well quantified.

BODY RESPONSES TO HEAT STRESS AS EXPOSURE LIMITS

By now, it should be clear that heat stress simply means: (1) heat losses by radiation and convection are less than the heat produced by metabolism so that a requirement for sweat evaporative cooling exists and (2) the degree of heat stress is a function of the extent to which the requirement for evaporative cooling can be met. As indicated above, the ratio E_{req}/E_{max} is perhaps the best single indicator of heat stress. A chart (modified from one originally developed by Belding) delineating physiological responses to heat stress is presented as

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Figure 10-6. These responses include, as a first line of defense, an initial rise in skin temperature as a result of vasodilation. The increased blood flow to the skin raises skin temperature and thus helps increase heat loss by convection and radiation, or reduce heat gain when the operative temperature is higher than skin temperature. This first line of defense is limited however, as the available circulating heat transfer fluid of the body (i.e., the blood) becomes depleted by sweating in the absence of adequate rehydration, or becomes pooled in the periphery in the absence of continued muscle activity massaging the venous blood back, past the valves in the veins, to the heart to provide adequate venous return for continued blood flow to the brain. Inadequate blood flow to the brain leads to heat exhaustion collapse. The transition from the vertical, upright posture during work, to the horizontal, recumbent posture of heat exhaustion collapse tends to solve the problem of inadequate venous return, but at an unacceptable cost. Heat exhaustion is most likely to occur in working individuals when, upon suddenly stopping work, they incur massive peripheral pooling and inadequate venous return, and suffer the consequent blackout. It can also occur in individuals while working. Inadequate venous return to the heart leads to decreased central blood pressure and blood flow to the brain, so a signal to "beat faster" is sent to the heart. As in most pumps, sufficient filling time must be allowed between strokes and, as heart rates exceed 180/min, inadequate filling time leads to further decreases in cardiac output with a resulting transition from the vertical to the horizontal state of the worker.

Obviously, there is a general, albeit complex relationship between body temperature and heart rate [Tanka et al., 1979]. In general, an increase in working heart rate of more than 30 bpm above the resting level may be considered unacceptable for an industrial workforce. Performance decrements may be expected if sustained heart rates exceed 100 bpm for 8-hrs, or perhaps 120 bpm for 8-hrs if the workers are extremely fit and well heat- acclimatized. For very fit and acclimatized young workers, sustained heart rates of 140 bpm may be compatible with 4 hrs of work; 160 bpm may be compatible with 2 hrs of work, but heart rates above 180-190 bpm are generally considered unacceptable for any sustained period. Such values, however, are only appropriate for a relatively young work force. The maximum heart rate for individuals can be characterized as a function of age by the relationship: maximum heart rate equals 220 bpm minus age in years. A more appropriate generalization, then, would be that heart rate increases of less than 20 percent of the difference between an individual's age adjusted, maximum heart rate and his resting level are quite reasonable. For example, the predicted maximum heart rate for a 60-year-old is 160 bpm and, if the resting rate is 70 bpm, then the working heart rate should be $\leq$ 88 bpm, that is, [70 + 0.2 (160 - 70)]. As

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general guidelines, increases of 40 percent of the difference between this age adjusted maximum and the resting level probably represent an uncomfortable level of work; for the 60-year-old above, this would be 106 bpm, while for a 20-year old it would be 122 bpm, given a 70 bpm resting value for both. Performance decrements may be expected at heart rates representing 40-60 percent of this "heart rate increase capacity," tolerance time limits will generally be associated with values between 60 and 80 percent of capacity, while damage may result at levels requiring more than 80 percent of an individual's heart rate increase capacity.

The body's second line of defense, sweating, is limited in the cooling it can provide to a sustainable rate of about 700 W, even if all the sweat can be evaporated efficiently at the skin surface. Sweating becomes increasingly ineffective as ambient humidities increase so that more sweat is wasted, or as sweat is absorbed into the clothing and evaporation takes place at sites more removed from the skin. Individuals wearing impregnated, but sweat permeable protective clothing frequently receive less than one-half the full cooling benefit of the sweat evaporation that takes place. Since, under conditions of work-associated environmental heat stress, the amount of sweat produced is directly titrated to the amount of sweat evaporation required and obtained, one of the best measures of the role of a clothing ensemble in stressing the wearer is the ratio of the sweat evaporated (E) during a given time period to the maximum sweat produced (P) by the individual. One simply obtains initial and final unclothed weights, adjusted for any water intake, as a measure of the total sweat production (P) and the initial and final clothed body weights as a measure of the total sweat evaporation (E). The E/P ratio with typical clothing ensembles under comfortable conditions will be close to 90 percent, but will decrease to about 70 percent with increasing humidity, decreasing air motion, or heavier than normal clothing. The E/P ratios decrease to 40 percent or less with most "semipermeable," encapsulating chemical protective ensembles, reaching about 20 percent when these are worn under hot humid conditions or during heavy work. The E/P ratio obviously approaches zero for totally impermeable, encapsulating clothing systems. Again, the relative stress can be divided into the five categories: comfortable, uncomfortable, performance decrementing, tolerance time limiting and perhaps damaging, using the 0-20 percent, 20-40 percent, etc., rubric. Thus, and E to P ratio between 80 and 100 percent will be quite comfortable, between 60 and 80 percent may be uncomfortable, between 40 and 60 percent will probably be performance decrementing, between 20 and 40 percent will be tolerance limiting, and an E/P ratio of less than 20 percent associated with high risk.

A common problem associated with heavy sweating is the induction of dehydration, since thirst is an inadequate stimulus for drinking enough water to

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prevent dehydration. Up to 2 percent of the total body weight may represent excess extracellular fluid that can be lost without major decrements in temperature regulation or work performance capacities, although subtle decrements in psychomotor performance may be associated with lower dehydration levels of 1 to 2 percent. However, individuals given unlimited access to water (albeit perhaps warm and not necessarily very palatable) have been shown [Adolph, 1974] to incur "voluntary dehydration" levels of 8 or 9 percent, with associated major performance decrements and greatly increased rates of rise of deep-body temperature. Using a 10 percent dehydration level as a maximum, (i.e., acute loss of 10 percent of body weight by dehydration although survival has been reported at 18-20 percent dehydration levels), levels of 0-2 percent dehydration (judged from body weight loss during a work shift) would be "comfortable," 2-4 percent would be uncomfortable, 4-6 percent would be performance decrementing, and levels above 6 percent would be associated with limited tolerance times, again using the 0-20, 20-40, 40-60 percent, etc., rubric of demand/capacity effects.

Another heat-associated syndrome which some individuals suffer is "hyperventilation," particularly in response to exposure to hot-wet environments. The overbreathing results in a reduction of the normal blood carbon dioxide concentrations. One of the first subjective sensations is a tingling around the lips and some dizziness. The phenomenon is associated with a reduction in blood flow to the brain, because of cerebral vasoconstriction, and can lead to blackout as well as to a very diagnostic cramping of the fine muscles of the hand and foot (carpopedal spasm). While not apt to occur in individuals performing hard work, and thus producing substantial volumes of carbon dioxide, it can cause collapse in individuals performing light work or at rest, and is probably a major contributor to the onset of heat exhaustion collapse in individuals taking a short break during periods of intensive work. In many experiments on heat stress, heat exhaustion collapse occurred during the period when the individual was asked to stop work so that his heart rate could be measured by palpation at the wrist; the resultant collapse during the one-to-two minutes subsequent to cessation of work probably is contributed to by both inadequate venous return from peripheral pooling, and reduction of the carbon dioxide levels in the blood due to hyperventilation. Hyperventilation may be more pronounced when respirators and full face masks are worn, and the restricted visual field of a gas mask may interact with heat stress to increase dizziness and nausea. The additional dead space of such respiratory protection may not adequately compensate for potential hyperventilation.

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PREDICTIVE MODELING AND HEAT STRESS GUIDELINES

As suggested previously, predictive modeling may be the most appropriate approach for establishing realistic guidelines for individuals or groups wearing chemical protective clothing. Such models are particularly well suited to simultaneously treating the possible variations in degree of protection, and the type of protective clothing worn (aprons, charcoal-in-foam, air-permeable but chemical-impermeable, or totally impermeable ensembles worn open or closed). Such models can also handle simultaneously such questions as age and gender, as well as body weight, height, air temperature, solar load, humidity, and air motion, without concern as to whether an index relying on ambient vapor pressure, or on psychrometric instead of non-psychrometric wet bulb temperature needs to be used. One such model rigorously addresses the physical heat transfers allowed by the worker's clothing between an environment and the worker, and can make adjustment for individual (or group) capacities to meet heat stress, including degree of heat acclimatization, and extent of dehydration. Model outputs include predicted subjective comfort vote (PMV, on a scale of +3 to -3, where 0 is comfortable, +3 is very hot), deep-body temperature and heart rate, W of required and maximum evaporative cooling, and percent sweat-wetted skin area and grams of sweat produced. This model assumes a relatively fixed skin temperature, in the 35-36^{o}C range. The model has been programmed to provide tabulated outputs of rectal temperature and heart rate as a function of time. It can also provide values of the equilibrium rectal temperatures and heart rates that the body will attempt to achieve to establish heat balance, without recognition of whether or not these required equilibrium levels may be totally incompatible with tolerance limitations and, thus, may lead to collapse long before any equilibrium is reached. In this equilibrium state mode, the output also identifies the relative contributions of the work level [Nielsen, 1938] of any non-evaporative heat transfer limitations associated with high ambient temperatures or heavy insulation and also differentiates any problems associated with high ambient vapor pressures or inadequate permeability. A sample output showing the changes associated with changing the insulation of a protective ensemble (from the 1.4 clo value of a standard long-sleeved shirt and trousers, by $\pm$ 0.2 clo increments) is presented in Table 10-11 for men, at rest or working at 250 or 500 W at 20^{o}C (68^{o}F), 25 percent R.H. with low air movement (0.3m/s). The output can also identify the effects of lack of (or improved) heat acclimatization and of limited (or enhanced) water ingestion programs.

A third output format simply graphs the predicted rectal temperatures and heart rates over time as a function of any sequence of rest-work-recovery-work-recovery, etc. cycles of various durations. This allows optimum

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relationships between work and rest periods to be set up either to keep body heat storage below the 80 kcal/hr associated with unwillingness to continue work, or keep deep-body temperatures below the 39.2°C (102.5°F) level at which there is roughly a 25 percent risk of heat exhaustion collapse for individuals wearing chemical protective ensembles. For example, this could occur under conditions in which skin temperature cannot be reduced as a result of sweat evaporation with the increased effective wind velocity during work because of clothing impermeability. Such graphic outputs can be color-coded to represent acceptable heart rate and rectal temperatures for a civilian workforce under OSHA regulations in one color (i.e., $T_{re} < 38.2°C$; heart rate < 120 b/m). A different color can be used to reflect "safe," albeit stressful, conditions for fit young adults (i.e., $T_{re} < 39.2°C$; heart rate < 140, or 160, or 180 b/m depending on duration of the exposure in chemical protective garments). For older, or less fit individuals, the age adjustment in their maximum heart rate (.e., 220 bpm - age in years) should be used to modify any heart rate based limits. Transition to still another color can indicate conditions of potential heat exhaustion collapse (i.e., T_{re} between 39.2 and 41°C). Finally, another color (or symbol) can be used for temperatures above 41°C where risk of heatstroke exists.

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Table 10-11
Predicted Responses to Changes in Clothing
Ta = 20C, RH = 25 percent, WV = 0.3m/s. Clo = a/s, Im-.43 p =.25

REST						
Clo eff	**PMV**	**Tref**	**Ereq**	**Emax**	**percent SW**	**Sweat**
0	-2	37	-128	545	00	00
1	-1	37	-82	436	00	00
1	-1	37	-51	363	00	00
1	-0	37	-28	311	00	00
2	-0	37	-12	273	00	00
2	-0	37	-1	242	1	2
2	00	37	12	218	5	25
M = 250 W						
0	-0	37	-56	934	00	00
0	-0	38	6	747	1	7
0	0	38	46	622	7	61
1	0	38	75	533	14	106
1	0	38	97	467	21	145
1	1	38	114	415	28	180
2	1	38	128	373	34	211
M = 500 W						
0	0	38	131	1365	10	120
0	0	38	205	1092	19	208
0	1	39	254	910	28	280
0	2	39	289	780	37	342
1	2	39	315	682	46	397
1	3	39	336	606	55	446
1	3	39	352	546	65	490

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"CONVERGENCE": THE BEST PHYSIOLOGICAL GUIDE TO HEAT LIMITS

Any tolerance limit established simply on deep-body temperature or heart rate will not address the critical problem termed "skin temperature convergence" [Pandolf and Goldman, 1978]. Heat exhaustion collapse has occurred in individuals with deep-body temperatures 38.1°C (100.6°F) with heart rates, measured only minutes before collapse ensued, on the order of 120-130 bpm after some 30 minutes of exposure to work in the heat while wearing impermeable protective garments. The critical event in such cases is that skin temperature rises, converging toward rectal temperature. A core to skin temperature difference of less than 1°C is a strong indication of inability to continue work in the heat much longer (see Figure 10-6).

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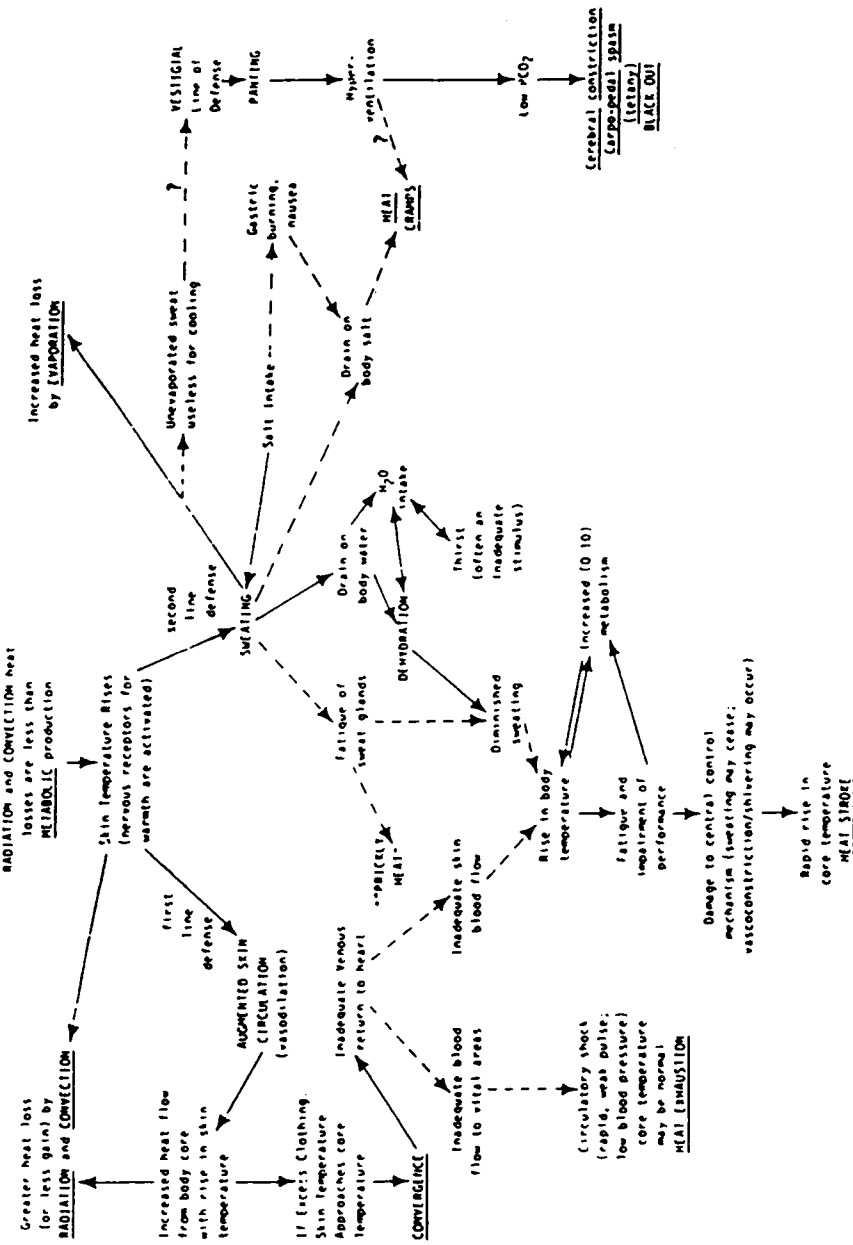


Figure 10-6
Heat stress and its associated physiologic responses and pathologies.

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As skin temperature converges toward deep-body temperature, as indicated previously, each liter of blood has a reduced capacity for moving heat from the deep-body centers to the skin from which, in normal clothing, it is eliminated. Associated with this convergence is an increased accumulation of blood in the periphery, and increased heart rates in an attempt to maintain heat balance and blood flow to the brain. In field trials in troops wearing chemical protective clothing ensembles, voluntary discontinuance occurred almost contemporaneously with skin temperature reaching deep-body temperature, even though deep-body temperature was well below the usual 39.5°C (103°F) used as a limiting criterion for fit, young, heat-acclimatized troops.

Except as an indicator of risk of heat stroke, deep-body temperature should not be used alone for individuals wearing chemical protective clothing since heat exhaustion collapse can occur at deep-body temperatures close to 38°C. Also, deep-body temperatures frequently continue to rise after cessation of work, particularly in situations with low evaporative cooling potential (e.g., a high vapor pressure inside protective clothing), simply because of the lag time of deep-body temperature as measured by rectal temperature. Since heart rates can rise much too rapidly upon convergence of skin and rectal temperatures to be used safely as a criterion for removal of workers from the heat, what physiological end-point, if any, should be used?

Some years ago, Iampietro and Goldman [1965] indicated that skin temperature achieved its equilibrium value very rapidly during work in the heat; the skin temperature at the end of 10 minutes of exposure to work in a given hot condition was generally fairly close to the equilibrium skin temperature that would be established, at least until rising deep-body temperatures drove skin temperature up further. They suggested that a reasonable estimate of tolerance time for work in the heat could be obtained based on the skin temperature at 10 minutes after onset of work in the heat. Schwartz, subsequently, drew similar conclusions [Shvartz and Benor, 1972]. In view of the critical relationship of skin temperature convergence as an end-point for men working in the heat when wearing chemical protective clothing systems, it is recommended that, if any physiological end-points are to be adopted as safety criterion for individuals working in chemical protective clothing, skin temperature should be one of the most important physiological criteria. Skin temperature can be measured at a number of sites, with three sites (chest weighted at 50 percent, forearm weighted at 14 percent, and calf weighted at 36 percent) usually being used to obtain a mean-weighted skin temperature. Under heat stress conditions, however, particularly when wearing complete chemical protective encapsulation systems, skin temperatures become remarkably uniform and measurement of a single skin temperature should suffice. Soule and Goldman have suggested that a lateral or medial thigh

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temperature is probably the most representative of average skin temperature, and a medial thigh temperature would be least apt to be influenced by direct impingement of solar or other radiant heat sources. A skin temperature at that point (or an average mean weighted skin temperature) in excess of 36°C should be considered prognostic of difficulty in maintaining an acceptable heat balance. A skin temperature above 37°C should be cause for cessation of work in the heat.

It is important to note that in many of the heat stress problems that reach litigation, whether to assign cause and effect, or to assess compensation for injury or reduced productivity, lack of any actual on-site measurements of environmental conditions is often a major problem. Even the work being done is inadequately characterized in terms of the three key characteristics of task intensity, duration and frequency. Obviously, such a lack of factual data lends itself to extended litigation and confounds the ability to use any of the scientific analytic approaches to resolve such questions cleanly. At a minimum, whenever heat stress is seen as a potential problem, on site *measurements* of air temperature and humidity, *plus estimates* of air motion and cloud cover, should be recorded hourly between 10 A.M. and 3 P.M. These should be *supplemented* by a simple task/time/activity log characterizing the actual work levels whenever any heat stress associated illness or loss of productivity is of concern.

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11

DECONTAMINATION

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Timothy G. Prothero, B.A.

The purpose of decontamination, as discussed in this chapter, is the removal or neutralization of hazardous substances on vehicles, clothing, tools, equipment, and instruments. The purpose of decontamination is to prevent or minimize human exposures to hazardous substances. Decontamination is also the means to prevent the spread of contamination when workers and equipment exit contaminated sites. Controlling the spread of contamination is necessary to prevent harm to human health and the environment that can result from the spreading of contaminants to air, water, soils, plants and animals.

Decontamination is an integral part of the requirements established by the Occupational Safety and Health Administration (OSHA) for protection of workers and the U.S. Environmental Protection Agency (USEPA) for protection of human health and the environment. Although guidelines and requirements to address decontamination needs are available from government agencies and professional associations, it is important to note that there are no comprehensive, uniform standards for decontamination methods. The type and extent of decontamination required is dependent upon the hazards associated with exposure to the contaminant, the properties of the item to be decontaminated and the anticipated use or disposition of the item.

This chapter discusses the principles and objectives that need to be addressed in the planning and implementation of decontamination procedures at a hazardous waste site. These discussions should be considered in the context of the related issues and requirements addressed in the other chapters of this book.

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PRINCIPLES AND OBJECTIVES OF DECONTAMINATION

To remove a contaminant, it is necessary to consider the extent to which the contamination has permeated and/or penetrated the surface and the binding forces between the contaminant and the object to be decontaminated. The severity of permeation (i.e., the movement of contamination into a material at a molecular level) is related to duration of contact, the physical and chemical properties of the contaminant, the concentration of the contaminant and the properties of the objects to be decontaminated. The severity of penetration (i.e., movement of contaminants through the structure of a material) is a function of the physical properties of materials relative to physical properties of the contaminant. The decontamination of objects that are penetrated or permeated requires the breaking of the binding forces, and driving the contaminants to the surface for removal. In general, the closer the contaminant is to the surface the easier it is to be removed. The nature of binding force will influence the effectiveness of the decontamination.

Permeation is primarily a function of time and concentration. Simply stated, the longer a contaminant remains in contact with a material and the greater the concentration of the contaminant, the more that contaminant will migrate into the material. Restricting the duration of contact is the simplest method to limit the amount of permeation. Since no material is totally impervious to all possible contaminants at all concentrations, appropriate time restrictions should be established for all site activities involving direct contact with contaminants. The time restrictions must be based on the suspected contaminants, the anticipated concentration of the contaminants and the potential for permeation into the vehicles, tools, equipment, and PPE used.

Permeation is also related to the physical space between molecules of a material and the ability of a contaminant to move through those spaces. The density and rigidity of the molecular structure of the material being contaminated will affect the ability of contaminants to permeate a material. Also, the density, cohesive properties and mobility of the contaminant will affect its ability to permeate into another material. In general, resistance to permeation increases with the density and rigidity of the material being permeated. This is the main reason that permeation of metals is limited, and metals are easier to decontaminate than plastics or fabrics. Conversely, as the density and cohesive properties of materials decrease, the contaminant's mobility increases.

The ability of a contaminant to permeate another material is also greatly influence by its mobility that is related to its temperature and physical state. An increase in temperature increases the movement of contaminant molecules and provides increased energy to overcome the material's resistance to permeation. Increased temperatures may also change the physical state of the

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contaminant yielding greater mobility for liquids over solids and gases over liquids.

Penetration of personnel protective clothing and equipment (PPE) is affected by the size of the spaces between the threads of woven fabrics and the seams where sections of fabrics are joined. Penetration of structures, tools, equipment and vehicles generally occurs through crevices, cracks, surface irregularities, seams, hinges, and joints.

Other physical driving forces can also help to push contamination into a material. Increasing contaminant concentration increases diffusion into material to equalize the concentration gradient. Also, a contaminant propelled by a sudden release of pressure or thrown by grinding or sandblasting can be physically pushed into a material.

Any chemical interaction between contaminants and items to be decontaminated will affect permeation and penetration. Chemical degradation of a material changes the structural integrity of the material and affects the rate of permeation. Contaminants that adhere to and coat surfaces tend to restrict penetration.

Contaminants can be bound to a material through electrostatic, chemical and physical attractive forces and mechanical entrapment. These binding forces must be broken to remove a contaminant. Decontamination methods used to break these binding forces are discussed later in this chapter.

PLANNING AND IMPLEMENTATION OF A DECONTAMINATION PROGRAM

Decontamination procedures are established to provide four basic functions:

1. Removing and controlling contaminants that have accumulated on PPE, tools, equipment, and vehicles used in the contaminated areas to prevent dispersal of contamination into adjacent uncontaminated areas on-site and surrounding areas off-site;
2. Minimizing worker contact with contaminants during removal of PPE;
3. Preventing inadvertent mixing of wastes with other potentially incompatible wastes or compounds; and
4. Removal or detoxification of wastes from equipment, vehicles, buildings, and structures to prevent further releases and/or exposures and enable future use after completing activities involving contact with contaminants.

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General Design Principles

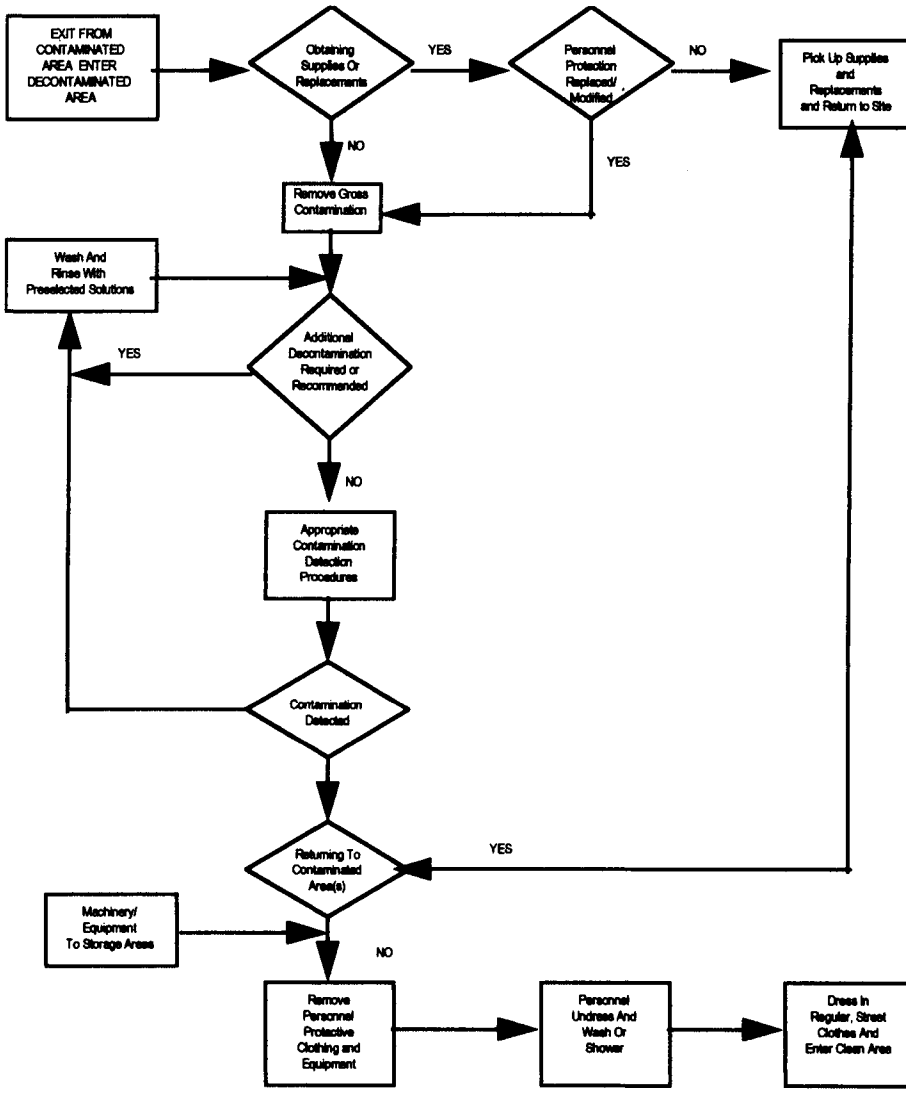
In concept, the design of a decontamination procedure is straight forward, but in practice it requires evaluation of many different variables. A general decision logic, as shown in Figure 11-1 can be used to organize decontamination procedures on a site. Within the decision logic, factors must be considered according to the site conditions, characteristics of the waste, activities being conducted, and so forth. The decontamination of PPE, tools, equipment, vehicles, structures, and buildings will be different because of the differences in materials and contaminants. Table 11-1 is a list of factors that impact on decontamination design requirements.

Decontamination facilities on a hazardous waste site should be located in the contamination reduction area between areas contaminated by the wastes and clean support areas, as shown in Figure 11-2. Decontamination designs and procedures must include the containment, collection, and disposal of contaminated solutions and residues generated during the process, unless the specific contaminant has been judged to be acceptable for release on the site. This must be decided on a case-by-case basis. Controls may include items such as spray booths with side walls or curtains to contain splashes and sprays, a collection tank for waste liquids, and drums for disposal of excessively contaminated materials and solid wastes from the process. Separate facilities should be provided for decontamination of large equipment to prevent cross-contamination of personnel decontamination facilities. Each stage of decontamination from gross decontamination through the repetitive wash/rinse cycles should be conducted at different stations.

Stations used should be physically separated to prevent cross-contact between stations. The stations should be arranged in order of decreasing level of contamination, preferably in a straight line. Separate flow patterns and stations should be provided when it is necessary to isolate workers from different contamination zones containing incompatible waste. Entry and exit points should be well marked and controlled. The decontamination area should be separate from the entry path to the contaminated area (exclusion zone) from the clean area (support zone). Dressing stations for entry should be separate from re-dressing areas for exit. Entry into clean areas of the decontamination facility such as the dress out locker rooms requires full decontamination.

Procedures should be established for minimum decontamination prior to use of restroom facilities. If deemed appropriate by a safety assessment, restroom facilities can be located within the contamination reduction zone preceded by the minimum decontamination procedures established.

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* Site clothes should be washed separately from nonsite and other family clothing.

Figure 11-1 Decontamination procedure logic

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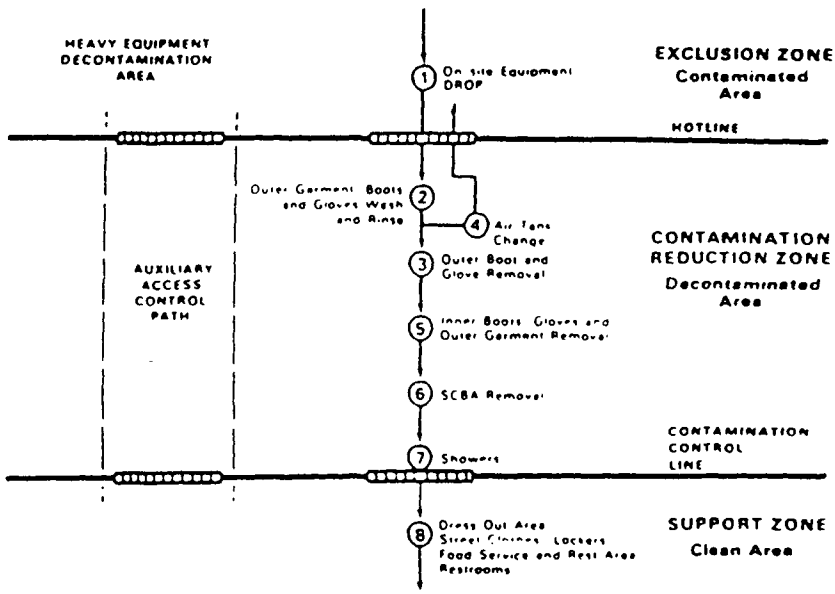


Figure 11-2 Minimum decontamination stations for hazardous waste sites that require respiratory and skin protection.

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Table 11-1 Factors Impacting Decontamination Design Requirements
1. The chemical, physical, and toxicological properties of chemical wastes.
2. The pathogenicity and virulency of infectious wastes.
3. The amount and location of contamination, including possible permeation and penetration of contaminants.
4. The potential exposures based on assigned duties, uses, activities, and functions.
5. The potential for degradation of PPE, vehicles, tools, equipment, buildings, and structures during decontamination.
6. The design and construction of PPE, vehicles, tools, equipment, buildings, and structures.
7. The proximity of incompatible wastes.
8. The intended use of equipment being removed and reason for personnel exiting from the controlled contamination area.
9. The methods available for protection of workers during decontamination procedures.
10. The impact of the decontamination process and compounds on worker safety and health.

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Table 11-2 is a list of recommended supplies for decontamination of personnel, clothing, and equipment. Table 11-3 is a list of recommended supplies for large equipment and vehicle decontamination. These lists are not inclusive for all needs, but should give general guidance on the types of supplies to be provided.

The actual design and setup of decontamination facilities will vary depending on:

1. The availability of utility services;
2. Mobilization time and duration of site activities;
3. Site conditions and the level of on-site activity anticipated;
4. The volume and level of decontamination required;
5. Available space in uncontaminated area contiguous with the contaminated areas of a site; and
6. Potential hazards associated with the decontamination procedures and wastes generated.

The availability of utility services will determine the requirements for providing and storing portable water supplies for use in decontamination. If electrical service is necessary, portable generators could be required. Availability and access to waste water and waste water disposal systems may impact storage and handling requirements for decontamination waste waters. Time requirements for mobilization and demobilization influence the design of decontamination facilities. Emergency response to accidents, spills, fires, or explosion do not allow sufficient time for elaborate facilities. An increasingly common practice is the use of mobile decontamination facilities that are self-contained and fully equipped for personnel decontamination. However, in situations where mobile facilities are not available, decontamination kits should be devised. Table 11-4 is an example of a decontamination kit that could be used.

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Table 11-2 Recommended Supplies for Decontamination of Personnel, Clothing, and Equipment

- Drop cloths (plastic or other suitable material) for heavily contaminated equipment and outer protective clothing such as over boots, outer pair of gloves, monitoring equipment, drum wrenches, etc.
- Disposal collection containers (drums or suitable lined trash cans) for disposable clothing and heavily contaminated PPE.
- Storage containers for contaminated wash and rinse solutions.
- Lined box with absorbents for collection and control of wastes from scraping, wiping or rinsing off gross contamination.
- Wash tubs of sufficient size to enable workers to place booted foot in and wash off contaminants (without drains unless connected to a suitable collection tank or treatment system).
- Rinse tubs of sufficient size to enable workers to place booted foot in and hold the solution used to rinse the wash solutions and contaminants after washing (without drains unless connected to a suitable collection tank or treatment system).
- Wash solutions pretested against contaminants for effectiveness and compatibility.
- Rinse solutions (also pretested) to remove or neutralize contaminants and rinse off residues of wash solutions.
- Long-handled, soft-bristled brushes to help wash and rinse off contaminants.
- Lockers and cabinets for storage of decontaminated clothing and equipment.
- Plastic sheeting, sealed pads with drains, or other appropriate method for containing and collecting contaminated wash and rinse water spilled during decontamination.
- Shower facilities for full body wash or, at a minimum, personal wash sinks (with drains connected to collection tank or appropriate treatment system).
- Soap or wash solution, wash cloths, and towels for personnel showering.
- Clean clothing and personal item storage lockers and/or closets.

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Table 11-3 Recommended Supplies for Large Equipment and Vehicle Decontamination

- Containers for gross contamination involving removal of wastes and contaminated soils caught in tires, and the underside of vehicles or equipment.
- Pads for collection of contaminated wash and rinse solutions with drains or sumps connected to storage tanks or approved treatment system.
- Shovels, rods, and long-handled brushes for dislodging and removing wastes and contaminated soils caught in tires, and the underside of vehicles or equipment.
- Pressurized water and/or steam sprayer(s) for pressure washing, steam cleaning, and rinsing (particularly hard to reach areas).
- Spray booths, curtains, or enclosures to contain splashes from pressurized sprays used to dislodge materials and clean hard to reach areas.
- Long-handled brushes for general cleaning of exterior.
- Wash solutions pretested against contaminants for effectiveness and compatibility.
- Rinse solutions (also pretested) to remove or neutralize contaminants and rinse off residues of wash solutions.
- Wash and rinse buckets for use in decontamination of operator areas inside the vehicle and equipment.
- Brooms and brushes for cleaning operator areas inside the vehicles and equipment.
- Containers for storage and/or disposal of contaminated rinse and wash solutions and damaged or heavily contaminated parts and equipment to be discarded.

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Table 11-4 Example of Personnel Decontamination Kit

- Five-gallon container(s) of potable water (for decontamination only)
- Soft- and stiff-bristled brushes
- Detergent (solid or liquid)
- Plastic wading pool(s)
- Buckets or sprinkler cans for rinsing
- Paper towels or other disposable cleaning cloths
- Chemical-resistant container(s) (minimum five gallons for wash/rinse solutions)
- Plastic garbage bags (5 or 6 mil thick) for storage of equipment and disposal of solid/hazardous wastes.

The use of temporary facilities versus permanent facilities (such as the installation of a full-sized decontamination trailer or construction of on-site buildings and facilities) will be dependent on the type and duration of site activity anticipated. The level of on-site activity will determine, to a large extent, the potential for contamination of workers. Decontamination for investigations involving limited contact with contaminants for purposes of sampling is usually less elaborate than decontamination of workers involved in handling and packing of wastes during site cleanup. Similarly, sites on which releases of wastes have resulted in extensive contamination will require more decontamination of site workers than a site on which wastes have been contained and adequately controlled to minimize contamination.

The number and frequency of workers undergoing decontamination will impact the flow design, size, and number of stations used. Likewise, the number and frequency of vehicle and large equipment decontaminated will impact designs for those facilities.

One of the most limiting factors for decontamination facility design and setup is the availability of space in uncontaminated areas contiguous with contamination zones. Maintaining sufficient separations between stations may require use of fewer stations. Also the flow design may be arranged in rows or serpentine-fashion as opposed to the preferred straight-line design. The design of many of the mobile trailer facilities in use requires such modifications from the straight-line design to make efficient use of available space. In confined areas, it is essential that procedures and practices are implemented to minimize

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splashing, sprays, dusting, and aerosols that may cross-contaminate stations. In enclosed areas, such as mobile trailers, effective ventilation controls are also critical.

Concerns for cross-contamination and protection of decontamination facility workers may require special designs and controls if potential hazards during decontamination are significant. Ventilation hoods, spray booths, wet wells, chemical treatment tanks for wastes, and specialized storage containers are examples of specialized components that may be used to control dispersion of wastes during decontamination. Standard controls will prevent or minimize run-off, air diffusion/dispersion, and movement of wastes from each decontamination station.

Selection of Appropriate Decontamination Solutions

In choosing the appropriate wash and rinsing solutions for a decontamination project, one must consider the following factors:

1. *Solubility* behavior of contaminant;
2. *Compatibility* of choice solutions with contaminant and object/items to be decontaminated;
3. *Accessibility and availability* of solutions;
4. *Effectiveness* of solutions and methods;
5. *Storage, handling, and disposal requirements* of solutions; and
6. *Hazards* associated with cleaning solutions (e.g., flammability and toxicity).

In general, the more common solvents and the compounds they work best on are presented below:

1. *Water*: Dissolves low chain hydrocarbons, inorganics, salts, some organic acids, and other polar compounds;

2. *Dilute Acid*: Dissolves caustic (basic) compounds, amines, hydrazines and metal salts;

3. *Dilute Base*: Dissolves acidic compounds, phenols, thiols, and some nitro and sulfonic compounds; and

4. *Organic Solvents*: Dissolve nonpolar compounds such as other organics. May also damage some types of PPE fabrics and materials.

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It is very important to pretest cleaning solutions for compatibility with the materials being cleaned. The choice of solvent wash and rinse solutions will depend largely on its compatibility with the material of the equipment that is being decontaminated. For example, most of the fabrics of PPE are made of polymer organics that can be dissolved or destroyed by organic solvents. The metals and gaskets of tools and equipment can be damaged by strongly acidic or caustic compounds.

Another important requirement is that the chemical waste and the cleaning solutions be compatible. Figure 11-3 diagrams the decision logic for selection of decontamination wash/rinse solutions. Incompatible reactions resulting in excessive heat, fire, or generation of toxic gases are not desired in the contamination reduction areas where decontamination crews might not be adequately protected.

The ready access to wash and rinse solutions is the most practical limitation. The availability of water has resulted in its use in most decontamination cases. Water and detergents can be easily obtained and they are easily stored and handled.

The hazards involved with the solutions themselves must be considered during any decontamination project. Organic solvents, especially flammable and highly toxic ones, are more difficult to store, handle, and control. Besides the hazardous properties of the cleaning solutions, one must remember that even water may become hazardous after it has been used for cleaning contaminated equipment.

The disposal of cleaning solutions will depend on the type of solution (aqueous or organic), and the types and amounts of contamination it contains after use. Depending on the site and situation, cleaning solutions may be collected after use and added to waste streams at the site for treatment and disposal.

Disinfection solutions for use following removal of gross contamination will require consideration of several factors as presented in Table 11-5. A disinfection activity level based on field conditions should be established before extensive site work.

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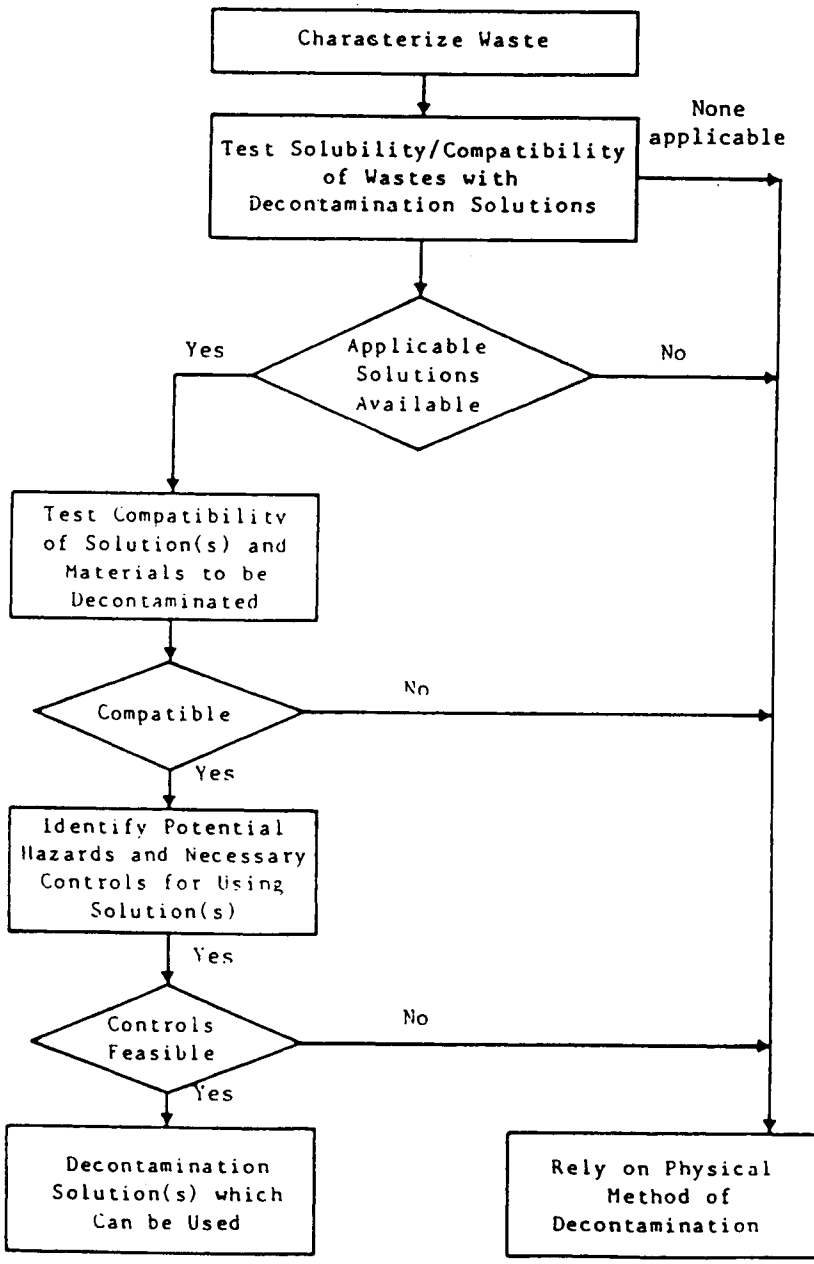


Figure 11-3 Decision logic for selecting decontamination wash/rinse solutions.

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Table 11-5 Factors Influencing Chemical Disinfection
1. The types of organism
2. The degree of contamination
3. The amount of proteinaceous materials present in the waste
4. The type of chemical
5. The concentration and quantity of chemical disinfectant
6. The contact time
7. Possible interferences from other chemicals in wastes
8. The temperature of the item(s) being disinfected

Emergency Decontamination

In addition to normal decontamination procedures, emergency decontamination procedures should be established (see Figure 11-4). In an emergency, decontamination may not occur at the site when immediate treatment is required to save a life. If decontamination can be provided without interfering with essential first aid and life-saving techniques, such as CPR, then it should be done. Clothing and equipment may be washed, rinsed, and/or cut off when necessary. Otherwise, the individual should be covered with a blanket or other suitable material. Covering serves to prevent contamination of ambulance and medical personnel. Alternatively, to minimize possible heat stress to the patient, PPE may be used by the emergency response personnel (assuming appropriate training has been provided during planning stages of the project).

It is important to coordinate procedures for decontamination protection of medical personnel, and disposal of contaminated clothing and equipment. These procedures are necessary to minimize the risk of exposure to emergency medical personnel. Such procedures should be established during planning of site activities before any site work.

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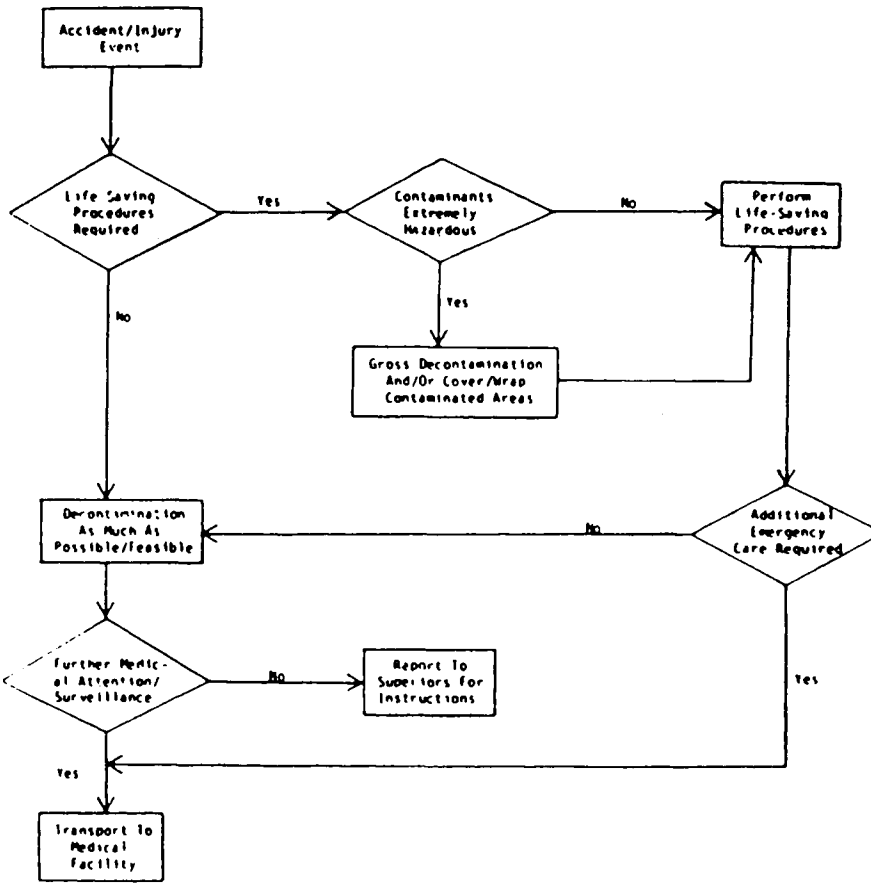


Figure 11-4 Emergency decontamination design logic outlines the decision logic that should be followed in an emergency.

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DECONTAMINATION METHODS AND PROCEDURES

Much of the research and development of decontamination technologies is being conducted or sponsored by various federal agencies and departments in support of various program needs. These include, the U.S. Environmental Protection Agency (EPA), U.S. Occupational Safety and Health (OSHA), U.S. Department of Defense (DoD), U.S. Department of Energy (DoE), the National Institutes of Health (NIH)/National Institute of Environmental Health Sciences (NIEHS) and Center for Disease Control (CDC). For example, the USEPA maintains the Superfund Innovative Technology Evaluation (SITE) Program, established regulatory requirements for Worker Protection Standard (WPS) for pesticide applications, including decontamination, under (see 40 CFR Parts 170. Part 170--Worker Protection Standard), and established performance standards for treatment of hazardous debris under Hazardous Waste Land Ban Disposal regulations in Title 40 Part 268.45. OSHA has established decontamination requirements for asbestos abatement activities for general industry (29 CFR 1910.1001) and construction industry (29 CFR 1926.1101) and asbestos work activities in the shipyard industry (29 CFR 1915.1001). The DoE and DoD are working on technologies to support facility Deactivation and Decommissioning (D&D) activities, particularly deactivated DoD weapons support facilities. The NIEHS conducts a Superfund Basic Research Program which includes evaluation of decontamination technologies. Although it is not possible to list all available Internet sites, Table 11-6 lists several Internet sites that can be used as a jumpoff point to access additional information. It is important to note that information obtained from Internet sites can contain errors or have unauthorized modifications. The authors recommend cross-referencing information with independent sources to verify or confirm accuracy before using the information obtained from the Internet.

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Table 11-6 Internet Access Sites

CDC	- http://cdc.gov - http://aepo-xdv-www.epo.cdc.gov/wonder/prevguid
DoD	- http://www.ndcee.ctc.com/index. - htmhttp://www.nbc-med.org/docs.html
DoE	- http://www.em.doe.gov/ - http://www.ofo_cl.doe.gov/Bcldp/Tech/Links.htm - http://www.ofo_cl.doe.gov/Bcldp/Tech/Resource.htm
NEIHS	- http://www.niehs.nih.gov/sbrp/newweb/sbrpsrch.htm
OSHA	- http://www.osha-slc.gov/SLTC/Search.html
USEPA	- http://www.epa.gov/epahome/ - http://www.epa.gov/rtirmd11/toolind.htm

Probably the most commonly used decontamination method is scrubbing with soap and water. Scrubbing, however, is effective at cleaning the surfaces only. Alternate methods of decontamination must be considered to ensure as complete removal of the contaminants as possible. Table 11-7 lists common methods of decontamination presently in use.

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Table 11-7 Common Decontamination Methods	**Personnel**	**PPE**	**Buildings and Heavy Equipment**
1. Contaminant Removal			
Scrubbing/scraping with brushes, scrapers, sponges, etc. (commonly used in combination with solvent cleaning solutions).	X	X	X
Water rinse (pressurized or gravity flow)	X	X	X
Pressurized wash		X	X
Steam jets (commonly used with solvent cleaning solutions)			X
Evaporation/vaporization (e.g., hot air drying)		X	X
Chemical leaching (e.g., dry cleaning or Freon cleaning)		X	
Solvent extraction liquid or vapor phase			X
2. Detoxification			
Oxidation/reduction (e.g., bleach or sulfur dioxide, respectively)		X	X
Neutralization		X	X
Thermal desorption		X	X
Thermal degradation/destruction			X
3. Physical Removal or Sealing of Contaminated Surfaces and Materials			
Abrasive blasting, scarification, grinding and planning, spalling, vibratory finishing, high pressure water or steam			X
Disposal of permeated materials (e.g., seats, floor mats, clothing, coatings, disposable coveralls)		X	X
Sealing or encapsulation			X
4. Disinfection/Sterilization (infectious wastes)			
Steam sterilization			
Dry heat sterilization		X	X
Irradiation (e.g., UV)		X	X
Chemical disinfection		X	X
	X	X	X

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Personnel and Personal Protective Equipment Decontamination:

1. *Washing with water and detergents/disinfectants.* PPE cleaning is perhaps the most frequent decontamination procedure used. Sequential wash and rinse cycles in a series of galvanized tubs are common procedures for decontamination of PPE. As contamination is reduced the layers of clothing and equipment are removed. A personnel shower is the last step of the decontamination protocol. The washing of personnel and equipment can involve the use of water, detergents or soaps, and if necessary, disinfectants. Figure 11-2 depicts a combination personnel and personal protective clothing decontamination sequence.

   Washing is only effective for removal of topical contaminants. Scrubbing does not remove entrapped or permeated contaminants. Nor does scrubbing with soap and water prevent redeposition of nonpolar materials that would have a greater affinity for the surfaces of nonpolar materials than for the polar solution of surfactants and water. Removal of entrained, or permeated, contaminants from the fabrics of personal protective clothing requires alternate methods be used, preferably, as an addition to scrubbing with water and detergents. Alternative methods are referenced in Table 11-7 and discussed below.
2. *Freon and dry-cleaning.* Freon cleaning has been used in some situations to remove nonpolar organics from protective clothing. Removal efficiencies have been reported ranging from about 65 percent to 99 percent for removal of PCBs in firefighters' turnout gear [Ashley, 1986]. Freon and dry-cleaning work similarly to washing with the advantage that Freon and dry-cleaning fluids are nonpolar solvents able to dissolve and remove other non-polar chemicals better than water. The disadvantages of Freon and dry-cleaning are that the solvents can permeate the protective clothing and will then become themselves contaminants.
3. *Hot Air Treatment.* Research has determined that permeated volatile and semi-volatile compounds may be removed from personal protective clothing by "baking" the clothing at 50°C (about 120°F) for 24 hours. The temperature is sufficiently high to drive off the organic contaminants without damaging the several types of personal protective clothing tested. At temperatures higher than 50°C, the protective clothing was damaged sometimes, either by loss of plasticizers, elastomers, or cracking of the material [Perkins et al., 1987].

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Generally, hot air treatment is very effective at removal of organic contaminants and restores the protective clothing to very near the protective breakthrough qualities that it had when new.

4. *Disposal of Contaminated Coverings.* Although disposal of contaminated materials is not "decontamination" *per se*, it is a very effective means of controlling contamination and contaminant spread. A disposable coating, for example, disposable treated paper coveralls, may be used as a barrier to contamination. Although the breakthrough times of coverings are likely to be very brief, the concentration gradients on the insides of the coverings are so low as to retard the permeation of the covered materials. Therefore, the coverings may be disposed of, and the materials that were covered will be less likely to have been seriously permeated.
5. *Disinfectants.* Areas may be contaminated with microorganisms, such as when cleaning up abandoned medical wastes. To ensure proper decontamination in these cases, disinfectants must be used. Usually, the only decontamination that can be done by field personnel is to use topical disinfectants. Any exposures that might have occurred from cuts or punctures should be treated by medical professionals. Factors influencing disinfectants were previously listed in Table 11-5. Table 11-8 provides disinfectant activity levels for selected classes of disinfectants.

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Table 11-8 Activity Levels of Selected Classes of Liquid Disinfectants		
Class	Use-Concentration	Activity Level[a]
Glutaraldehyde, aqueous	2%	high
Formaldehyde + alcohol	8% + 70%	high
Formaldehyde, aqueous*	3% to 8%	high to intermediate
Iodine + alcohol	0.5% + 70%	intermediate
Alcohols	70% to 90%	intermediate
Chlorine compounds	500 to 5000 ppm[b]	intermediate
Phenolic compounds	1% to 3%[c]	intermediate
Iodine, aqueous	1%	intermediate
Iodophors	75 to 50 ppm[d]	intermediate to low
Quaternary ammonium compounds	1:750 to 1:500[e]	low
Hexachlorophene	1%	low
Mercurical compounds**	1:1000 to 1:500[e]	low

Courtesy of American Sterilizer Company, Erie, PA.
[a] Degree of disinfecting activity.
[b] Available chlorine.
[c] Dilution of Concentrate containing 5% to 10% phenolics.
[d] Available iodine.
[e] In appropriate diluent.

* See Section 4.7 of source reference for discussion of formaldehyde toxicity and necessary precautions for personnel protection.

** Should not be released into the environment, and therefore, is no longer used.

Source: U.S. EPA Office of Solid Waste, 1982.

Decontamination Methods for Heavy Equipment, Buildings, Structures, Vehicles, and Vessels

1. *Steam Jetting and Pressure Washing.* Surface contaminants can be removed from heavy equipment, trucks, buildings, and the like, with hot, high-pressure wash, steam jetting, at temperatures around 18^0 F. The higher temperatures of the water provide increased solubility for most compounds, and the high-pressures of the wash will physically "scrub"

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the contaminant off the surfaces being cleaned. For materials that are resistant to this method, scrubbing with brushes or brooms may help in the removal of the contaminants. These topical cleaning methods will have little effect on permeated contamination, except that the pressure differential and temperature gradients may increase permeation rates. Note that the time factors necessary for permeation are much greater than for removal of surface contaminants; therefore, pressure or steam cleaning are good methods to remove surface contamination. *Also, note that under no circumstance may any pressure or steam washing be used on a person or on a material being worn by a person, because the pressure can cause contaminants to be injected through the skin and steam will burn.*

2. *Disinfectants.* Heavy duty disinfectants, including highly concentrated solutions, may be used on heavy equipment, buildings, or other similar materials that are contaminated with microorganisms. Tables 11-5 and 11-8 list some factors and activity levels for the use of disinfectants.
3. *Thermal Treatment.* Structures or heavy equipment may be thermal treated through a variety of methods. Microwaves or special frequency radio waves may be used to heat up a material to drive off organic contaminants. Sufficient heat can also destroy some classes of organic contaminants.

   Thermal treatment has been used in treating a formaldehyde contaminated mobile home. The home was heated to around 90^{0}F for several days to remove the formaldehyde from the materials of construction.
4. *Detoxification.* In instances when the identity of the contaminant that has permeated a material is known, the contaminant may be detoxified or neutralized. For example, cyanide wastes permeated into porous media, such as bricks, may be oxidized to cyanate by using bleach. Likewise, acids or bases may be neutralized. The treatment of penetrated or permeated contaminants in place requires careful planning and testing to ensure effective and safe treatment.
5. *Disposal of Contaminated Coverings and Coatings.* Finally, although disposal of contaminated materials is not a method to decontaminate that material, it is a very effective method to control contamination. By prior planning, disposable coverings or coatings may be used on materials and equipment before encountering the contamination. Then the coating or covering may be removed and disposed.

   Nuclear power plant containment buildings are coated inside with special permeation resistant paints that may be stripped off when contaminated [Bernaola and Filevich, 1970]. Sand blasting, pressure

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washing or stream cleaning are examples of methods used to remove protective coatings.

Measuring the Effectiveness of Decontamination Procedures

The effectiveness of decontamination procedures is often questioned because of the inability to perform real time measurements of their efficiency. Thus, it is necessary for an arbitrary decision to be made concerning the endpoint of the procedures. The state of the art in chemical analysis of surface contamination is still developing; however, several methods do exist (or can be created from available technology) for observing and measuring the decontamination procedures.

Methods available for measuring and inspecting effectiveness of decontamination includes

1. *Visual Inspection.*
   a. *Natural Light.* Visual inspection, using natural or artificial white light, entails the search for stains, discolorations, visible dirt, or alterations in the fabric of clothing as evidence of chemical contamination. The most obvious limitation is that not all contamination will result in visible staining or other similar traces. When such visual inspections are used, it is important that the searches include problem areas such as creases, boot treads, seams, and the like, of personal protective equipment. Wheel wells, tool boxes, fixtures, etc. on heavy equipment also have problem areas that are difficult to inspect visually.
   b. *Ultraviolet.* Ultraviolet light is useful to detect certain contaminants that fluoresce, such as polycyclic aromatic hydrocarbons. These contaminants are common in many refined oils and solvent wastes. Ultraviolet light can be used to observe skin contamination, but one must be already aware of the areas of the subject's skin that naturally fluoresces. A disadvantage of such uses of ultraviolet light is the added risk of increasing carcinogenic effects on the skin and the potential of damaging the eye.
2. *Surface Analysis.* Most available analytical methods for quantifying surface contamination are destructive of the sample. Collection of samples for analysis requires removal of part of the substrate surface for laboratory extraction and analysis of contaminates of concern. This technique is usually limited to demonstrating contaminate removal from structural surfaces.

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3. *Swab or Smear Samples.* To preserve the clothing or equipment, it is necessary to transfer the suspected contaminant to another surface or solution. A smear or swab sample can be taken from selected and measured areas of the equipment or clothing. These smears or swabs can be taken using a saturated sampling swab or pad (saturated with a solution in which the contaminant is soluble) or can be used dry if the contaminant can be readily wiped off. The samples may then be analyzed by wet chemistry field tests if the contaminant is known or sent to a laboratory for further qualification or quantification. A qualified analytical chemist should choose the sampling liquids and procedure so they are compatible with the contaminant, the surface sampled, and the test(s) to be performed.
4. *Rinse Solution Testing.* Rinsing surface areas with water or other suitable solutions in which the contaminant is soluble is a common method for qualitative evaluations of surface contamination. Too much contaminant in the final rinse solution would indicate that additional cleaning and rinsing is advisable. When the type of contaminant is specifically known, a qualified chemist might devise some wet chemistry spot tests or other field tests to analyze the solutions. More complete analyses can be obtained by sending a sample of the solutions to be tested to a laboratory; however, time constraints for laboratory analysis can limit use of this option to evaluation of structures and PPE and equipment that can be set aside pending results of analysis.
5. *Disinfectant Solution Testing.* When dealing with infectious wastes, concentrations of active disinfectants can be measured in the spent solutions to determine if sufficient levels of active ingredients were available. The length of treatment with the measured level of activity can be compared to previous testing by qualified microbiologists to determine time/concentration ratios required to provide the necessary disinfection under actual or simulated conditions. As shown in Table 11-5, several factors can impact the disinfection efficiency. Therefore, it is advisable to confirm the assumed level of disinfection by laboratory culture of swab samples.
6. *Microbial Swab Samples.* Swab samples for infectious organisms taken from decontaminated surfaces or field controls (e.g., surfaces contaminated with another indicator organism, which requires similar levels of active disinfectants, length of treatment, temperatures, etc., or active cultures of the organisms of concern) should be transferred to testing laboratories for culturing under controlled temperature, atmosphere, nutrient, etc., conditions. Optimum growth and culture conditions are variable depending on the type of infectious organisms involved. Design of appropriate sampling and laboratory testing

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procedures should be developed by a trained microbiologist. Every effort should be made to design and select procedures that will provide the necessary confirmation as soon as possible. Unfortunately, while some procedures require only a few hours, others can require several days.

Decisions concerning decontamination endpoints are often based on the lack of visible contamination. Unfortunately, this does not address problems of permeation, thin layers of contamination, compounds that are not readily observable with the unaided eye, or infectious organisms that can only be observed under a microscope. As a precaution, unless sufficient field experience with laboratory confirmation is available for the compounds and conditions under which decontamination is being conducted, it is advisable to assume some level of contamination may remain. If the wastes involved are extremely hazardous, repetitive decontamination may be warranted though obvious contamination has been removed. In addition, procedures for removal should be designed to prevent or minimize contact of unprotected skin surfaces with the exposed surfaces of clothing, equipment, tools, and the like, which have been cleaned but may require further decontamination.

CONCLUSION

Although regulatory requirements include provisions for decontamination, no comprehensive standards on effective decontamination techniques exist. The methods discussed in this chapter are in common use. Where standards or guidelines do not exist, the following guidelines are most common and effective:

Take all reasonable precautions to prevent direct contamination.

Limit the duration of contact with contaminated materials between decontamination and/or replacement of PPE to minimize time available for permeation and subsequent worker exposure. This can be accomplished by rotating tasks involving work in contaminated areas and work in support areas, scheduled replacement of PPE during breaks and limiting individual work shift in high risk areas.

Establish written SOPs for worker training and monitoring of decontamination procedures. Include guidelines for replacement of reusable PPE such as respirators. Maintain records of training and

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field inspection to insure that decontamination is being conducted according to the SOPs.

Remove surface contamination from PPE as soon as possible to limit the time available for permeation, especially for reusable PPE.

At present, the most effective method for removal of permeated volatile and semi-volatile contaminants in PPE is hot air drying.

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12

TRAINING

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Hazardous materials and hazardous waste training have long been topics of discussion among industrial personnel, emergency response teams, regulatory agencies, and allied groups. A number of successful programs have been designed to meet specific needs [Hughes et al., 1990]. While it is not possible to design one single curriculum to meet all training needs, it should be equally obvious that a number of generalities and guidelines exist that are useful in developing adult training programs [Taba, 1962].

Anyone who enters a hazardous waste site must be able to recognize and understand the potential health and safety hazards associated with the cleanup of the site. Personnel working on the site must be thoroughly familiar with work practices and procedures contained in the site health and safety plan (see Chapter 13, Health and Safety Plans and Contingency Plans). Site workers must be trained to work safely and use sound environmental management practices wherever there is a reasonable possibility of employee exposure to safety, health, or environmental hazards.

The training program objectives for hazardous waste site activities include the following:

- To ensure that workers are aware of the potential hazards they may encounter;
- To provide the knowledge and skills necessary to perform the work with minimal risk to worker health and safety and the environment;
- To ensure that workers are aware of the use and limitations of safety equipment; and
- To ensure that workers can safely avoid or escape from hazardous situations that may occur.

The minimum content of the training program may be found in 29 CFR 1910, 40 CFR 265 and 49 CFR 126. Workers may not participate in or

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supervise field activities until they have been trained to a level required by their job function and responsibility.

TRAINING REQUIREMENTS

OSHA regulation 29 CFR 1910.120 identifies the hazardous waste worker and the type of training as follows:

(1) *General* (e) *Training* (i) All employees working on site (such as but not limited to equipment operators, general laborers and others) exposed to hazardous substances, health hazards, or safety hazards and their supervisors and management responsible for the site shall receive training meeting the requirements of this paragraph before they are permitted to engage in hazardous waste operations that could expose them to hazardous substances, safety, or health hazards, and they shall receive review training as specified in this paragraph.

(ii) Employees shall not be permitted to participate in or supervise field activities until they have been trained to a level required by their job function and responsibility.

(2) *Elements to be covered.* The training shall thoroughly cover the following:

(i) Names of personnel and alternates responsible for site safety and health;

(ii) Safety, health and other hazards present on the site;

(iii) Use of personal protective equipment;

(iv) Work practices by which the employee can minimize risks from hazards;

(v) Safe use of engineering controls and equipment on the site;

(vi) Medical surveillance requirements, including recognition of symptoms and signs which might indicate overexposure to hazards.

(3) *Initial training.* (i) General site workers (such as equipment operators, general laborers and supervisory personnel) engaged in hazardous substance removal or other activities which expose or potentially expose workers to hazardous substances and health hazards shall receive a minimum of 40 hours of instruction off the site, and a minimum of three days actual field experience under the direct supervision of a trained, experienced supervisor.

(ii) Workers on site only occasionally for a specific limited task (such as, but not limited to, groundwater monitoring, land surveying, or geophysical surveying) and who are unlikely to be exposed over permissible exposure limits and published exposure limits shall receive a minimum of 24 hours of instruction off the site, and the minimum of one day actual field experience under the direct supervision of a trained, experienced supervisor.

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(iii) Workers regularly on site who work in areas which have been monitored and fully characterized indicating that exposures are under permissible exposure limits and published exposure limits where respirators are not necessary, and the characterization indicates that there are no health hazards or the possibility of an emergency developing, shall receive a minimum of 24 hours of instruction off the site and the minimum of one day actual field experience under the direct supervision of a trained, experienced supervisor.

(iv) Workers with 24 hours of training who are covered by paragraphs (e)(3)(ii) and (e)(3)(iii) of this section, and who become general site workers who are required to wear respirators, shall have the additional 16 hours of training necessary to total the training specified in paragraph (e)(3)(i).

(4) *Management and supervisor training.* On-site management and supervisors directly responsible for, or who supervise employees engaged in hazardous waste operations shall receive 40 hours initial training, and three days of supervised field experience (the training may be reduced to 24 hours and one day if the only area of their responsibility is employees covered by paragraphs (e)(3)(ii) and (e)(3)(iii) and at least 8 additional hours of specialized training at the time of job assignment on such topics as, but not limited to, the employer's safety and health program and the associated employee training program, personal protective equipment program, spill containment program and health hazard monitoring procedure and techniques.

(5) *Qualifications for trainers.* Trainers shall be qualified to instruct employees about the subject matter that is being presented in training. Such trainers shall have satisfactorily completed a training program for teaching the subjects they are expected to teach, or they shall have the academic credentials and instructional experience necessary for teaching the subjects. Instructors shall demonstrate competent instructional skills and knowledge of the applicable subject matter.

(6) *Training certification.* Employees and supervisors that have received and successfully completed the training and field experience specified in paragraphs (e)(1) through (e)(4) of this section shall be certified by their instructor or the head instructor and trained supervisor as having successfully completed the necessary training. A written certificate shall be given to each person so certified. Any person who has not been so certified or who does not meet the requirements of paragraph (e)(9) of this section shall be prohibited from engaging in hazardous waste operations.

(7) *Emergency response.* Employees who are engaged in responding to hazardous emergency situations at hazardous waste cleanup sites that may expose them to hazardous substances shall be trained in how to respond to such expected emergencies.

(8) *Refresher training.* Employees specified in paragraph (e)(1) of this section, and managers and supervisors specified in paragraph (e)(4) of this

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section, shall receive 8 hours of refresher training annually on the items specified in paragraph (e)(2) and/or (e)(4) of this section, any critique of incidents that have occurred in the past year that can serve as training examples of related work, and other relevant topics.

(9) *Equivalent training.* Employers who can show by documentation or certification that an employee's work experience and/or training has resulted in training equivalent to that training required in paragraphs (e)(1) through (e)(4) of this section shall not be required to provide the initial training requirements of those paragraphs to such employees. However, certified employees or employees with equivalent training new to a site shall receive appropriate, site specific training before site entry and have appropriate supervised field experience at the new site. Equivalent training includes any academic training or the training that existing employees might have already received from actual hazardous waste site work experience.

CONTENT OF TRAINING PROGRAM

The training program must contain fundamental information such as effects and risks of safety and health hazards, as well as site-specific information such as the names of site personnel in charge. Table 12-1 lists the course content proposed by OSHA for workers at hazardous waste cleanup projects and RCRA treatment storage and disposal (TSD) facilities.

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Table 12-1 Proposed Content of Training Course[a]			
		40-hr	24-hr
1	Overview of the applicable paragraphs of 29 CFR 1910.120 and the elements of an employer's effective occupational safety and health program.	X	X
2	Effect of chemical exposures to hazardous substances (i.e., toxicity, carcinogens, irritants, sensitizers, etc.).	X	X
3	Effects of biological and radiological exposures.	X	X
4	Fire and explosion hazards (i.e., flammable and combustible liquids, reactive materials).	X	X
5	General safety hazards, including electrical hazards, powered equipment hazards, walking-working surface hazards and those hazards associated with hot and cold temperature extremes.	X	X
6	Confined space, tank and vault hazards and entry procedures.	X	X
7	Names of personnel and alternates, where appropriate, responsible for site safety and health at the site.	X	
8	Specific safety, health and other hazards that are to be addressed at a site and in the site safety and health plan.	X	X
9	Use of personal protective equipment and the implementation of the personal protective equipment program.	X	X
10	Work practices that will minimize employee risk from site hazards.	X	X
11	Safe use of engineering controls and equipment and any new relevant technology or procedure.	X	X
12	Content of the medical surveillance program and requirements, including the recognition of signs and symptoms of overexposure to hazardous substances.	X	X
13	The contents of an effective site safety and health plan.	X	X
14	Use of monitoring equipment with "hands-on" experience and the implementation of the employee and site monitoring program.	X	X
15	Implementation and use of the informational program.	X	
16	Drum and container handling procedures and the elements of a spill containment program.	X	X
17	Selection and use of material handling equipment.	X	
18	Methods for assessment of risk and handling of radioactive wastes.	X	
19	Methods for handling shock-sensitive wastes.	X	
20	Laboratory waste pack handling procedures.	X	
21	Container sampling procedures and safeguards.	X	
22	Safe preparation procedures for shipping and transport of containers.	X	
23	Decontamination program and procedures.	X	X
24	Emergency response plan and procedures including first-aid.	X	X
25	Safe site illumination levels.	X	
26	Site sanitation procedures and equipment for employee needs.	X	
27	Review of the applicable appendices to 29 CFR 1910.120.	X	X
28	Overview and explanation of OSHA's hazard communication standard (29 CFR 1910.1200).	X	X
29	Sources of reference, additional information and efficient use of relevant manuals and hazard coding systems.	X	X
30	Principles of toxicology and biological monitoring	X	X
31	Rights and responsibilities of employees and employers under OSHA and CERCLA.	X	X
32	"Hands-on" field exercises and demonstrations.	X	X
33	Review of employer's training program and personnel responsible for that program.		X
34	Final examination.	X	X
35	Management of hazardous wastes and their disposal.		
36	Federal, state and local agencies to be contacted in the event of a release of hazardous substances.		
37	Management of emergency procedures in the event of a release of hazardous substances.		

[a] Source: From OSHA Hazardous Waste Training 29 CFR 1910.120.

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Table 12-2 indicates how four training organizations in differnt locations have met the 40-hour course requirements, with variations in the time and emphasis placed on subjects/topics.

Table 12-2 TRAINING COURSE OUTLINES

Subject	A*	B*	C*	D*
Administration , Registration & Exams	3	2	3	2
Introduction/History	2	1	2	1
Superfund, DOT & RCRA Regulations	2	2	3	1
Chemistry	2	2	1	4
Information Gathering	1	1	1	2
Toxicology & Risk Assessment	2	1	1	2
Confined Spaces & Lock Out-Tag Out	1	1	1	1
Bio-Hazards	1	1	1	1
Health Effects & Symptom Recognition	1	2	1	2
Hazard Recognition	2	3	2	4
Site Safety Plans	4	2	3	1
Work Practices	3	3	2	1
Engineering Controls	2	3	2	2
Decontamination	2	2	3	1
Personal Protective Equipment	8	9	11	10
Medical Surveillance	1	1	1	1
Air Monitoring & Sampling	2	3	1	3
Worker & Community Right-to-Know MSDS	1	1	1	1
Total Hours	40	40	40	40

*A, Florida; *B, Michigan; *C, South Carolina; *D, NIOSH, EPA Pilot Course

Many other approaches can be used to meet the OSHA and EPA training requirements. One example is using the Health and Safety Plan as the training course manual. See Appendix E, DoD Site Health and Safety Plan, for such an example.

This HASP contained the OSHA required training content as well as the safety plan. Specialized training and awareness can be accomplished by job specific training. See Appendix H for an example of emphasizing for a group of works such as ecological workers.

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TYPES OF TRAINING

General Site Workers

General site workers, including equipment operators, general laborers, technicians, and other supervised personnel, should have training that provides an overview of the site, specific hazards and their risks, hazard recognition, and how to properly use the engineered controls and other means of controlling the site's hazards and risks. General site workers should receive close supervision from a trained, experienced supervisor at least during the three days of work following training. Some employees require additional follow-up training to develop good work practices on new tasks. Daily safety reviews just prior to commencing site work for the shift are a good way to give refresher training, make sure that everyone understands the tasks for the day, and inform workers of any new conditions on the site.

A few general site workers who may occasionally supervise others or must deal with special hazards should receive additional training in the following areas:

- Site surveillance;
- Management of hazardous wastes and their disposal;
- Use and decontamination of fully encapsulating protective clothing and equipment;
- Federal, state and local agencies to be contacted in the event of a release of hazardous substances; and
- Management of emergency procedures in the event of a release of hazardous substances.

On-site Management and Supervisors

On-site management and supervisors, such as team leaders, who are responsible for directing others should receive the same training as the general site workers for whom they are responsible. They also need additional training to enhance their ability to provide guidance and make informed decisions. This training should include supervisory skills, planning and management of site cleanup operations, and techniques to communicate with the press and community.

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Health and Safety Staff

Those with specific responsibilities for health and safety guidance on-site should be familiar with the training provided to general site workers and their supervisors and should receive advanced training in hazardous substance health and safety sampling, monitoring, surveillance, evaluation, and control procedures.

On-site Emergency Personnel

Those who have emergency roles in addition to their ordinary duties must have a thorough grounding in emergency response. Training should be directly related to their specific roles and should include subjects such as the following:

- Emergency chain of command;
- Communication methods and signals;
- How to call for help;
- Emergency equipment and its use;
- Emergency evacuation while wearing PPE;
- Removing injured personnel from enclosed spaces; and
- Off-site support and how to use it.

These personnel should obtain certification in first aid and CPR and practice treatment techniques regularly, with an emphasis on (1) recognizing and treating chemical and physical injuries and (2) recognizing and treating heat and cold stress.

Off-site Emergency Personnel

Off-site emergency personnel include, for example, local fire fighters and ambulance crews, who often provide front-line response and run the risk of acute hazard exposure equal to that of any on-site worker. These personnel must be trained to recognize and deal effectively with on-site hazards. Lack of training may lead to their inadvertently worsening an emergency by improper actions (e.g., spraying water on a water-reactive chemical and causing an explosion). Inadequate knowledge of the on-site emergency chain of command may cause confusion and delays. Site management should, at a minimum, supplement off-site personnel emergency training with the following information:

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- Site-specific hazards;
- Appropriate response techniques;
- Site emergency procedures; and
- Decontamination procedures.

Visitors

Visitors to the site, including elected and appointed officials, reporters, and senior-level management, should receive a safety briefing. These visitors should not be permitted in the exclusion zone unless they have been trained, fit-tested, and medically approved for respirator use. An observation tower in the clean zone reduces the need for visitors to enter the contaminated area.

TRANSPORTERS OF HAZARDOUS WASTE OR OTHER HAZARDOUS MATERIALS

Transporters of hazardous waste and other hazardous materials are required to be trained prior to start of work. Training may be required even if the job is not a hazardous cleanup site. There are different training requirements depending on how the material is being transported. There is designated general training which provides an overview of the transportation efforts. Separate specialized training for those participating in land transport, which included shipment by rail: sea or water transport; and transportation by air.

RECORD OF TRAINING

A record of training should be maintained to confirm that every person assigned to a task has had adequate training for that task and that every employee's training is up to date. It is very important to document the training. Performance measurements prior to site entry are good personnel management and protection against future liability.

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A CONCEPTUAL FRAMEWORK FOR PROGRAM DEVELOPMENT

In order to develop a good sound hazardous waste worker training program in an orderly and systematic fashion, one must view the task in conceptual terms. Typically, program start-up involves a preparation stage, a development stage, an implementation stage, and an evaluation stage. If the program status goes beyond that of a pilot, an improvement feedback loop develops between the evaluation and implementation stages.

THE PREPARATION STAGE

During this preliminary phase, a number of considerations must be addressed, including a complete needs assessment. In assessing the needs for a hazardous material control program, questionnaires, pre-tests, and standard compilations of sociometric data can be relied upon. During this phase of operations in developing the program, staff members evaluate existing hazardous material training programs and seminars.

Audience analysis represents another often neglected part of this preparatory phase of development. The creation of a successful hazardous material control program must begin with an adequate audience analysis. Various tools can be used to compile data on potential audiences, but it remains the sole responsibility of the program development team to analyze, assimilate, and apply such data. The goals and objectives for a program on proper use and maintenance of a self-contained breathing apparatus will vary significantly depending upon whether the primary audience is composed of experienced response team members or novices. Similarly, there may be considerable gaps between the manipulative abilities of an experienced response person and those of a lab technician. Again, no single program can accommodate all the needs of a highly diversified audience; however, in order to succeed, a program must be directed toward a specific target audience.

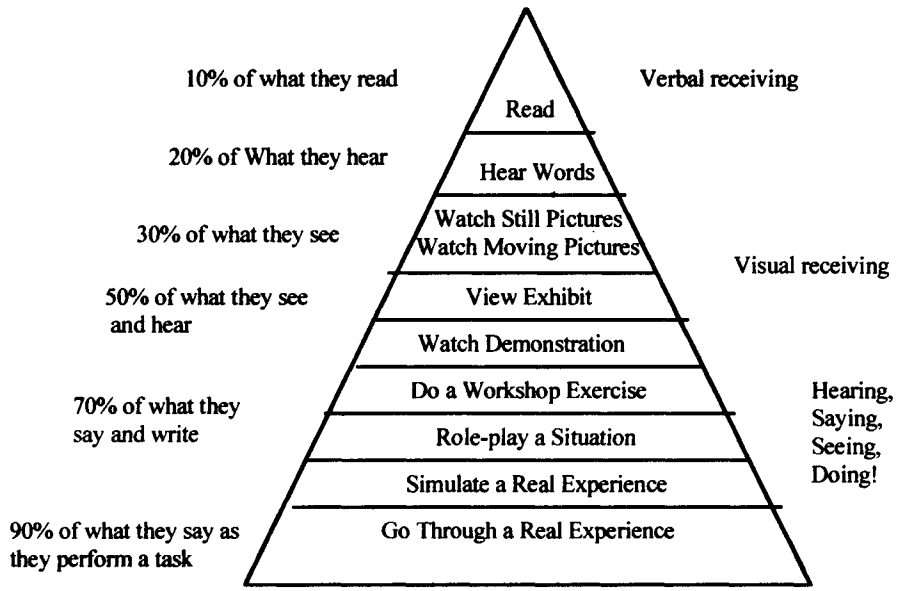
Adult education has developed several education and training methods to effectively deal with side student variance in education and experience. A publication, "A Guide for Planning and Implementing Instruction for Adults/A Theme Based Approach" by John M. Dirkx, gives one example that can be adapted to the Hazwoper 40 Hour course. The concept of integrated, theme based (ITB) instructions for adults utilizes the individual student's life experiences to bring the total class to a more thorough understanding of one theme, such as Hazardous Waste Health & Safety [Dirkx and Prenger, 1997].

The illustration in Figure 12-1 reminds us of the cumulative effects of training methods that utilize audio, visual, demonstration, exercise and

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performance [Dale, 1954]. This building of information reinforced by multimedia is well suited to adult classes.

Figure 12-1 Cone of experience

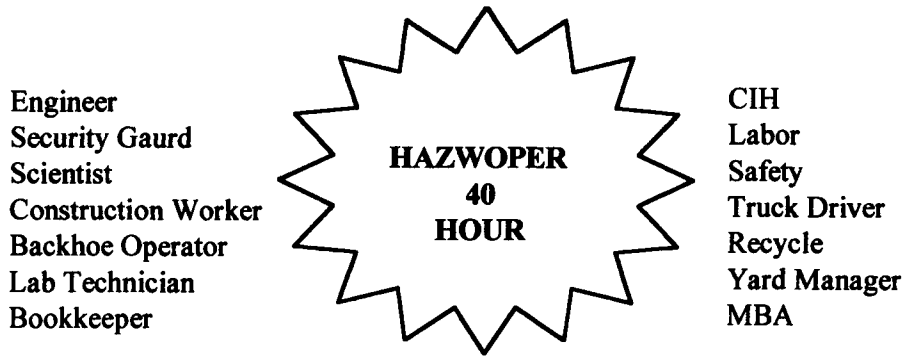


[Dale, 1954]

Adult educators have found that linking an individual's life experience with the new information will help the student incorporate the information into use plus cause the learner to pursue the learning process. This process is sometimes labeled contextual learning. The following multidisciplinary approach is illustrated in Figure 12-2. Students of many different experiences, vocations and educational levels can contribute to the group's goal of learning the topic (in this case, Health & Safety for Hazardous Waste Activities).

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Figure 12-2 Contributions of experienced students.



The interdisciplinary approach relies on storytelling, literacy, collaborative learning, research skills, small group discussion, class projects and exercise. Success is most fully realized when the training topic connects to the concerns of the individual. This is most likely to occur when the student can contribute something of his past experience and knowledge to other group and get positive feedback for the contribution. This then prepares the learner to be more open for new information from other students and instructors; thus completing the circle of contextual learning. The student is then more receptive to class participation and attaches the new information to his existing knowledge. This cycle often generates the desire for continual learning and the use of the new information [Gutloff, 1996].

Before turning away from the topic of program preparation, the role of the advisory committee as a means of diagnosing needs and analyzing audiences needs to be mentioned. Well-selected advisory groups representing industry and other appropriate agencies are critical to the viability of spill and incident control training programs. One case in point is the Oil Spill Control Course Advisory Committee composed of members from the American Petroleum Institute (API) and major oil companies. Another example is the Hazardous Material Control Course Oversight Committee, chaired by the representative from a major chemical company and made up of representatives from various sectors of the chemical, transportation, and petrochemical industries.

These advisors' groups should carefully refrain from promoting any specific training program. Their purpose is not to endorse the programs, but to provide insights and information regarding how the programs might be better organized and improved in order to meet the most pressing needs of industry. Representatives from the industrial sectors offer excellent sources of information regarding basic training needs as well as valuable audience analysis data. By selecting representatives from a variety of industrial

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backgrounds and from different geographical locations, it is possible to avoid the parochialism that might otherwise develop in a state or regional training program.

THE DEVELOPMENT STAGE

Once the stage has been set, it is necessary to move into the developmental phase of operations. The bulk of the work to be done in this area entails the development of teaching/learning materials that will be compatible with the needs and audiences identified earlier. The use of modular training units can facilitate continuing education, flexible delivery, and ease of update.

Two major areas of activity can be identified in this stage: (1) formulating objectives, and (2) selecting and organizing content [Taba, 1962]. As one might expect, the two areas involving objectives and content have a tendency to overlap. Therefore, it is impractical to regard them as totally separate and distinct; objectives will influence content and vice versa.

In formulating broad-based objectives for a hazardous material control program, the goals of a course should:

1. Meet the general needs of those concerned with hazardous material spills including waste handling reporting regulations, control techniques, and recovery operations;
2. Focus upon a variety of hazardous substances such that participants could become familiar with a wide range of hazardous materials;
3. Cover lower cognitive and theoretical material in the classroom, reinforcing and expanding bases with hands-on manipulative training;
4. Introduce participants to pragmatic aspects of personnel protection, toxicology, and site safety operations;
5. Familiarize attendees with fire control tactics and strategies that might be relevant and applicable to hazardous material incidents;
6. Offer an opportunity for participants to test and evaluate their capabilities by responding to simulated hazardous materials incidents; and
7. Serve as a clearinghouse through which attendees could obtain information on the latest equipment, apparatus, and procedures for controlling hazardous material incidents [Payne and Strong, 1980].

By using this basic format and making modifications where necessary, it is possible to establish suitable underpinnings not only for a single program, but for a number of spin-off activities as well.

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Although these objectives can certainly provide an adequate nucleus for a training program for handling hazardous materials, most instructional staff members find it useful to fine tune such broad-based objectives into more specific *behavioral objectives*. Well-defined behavioral objectives should be written clearly in a manner that incorporates: (1) a readily observable behavior, (2) the conditions or restrictions under which such behavior is to be observed, and (3) the performance level expected of the learner [Mager, 1962]. For example, a behavioral objective involving hazardous waste site assessment might be phrased as follows: "The learner, while wearing an encapsulated suit, will use a standard field identification kit to correctly identify an unknown waste sample taken from an overpack drum within one hour." The components of the behavioral objective are identified below:

Observable behavior	-	will identify unknown waste sample
Conditions of behavior	-	while wearing an encapsulated suit and using a standard field I.D. kit
Performance level	-	*correctly* identify within 1 hour

Such behavioral objectives are useful in providing coherence and unity. Yet, if not used carefully, they may become awkward, restricting program flexibility. For instance, if such detailed objectives actually become an integral part of the course manual, then in order to remain truly accurate each time an objective is altered, the manual itself will have to be modified. For this reason, it is often helpful to include the behavioral objectives on the instructor's lesson plans where they might be altered without disrupting overall program flexibility.

The second major activity in the development stage involves selecting and organizing content. Content selection is normally thought of as a straightforward, linear process. It is commonly thought that one would be able to simply list the major topics of concern, and merely subdivide them in order to prepare a curriculum outline. Unfortunately, this approach presupposes unlimited time and a learning process that proceeds in a predictable, clockwise fashion.

Perhaps one of the greatest difficulties faced by an individual attempting to select content for a training program of this nature is in determining what to include and what not to include. As suggested earlier, a careful audience analysis and well-formulated objectives make this task easier. Still, program developers often find themselves with too much material and too little time. Content must be selected such that the material can be presented to the *target audience* within the specified time constraints. The key here lies within the ability to reach the specific target audience identified earlier. Participants on the periphery of this audience should not be ignored; nor can they expect the

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program to accommodate them at the expense of the target group. As a matter of fact, such peripheral participants will generally derive at least some benefit from the content selected for the target audience. Priorities must be established so that the most important information receives primary consideration.

Coincidental to content selection is content organization. Topics should generally be structured so that there is movement from the known to the unknown, from the simple to the complex, from the easy to the difficult [Taba, 1962, Dirkx and Prenger, 1997]. It is often advantageous to identify certain core ideas that seem to represent the very essence of certain topics. Without fail these ideas and concepts fall within the realm of both basic and vital. Surrounding these vital kernels are myriads of information which are mostly represented in as basic. What must be done, then, is to select certain clusters of information from these areas that will selectively reinforce and expand the core ideas. This concept of organizing content with respect to core and cluster areas is not new, yet it is seldom applied in the areas of training for hazardous material and hazardous waste handling.

THE IMPLEMENTATION STAGE

The third major phase of program development, that of implementation, involves translating what has previously existed as theory into practice. Of particular interest are the subjects of selecting and organizing learning experiences, and applying teaching methodologies.

Hazardous material control training offers an excellent opportunity to apply a well-balanced mixture of classroom and field training techniques. This basic teaching-learning design was used by the Texas Engineering Extension Service's Oil Spill Control Course in 1976 as an attempt to successfully mesh traditional classroom presentations with pragmatic hands-on training. In order to achieve the necessary balance between classroom and field training for this program, it was necessary to provide traditional classroom theory as a complement to pragmatic field application. In order to subordinate formal classroom sessions to hands-on training, instructors introduced each major topic through a brief classroom presentation and relied upon field exercises for reinforcement and practical clarification. Instructors also attempted to enhance student participation through discussion groups, problem-solving exercises, and question and answer periods. Subsequent evaluation of this early program revealed four primary benefits:

1. By encouraging participation, students benefit from *active* as opposed to *passive* learning;

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2. Similarly, student participation in a seminar atmosphere provides for valuable exchange of information among the students themselves;
3. Introducing basics in class and reinforcing and expanding them with hands-on training tempers textbook learning with actual experience; and
4. Finally, this type of arrangement allows the course to be taught effectively, by following the "spiral step" method.

The spiral step methodology is the underlying strategy inherent in this type of program. This approach exposes course participants to units of subject matter in increasing order of complexity, continuously reinforcing them with appropriate skill developing exercises. Hence, the order of moving from the simple to the complex, the known to the unknown, and the easy to the difficult is maintained. Moreover, this pedagogical approach helps to preserve the unity of the curriculum as established during the preparation and development stages by providing certain "threads" or common denominators that link basic concepts in an overall spiral configuration. One of the greatest arguments in favor of this strategy lies not in its ability to preserve order and unity, but in its tendency to promote what has been called cumulative learning. Learning involves the cumulative development of mental skills such that each succeeding idea or question requires an increasingly difficult mental operation [Taba, 1962]. When training in hazardous material control, however, this cumulative effect involves not only the cognitive but also the manipulative domain. Participants are thereby able to simultaneously expand both dimensions of their abilities. The schematic in Figure 12-3 depicts how one isolated area—toxicological considerations—is introduced, expanded, and reinforced in a spiral step manner. It is important to note that the curriculum is designed such that each successive upward spiral represents an increase in both the complexity of the material covered and the difficulty with which physical skills are mastered, thus helping to foster cumulative learning.

While the spiral step approach is a crucial element in curriculum design and integration, there are other teaching methodologies and precepts that also bear mentioning. One such element involves the depth with which field training is carried out. Care must be taken to avoid structuring practical exercises as demonstrations. While certain demonstrations are useful, they simply cannot replace active student participation. In addition, field training must be carried out under realistic conditions in order to be most effective. Of course such realistic field training necessitates careful supervision by qualified instructors as well as enthusiastic participation by course attendees. Often overlooked in many programs is the need to keep such practical exercises small in order to maintain an adequate instructor-participant ratio. Depending on the exact nature of the exercise, an adequate ratio for field training may be maintained

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by providing one instructor for every 5 to 10 participants. Going beyond a limit of 10 participants per instructor may create logistics problems as well as safety hazards under certain conditions. Likewise, it may force the instructor to rely more heavily upon strategies normally reserved for demonstrations, diminishing the desired effect of the field exercises.

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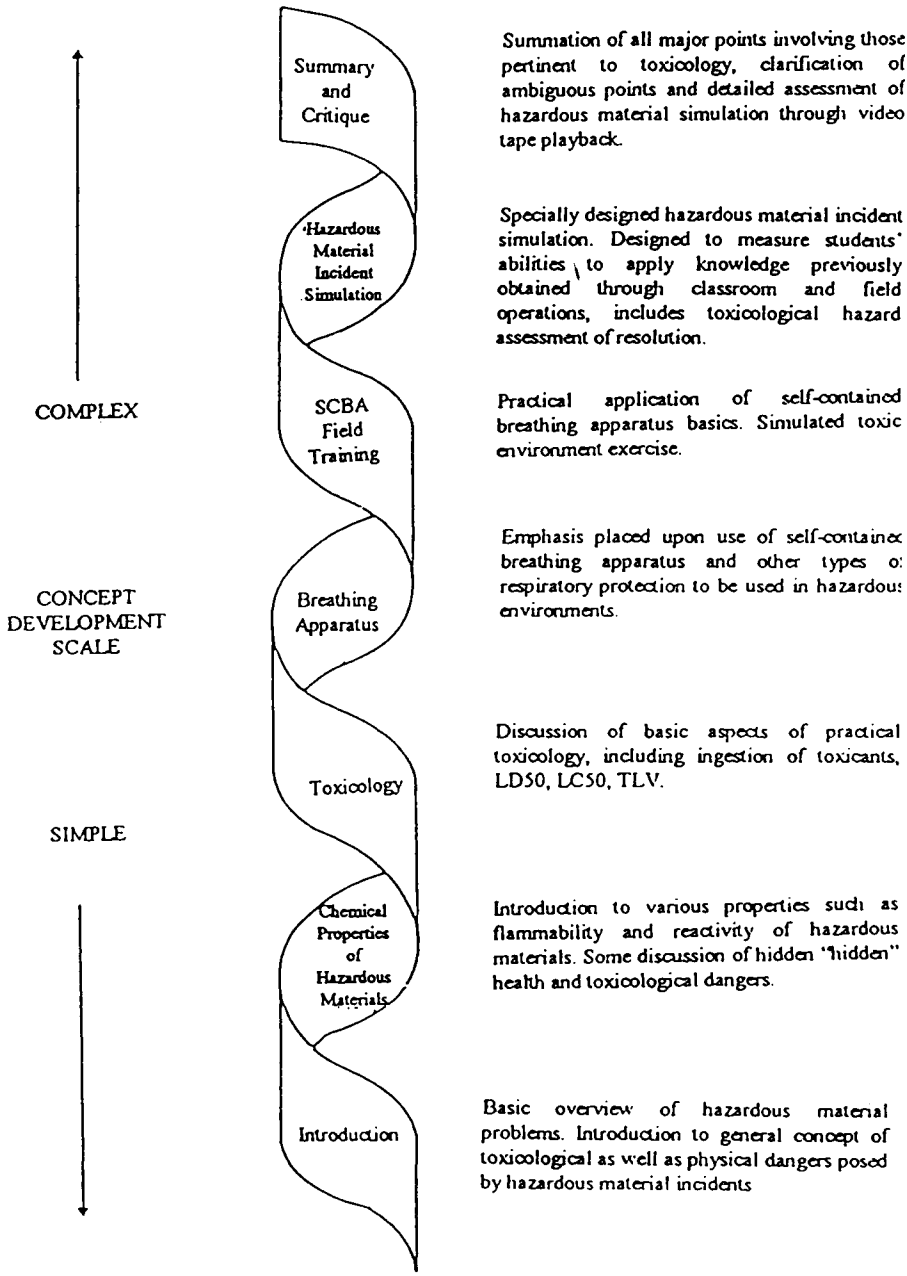


Figure 12-3 Spiral step curriculum design.

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In addition to the spiral step approach, techniques to help bridge the gap between theory and application need to be applied to training programs involving hazardous materials control. It has been previously noted that a well-designed spiral step curriculum can provide a sound basis for cumulative learning. Well-formulated objectives, properly selected content, and carefully chosen teaching methods all combine to form an integrated and balanced program. Basic topics are presented in classroom sessions, and expanded and specifically applied under field conditions. Thus, a student may learn a considerable amount about SCBAs in the classroom and may develop a fair amount of expertise in using them under field conditions. The same might be said for a number of other topics such as protective clothing, waste recovery, and spill control. However, there must exist a means of helping the course participants to assimilate this knowledge into a broad perspective. In other words, they must be able to take this information and apply it to a greater scenario such as a hazardous waste dump site, a train derailment, or a hazardous material spill.

One way of bridging the gap between the acquisition and the application of information is through a written problem session. Such a problem session must necessarily come after participants have covered the bulk of the course material. Inserted into the programming at this point, the problem session becomes a tool with which the instructors and participants might generate a positive attitude and response. Attempting to place the problem session too early in the programming before all basic materials have been covered would lead to confusion and probably a feeling of negativism.

Such a session usually works best if it is carefully thought out and uses accurate maps and descriptions of the problem scenario. All variables such as date, location, meteorological conditions, logistics, and available supplies and manpower are generally given by the instructor. All that remains, then, is for the participants to respond to the scenario within these guidelines. Of course some double-sided problems are included, not to trick participants, but to alert them to hidden difficulties that may not be readily apparent. As a group response this strategy works well; not only do the group members use what they have learned as a result of the training program, but they also draw upon their own experiences and those of their peers. Most importantly, they are allowed the luxury of seeing a complete scenario unfold and develop before their eyes. Quite literally, they may respond to a full-blown incident without leaving their chairs. At this point they begin to make the transition from simply acquiring the information to applying it.

Finally, some means of going beyond this armchair quarterback situation is desirable as both a measuring device and confidence builder. The full-scale field simulation provides this means. Incorporated into a program after all basic knowledge and skills have been introduced and expanded, the field

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simulation is designed to approximate as nearly as possible "the real thing." Because it is designed as a test of sorts, the simulation should not be used by instructors as a device to measure individual skills and competencies. Rather, it should be seen as a measure of the entire group's ability to function under the stress of an actual incident. Individuals must assess the overall situation, sort through the relevant variables, determine appropriate response measures, and initiate them accordingly. The more realistic the controlled conditions are, the more successful the simulation is likely to be. Performing under such conditions has a tendency to dispel any attitude of "it's only a game." Realistic conditions also have a way of producing stress in individuals to a point where they perform at the upper limits of their capabilities. Furthermore, such simulations often serve as confidence builders. For maximum effectiveness, it is helpful to videotape the simulated incident for prompt playback. The videotape playback serves as an informal critique of the group's overall response. Instructors must be careful to avoid playing too obvious a role in the critique. Emphasis must be placed upon constructive criticism. It is imperative that the instructor moderate this critique work skillfully to allow the participants to provide the greatest bulk of the feedback. Experience has shown in many cases that the enthusiasm from a well-designed simulation carries over so that those involved actually do a better job of evaluating their performances than the instructors.

THE EVALUATION STAGE

One of the most important aspects of any educational program involves an assessment of the success of the program as perceived by the instructor and participant. In most traditional settings the primary evaluative tool directed toward the student is the formal examination. In hazardous materials control training courses, the use of formal examinations is recommended. In addition, in these courses and other short industrial courses, it appears that the use of individualized instruction tactics might be applied effectively. Such tactics normally require that the instructors develop a rapport with course participants so that they might continuously receive and digest feedback from them. By so doing, the instructor can accommodate participants by clarifying and expanding upon course information as required. Although this tactic develops around and exists upon a relatively informal phase, it nonetheless offers a reasonable means of monitoring and improving student performance.

Another evaluative tool mentioned earlier is the hazardous material simulation. As discussed, the simulation provides the basis for a postincident critique that may be helpful in evaluating the group's overall response; however, it rarely develops enough detail to allow for individual evaluation.

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Indiscriminate use of such critiques can often do more damage than good by attempting to place blame and highlight individual mistakes.

Although it is important to assess levels of student performance, it is perhaps even more important to determine the strengths and weaknesses of the program itself. This may be especially true in the case of short, continuing education courses. Course evaluations provide basic feedback essential to program improvement. Such an evaluation should be simple, easily tallied, and should allow for comments regarding each specific topic of presentation of a program. Moreover, an attempt should be made to ensure that students regard such evaluations as important tools. Accuracy and honesty must be emphasized in the name of constructive criticism. An important point here is that the actual presentation, not the instructor, should be evaluated. It is wise to prompt course participants to evaluate each session as it concludes rather than evaluating all the sessions at the end of the course. It is also important to solicit suggestions and other comments that might be helpful in improving the course. Anonymity often helps to ensure objective ratings. Figure 12-4 illustrates one typical course evaluation sheet used successfully by the Texas Engineering Extension Service.

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Session Date _____

HAZARDOUS MATERIAL CONTROL COURSE
EVALUATION SHEET

This evaluation sheet will provide important feedback that will allow us to make improvements in the course. Please assist us by responding completely.

1. Circle the appropriate response. Rank only the presentation--not the instructor or topic.

Chemical Properties of hazardous materials: 1 2 3 4 5 6 7 8 9 10 (Poor — Average — Good)

Comments: _____

Toxicology: 1 2 3 4 5 6 7 8 9 10 (Poor — Average — Good)

Comments: _____

Breathing Apparatus-SCBA Training: 1 2 3 4 5 6 7 8 9 10 (Poor — Average — Good)

Comments: _____

Hazardous Environment: 1 2 3 4 5 6 7 8 9 10 (Poor — Average — Good)

Comments: _____

2. What did you like least?

3. What additional topics or exercises would you like to see added?

4. Were staff members and instructors professional, well-versed and generally capable?

5. Were visual aids and teaching materials of a professional quality, and were they suitable?

Figure 12-4 Typical Course Evaluation Sheet.

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CULTIVATING THE IMPROVEMENT FEEDBACK LOOP

Course evaluations including written critiques and informal comments must somehow be systematically analyzed if they are to help establish a means of improving the program. Objective tallies might help to identify generic weaknesses in a program, but when used alone often fall short in offering any remedy. Hence, an instructor may receive average ratings of 2 (poor) on three of his five sessions but may receive marks of 9 (good) on the remaining two sessions. Clearly something is amiss with three sections; however, simple numerical marks offer no explanation or possible solution to the problem.

In order to move beyond the identification of generic weaknesses, one must look carefully at specific comments provided by participants. Perhaps in the earlier example a common weakness in visual aids might be suggested by student comments such as "slides were poorly developed and often out of focus" or "transparency materials were smudged and not readable." Such comments provide the functional basis for the improvement feedback loop. Such comments almost always identify what the participant perceives as a weakness. Of course, invalid criticisms are often made and must be regarded as such.

The feedback loop might also be expanded through informal discussions between instructors and course participants. In fact, the suggestion to videotape the Oil Spill Control Course simulation as a critique came about partly as a result of such an informal discussion. Advisory group suggestions often surface in this feedback loop and emerge as significant course improvements.

In summation, it is necessary to view the four-stage program development process as a dynamic one. The first stage of preparation helps to establish a basis for further development. The second stage involves formulating objectives and choosing and arranging content material in a manner to best facilitate learning. The third phase of the development process involves the actual methodologies required to translate theory into practice. The fourth stage concerns analysis of both the program and its participants. Finally, an improvement feedback loop develops as a logical outgrowth of program evaluation. It is through this link between the evaluation and implementation stages that a program may be updated and improved. The loop itself helps to ensure that the program development process remains dynamic.

ORGANIZATIONS OFFERING TRAINING PROGRAMS

A wide variety of hazardous waste training programs have been developed by other government and industrial organizations in the United States. Many of

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these programs are available to the public for a registration fee [Keller and Associates, 1987; Fournier, 1985]. Community Colleges are frequent sources for the 40 Hour HAZWOPER courses.

A survey, sponsored by Wayne State University, was integrated into a United States Public Health Service, Bureau of Health Professions contract designed to investigate the appropriateness and adequacy of hazardous waste education in the United States. The study covers two areas: (1) hazardous waste education provided by academic institutions in the form of regular, credit course work and degrees and (2) hazardous waste education provided through non-credit continuing education short courses, workshops, and training sessions. The results of the survey were converted into a public access electronic bulletin board. The following several pages provide an abstract of the Wayne State University Survey [Hughes et al, 1990].

Data Gathering Procedure

For this part of the study, information was collected using a questionnaire. This questionnaire was designed to collect information on:

1. The type of hazardous waste education offered (undergraduate, graduate, or non-credit);
2. The colleges and/or departments participating in each type of education offered;
3. The degrees offered which contain hazardous waste education and whether that offering is required, elective or part of an option;
4. Whether the hazardous waste program is accredited;
5. The inception date of any degrees, options, certifications, individual credit courses or non-credit courses offered in hazardous waste; and
6. A request for program brochures and course outlines.

It was necessary in some cases to augment the responses on the questionnaire using references such as the *1989 Peterson's Guide to Graduate Programs in Engineering and Applied Science*, the *1988 Graduate School Guide* and the *AICHE Graduate School Directory.*

Initially, the survey was mailed selectively to groups of schools which were likely to have programs. These groups included:

- National Environmental Health Association (NEHA) Educational Institution members
- Accredited U.S. Schools of Public Health

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- National Institute for Occupational Safety and Health (NIOSH) funded schools
- National Institute of Environmental Health Sciences (NIEHS) funded schools
- Directors of Centers for Superfund Research
- Directors of Centers for Hazardous Waste Management
- Schools offering degrees in Industrial Safety and Health or Environmental and Occupational Health
- Members of the Association of Environmental Engineering Professors

After some replies were received and the questionnaire was refined using comments from the expert review panel, a comprehensive mailing of 1,469 was conducted. This mailing list was obtained from the *1989 HEP Higher Education Directory* which contains a listing of all accredited institutions of post-secondary education in the United States which meet the U.S. Department of Education eligibility requirements.

A telephone follow-up was used to contact institutions which did not respond to the mail survey. Sources which were used to identify institutions for the follow-up included:

The original mailing list from the *1989 HEP Higher Education Director*

An EPA Database on Educational Opportunities for Environmental Professionals

The EPA National Evaluation of Training and Technical Assistance in State RCRA Programs

An Illinois Institute of Technology list of college and university-based research centers in hazardous waste

Wayne State University Survey Results

Of the 1469 institutions contacted, 799 replied (54 percent). Of those 799, 591 (74 percent) have no hazardous waste education of any kind. Of the 208 remaining institutions, 167 offer at least one credit course as part of a degree program and 89 have noncredit training programs. Forty-one offer only non-credit continuing education courses. Of the 167 offering credit courses, about half (82) have hazardous waste courses that are required for the respective degree. The majority of degrees containing hazardous waste education are in engineering, particularly civil, environmental and chemical engineering.

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Offerings through environmental science, public health and environmental health are slightly less numerous.

Figure 12-5 provides a profile of the types of hazardous waste instruction offered at either or both (if applicable) undergraduate and graduate levels. Since courses are often offered at both levels and courses required of some students are electives for others, there is an overlap between the designated bars. While 117 universities offer at least one course at the undergraduate level and 116 at the graduate level, elimination of duplication yields 167 different institutions offering credit courses in hazardous waste management.

The survey identified four masters degrees, 13 graduate options, and three credit-based certificates in hazardous waste/materials management. The four masters degree programs are offered by New Jersey Institute of Technology in Newark, Tufts University in Medford, Wayne State University in Detroit and the University of San Francisco.

A total of 675 distinct short courses were evaluated. The largest segment of the short courses deal with legal, administrative and compliance related issues. Figure 12-6 presents a breakdown of the nondegree short courses Subject.

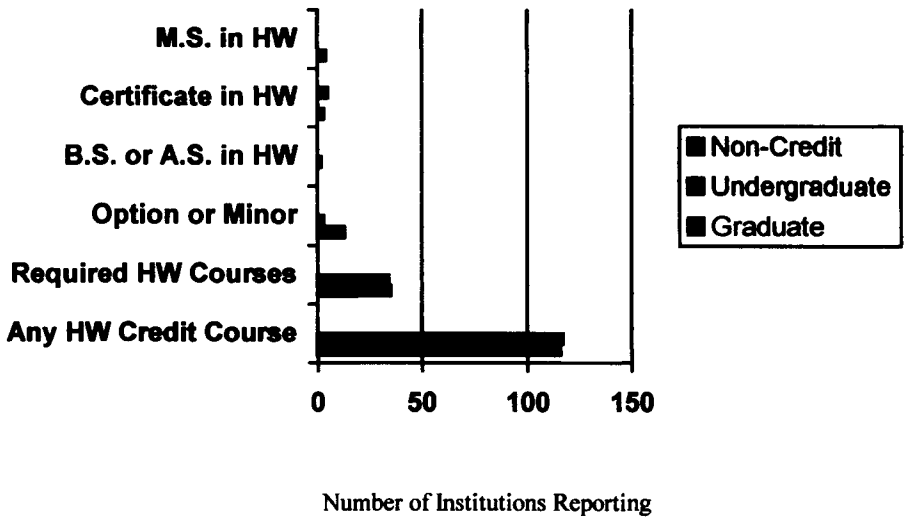


Figure 12-5 Profile of education institutions hazardous waste instruction offerings

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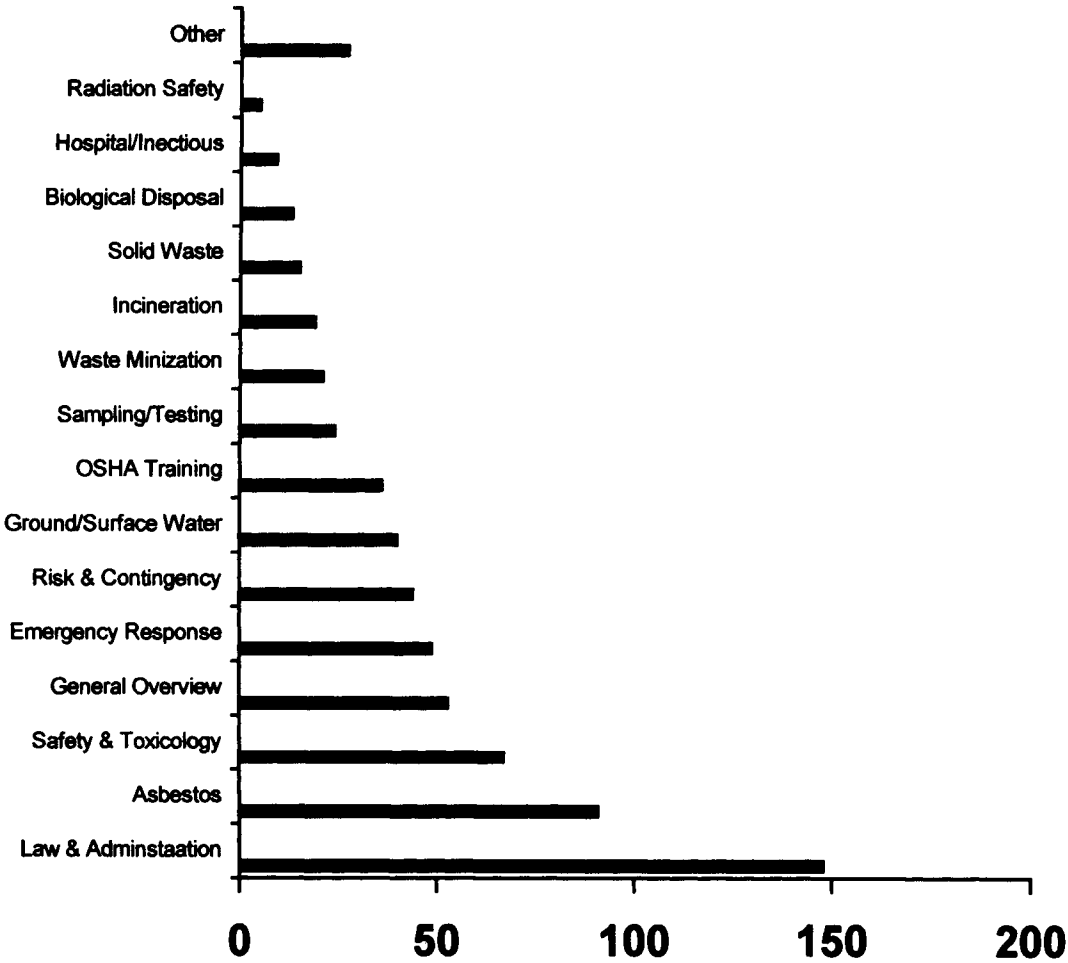


Figure 12-6 Nondegree short courses breakdown by subject [Hughes et al., 1990]

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Courses are offered through a variety of different avenues including government, universities, professional organizations, and private industry. The U.S. EPA Office of Solid Waste and Emergency Response has been identified as the largest single provider of hazardous waste related short courses, offering approximately 36 distinct short courses per quarter and 154 total courses per quarter including replications. The next three largest suppliers are Executive Enterprises, Inc., Georgia Institute of Technology, and Texas A&M University, respectively.

Additional Sources of Training Program Information

A number of companies have developed excellent training programs, many of which began as in-house projects designed to meet specific corporate needs. One presentation developed along these lines is Texaco's videotaped hazardous materials program.

Developed in 1982, the program was targeted at the multidisciplined, broad-based spill cleanup management teams that had previously undergone Texaco's similarly developed oil spill response training program [Weiss and Leigh, 1982]. The videotape format was selected as the most viable for a number of reasons including cost and in-house availability of existing playback equipment.

The Texaco program appears to be well grounded in its topical approach to subject matter. The program is also well designed in that it makes use of a tutored videotape instruction concept that allows for student-instructor dialogue and employs strategically placed breaks to avoid taxing the attention span of the student. Texaco's premise is that if properly used, the program teaches through repetition [Weiss and Leigh, 1982]. The program appears to be a well-constructed in-house program with enough flexibility for a variety of job levels. While the program lacks significant hands-on activities, Texaco has been careful to point out that this particular program is not directed toward individuals involved in actual hands-on activities relating to hazardous materials incidents.

Other corporate developed courses are Du Pont's "RIT" series and Union Carbide's "H.E.L.P." programs. These programs, similar to Texaco's, were developed in-house for the purpose of training company employees to handle hazardous materials emergencies specific to their industries.

In addition to these types of industry programs, a number of governmental agencies offer training activities. Swiss, et al., describe a response training program developed through a cooperative effort between the Environmental Emergency Division of the Canadian Environmental Protection Service, Atlantic Region and the provincial Environment and Emergency Measures

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Organization. This training activity is largely directed at volunteer firefighters and is designed to be presented at various extension centers throughout each province [Swiss et al., 1982].

Leading educational institutions including Iowa State University, The University of Michigan, and Louisiana State University offer various programs in hazardous material and waste control. Other training courses include those offered by cleanup contractors, consultants, and similar groups. Weiss and Leigh in their description of Texaco's in-house training program provided an interesting comparison of hazardous materials control programs offered by a number of groups [Weiss and Leigh, 1982]. Such an overview is interesting only as a topical comparison of curriculum design, methodologies, and philosophical approaches.

NIOSH developed in 1983-84, an occupational safety and health training program for superfund activities. The three-day course materials concentrate on hazard recognition and hazard control. The courses are available through educational resource centers in universities that have training grants from NIOSH, located throughout the United States [Martin et al., 1984].

The Department of Defense (DoD) has developed an entire range of training programs to prepare their employees for the environmental cleanup task facing the U.S. military organizations. The Environmental Training Center, U.S. Army, Fort Sill, Oklahoma, has undertaken a major portion of this task with courses specifically designed to protect the environment, personnel and the public. The Army's training courses emphasize practical hands-on training, a very good adaptation of DoD's long standing use of performance-type training. State and local employees have been given access to these courses as the DoD prepares to transfer property and facilities to local control.

The DoD has several specialized training programs that have world-wide recognition such as Explosive Ordnance Disposal (EOD) located at the Naval Ordnance Station in Indian Head, Maryland; a satellite facility at Eglin Air Force Base, Florida; and the Huntsville Corps of Engineers, Huntsville, Alabama (see Chapter 15, Ordnance, Explosive Waste, and Unexploded Ordnance for more details).

The U.S. Army Environmental Center at Aberdeen Proving Ground, Maryland has developed a computer based program that lists more than 4500 environmental related courses from more than 2000 environmental training providers within the continental United States. The list was developed by the Environmental Awareness Resource Center, U.S. Corps of Engineers Professional Development Support Center at Huntsville, Alabama. It is updated annually and is available on the World Wide Web.

Several groups such as the states of Utah and California, and USEPA Region 7, have taken the hazardous waste training far beyond the minimum 40

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hours of HAZWOPER. USEPA Region 7, Kansas City, Kansas, has developed an excellent modular training program that consists of between 200 and 300 contract hours. The modular concept facilitates continuing education, ease of updates and flexibility of delivery over time. Much of the modular training content was developed by Ecology and Environmental, Inc., Overland, Kansas with direct input from EPA offices in Cincinnati, Ohio; Edison, New Jersey; and Kansas City, Kansas.

With today's emphasis on controlling hazardous materials, wastes, and by-products, a proliferation of training programs aimed at these audiences is hardly unexpected. Many diverse groups are offering programs directed at managing and controlling releases of hazardous materials. The text by Shaye, adapted from Volume II of the *EPA Directory of Hazardous Materials Response Training*, gives a regional listing of the programs being offered and their major points of emphasis [29 CFR 1910.120]. The *Directory* itself is approximately 190 pages long and gives detailed information about each training program.

Another similar publication, Hazardous Materials Spills Management Review, prepared for the American Petroleum Institute by the Texas Transportation Institute and the Texas Engineering Extension Service, provides statistical data about hazardous materials training programs. Of those programs documented by this review, 50 percent constitute training courses of some length while the remaining 50 percent are composed of short conferences and seminars. Hands-on training of some type appears in approximately 54 percent of the programs. Most of the programs are oriented toward public safety personnel (38 percent) with a slightly smaller percentage (34 percent) oriented toward private industry audiences. The remainder (28 percent) of the courses are directed toward governmental personnel and others [Texas A&M, 1990]. These statistics suggest that high priorities are placed upon providing training to both public and private company response personnel. One might conclude that such training would emphasize emergency control and stabilization techniques as opposed to management overviews of hazardous materials. Moreover, the fact that 54 percent of the programs offer some type of hands-on training seems to indicate that programs which are both practical and applicable are favored by a majority of trainees. As in the case of the *EPA Directory*, the *Hazardous Materials - Spills Management Review* provides details including course length, topics, tuition costs, and contact person for each program catalogued.

In addition to these two major directories of hazardous material control training programs, there are several other sources of information. Federal agencies such as the Department of Transportation, the Environmental Protection Agency, the National Institute for Occupational Safety and Health, and the Occupational Safety and Health Administration may provide valuable

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information on program availability. Other groups such as the Chemical Manufacturers' Association, National Environmental Training Association, and the National Tank Truck Carriers Association may also be able to provide information on programs. See Chapter 17, Transportation Safety for more details on health and safety training for hazardous materials haulers.

CONCLUSION

Today's burgeoning technology brings with it tomorrow's promise of increased production of hazardous materials and wastes. The common challenge facing industry, state and local government, and leading academic institutions is that of ensuring that such technical advances do not occur at the expense of public health and safety.

Waste minimization has become an integral part of the pollution control legislation in recent years. Hazardous waste health and safety training programs should recognize this change. Often the results of waste minimization produces higher concentrations in a reduced volume. Another outcome is the constantly changing chemical characteristics of hazardous waste due to process changes and chemical substitution. These changes must be identified and incorporated into training programs to keep them current

A practical part of this challenge involves hazardous material and waste control training. Those on the cutting edge of technology must endeavor to see that training should develop in conjunction with emerging technologies. Traditional approaches to training must be critically evaluated and bolstered where necessary with new and perceptive insights. Training techniques cannot remain static; for only through systematic growth and development will training help society rise to meet the challenge of the future.

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13

HEALTH AND SAFETY PLANS AND CONTINGENCY PLANS

Charles J. Sawyer, C.I.H., P.E.
William F. Martin, P.E.

Uncontrolled hazardous waste sites can present a broad range of potential environmental health and safety problems. Occupational exposure to hazards associated with waste site exploration, sampling, evaluation, and subsequent remediation can be controlled or avoided. The success in controlling adverse exposures depends on the detailed planning, training, scheduling, and execution of a well defined plan to remediate the hazardous waste site. Such a plan should be drafted utilizing an interdisciplinary team of technical experts, including analytical chemistry, geology, hydrology, environmental engineering, industrial hygiene, medicine, toxicology, safety and fire protection, civil engineering, and engineering project management.

A key element of the plan is a detailed health and safety plan (HASP). Because of the range of complexities associated with various uncontrolled hazardous waste sites, site specific information must be carefully integrated to develop a satisfactory remedial action/contingency plan. A contingency plan with all its elements is necessary insurance to protect against upset conditions possibly threatening the health and safety of the workers, and/or the surrounding environment. A well-developed HASP plan should minimize the need to ever effect the call-up of a contingency plan. However, if and when an uncontrolled chain of events leads to an emergency situation, a readily adaptable contingency plan with clear responsibilities and sequenced program of activities brought into action should be effective towards prompt restoration of normal operations. Presented in this chapter are those elements that are essential to a remediation plan. The key elements for discussion are divided into two categories: preventative and emergency requirements.

The hazardous waste site health and safety plan is the document that brings all the various health and safety information into an operational plan. It is a dynamic document in that it must be continually updated if and when new information is discovered.

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These health and safety plans vary greatly depending on the experience of the contractor, reviewing agency, and scope of project. Health and safety plans may be only a few pages that list the operational procedures which are then followed up by hundreds of pages of background and training materials selected employees are required to study.

Most plans will identify the hazards, evaluate the risk to workers and provide methods or work practices to minimize potential exposure or accidents, thus preventing illness or injury. Lines of authority and responsibility along with communication channels are normally required by state and federal agencies. The training and/or experience required for each task is generally included.

Many health and safety plans will reference the state or federal regulation such as 29 CFR 1910.120, then leave it up to the on-site health and safety officer to interpret and enforce the appropriate regulations. It has become a more common practice to restate the key applicable regulation in the health and safety plan.

Due to the potential for high-cost liabilities at hazardous waste sites, it is a good idea to train the site personnel using the indepth site specific health and safety plan. This accomplishes the mandated training requirements, assures the employers that site personnel have read the health and safety plan, and documents, by employee signature, that training and instructions were received.

The documentation of employee training brings us to another potential legal problem. The health and safety plan must be specific enough to give good clear instructions but broad enough to allow the work to be accomplished without violating the written instructions. No employer wants to be brought into court in violation of his/her own health and safety plan. The health and safety plan must be written with the expectation that any disputes or accidents that occur on the site will reach the courts. Thus, do not say more than you can do; do not write anything you do not know, and prepare the health and safety documents with the expectation that they will be interpreted by the *judge*. The longer and more extensive the health and safety plan, the more likely that an opposing lawyer can find a challenging point. However, an indepth and well-documented health and safety plan can be used as evidence that the employer went to great lengths in their efforts to protect the workers and the environment. Each site and subsequent health and safety plan has to be evaluated with these legal dilemmas in mind.

An example of a site health and safety plan has been provided in Appendix E. This is a military base investigation and cleanup with a dollar value in the range of $5 to $15 million covering a variety of activities. The hazardous waste regulations have not specified any particular format, however most regional EPA and state agencies will often identify the minimum topics that must be covered by the particular site health and safety plan. The U.S. Environmental

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Protection Agency (USEPA) has developed a generic health and safety plan (HASP) available on both 3.5- and 5.25-inch disks for most computer floppy drives. This publicly available health and safety planner can be ordered from the USEPA, Response, Engineering and Analytical Contract (REAC) at 2890 Woodbridge Avenue, Edison, New Jersey, 08837-3679, or call 800-999-6990.

Also see EPA publication 9285-8-01, March, 1992 for guidelines on the use of the computer disk. Early contact with the local environmental plus health and safety regulatory agencies may save a lot of time, expense, and delays.

The impact of stricter environmental regulations in the United States has created more focus on the importance of the contingency planning process for hazardous wastes site remediation activities. In particular, the Comprehensive Environmental Response, Compensation, and Liability Act, commonly known as "CERCLA" or "Superfund" as enacted into law on December 11, 1980, was substantially amended by the Superfund Amendments and Reauthorization Act of 1986: "SARA." On March 8, 1990, EPA promulgated a major revision to the National Contingency Plan (the original NCP was developed by EPA under Section 311 of the Clean Water Act) to serve as the blueprint for remedial response action. These revisions to the NCP serve to not only implement the statutory SARA amendments, but also to codify various procedures and requirements which have evolved during EPA's first 10 years experience with Superfund. Subpart C of the revised NCP discusses the Federal contingency plans which are to be developed, and summarizes the state and local emergency response plans which are required by SARA Title III. Subpart E (formerly Subpart F) is referred to as the National Hazardous Substances Response Plan that establishes the methods and criteria for determining the appropriate response to releases of hazardous substances.

Additionally, under the OSHA regulations entitled Hazardous Waste Operations and Emergency Response (HAZWOPER), embodied under Title 29, Part 1910.120, Subpart H, employee health and safety requirements and training are identified as an important resource for input to the contingency planning process. As federal, state, and county environmental regulations change, it is important to include such regulatory impacts on drafting contingency plans both now and in the future.

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PREVENTATIVE REQUIREMENTS

The essentials of the uncontrolled hazardous wastes site HASP plan relative to preventative requirements are discussed in detail under the following individual headings.

Know the Inherent Site Characteristics

One of the key steps in the preventative aspects of an HASP plan is the need for an accurate collection and evaluation of all known and available information on the remediation waste site itself. Table 13-1 summarizes the important items needed to evaluate and understand the inherent site characteristics [Allcott et al., 1981]. Information gaps should be identified and efforts made to deal with prioritizing those areas that could most influence the safe conduct of on-site activities.

Table 13-1 Site Characteristics of Uncontrolled Hazardous Waste Sites [Allcott et al., 1981]

Site Characteristics	Related Considerations
Topography	Adjacent tenants
Geology	Nearby population centers
Hydrology	Hospital facilities
Climatology	Ambulance service
Wildlife (reptile, animal, insect)	Fire district
Ground cover	Utilities available/proximity
History of sampling/exploration	Industrial equipment rental
Accessibility	Law enforcement
Security	

Know the Waste Parameters at the Site

The degree of hazard in remediating the site essentially depends on the specific waste chemical types, quantities, method of disposal and so forth. Table 13-2 summarizes key information relative to assessing the waste characteristics at the site [Allcott et al., 1981]. Initially (or at any time) when workers will be venturing into unknown conditions the most conservative protective requirements should be incorporated. If there are mixtures of wastes, controls should be set up to deal with the most toxic chemicals, or the greatest

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potential hazard, for example, flammability or explosion. Extreme care is required when dealing with potential incompatibilities of various hazardous waste sources at the site.

Table 13-2 Assessment of Key Waste Characteristics at the Site [Allcott et al., 1981]

1. Sources/volume/form
2. History of waste deposits
   - Dates
   - Sources of waste
   - Type and quantity of wastes
3. Sources of additional information
4. Containment/confinement of waste
5. Waste containers
   - Types, age, condition
6. Designed confinements
   - Pits, lagoons, cells, trenches, cover
7. Uncontrolled practices at the site
   - Open dumping
   - Open burning
   - Flooding/evaporation/percolation
8. Hazardous properties of waste site chemicals
   - Physical and chemical properties - flammability, corrosivity, reactivity
   - Potential toxicity - acute, chronic
   - Other available MSDS information
9. On-site wastes compatibility considerations

Effective Project/Site Management

The conduct of cleanup activities must be under the key control of a single project manager (on scene coordinator) whose day-to-day responsibilities include:

- Monitoring and directing the site activities (including any subcontractors);
- Planning and scheduling;

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- Direct resource management: manpower, materials, equipment; and
- Establishing clear communications to field staff, on-site government agency coordinators, the safety coordinator, as well as press and local government officials.

The need to maintain the highest commitment to safety and health at a site rests with one responsible party who is fully knowledgeable, experienced, and capable of acting with dispatch to monitor the day-to-day activities of personal protective procedures, industrial hygiene sampling and air monitoring, decontamination procedures, weather conditions, and the like. The role of the on-site health and safety coordinator clearly is to provide routine advice and counsel to the project (site) manager relative to health and safety matters. Unsafe conduct or disobedience to the documented safety/health procedures serves as a clear reason for ceasing activities until corrective actions are taken.

Training

All cleanup workers must be fully trained and informed on the potential safety hazards at the site, the toxicity parameters of the waste chemicals at the site, protective equipment requirements, decontamination procedures, safe operation of remediation equipment, fire protection, emergency backup, and so on. Table 13-3 presents pertinent subjects for these workers [Streng et al., 1982]. Classroom education prior to startup is an effective means to en*sure* adequate worker training. This should include instruction by various technical disciplines, (e.g., industrial hygiene, toxicology, etc.), as well as trial runs using requisite safety and remediation equipment for practice under controlled, no risk test environments.

The scope and length of the training program should be adjusted to fit the needs of specific worker tasks as well as the complexities and risks of the individual site. All training sessions should be attended by the official on-scene representatives of the various federal, state, and local government agencies. See Chapter 12, Training for more details on hazardous waste operations training.

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Table 13-3 Training [Streng et al., 1982]

A. Toxicity of waste site chemicals
   1. Acute toxicity
   2. Chronic toxicity
   3. Dermatologic effects
      a. Chloracne
      b. Other
   4. Epidemiologic studies
   5. Other possible health effects

B. Material Safety Data Sheets (MSDS) for major waste site chemicals

C. Potential routes of waste chemical exposure
   1. Skin contact
   2. Inhalation
   3. Ingestion

D. Respiratory protection

E. Protective clothing/equipment requirements

F. Industrial hygiene and safety requirements

G. Change room requirements

H. Fire fighting techniques

I. Medical monitoring requirements
   - First-aid
   - CPR

J. Trained to recognize individual medical symptoms possibly indicative of overexposure to toxic substances:
   1. Irritation of skin, eyes, nose, throat or respiratory tract
   2. Changes in complexion or skin discoloration
   3. Headaches
   4. Difficulty in breathing
   5. Nausea
   6. Dizziness or light-headedness
   7. Excessive salivation or drooling
   8. Lack or coordination
   9. Blurred vision
   10. Cramps and/or diarrhea
   11. Changes in behavior patterns

K. Standard operating procedures

L. Equipment operation training

M. Decontamination procedures

N. Wastes handling techniques

O. Emergency response plans

P. Hazardous spill control

Q. Personal hygiene and cleanliness

R. Off-site hands-on practice

S. On-site dry runs prior to startup

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Personal Protective Systems

The formulation of the preventative aspects of an HASP plan places the highest priority on the protection of the health and safety of the workers. Each phase of cleanup activities must receive a detailed review, focusing primarily on preventing possible exposures to the most toxic chemicals, and secondarily on preventing exposure to other materials of somewhat lower toxicity. Particular attention should be given to the various routes of possible exposure to workers via the respiratory tract, skin, and mucous membranes (eyes, nose, and mouth).

Typically there are four levels or categories of personal protective equipment (PPE) for hazardous material workers. Selection of specific equipment should reflect the degree of risk associated with specific remediation tasks. See Chapter 9 for a more in-depth discussion of personal protective equipment.

All respirators must be fit-tested according to established industrial hygiene practices. Workers wearing respirators will be trained to assure proper usage, storage, and maintenance. The choice of Levels A-D will be made after appropriate consultation with the on-site safety and health coordinator. Whenever the risk is unknown, the maximum personal protection of the workers needs to be assured.

Medical Programs

All workers and supervisory personnel who are required to handle contaminated materials should be given a comprehensive preemployment physical examination. Table 13-4 summarizes the minimum medical baseline requirements for each employee [Sawyer and Stormer, 1982]. The baseline medical tests should be modified to reflect specific health risks for certain highly toxic chemicals. For more information, see Chapter 7, Medical Surveillance for Hazardous Waste Workers.

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Table 13-4 Health Screening Examination - Minimum Standards Requirement [Streng et al., 1982]

A. MEDICAL HISTORY
- Medical information questionnaire acquired from participant

B. PHYSIOLOGICAL TESTS
- Height
- Weight
- Blood pressure
  - Systolic
  - Diastolic
- Vision
  - Distance visual
  - Acuity
    - Left eye
    - Right eye
    - Both eyes
  - Near visual
  - Acuity
    - Left eye
    - Right eye
    - Both eyes
- Tonometry (Noncontact)
- Electrocardiogram
  - 12 lead
- Audiometry

Right Ear	Left Ear
500 CPS	500 CPS
1000 CPS	1000 CPS
2000 CPS	2000 CPS
4000 CPS	4000 CPS
8000 CPS	8000 CPS

- Chest x-ray
  - 14" x 17" PA View
- Spirometry
  - FVC
  - FEV_1

C. HEMATOLOGICAL TESTS
- Hematocrit
- Hemoglobin
- Red blood count
- White blood count
- Differential (when indicated)
- MCH
- MCHC

D. BLOOD CHEMISTRY[a]
- Calcium
- Phosphorus
- BUN
- Creatinine
- BUN/Creatinine
- Uric Acid
- Glucose
- Total protein
- Albumin
- Albumin/Globulin
- Direct Bilirubin
- Total Bilirubin
- SGOT
- SGPT
- Alkaline phosphatase
- LDH
- Iron
- Cholesterol
- Sodium
- Magnesium
- Potassium
- Chloride
- GGTP
- Triglycerides

E. URINALYSIS
- Occult blood
- pH
- Protein
- Glucose

[a]SMA-24 is routine (standard test conducted by autoanalyzer).

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Among the list of the key employee medical history and physical examination parameters evaluated by a physician to establish worker preclearance are:

a. History of nervous disorders, drinking habits;
b. Evidence of preexisting chronic illnesses;
c. Skin and liver function evaluation; and
d. Evaluation of suitability to wear respiratory protective equipment.

Upon completion of all remedial and closure work, the workers should be given a follow-up physical examination, and another one 6 to 12 months later. This baseline and follow-up documentation reflects appropriate tracking of hazardous waste site workers medical health information.

Site Work Zones

One method for the reduction of possible contamination or release of toxic materials is to classify the uncontrolled hazardous waste site into specific delineated work zones or work areas wherein expected or known levels of contamination exist. Within these zones, prescribed operations occur utilizing appropriate personal protective equipment. Movement between areas should be controlled at specified checkpoints. The three recommended zones are:

1. *Exclusion Zone* - The contaminated area typically requiring the most stringent categories of personal protective equipment. Within this area protective equipment requirements may vary based on different levels of contamination within the zoned area. This area is refereed to as the h*ot zone.*
2. *Contamination Reduction Zone* - An intermediate buffer zone between contaminated and uncontaminated work areas. (All decontamination activities occur in this area.) Emergency personnel and fire fighters refer to this as the *warm zone.*
3. *Noncontaminated or Clean Zone* - The outermost area of the site where no contamination exists. Typically this area contains the bulk of the administrative and support services, and serves as the focal point for controlled access of authorized support personnel and equipment. Another name for this support area is the *cold zone.*

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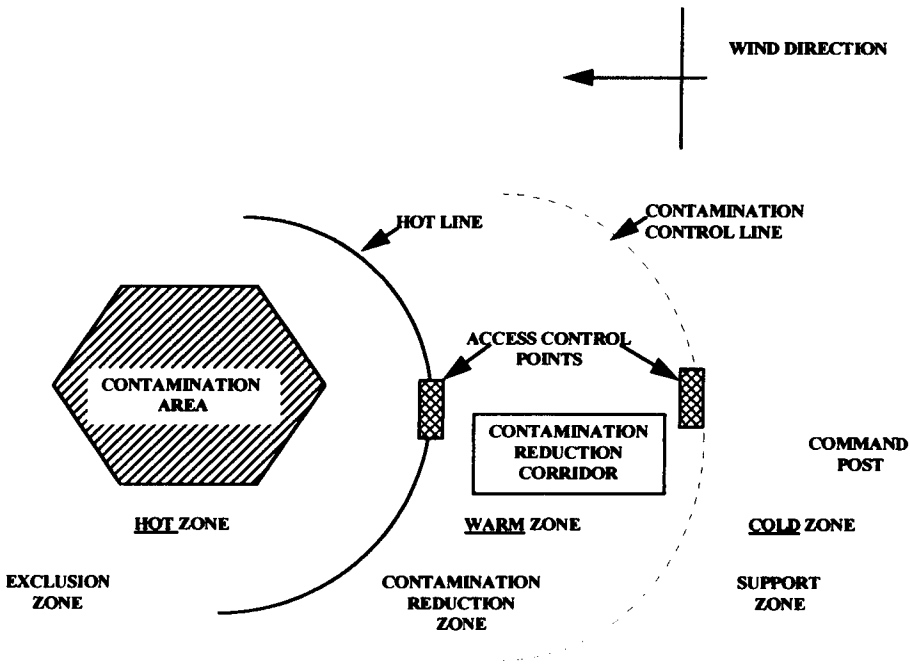


Figure 13-1 A typical layout delineating the three zones.

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Air Monitoring Requirements

A variety of air monitoring equipment is necessary to characterize and monitor the ambient air at a hazardous waste site. Air monitoring can document that toxic materials are not being released at the perimeter boundaries (both in upwind and downwind directions) during site activities, as well as to provide information for selecting the proper respiratory equipment. In addition, continuous air monitoring is required because workers may encounter hazards such as explosive atmospheres or high levels of radiation for which their existing protective equipment would not be adequate. Such continuous monitoring then serves as a basis by which the health and safety coordinator can establish the minimum level of protective equipment consistent with maintaining worker health and safety. Table 13-5 provides a detailed list of air monitoring equipment available for ambient and perimeter boundary air sampling, and personal breathing zone sampling [Mathamel, 1981]. See Chapter 5, Air Monitoring at Hazardous Waste Sites, for more details on air monitoring.

Meteorological Monitoring

During all on-site activities, continuous analysis of the site and vicinity weather is necessary. A portable wind station should be established at a point as high as possible on the site. Continuous recording of prevailing wind speed (mph) and average wind direction (degrees) is important to establish locations of upwind and downwind perimeter boundary air sampling. In addition, wind monitoring will provide readily available documented wind condition information by which an uncontrolled release of airborne toxic materials can be tracked immediately after the incident. Because of certain instrument calibration requirements for on-site industrial hygiene monitoring equipment, it is good practice to routinely record relative humidity at all times during the site remedial activities.

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Table 13-5 Ambient/Boundary and Personal Breathing Zone Air Sampling Equipment [Mathamel, 1981]

Ambient/Boundary:		
Hazard	**Direct Reading**	**Collection System**
Explosive atmosphere[a]	Combustible gas indicator	Not used
Oxygen-deficient atmosphere[b]	Oxygen level meter	Not used
Toxic atmosphere	1. Portable photo-ionization detector (PID) 2. Portable flame ionization detector (FID) w/gas chromatograph (GC) option 3. Colorimetric tubes	Sampling pumps in conjunction with adsorption tubes, filters, and impingers (similar to personal breathing measurements)
Radioactivity[c]	1. Radiation survey (alpha, beta, gamma) 2. Passive monitors (alarms)	Dosimeters (film badges)
Personal Breathing Zone:		
Pollutant	**Collection Media[d]**	**Laboratory Analysis**
Volatile organics	Carbon tubes, Tenax tubes, XAD-2 tubes, Silica gel tubes	Gas chromatograph/Mass spectroscopy (GS/MS)
Particulate organics	Gas fiber filters	GC/MS
Pesticides (including PCBs)	Florisil tubes, polyurethane plugs	GC/MS GC/Electron capture
PBBs	Glass fiber filters	GC/MS
Metals	Membrane filters	Atomic absorption (AA)
Volatile inorganics	Impingers/reagent solutions	Wet chemical methods
Particulate inorganics	Membrane filters, glass fiber filters	Wet chemical methods
Cyanides	Filters/impingers	Wet chemicals

[a]At a vapor explosiveness of greater than 20 percent, all work activity in the site where reading taken is ceased. At 10 percent, an alert is made to carefully evaluate explosiveness at various levels in reference to ground level.

[b]At less than 19.5 percent oxygen, supplied air or SCBA is required.

[c]0.02MR is normal; at levels greater than 2.0MR, operations should cease.

[d]Any of these, depending on the specific site hazards, can be used with a sampling pump to monitor at the uncontrolled site boundaries for possible off-site release.

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Security

As much as possible, the site should be fenced and isolated from the surrounding population environment. Only those people approved by the project (site) manager will be allowed access to the noncontaminated work zone. Only those workers having completed the employee medical examination will be allowed into the intermediate and/or contaminated work zones. Daily reports from the on-site manager should be made to local government representatives and/or the press to describe remedial progress and activities. A security guard service should be employed on a 24-hour basis to provide on-site security notice of potential exposure problems, (e.g., fire, weather, etc). The guard should maintain a security log for all workers and visitors entering the site. The log should indicate name, organization, dates, and arrival and departure times for each worker or visitor. At least one or more access routes for emergency vehicles must be maintained throughout the site activities. Walkie-talkie communications to remote field locations are needed to communicate potential hazard conditions. If at all possible, Federal Aviation Administration (FAA) air space restrictions over the site at key activity periods should be enforced using USEPA to facilitate the requirements.

EMERGENCY REQUIREMENTS

Regardless of the care undertaken to address the major elements of a remediation plan that can protect (routinely) against an unforeseen event, there always exists the potential of an upset condition. The basic objectives for an emergency contingency plan are threefold: (1) to be prepared to minimize, control, and contain any possible release of hazardous wastes from the remediation site; (2) to provide coordination of all related emergency response groups in a safe manner; and (3) to promote safety in any necessary cleanup operation so as to prevent harm to the workers, the surrounding community, or to the environment. The heart of the documented contingency plan, as identified below, deals with specific emergencies and how each best could be handled [Sawyer, 1982]. Users should review the latest regulations, such as 29 CFR 1910.120 pp "q."

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Fire

a. Fire extinguishers designed for solvent and electrical fires must be within easy access of various phases of site remediations. (No worker should have to move more than 75 lineal feet to obtain fire extinguishers.) Backup foam systems and emergency fire water supplies should be available as needed to protect against the spread of fire.
b. All personnel must be trained in the use of the fire extinguishers.
c. A skilled fire brigade must be available, and on call, should a major fire occur. Workers in close contact with the source of the fire should be in Category IV emergency equipment with at least two people participating together.
d. Telephone (or radio) contact must be made immediately with the local fire department to obtain their response, if necessary, to contain the blaze. Before remedial operations are begun, all fire department personnel should be briefed on the chemical waste hazards at the site.
e. All site activities will be immediately terminated until the threat of fire hazard is removed. If possible, evacuation from the affected areas should be in an upwind direction.
f. Electrical power to the work area must be disconnected until the hazard is removed.
g. All personnel not involved in fire fighting activities should be evacuated to a safe location.
h. The general plant fire alarm should be activated to notify all personnel of the problem. (Portable air horns will be distributed across the site area for easy access to sound an emergency alarm.)
i. All appropriate federal, state, and local government agencies must be notified of the fire.
j. After the fire has been extinguished, the damage should be immediately assessed and any required spill control or cleanup activities initiated.

Severe Storm

a. At the imminent presence of severe weather conditions, all cleanup activities must cease.
b. Workers should be instructed in proper procedures for securing the site before leaving the work area.
c. As soon as the work area has been secured, all personnel must evacuate the work area, decontaminate, and proceed to a safe area.
d. All electrical power must be disconnected to the work area.
e. As soon as the severe weather passes, the work area should be assessed for damage and any required spill control or cleanup measures initiated.

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Toxic Vapor Release

a. Although extremely unlikely, should an unsatisfactory air quality measurement be noted, all site activities must be ceased until the problem is corrected. A well-designed system will have taken into consideration the occasional release of hazardous materials with adequate on-site controls.
b. If necessary, all downwind persons should be notified and evacuated.
c. All appropriate federal, state, and local agencies must be notified.
d. Personnel in appropriate protective equipment will determine the source of the release and proceed to correct the problem.

Medical Emergency

a. Personnel from local medical facilities must be briefed on the nature of the project so they can make preparations for medical emergencies.
b. Emergency medical transportation must be notified immediately, as well as the nearest hospital.
c. The medical problem should be treated with emergency first aid procedures by qualified trained persons from the site crews until medical help arrives.
d. The affected person, as soon as practicable, will be removed from the work area and protective clothing will be removed, if possible.
e. A designated supervisory person should accompany the person to the hospital to provide the medical team with an accurate description of how the accident or emergency occurred.

Liquid or Solid Wastes Spill

a. Adequate spill control and containment materials must be available on-site to deal with any spill that might occur.
b. All areas subject to potential spills must be diked to prevent migration from the work area off the site boundary.
c. All personnel should be trained in proper spill control measures and must respond immediately to contain, then clean up, the spilled material.
d. All appropriate federal, state, and local agencies must be notified. Any other unforeseen emergencies should be dealt with by the on-site project manager, and all appropriate agencies will be notified of any additional problems as warranted.

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Evacuation

In the unlikely event that the release of toxic materials and/or flammable or explosive mixtures threaten nearby population centers, the following steps should be directed to facilitate the evacuation process:

a. Have a preestablished means to quickly inform nearby population areas. Alternative information contacts include going door-to-door, radio/television broadcasts, or a public address system attached to a motor vehicle driven through the nearby population areas.
b. Have preassigned evacuation routes to facilitate transport by private automobile to safe centers wherein temporary food and shelter is available.
c. Secure, monitor, and decontaminate as necessary affected areas prior to any inhabitants returning to their dwellings.
d. Have the evacuation protocol on file with local authorities: Civil Defense, National Guard, fire and police departments, EPA, and local hospitals.
e. Have a readily available list of phone numbers and name contacts for emergency situations:

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Agency	Telephone	Person to Contact
Fire		
Police		
Ambulance Service		
Hospital Emergency Room		
EPA and EPA Emergency Response Team		
Mayors of Nearby Communities		
Civil Defense		
Local National Guard Units		
Cleanup Contractor Management Officials		

f. A local communications spokesperson must be established to assure rapid, accurate, thorough, and timely communications to the public during any threat of emergency or evacuation. This is typically the responsibility of the project (site) manager. Joint communications should be drafted and issued among the project (site) manager, USEPA, and local government authorities to assure continuity and consistent appraisal of the emergency status. The utmost care *must* be taken to prevent a public communications vacuum that can lead to possible panic and misunderstanding to the surrounding populace.

Hazard Risk Assessment

Before startup of any major activity at the uncontrolled hazardous wastes site, an attempt to address the logical consequences of various uncontrolled exposure incidents should be made. Table 13-6 lists several of the uncontrolled incident cases to which responses can be drafted in case such emergency situations arise [Allcott et al., 1981]. These scenario responses should be documented as a key part of any contingency plan. The response to these issues requires probable and worst case answers by which careful analysis and study can identify beforehand important areas of uncertainty or high hazards.

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Table 13-6 Uncontrolled Hazardous Waste Site Incident Cases [Allcott et al., 1981]

1) Fire and/or explosion of flammable or combustible solvents or pesticide mixtures.
2) Explosion of waste containers containing shock, pressure or heat sensitive materials.
3) Penetration or rupture of compressed gas cylinders (buried or at the surface) containing toxic materials.
4) Penetration of protective gear by toxic liquids, gases or vapors.
5) Penetration of protective gear by equipment movement, flying debris, or contact with sharp objects.
6) Interruption or contamination of supplied breathing air.
7) Excavation and surface cave-ins.
8) Equipment rollovers.
9) In transit leaking or rupture of sample containers.
10) Rupture or leakage of sample containers while in storage.
11) Violent reaction of waste samples with analytical reagents.
12) Medical emergency in hazardous area (e.g., heart attack).
13) Severe storms.
14) General loss of utilities.
15) Public protests and harassments.

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CONCLUSION

This chapter has dealt in broad terms with the key elements of both the HASP plan and contingency plan for remediation at uncontrolled hazardous waste sites. Those elements that are truly preventative in nature are planned for in the HASP. Those that deal with an emergency situation arising from the remediation activities at the site are planned for in the contingency plan. No one uncontrolled hazardous waste site is exactly like any other. There is no real substitute for a definitive contingency plan in order to protect workers, the surrounding community, and the environment. Each contingency plan needs to be modified reflecting those site or wastes characteristics unique to a particular situation. However, the core elements addressed in this chapter must all be considered preparatory to fine tuning for specialized hazard situations.

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14

RADIATION SAFETY

Leslie W. Cole, M.S.

INTRODUCTION

The presence of radioactive materials cannot be ruled out at any location, particularly one where other hazardous materials are present. Regulated radioactive materials have been generally well controlled but, in the past, there were radioactive materials that were either not recognized as radioactive or not controlled. For instance, in oil field operations, there may be contamination from naturally occurring radioactive materials (NORM). NORM is present in almost all soil and rock but, in deep oil deposits, compounds (salts) of these radioactive materials, along with other salts dissolve in the oil and water. As the oil and water is brought to the surface, the dissolved materials precipitate out of the liquids and plate the inner surfaces of pipe, valves, and tanks. In many oil fields, as the pipe, valves and tanks were cleaned either in the field or at other locations, the radioactive residues were not always recognized or disposed of properly or, in some cases, not at all. In fact, the presence of the NORM may not have been known to the oil field operators or their employees.

Naturally occurring radioactive materials are most frequently composed of the long-lived radioactive series beginning with uranium and thorium. These elements are unstable and undergo radioactive decay that results in other radioactive elements generally referred to as "daughter" products. One of the daughter products is radium and it is the most prevalent of the NORM found in oil residues. (Technically, there are three different "isotopes" of radium, one in each of the radioactive series: radium-226 from uranium-238, radium-228 from thorium-232, and radium-227 from uranium-235. The naming convention used here identifies the isotopes by the use of the chemical symbol followed by the number indicating their atomic mass. Most of the heavier elements have several isotopes.

Radium may also be found in other places. It was widely used for many years in the manufacture of watch dials and aircraft instruments. Paint washes from this manufacturing in New Jersey have been the focus of landfill remediation efforts that cost over $16 million in the early 1970s. This same

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type of waste was the object of several Superfund sites from the 1920s in Ottawa, Illinois. Coal clinkers from a heating furnace in one plant became radioactive when radium paint wastes were burned in the furnace. The clinkers were subsequently incorporated into road materials and cement on both private and municipal properties. Radium paint washes have contaminated several disposal and landfill sites in the area.

Thorium has been in use for many years and some of the uses are still not fully regulated. The small mantles used in certain gas lanterns contain a thorium compound. At the consumer level, this material is not regulated at all. In recent times, the processing of thorium up to the point of distribution of the finished product was brought under strict regulatory control. While the production of lantern mantles has been discontinued in the United States, there are several sites in the country where wastes from thorium processing are present that may be unknown to those who may be required to work at these sites.

Uranium is quite well known to most people as a radioactive material. In the beginning of the nuclear age, uranium was mined in many locations throughout the country. The residue materials from the mining and milling contain radium and other daughter products from uranium and are quite hazardous. The waste was initially not properly controlled and has cost a great deal to bring under control. There may be areas where some of this material is present that has not been discovered and it could be present with other hazardous materials. In some areas, this mining and milling waste was used for construction fill at sites subsequently developed for commercial or residential use.

Most radioactive materials are "man-made", that is, they are not present in nature. These man-made radioactive materials are generally more hazardous than the materials mentioned above. In one incident, radioactive cobalt was involved in a major problem in the steel industry. A small, but very radioactive, bit of radioactive cobalt was apparently smelted into some steel in a Mexican steel mill. The steel was used in several applications from outdoor furniture to building construction materials. The discovery of this material led to widespread changes in transportation procedures for the trucking industry.

In another widely publicized incident, some radioactive cesium was carried from a "junk yard" and left in a residential area. Some small children found the material and thought it was a wonderful toy. The result was a real tragedy for the people involved. Several people died and many others were seriously injured.

While the products containing the radioactive cobalt presented only a small heath hazard and the radioactive cesium incident was, for the people involved, deadly, neither of these incidents are related here as something hazardous waste workers are likely to encounter. These two incidents point out that very

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dangerous radioactive materials can be in places where they are unexpected. They could end up in a waste site. Most of the radiological hazards encountered in a hazardous site remediation will not be the immediate hazard experienced in these two incidents but a long term and delayed effect hazard.

These examples document the necessity of including radiation survey in a Phase I site assessment. As more states issue NORM regulations, more people will become aware of the potential hazards of NORM and radiation survey of any potential hazardous site will become routine. Survey requirements for radioactive materials should extend to cover municipal treatment sludge, hard rock mining areas and "junk yards."

The purpose of this chapter is to outline some simple procedures to assist in identifying radiological hazards in a hazardous waste site and to assist in minimizing the health hazards to workers in the area. For this discussion, the workers are not radiation qualified, that is, they have not received special training for working in a radiation area and are not working under the provisions of a radioactive material license. As a prologue, it must be emphasized that the health hazards from radioactive materials that may be encountered in any inadvertent location are probably not nearly as great as most chemical hazards. In addition, the initial protective actions taken for chemical hazards are appropriate for most radiological hazards particularly if the first assessment team has a simple radiation detector. The presence of really hazardous radioactive materials is immediately discernable.

COMMON TERMS

ALPHA PARTICLE (alpha radiation): A positively charged particle having a mass and charge equal in magnitude to a helium nucleus (two protons and two neutrons). They are emitted by certain radioactive materials. They will travel only a few inches through the air before being stopped by air molecules. They are most dangerous when materials emitting them are inhaled or ingested. The hazard of radon gas is due to emission of alpha particles in the lungs.

BECQUEREL (Bq): A unit of activity equal to one nuclear transformation per second (1 Bq = 1 s-1). The former special named unit of activity, the curie, is related to the becquerel according to 1 Ci = 3.7 x 1010 Bq and 1 picocurie (pCi) = 0.037 Bq.

BETA PARTICLE (beta radiation): A charged particle emitted from the nucleus of an atom, with a mass and charge equal in magnitude to that of the electron. They are faster and lighter than an alpha particle.

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CONTROLLED AREA: A specified area in which exposure of personnel to radiation or radioactive material is controlled and which is under the supervision of a person having knowledge of the appropriate radiation protection practices, including pertinent regulations, and who has responsibility for applying them.

CURIE, Ci: The unit of radioactivity, being the quantity of radioactive material in which 3.7 X 1010 nuclei disintegrate every second. Originally it was the activity of 1 gram of radium-226. The curie has now been superseded under the SI system by the becquerel (Bq), equal to 1 disintegration per second.

DECAY, RADIOACTIVE: A spontaneous nuclear transformation in which particles or gamma radiation is emitted, or X radiation is emitted following orbital electron capture, or the nucleus undergoes spontaneous fission.

DOSE: A general term denoting the quantity of radiation or energy absorbed. Most people receive between 150 and 200 millirems a year from naturally occurring background radiation, and any level less than 5000 millirems a year is considered low-level. Scientists have found that radiation doses of over 100,000 millirem will usually cause radiation sickness. Doses of over 500,000 millirems, if received in three days or less, will usually kill a person.

GAMMA RADIATION: A type of radiation that is released in waves by unstable atoms when they stabilize. They are a very strong (range of energy from 10 keV to 9 MeV) type of electromagnetic wave. Gamma waves have no weight and travel even faster than alpha and beta radiation.

GAMMA-RAY SCINTILLATION DETECTOR: A gamma-ray detector consisting of a scintillator, such as sodium iodide, thallium-activated, NaI(Tl), and a photomultiplier tube housed in a light-tight container

GRAY, (Gy): The SI unit of absorbed radiation dose, one joule per kilogram. 1 Gy = 100 rads.

HEALTH PHYSICS: The science of radiation protection.

MONITOR, RADIATION: A radiation detector the purpose of which is to measure the level of ionizing radiation (or quantity of radioactive material). It may also give quantitative information on dose or dose rate. The term is frequently prefixed with a word indicating the purpose of the monitor such as an area monitor, or air particle monitor.

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MONITORING, RADIATION (RADIATION PROTECTION): The continuing collection and assessment of the pertinent information to determine the adequacy of radiation protection practices and to indicate potentially significant changes in conditions or protection performance.

NATURALLY OCCURRING RADIOACTIVE MATERIAL (NORM): Any radioactive materials other than man-made.

NEUTRON: A non-charged particle in the center of the atom. Together with the proton it forms the nucleus.

OCCUPATION DOSE (REGULATORY): Dose (or dose equivalent) resulting from exposure of an individual to radiation in a restricted area or in the course of employment in which the individual's duties involve exposure to radiation (see 10 CFR 20).

RAD: The historic unit of measure of absorbed radiation energy (dose). The rad is equal to the absorption of 100 ergs per gram by any material exposed to ionizing radiation.

RADIATION: Electromagnetic waves especially (in the context of nuclear energy), X-rays and gamma rays, or streams of fast-moving particles (electrons, alpha particles, neutrons, protons), i.e., all the ways in which an atom gives off energy.

RADIATION HAZARD: A situation or condition that could result in deleterious effects attributable to deliberate, accidental, occupational, or natural exposure to radiation.

RADIATION PROTECTION: All measures concerned with reducing deleterious effects of radiation to persons or materials (also called "radiological protection").

RADIOACTIVE MATERIAL: A material of which one or more constituents exhibit radioactivity. Note: For special purposes such as regulation, this term may be restricted to radioactive material with an activity or a specific activity greater than a specified value.

RADIOACTIVE WASTE: Unwanted radioactive materials obtained in the processing or handling of radioactive materials.

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REM: Unit of dose equivalent. The dose equivalent in "rem" is numerically equal to the absorbed dose in "rad" multiplied by the "quality factor," the distribution factor and any other necessary modifying factor.

RESTRICTED AREA: An area to which access is controlled for the protection of individuals from exposure to radiation and radioactive materials.

ROENTGEN (R): A unit of exposure; 1 R = 2.58 x 10-4 C/kg.

SCINTILLATION COUNTER: A counter in which the light flashes produced in scintillation by ionizing radiation are converted into electrical pulses by a photomultiplier tube.

SIEVERT (Sv): A unit of radiation dose equivalent. The sievert has identical units to the gray. It is arrived at by multiplying the absorbed dose by the quality factor. It is given numerically by 1 Sv = 1 J * kg-1 (= 100 rem).

RADIATION HAZARDS

Ionizing radiation is classed as a carcinogen. Exposures to man-made or technology enhanced radioactive materials are regulated by the U.S. Nuclear Regulatory Commission (NRC) or by the individual states through agreement with the NRC. Naturally occurring radioactive materials are regulated by several states and by the Environmental Protection Agency. The state regulations for NORM generally follow a model set of regulations developed by the Council of Radiation Control Directors, an organization of the state radiological regulatory offices. The current versions of these regulations, for the large part, are aimed at NORM associated with oil production facilities. All these regulations provide radiation exposure limits for radiation workers, those workers who have received specialized training for handling radioactive materials under provision of a radioactive materials license, and for "members of the public," personnel other than radiation workers.

The regulatory limits on doses for radiation workers are set so the risk from radiation exposure for these workers is comparable to the normal safety risks to worker in "safe" industries. These dose limits are referred to as "occupation limits" to distinguish them from the dose limits for members of the public. The workers at a hazardous waste site are not normally radiation workers, so the regulatory radiation dose limit for members of the public would apply. The current dose limit for members of the public specified in the NRC regulations and in the state regulations under the NRC agreements is 100 mrem per year above the normal background radiation level, compared with the

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occupational dose limit of 5000 mrem per year. The level of risk from radiation exposure is proportional to the dose thus the level so the risk from radiation exposure while working at a hazardous waste site is much less than the overall safety risk from working in "safe" industries.

The risk from radiation exposure is directly proportional to the radiation dose. Radiation doses are measured in units of rem or sieverts (Sv). The risk of cancer from radiation exposure is approximately four in one hundred per sievert (four in ten thousand per rem). Exposure at the level of the annual limit for nonradiation workers, 100 mrem, is approximately two chances in one hundred thousand of a fatal cancer. Note that this level of exposure is about the same as the average external radiation exposure throughout the country. The lifetime risk of fatal cancer from background radiation is approximately 3 in one 1000 (3×10^{-3}).

RADIATION DETECTION

In operation in a location such as a hazardous waste site, the usual radiation detection method is to concentrate on detection of gamma radiation. A simple gamma ray scintillation detector survey meter is usually adequate for initial assessments. Positive indication on the survey meter will determine the presence of radioactive material but it cannot be a quantitative measure of the long-term hazard. The absence of a positive measurement with the survey meter is not sufficient to rule out the presence of radioactive materials. Some radioactive materials will not cause the meter to respond because they do not emit gamma rays and buried radioactive materials that emit gamma rays may be sufficiently shielded to be not detectable. Contamination in the surface soil by radionuclides that are not gamma emitters can be absolutely determined only through laboratory analysis. If there is any indication or suspicion of the presence of radioactive materials, it may be prudent to include sampling and analysis for radioactive materials from the suspected location or locations. A laboratory that has the capability to analyze materials for the presence of radioactive materials will be able to advise on the sampling that may be necessary for a screening survey. It may be necessary to consult a health physicist familiar with environmental radiological characterization for specific advice if radioactive materials are suspected.

MODES OF EXPOSURE

Exposure to radiation can be either or both of two different modes. The source of the radiation can be outside the individual's body (external) or it may

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be inside the body (internal). The type of radiation is the major factor on the total dose received whether external or internal.

External Exposure

The radioactive emissions from a radioactive substance, a source, outside an individual's body travel through the space between the source and the individual and impact on and inside his or her body. The materials between the source and the individual absorb some of the energy. Even the individual's clothing and the outer layer of skin absorb some of the energy. In the case of alpha radiation, the dead skin is capable of absorbing all the energy. If someone were to pick up a quantity of a pure alpha radiation emitter, no harm at all would come of it since the inert layer of skin on the hand would provide adequate shielding of the alpha particles. The same is true of some beta emitting substances because the inert layer of the skin on the hands is relatively thick. Some beta particles may penetrate into the live skin and the most energetic beta particles from some radioactive materials may penetrate into the tissue below the skin. It is quite unlikely that any significant damage would result to any of the vital organs inside the body from beta radiation. Gamma radiation is capable of penetrating into the body and impacting the internal organs. Some gamma radiation will be stopped by the skin if it is of "low" energy but there are many gamma radiation emitting substances that emit gamma radiation of quite powerful energies. Gamma radiation, from the substance we collectively refer to as NORM, in soil and rock, building materials and from the atmosphere is continually bombarding the body. This forms the "background" external radiation dose of approximately 80 mrem each year for most people in the United States.

Most of the NORM substances emit more than one type of radiation and can be classed as potentially harmful as external radiation exposure sources. One cannot assume that any radioactive material is harmless. Even the pure alpha radiation emitter mentioned above could lead to some harm if one were to pick it up and transfer some residual material that may be left on his hand to his mouth. This would lead to an internal exposure.

Internal Exposure

Radioactive materials inside the body can irradiate the internal organs directly. There is no intervening matter to act as a shield as with external radiation. While alpha radiation can cause no harm as an external radiation source, alpha particles from internally deposited radioactive material can cause significant damage, particularly when the radioactive substance is inside the

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cells within an organ. In fact, alpha radiation emitters are potentially the most dangerous type of radioactive substances.

It is not possible to avoid some internal radiation exposure. A small part of the element potassium is radioactive. We all carry around a small amount, about one microcurie, of radioactive potassium. It is a gamma emitter that gives us a dose of about 15 mrem each year. Most of us receive the largest portion of our radiation dose from the radioactive gas radon. This gas is present everywhere although it is higher in some areas or from some subsurface formations than others. The average person receives a radiation dose of about 200 mrem a year from radon and its radioactive decay daughter products.

Internally deposited radioactive materials may stay in the body for long periods and continue their irradiation all the time they are present. This requires the use of adequate protective measures when radioactive substances are encountered that may be inhaled or ingested. Fortunately, the normal protective actions prescribed for handling other hazardous materials will provide a high level of protection from radioactive substances.

RADIATION DOSE STANDARDS

There is a set of standards for radiation dose but the standards may not be applicable to a hazardous material site unless the site is part of a facility that has a radioactive material license issued by the NRC or a state agency under agreement with the NRC. Not all radioactive materials operations are licensed by the NRC or an agreement state. Some states have extended the licensing of radioactive materials to include NORM, but most have not. The NRC standards are (from 10 CFR 20):

20.1201 Occupational dose limits for adults.

(A) The licensee shall control the occupational dose to individual adults, except for planned special exposures under 20.1206, to the following dose limits.

1. An annual limit, which is the more limiting of:

(i) The total effective dose equivalent being equal to 5 rems (0.05 Sv); or

(ii) The sum of the deep-dose equivalent and the committed dose equivalent to any individual organ or tissue other than the lens of the eye being equal to 50 rems (0.5 Sv).

2. The annual limits to the lens of the eye, to the skin, and to the extremities, which are:

(i) An eye dose equivalent of 15 rems (0.15 Sv), and

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(ii) A shallow-dose equivalent of 50 rems (0.50 Sv) to the skin or to any extremity.

The state regulations for NORM are not all identical but the exposure standards are generally the same. The Mississippi regulations are relatively straightforward and contain the following standards for radiation exposure:

Part of the Body	Column I Dose in Rem*	Column II Dose in Rem*
Whole body; head and trunk; active blood-forming organs; gonads; or lens of eye	0.005 (0.05 mSv)	0.5 (5 mSv)
Hands & Forearms; feet and ankles; localized areas of skin averaged over areas no larger than 1 sq centimeter	0.075 (0.75 mSv)	7.7 (75 mSv)
Other Organs	0.015 (0.15 mSv)	1.5 (5 mSv)

*Dose limit is the dose above background from the product.

Column I identifies the dose limit for individuals who may come into contact with NORM in a product or in a remediated area and Column II is the limit for workers who handle or store large quantities of NORM. For workers at a hazardous waste site for which an NRC or agreement state radioactive material license is not available, the dose standard should be similar to the Column I limits above. Even if the workers are qualified as radiation workers, if there is no license for the site or the workers are not members of a company that has a remediation license that can be implemented at any location, they do not qualify as radiation workers.

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INDIVIDUAL PROTECTIVE MEASURES

The actions taken for individual protection against chemical hazards are all appropriate for protection against radiation hazards. While it is true that the energetic gamma radiation can penetrate the protective clothing worn to avoid chemical hazards, the very fact that they are so penetrating makes them easy to detect. If the simple measure of beginning each remedial action with a preliminary radiation survey is undertaken, the radiation risk can be reasonably quantified. Radiation safety specialists and health physicists can quickly evaluate the hazard level to determine if the use of specially trained radiation workers is necessary. If the potential exposure level is below the regulatory standard for exposure to members of the public (100 μrem per year or approximately 11 μrem per hour above background) there should be little concern for the radiation risk. This assumes that there are not predominately alpha (polonium-210) or beta emitting (strontium-90) radioactive materials at the site. These two radionuclides are unique in that they have no gamma emissions and could be hazardous if inhaled or ingested.

An exposure level higher than 11 μrem per hour above background may not be hazardous for the site workers since they are not likely to be at the site for 24 hours a day for a full year. For a normal work year of 2000 hours, the exposure level would have to be 50 (rem per hour above background to exceed the NRC limit of 100 μrem dose per year for members of the public. NRC defines a radiation area as a location in which an individual may receive a dose greater than 0.5 μrem in one hour. Under 40 CFR 192, an exposure level of 20 μR/hr for residual radium contamination from uranium and milling activities is set as the standard. This level has been applied to non-NRC regulated sites as a clean-up criterion. Some of the state regulations for NORM specify that exposure levels should not exceed 0.2 μrem/hr in an NORM remediated site. An exposure level greater than 20 μrem per hour above background may trigger the necessity to perform a radiological remediation in addition to the hazardous remediation. A radiological environmental specialist should be consulted in this case.

When there is potential for the radioactive to become airborne, it may be necessary to wear individual respiratory protection. A radiation safety specialist may be required to make the evaluation. The respiratory protection requirement is little different than the one for airborne chemical hazards. There may be a different or additional filter device on the respirator but all other requirements are the same.

The one difference that may exist is the requirement to actively monitor personnel and equipment exiting a radiologically contaminated area. Each individual must be monitored as he departs an area where radioactive materials

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are present in any condition where an individual could become contaminated. If contamination is found on an individual, he must be decontaminated before departing from the area. Note again that sensitive, but simple, equipment is available to monitor individuals leaving a contaminated area and the decontamination measures are also simple.

RADIATION CONTROL MEASURES AT A HAZARDOUS MATERIALS WORK SITE

Restricted Areas

NRC regulations require that if radiation exposure levels greater than 2 mrem/hr are identified in the work site, a radiation area should be established. Neither the EPA nor the state NORM regulations state any similar requirement for mill tailing or NORM. It may be necessary to establish a restricted area if radioactive materials are identified and the dose levels are significantly above background. The restriction generally in place for the hazardous materials will probably restrict the area from inadvertent entry. A radiation area, if established, must be clearly delineated and posted. There are special signs required for this posting. These signs, as specified in 10 CFR 20.1901, are generally familiar to most people. If radioactive materials are present, the use of these signs is recommended.

All personnel entering an area where radioactive materials are present must be instructed specifically of the radiological hazard. This instruction must include the personal protective equipment requirements, exposure risks, personal radiation monitoring, and the requirements for exiting. Records of this instruction, both the topic covered and the personnel attending should become part of the permanent record of the operation. The radiological instruction can be included with the instruction for the hazardous materials.

Protective Clothing

Protective outer garments are essential in working in a radiologically contaminated area. No one can be allowed in a radiologically contaminated area who is not fully clothed. As a minimum, disposable gloves and shoe covers along with some light overgarment, (i.e., lab coat), are essential for working in even lightly radiologically contaminated areas. These can be removed easily as the individual exits the contaminated area and can provide a high level of assurance that no contamination will remain on the individual. Nondisposable overgarments can be monitored and reused if not contaminated. Contamination that is significant will require more stringent protective clothing

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requirements including coveralls, head covers, taping all openings in protective clothing, etc. Most of these protective clothing requirements are similar to the requirements for working in a hazardous materials area.

Personal Radiation Monitors

Normally, personal radiation monitors are used in a radiation protection program as part of a radioactive material license. It is quite possible that there may be radioactive materials that are not subject to licensing. The general requirements for a licensed radiation protection are certainly good procedures to follow even if a license is not needed.

The use of personal radiation monitors assigned to each worker at a site where radioactive materials are present is recommended. The record established will serve to verify the actual radiation exposure received in the operation and eliminated a future liability regarding delayed effects of the exposure. A radiation safety specialist can advise on the proper procedure for this action.

Quite often, workers request personal radiation monitors (badges) when there is no radiation hazard. There are a number of companies that provide complete dosimetry services. The cost of the individual monitors is nominal, but the record maintenance may be burdensome. However, it may be easier to provide the monitors than to have workers with concern about their radiation exposure. Some companies ask the workers to pay for the individual monitors in these situations.

Air Monitoring

If there is any potential for airborne radioactive contamination, air sampling is recommended. The collection procedures are the same as for chemical hazard sampling in the form of particulate matter. Evaluation requires knowledge of the air sampling procedures for radioactive materials. A radiation safety specialist should be consulted for assistance in this procedure.

LICENSING ISSUES

Normally, working with radioactive materials requires a license issued by the NRC or a state licensing agency under agreement from the NRC. There may be radioactive materials either inadvertently left in a hazardous materials site or purposely left there. In either case, if radioactive materials were identified at such a site with no prior information about the materials, it would be reasonable to contact the state radiological office or regional NRC office to

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determine if a license may be necessary for the planned operation. If a license is required, adequate time must be allowed to prepare the application and complete the necessary follow-up.

DEPARTMENT OF ENERGY SITES

The Department of Energy is responsible for many sites where there are radioactive waste materials. DoE has a series of requirements for all contractors hired to remediate these wastes. These include site health and safety plans and a radiation protection program. Work cannot commence until contractors have received a radiation permit from the DoE's site operator.

SUMMARY

The awareness of potential radiological hazardous at any hazardous waste site is essential. Most of the actions taken for protection from chemical hazards are appropriate for the chemical hazards and the extension of the protective actions necessary for protection from the radiological hazards are not difficult. This assumes, of course, that the radiological hazard is a limited one. Identification of a severe radiological hazard is simple and the initial evaluation of any site should include a radiological screening.

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15

ORDNANCE, EXPLOSIVE WASTE, AND UNEXPLODED ORDNANCE

James P. Pastorick, B.A.

Environmental technicians, scientists, and project managers working on active and former Department of Defense (DoD) facilities are frequently finding that their environmental investigation and remediation sites are potentially contaminated with ordnance and explosive waste (OEW). The U.S. Army Corps of Engineers has identified over 7600 formerly used defense sites of which approximately 1200 are potentially contaminated with OEW.

The ability to safely perform environmental remediation projects in an environment contaminated, or potentially contaminated, with OEW is critical to the safe and efficient performance of field activities on many current or former DoD installations. Accidents involving OEW usually result in severe consequences, including death, for those involved. An example of such an incident occurred recently at a scrap recycling yard in Fontana, California where an unexploded ordnance (UXO), removed from a live fire range and delivered to the recycling yard as scrap, detonated resulting in one death and several serious injuries [Gorman, 1997].

The U.S. Army Corps of Engineers has been dealing with the issue of OEW since the mid-1980s. Specifically, Congress established the Defense Environmental Restoration Program (DERP) in 1986 under Public Laws 99-190 and 99-499. The two subprograms established under DERP are the Installation Restoration Program (IRP), which deals with active DoD installations, and the Formerly Used Defense Sites (FUDS) Program which deals with formerly owned or used DoD sites that are no longer under DoD control.

Currently, within the U.S. Army Corps of Engineers, there are three organizations designated as ordnance and explosives (OE) design and execution districts. The Huntsville, Alabama, Engineering and Support Center is designated the OE Center of Expertise (CX) and, in addition to performing OEW cleanup projects, has the additional responsibilities to perform programmatic planning, training, research and development, and also is the controlling authority for the Army's Recovered Chemical Warfare Materiel design and execution mission. The U.S. Army Corps of Engineers Districts in

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Baltimore, Maryland, and Sacramento, California, are designated as regional OE design and execution districts and are authorized to perform OE project execution and design [Huntsville Center, 1996].

OEW is defined by the U.S. Army Corps of Engineers as "anything related to ordnance designed to cause damage to personnel or materiel through explosive force, incendiary action, or toxic effects. OEW is: Bombs and warheads; guided and ballistic missiles; artillery, mortar, and rocket ammunition; small arms ammunition; antipersonnel and antitank land mines; demolition charges; pyrotechnics; grenades; torpedoes and depth charges; uranium rounds; military chemical agents; and all similar and related components, explosive in nature or otherwise designed to cause damage to personnel or materiel (e.g., fuzes, boosters, bursters, rocket motors). Uncontainerized high explosives/propellants or soils with explosive constituents are considered explosive waste if the concentration is sufficient to be reactive and present an imminent safety hazard" [Huntsville MCX].

UXO is one component of OEW and is defined by the DoD as "Explosive ordnance which has been primed, fused (sic), armed or projected or placed in such a manner as to constitute a hazard to operations, installations, personnel or material and remains unexploded either by malfunction or design or for any other cause" [DOD, 1989].

PERSONNEL QUALIFICATIONS FOR UXO SPECIALISTS

Personnel working with UXO require specialized training. All four branches of the armed forces use the designation of explosive ordnance disposal (EOD) technician to describe their specialists in this field. EOD training has been consolidated under the administrative control of the U.S. Navy at the U.S. Naval School of EOD with training conducted at Eglin Air Force Base, Florida, and the Naval Ordnance Station, Indian Head, Maryland.

The Indian Head facility has been the main EOD training center for all of the U.S. armed services since World War II and attendance and graduation from this school are still the basic requirements for performing UXO work by the Huntsville CX. The new facility at Eglin Air Force Base was recently established to allow larger and improved facilities for future training requirements and command of the school has been moved there with the Indian Head facility now serving as a satellite facility for special instruction.

Civilian contractor specialists in this field are referred to as UXO specialists to differentiate them from their active duty counterparts. The skill classifications of UXO assistant, UXO specialist, UXO supervisor, and senior UXO supervisor generally relate to the military designations of EOD assistant, basic EOD technician, senior EOD technician, and master EOD technician

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(also known in the military as "master blaster") although all of the services have their own criteria for achieving these various military EOD skill levels. Although always subject to change, the current training and experience requirements, as determined by the Huntsville CX, for UXO project personnel and their primary on-site duties are as follows [Huntsville Center, 1997]:

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Project Title	Qualifications/Duties
Project Manager	At least 3 years experience in general contract project management on programs similar in size and complexity to the planned project.
Senior UXO Supervisor	Graduate of the U.S. Naval School of EOD with at least 6 years of military EOD experience and at least 15 years of combined military (EOD) and contractor (UXO) experience. At least 10 years of this experience must be in supervisory positions. Also must have documented experience with, or specialized training in, the type of OE expected to be encountered. This individual supervises all on-site UXO activities.
UXO Supervisor	A graduate of the U.S. Naval School of EOD with at least 10 years of combined military (EOD) and civilian (UXO) experience. Must also have experience in OE clearance operations and personnel supervision. This individual supervises UXO field teams under the direction of the Senior UXO Supervisor.
UXO Specialist	A graduate of the U.S. Naval School of EOD (no experience requirement) or a graduate of an EOD assistant course (Eglin AFB, Florida or Redstone Arsenal, Alabama) with 5 years of combined military (EOD) or civilian (UXO) experience. This individual performs OE field tasks under the supervision of a UXO Supervisor.
UXO Assistant	A graduate of an EOD assistant course (Eglin AFB, Florida or Redstone Arsenal, Alabama) with less than 5 years of experience. This individual performs OE field tasks under the direct supervision of a qualified UXO Specialist or Supervisor.
UXO Quality Control Specialist	Same minimum qualifications as UXO Supervisor with added documented experience and training in performing quality control inspections and reports. This individual implements the quality control program during OE projects.
UXO Site Safety Officer	Same minimum qualifications as UXO Supervisor with specific training, knowledge and experience in implementing safety plans and ensuring compliance with safety requirements. This individual implements the overall safety program during OE projects.

These training and experience requirements have been established by the Huntsville, Alabama, Engineering and Support Center and are frequently issued as requirements in their statements of work to contractors as "Data Item Description, Personnel/Work Standards," identification number OT-025, April 22, 1997.

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OEW PROJECTS

OEW projects are identified by examining the past use of the project site. Any active or formerly used DoD facility has the potential to be contaminated with OEW or UXO. Most often the past use by the DoD is obvious and documented. But, some DoD operations were not widely publicized due to wartime secrecy requirements and may not be obvious to the casual observer today. Conducting thorough site historical research is necessary to completely rule out the possibility of OEW hazards on an active or formerly used DoD installation.

One recent example of this is the bombs discovered in a rail yard in Roseville, California, in September 1997. A buried bomb was discovered by construction workers. Military EOD were called to dispose of the bomb and investigate the surrounding area. Several more bombs were discovered and disposed of by the EOD team. An investigation determined that the bombs resulted from an accidental detonation of ordnance loaded on rail cars that was being transported through the rail yard during the Vietnam War and a civilian contractor was hired to search the rail yard for additional UXO [The *Los Angeles Times*, 1997].

OEW projects fall into two main categories: OEW remediation/investigation and UXO avoidance services. OEW remediation/investigation involves the location and disposal of OEW from the project site and, although other waste considerations are frequently associated with these projects, the explosive hazard presented by the UXO is the overriding safety consideration.

OEW REMEDIATION/INVESTIGATION

During an OEW remediation/investigation project, the performance of UXO operations is the main project objective. These projects are usually performed by the U.S. Army Corps of Engineers through the OE Center of Expertise (CX) or one of the OE Design and Execution Districts. If the project is being conducted under another program, the Huntsville CX will often have some degree of project oversight responsibility. For example, the Huntsville CX may review the work plan prior to approval by the contracting authority, and may perform safety oversight during field remedial activities.

OEW remediation/investigation projects are often considered to be emergency removals of imminent and substantial hazards to the local population and are subject to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Section 104 and the Final National Contingency Plan (NCP). This interpretation has been supported by state and local agencies because it tends to streamline the remediation process

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in order to eliminate the extreme hazard of UXO on uncontrolled former DoD installations.

The level of effort required to complete an OEW remediation project depends on the size of the project and the conditions at the site. But generally, UXO work crews can work most efficiently when they are divided into distinct teams to accomplish specific objectives.

A field work team will generally work under the direction of a UXO supervisor and be staffed by a group of from three to seven UXO specialists, assistants, and skilled laborers. The exact number and type of personnel chosen depends on the work objective for which the team is being selected. A large surface survey team may have several skilled laborers trained in the use of handheld magnetometers. UXO work crews performing intrusive operations, such as UXO excavation, will be staffed solely by trained UXO specialists because this higher level of training is required to safely perform this potentially hazardous operation.

OEW AVOIDANCE

During OEW avoidance operations, in contrast to OEW remediation/investigation projects, UXO specialists are called on to provide their specific area of knowledge and expertise to a project with different objectives. An example of this is a remedial investigation/feasibility study (RI/FS) project requiring the generation of field data from an active or formerly used DoD installation. Because the installation is or was used by the DoD, the possibility of UXO or explosives being present should at least be considered. If the site history indicates that UXO was used or disposed of in the vicinity of project sampling activities, the project management authority will probably require that the work plan and safety plan consider OEW hazards.

Examples of OEW safety support to environmental sampling efforts are the avoidance of UXO hazards to allow access to well drilling sites and performing downhole magnetometer checks during well drilling operations to prevent contact with buried UXO. UXO specialists may escort field sampling teams to locate potentially hazardous UXO and ensure that such items are not disturbed. The emphasis of OEW safety support is not the removal and disposal of UXO hazards, but rather the avoidance of OEW hazards by non-EOD trained site personnel. This is the main difference between UXO support and UXO investigation/remediation operations.

UXO safety support operations are usually staffed with the minimum number of UXO specialists required to ensure the safety of field sampling personnel. Generally, the level of UXO staffing required is one UXO specialist for every individual field operation being conducted simultaneously. For

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example, if two well drilling rigs and one soil gas sampling team are working simultaneously in areas suspected to contain UXO, a minimum of three UXO specialists can be used to ensure the safety of the three sampling teams. Each field team should be assigned a UXO specialist who is responsible for the detection and avoidance of UXO for the team.

The disposal of UXO hazards may not be possible during a UXO support project because sufficient UXO personnel are not likely to be available to perform these functions. Intrusive activities, such as excavation of suspected UXO, require at least two UXO specialists, with support personnel nearby in case of the occurrence of an emergency. This level of staffing is rarely available on a UXO avoidance project which has other field priorities and usually involves the minimum number of UXO specialists required to escort the sampling teams.

EXPLOSIVES CONTAMINATION IN SOIL

Some hazardous material sites may not be contaminated with UXO but may be contaminated with OEW in the form of explosives. This is particularly true of active and former weapons production and demilitarization facilities where explosives settling lagoons were commonly used to separate residual explosives from water used in the production or demilitarization process.

Explosives settling lagoons (commonly referred to as "pink water lagoons") can possibly have accumulated enough bulk explosive to become reactive. Explosive contaminated soil exhibits reactivity to shock down to levels of 15 percent explosive content in the soil and reactivity to flame is retained down to 12 percent explosive content. In light of these reactivity characteristics the U.S. Army Environmental Center has established 10 percent explosive content of soil as the maximum explosive content allowable without instituting explosive safety controls during the handling of the explosively contaminated soil.

Field testing procedures to determine the percentage of TNT [Jenkins, 1990], RDX [Walsh, 1991], and DNT [Jenkins and Walsh, 1991] explosives have been developed by the U.S. Army Cold Regions Research and Engineering Laboratory under funding by the U.S. Army Environmental Center. It should also be noted that explosive compounds are extremely toxic even in quantities below reactive levels [Levine, 1983].

Explosive content in soil of 10 percent necessitates the institution of strict safety precautions when working with this potentially reactive media. Extreme measures should be taken to avoid subjecting a potentially reactive or explosive substance to the stress of heat, shock, and friction. The project work plan and safety plan should identify the specific methods for obtaining samples that do

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not subject the sample area to stress. Examples of methods that reduce or eliminate the chance of stressing potentially reactive soil are using non-sparking (beryllium) sampling and excavating tools, wetting the sampling or excavation area to reduce friction, and using plastic snap-top instead of screw-top sampling containers.

Also, the basic safety concept of minimizing the number of workers exposed to the hazard and minimizing the amount of time those workers are exposed should be enforced. Only the amount of personnel required to safely accomplish each work task should be allowed within the established exclusion area when working with potentially explosive or reactive soils.

If laboratory analysis of samples taken from the site indicate that the soil has an extremely high explosives content, consideration should be given to using remotely operated equipment for excavation and sampling. Remotely operated equipment is expensive and time-consuming to use but it has the advantage of eliminating the need to expose site workers to extreme hazards.

Open burning in outdoor trays has been a common method of treatment of explosives contaminated soils in the past. Some successful alternative remediation methods [U.S. Army, 1990], are incineration [Major,1992] composting [U.S. Army, 1989] and chemical treatment [Crim, 1990]. Soil with high levels of explosive content can be more safely handled after lowering the explosive content in the soil to below 10 percent by blending it with uncontaminated filler material [Bove, 1985].

UXO PROJECT PLANS

All field activities involving or potentially involving OEW/UXO should be performed in accordance with a work plan and a safety plan. The work plan should clearly state the project objective and provide detailed procedures governing the UXO related field operations.

If the project is being accomplished under the cognizance of the U.S. Army, the safety plan should include an accident prevention plan prepared in the format specified in the U.S. Army Corps of Engineers Safety and Health Requirements Manual [U.S. Army, 1986]. The procedures and guidance contained in the work plan and safety plan should not conflict with the specific safety procedures contained in the Huntsville Engineering and Support Center OEW safety criteria document [Huntsville Center, 1996] and this document should also be included as an appendix to the safety plan to ensure that it is available for reference at the project site.

One common exception to routine field safety plans involves the wearing of steel-toed safety shoes and hard hats by UXO specialists. When handling

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UXO, hard hats do not offer protection from a blast directed upward from the ground and can possibly deflect fragments from below into the head of the UXO specialist. Steel-toed safety shoes may interfere with the operation of UXO detection instruments which can create a very hazardous situation by causing UXO to be undetected during the geophysical survey. UXO specialists, therefore, are usually exempted in the project safety plan from wearing steel-toed safety shoes (fiberglass or other nonmetallic safety shoes are a good option) and hard hats unless they are working with a significant overhead drop hazard, such as when using a mechanized excavator to access a deeply buried UXO.

UXO TOOLS AND TECHNIQUES

This section provides a brief overview of the tools and techniques employed to perform OEW/UXO operations. The common tools and equipment used by UXO teams are designed for UXO detection, excavation and disposal.

Geophysical Detection Equipment

Although locating UXO by visual observation should never be discounted, most UXO is extremely difficult to locate by sight because it is usually in a deteriorated condition and camouflaged by soil, grasses, and leaves. Because of this, geophysical instruments are usually used to help locate potential UXO anomalies. A complete evaluation report of UXO detection methods has been completed by the U.S. Naval EOD Technology Division (formerly the U.S. Naval EOD Technology Center) [U.S. Navy, 1990]. More recent detection instrument evaluation efforts have resulted in extensive testing and evaluation of modern geophysical tools applied to the UXO detection application [U.S. Army, 1997].

One concern unique to the OEW/UXO field is the hazard presented by electromagnetic radiation (EMR) [U.S. Army, 1992]. Some types of ordnance fuzes (for example, pre-1960 proximity fuzes [U.S. Army, 1997] used electrical firing systems that can potentially be initiated, under ideal conditions, by EMR). Because of this, the safest approach to UXO detection is to use a detection instrument that is completely passive or emits only low levels of EMR.

The most common types of geophysical instruments used on UXO projects are described below:

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- *Low-Sensitivity Magnetometer (LSM)*: The low-sensitivity magnetometer is the most commonly used instrument for UXO detection because it is cost-effective and easy to use. Instruments used are typically the dual-fluxgate type originally developed for the detection of underground utilities. They are inexpensive, readily available, and easy to use. In addition, they have the added benefit of being completely nonintrusive in that they do not emit even low levels of EMR. A minor disadvantage of LSMs is that they detect only ferrous items, however, nonferrous UXO is fairly rare. LSMs are most frequently used to augment visual observation during surface and near-surface UXO searches and during UXO avoidance operations.
- *High-Sensitivity Magnetometer (HSM)*: Dual-fluxgate HSMs operate on the same principal as the LSM but can be calibrated and are much more sensitive. Some HSMs are designed specifically for subsurface UXO detection and are used by military EOD teams for that purpose. Some specific models have been extensively tested by the U.S. Naval EOD Technology Division and are capable of locating large UXO up to 20-feet underground. They may be equipped with a fluxgate sensor probe that can be detached from the electronics package and lowered underwater or downhole. The primary disadvantages of this instrument are increased cost, compared to the LSM, and increased weight and bulk. As such, an HSM is used only when greater detection capabilities are required or as a quality control detection tool to check areas previously searched by less capable instruments.
- Another type of HSM that is suitable for UXO detection is the cesium-vapor total field magnetometer/gradiometer. This instrument measures the total local magnetic field simultaneously within two sensors. These sensors are very sensitive and can measure variations of 0.01 nanoTeslas in the magnetic field making them generally capable of detecting UXO to greater depths than fluxgate magnetometers.
- *Metal Detector*: Metal detectors, similar to those commercially available as treasure finders, are useful if the project requires a second method of UXO detection. These instruments are inexpensive and can locate non-ferrous objects. However, they do emit low-frequency EMR, and the operating safety precautions in the following table should be observed. Underwater versions are also available for use by divers.
- *Time-Domain Electromagnetics (TDEM)*: TDEM use a primary transmitter coil to create a time-dependent electromagnetic (EM) field that induces eddy currents in nearby conducting (ferrous or nonferrous) objects. Secondary EM fields are induced briefly in conductive material and the magnitude of the induced field depends on the size, depth and material

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properties of the target object. TDEM measure the decaying induced EM field response in programed time gates that allow the system to discriminate between conductive earth and the prolonged response of buried metal. TDEM do emit EMR and the operating safety precautions in the following table should be observed.

- *Frequency-Domain Electromagnetics (FDEM):* FDEM are classified as either conductivity or multiple-frequency types. They both emit electromagnetic fields that induce eddy currents in metal objects. A bucking circuit eliminates the primary (emitted) field and allows the instrument to detect and measure the secondary (induced) field from the metal anomaly.
- *Ground Penetrating Radar (GPR):* Traditional (surface operated) GPR should not be used for UXO detection because of its potential to initiate electrically fuzed UXO with EMR. New research with airborne three-dimensional synthetic-aperture radar (3D SAR) are very promising and may potentially revolutionize the field of UXO detection.

The following table [U.S. Army, 1997] describes common geophysical instruments used for UXO detection and the precautions that should be followed when the instruments are operated in areas suspected to contain UXO:

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Type of Instrument	Safety Recommendations
Time-Domain Electromagnetic	Safe when carted 0.42 meters or carried at 1 meter above the surface except in areas containing buried trash piles. Do not operate at heights less than 0.4 meters above the surface.
Frequency-Domain Electromagnetic (Conductivity)	Safe when operated at 1 meter above the surface except in areas containing buried trash piles.
Cesium Vapor Magnetometer	Safe when operated at least 1 meter above the surface. Do not allow the electronics/ battery package to contact the ground.
Total Field Magnetometer	Safe when operated at least 1 meter above the surface. Do not allow the electronics/battery package to contact the ground.
Flux Gate Gradiometer	Safe when operated at least 1 meter above the surface. Do not allow the electronics/battery package to contact the ground.
Ground Penetrating Radar (Pulse or Time Domain)	Do not use for UXO activities. This is a ground contact instrument and may initiate low-activation energy fuses.
Field-Domain Electromagnetics	Safe when operated at 1 meter above the surface except at buried trash piles.

The information in this table is taken from the memorandum "Interim Safety Alert-Geophysical Instruments," October 29, 1997, U.S. Army Corps of Engineers Engineering and Support Center, Huntsville, Alabama. The referenced table has not been reproduced verbatim because it contains some technical information that is beyond the scope of this discussion.

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UXO Detection Techniques

The following general description of UXO methodology is not intended to train the reader in UXO operations and handling, but rather to make the reader aware of standard and accepted practices. This will allow the reader to more easily recognize potentially unsafe situations.

A group of UXO specialists surveying an area for UXO will most likely begin the project by marking the boundary of the area to be surveyed with wooden stakes and further dividing the area into 100-foot by 100-foot work grids. The location of all stakes should be checked with a geophysical instrument to ensure that no UXO are present prior to hammering a stake in the ground. They will then divide the area into 5-foot-wide search lanes by stringing surveyors line between stakes hammered in at opposite ends of the survey area. The UXO survey team will then use one or multiple geophysical instruments, described earlier, to examine each survey lane thoroughly.

Upon detecting a possible subsurface UXO, the UXO specialist will mark the spot with a pin flag or a spot of spray paint. A team of two UXO specialists will then excavate the marked items.

Consistent with the concept of exposing the minimum number of site personnel to the hazard of detonation, UXO excavation should not take place until the magnetometer survey team has advanced beyond the fragmentation hazard area of a possible accidental detonation caused by the excavation team. The determination of the fragmentation hazard area is a complex calculation that should be based on the reasonably probable worst-case (most hazardous) UXO that is likely to be encountered. The size and net explosive weight (NEW) of the anticipated UXO can be used to calculate the appropriate fragmentation hazard area. Appropriate fragmentation distances for UXO disposal are provided in that section of this chapter and will be appropriate, although possibly excessive, for application to UXO excavation scenarios.

UXO Excavation Techniques

Anomalies suspected to be UXO can only be positively identified by a trained UXO specialist after the item is accessed by excavation. The vast majority of UXO discovered are located within 2 feet of the surface and a variety of common hand tools are used to excavate these relatively shallow UXO. A backhoe can be used by a skilled UXO specialist/equipment operator for large projectiles and bombs that can be imbedded from 10 to 20 feet underground. Although the objective is to gain access to UXO, the UXO excavation process is still governed by OSHA [CFR 29.1926]. and U.S. Army [U.S. Army, 1987] worker protection requirements.

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Upon locating the suspected UXO, the members of the excavation team will attempt to identify it. First they will determine if it is UXO. If it is not UXO and is not hazardous, such as a piece of metallic scrap, the hole may be backfilled and the nonhazardous metallic item may be removed and discarded as scrap after being certified that it is free of explosive hazards.

If the item is identified as UXO, the excavation team will attempt to positively identify it. This may or may not be possible depending on the item and its state of deterioration. The results of the excavation should be recorded in a field UXO logbook.

UXO disposal Options

The following information, describing the rationale and logic for properly handling and disposing of UXO, is also illustrated in the logic diagram in Figure 15-1.

If the UXO is positively identified as armed and unsafe to move, or if it cannot be positively identified, it will usually be blown in place (BIP). If the UXO is positively identified and the fuze is determined to be unarmed and safe to move, the UXO may be disposed by BIP or it may be moved to a secure storage facility for collection and later disposal by detonation at a designated and prepared disposal site. This is most efficient on larger projects where a secure storage area is constructed and maintained for the storage of UXO and working explosives in proper and approved magazines.

UXO discovered during safety escort operations are usually reported to the military EOD team responsible for supporting the area because UXO disposal is usually not included in the statement of work for such projects. An important consideration during the planning for this kind of operation is to establish a clear understanding of who has custody of, and responsibility for, any UXO discovered during the project.

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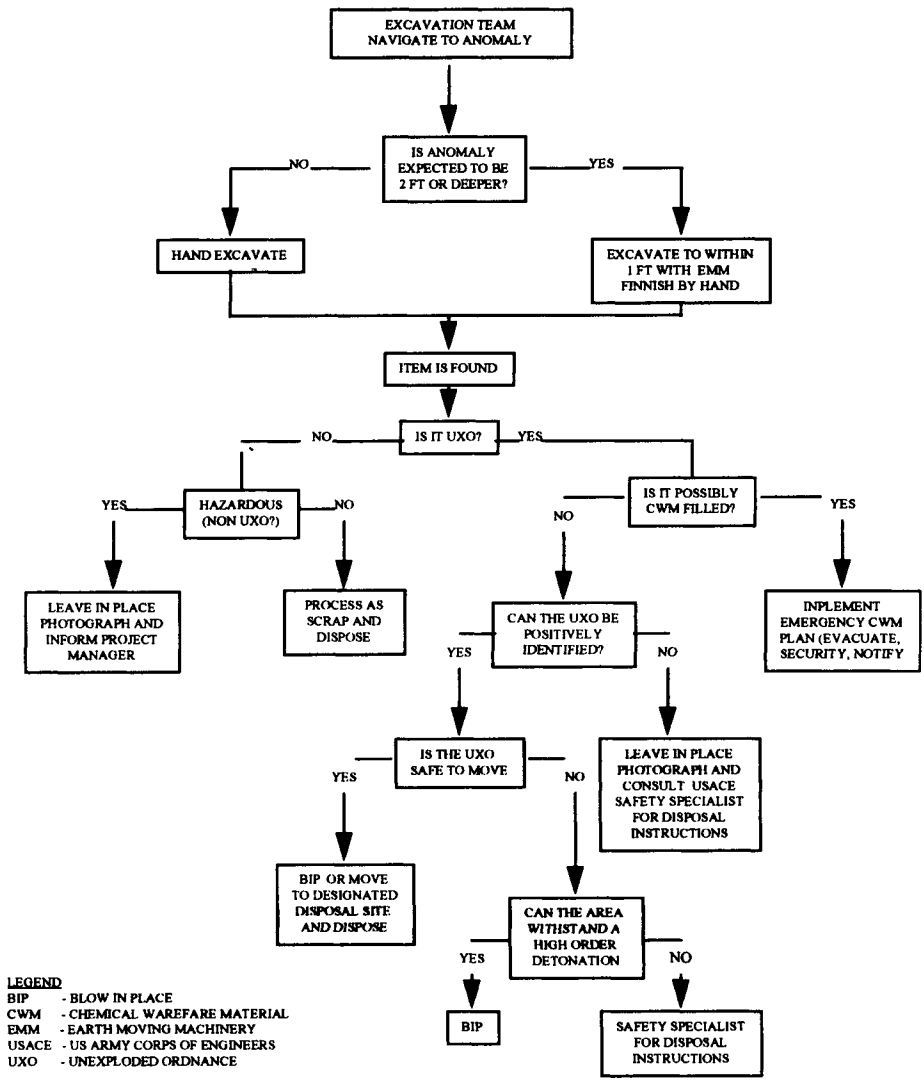


Figure 15-1

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UXO DISPOSAL TECHNIQUES

Disposal of UXO during a UXO remediation project can become a major task if large amounts of UXO are discovered. The following sections discuss the accepted methods of UXO disposal and the critical factors that must be considered when designing a safe and efficient UXO disposal operation.

Unpredictability of UXO

UXO is most often discovered in a deteriorated condition that results from years of exposure to the elements. It may have been buried for long periods of time or highly stressed by being fired downrange and failing to function as designed or being kicked out of an improperly constructed disposal detonation.

UXO fuzing is usually mechanical or electric, or a combination of both, and it is frequently impossible to tell the effect on the UXO of stress, such as the heat and shock of being propelled from an improperly constructed disposal detonation, and deterioration. For these reasons, it is sometimes impossible to determine the condition of certain UXO and those UXO should be considered unsafe to move.

Positive Identification

Before considering whether or not it is safe to move a UXO it must be positively identified. Positive identification is made more difficult by the stress to which the UXO has been subjected. Stress such as heat, shock, weather, and time tend to obliterate the key identification features that are used to positively identify UXO.

Positive identification by UXO specialists is made more difficult by the fact that UXO specialists do not have easy access to EOD publications. These publications are produced, by the EOD Technology Division in Indian Head, Maryland, as reference documents for EOD technicians to provide them with detailed information on the identification and functioning of specific ordnance.

These publications are frequently classified and are available to UXO specialists, through the Huntsville Engineering and Support Center or other DoD contracting authority, only on an as-needed basis for a specific type of UXO. UXO specialists are not authorized to maintain EOD 60-Series libraries which would require that the publications be guarded with the proper security and updated when changes to the publications are promulgated by the EOD Technology Division.

UXO specialists, therefore, are frequently required to identify UXO based on their experience. They should always err on the side of safety and consider

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a UXO to be not positively identified unless it is a common UXO and they are thoroughly familiar with its characteristics and functioning. If a UXO cannot be positively identified, it must be considered to be not safe to move and should be disposed of by BIP or, if the area cannot withstand a high order detonation, moved only after military EOD have performed an approved render-safe procedure (RSP).

Determining if UXO is Safe to Move

It is often much more efficient to consolidate UXO for disposal in a large detonation as opposed to disposing of all UXO on a project by BIP. This requires that the UXO be moved to the disposal site and safely stored until enough UXO is amassed for an efficient disposal detonation.

Before a UXO can be moved it must be positively identified as previously described. Once positive identification is made the decision to move a UXO is based on an understanding of the UXO's fuzing and condition.

The UXO specialist will determine if the UXO fuze has armed. Ordnance is designed so that the arming of the fuze occurs when the ordnance is fired, launched, dropped, or otherwise deployed as designed. Therefore, UXO that have been fired or otherwise deployed, and have failed to function as designed, are considered to be armed. Usually, armed UXO will be disposed of by BIP but some specific UXO are safe to be moved even in an armed condition. Detailed knowledge of the specific UXO is required to safely move armed UXO.

Even if the condition of a UXO is considered to be not armed the UXO specialist may decide that it is not safe to be moved based on the appearance of the particular UXO. UXO that has been subjected to stress, such as heat and shock, may be damaged internally and not safe to move. The UXO specialist should err on the side of safety and BIP any UXO that are questionable.

Disposal by Blow In Place

The most common method of UXO disposal by detonation is the BIP. This method is used to dispose of ordnance that cannot be safely moved by detonating it where it is found. BIP is accomplished by detonating a small initiation charge of explosives that has been properly placed in contact with, or close to, the UXO causing the UXO to detonate.

The advantage of disposing of UXO by BIP is that the UXO is not moved and, therefore, the maximum degree of safety is realized. On the other hand, some sites cannot withstand a high order detonation because of their proximity to valuable or sensitive assets and disposal by BIP is not possible. BIP is also

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a very time consuming and costly method for the disposal of large quantities of UXO.

Render Safe Procedures

One option that UXO specialists are not routinely authorized by the Huntsville Engineering and Support Center to perform is the RSP. These procedures require detailed knowledge of the UXO and the recommended RSP which is available only from EOD 60 Series publications. The issues involved with procuring, maintaining, and safeguarding EOD 60 Series publications have been discussed earlier. In addition, RSPs sometimes require special tools and practiced techniques that are generally considered to be in the mission area of military EOD units and not civilian UXO contractors.

Performing an RSP involves a detailed procedure designed to eliminate the possibility of detonation of the UXO. Most RSPs require the removal or disablement of the fuze. The act of performing and RSP is itself inherently hazardous and preparations for a high-order detonation should be taken in the event that the RSP is not successful. For this reason EOD technicians will frequently perform an RSP remotely so they do not subject themselves to the hazard of a detonation caused by an unsuccessful RSP.

Disposal of UXO in a Prepared Disposal Area

UXO specialists usually will establish a disposal operation using standard EOD procedures [EOD Pub., 1983] for disposal by detonation. An important aspect of a UXO disposal operation is the minimization of shock and fragmentation caused by the disposal operation to lessen the impact on the surrounding community. Common methods for reducing blast and fragmentation effects are to tamp each disposal shot using earth or sandbags.

It is often preferable to dispose of UXO by detonation in a prepared disposal area as opposed to performing all disposals by BIP. UXO disposal in a prepared disposal area has the advantages of being more efficient and confining the impact on the surrounding area to one specific location. The increased efficiency occurs because setting up one large disposal detonation only takes slightly longer than preparing a BIP. And large quantities of UXO can be disposed of at once at a prepared disposal area while a BIP will usually involve a single UXO or possibly a small cluster of UXO found in close proximity to each other.

The selected site will have less of a lasting impact on the environment because the disposal site can be chosen instead of being dictated by the location where the UXO was found. Previously disturbed sites can be selected for the UXO disposal area thereby limiting the impact to such areas. Also, the

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environmental impacts are contained in the selected area and it can be completely remediated after UXO disposal operations are finished.

Another advantage of using a prepared UXO disposal site is that it is possible to perform larger detonations while minimizing the effects of blast and fragmentation. This is usually accomplished by burying (known as tamping) the disposal detonation. A properly tamped disposal shot will consist of a hole, in which the UXO is placed and covered by at least 3 feet of earth prior to detonation. This will help to contain the detonation, thereby increasing the probability that the UXO is completely disposed of by the detonation, and reduce the amount of blast and fragmentation.

Storage and Security

The security requirements of a UXO disposal operation vary from site to site. Active military facilities may have fenced and guarded perimeters which provide adequate security without modification. On the other hand, a FUDS site that is no longer under DoD control may be open to the public and require that a considerable effort be expended to prevent the possibility of unauthorized personnel gaining access to the UXO.

Because of the extreme hazard presented by OEW/UXO, combined with the attractiveness of UXO to children as souvenirs, appropriate actions must be taken to ensure the security of the disposal site. Appropriate actions to enhance site security may include the erection of fencing and implementation of security patrols. Explosives storage magazines, in compliance with federal regulations [CFR, 27.55] , should be part of an overall program to enhance the safety and security of stored explosives and UXO.

Detonation Size Limits

The maximum size of disposal detonations allowable will depend on the size of the exclusion area available around the disposal site. The size of the exclusion area required is determined by the size, in pounds net explosive weight (lb NEW), of the UXO disposal detonation, including the explosive used for initiation of the detonation. There are two governing references for determining the required exclusion area and, in order to comply with both of them, the greater exclusion area should be observed.

The Huntsville Engineering and Support Center reference governing determination of the detonation exclusion area [U.S. Army, 1996] states that an unoccupied radius of 1250 feet is required for detonation of non-fragmenting explosive material. Fragmenting UXO requires an unoccupied radius of at least 2500 feet for disposal detonations of UXO smaller than 5 inches, and 4000 feet for disposal of UXO 5-inches and larger.

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The EOD standard governing reference [EOD Pub 60A-1-131] provides the following formula for determining the exclusion area:

$$\text{Fragmentation Hazard Area (in feet)} = 300 \text{ X } \sqrt[3]{N.E.W.(L.B.)}$$

In order to comply with both governing references, a detonation exclusion area smaller than 1250 feet cannot be used. An exclusion area of 2500 feet can be used to detonate UXO smaller than 5 inches in size and totaling no more than 570 lb. NEW. A 4000-foot exclusion area is required for disposal detonations containing UXO 5 inches or larger and totaling no more than 2350 lb. NEW.

Disposal of OEW Scrap

The disposal of scrap recovered from OEW sites has potentially fatal consequences when done improperly as demonstrated by the introductory section of this chapter. The inspection and certification of OEW scrap should be the subject of a strictly enforced quality control (QC) program.

All scrap from OEW sites should be carefully inspected by accountable QC inspectors to determine that it is free of explosive hazards. In addition, the requirements of the DoD Demilitarizaton Manual [DoD Manual 4160.21-M-1], including venting inert UXO to expose the inert filler thereby allowing positive identification of the inert filler and also eliminating the buildup of pressure inside a sealed casing when the inert UXO is heated during recycling, should be complied with. Once properly demilitarized and inspected, the certified OEW scrap should be positively controlled until it is turned over to the approved recycling contractor to prevent someone from adding noncertified, and possibly hazardous, items.

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16

MONITORING WELL HEALTH AND SAFETY

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Dennis Goldman, Ph.D.

The purpose of this section is to generally familiarize the reader with the health and safety issues related to groundwater monitoring wells. The installation and sampling of groundwater monitoring wells is one of the few methods of characterizing the subsurface environment at hazardous sites. The ability to perform environmental site characterizations and remediation typically includes the installation and monitoring of groundwater monitoring wells. *Groundwater and Wells* [Driscoll, 1986] is a general compendium of information relating to all aspects of well drilling and well construction. The American Society for Testing and Materials Environmental Sampling Manual [ASTM, 1995] includes 70 standards ranging from "Terminology Relating to Soil, Rock, and Contained Fluids" (D 653-90) to a "Guide for Sampling Groundwater Monitoring Wells" (D 4448-85a). The National Groundwater Association (NGWA) has published a *Handbook of Suggested Practices for the Design and Installation of Groundwater Monitoring Wells* [NGWA, 1989].

INTRODUCTION

The drilling and installation of monitoring wells became common practice in the late 1960s and proliferated in the 70s, with exponential growth through today. It is now estimated that there are more than 37,000 monitoring wells installed annually in the United States [McCray, 1997].

As the extent of the groundwater contamination problem in the United States became better understood, regulatory requirements became the primary driver in monitoring well installation, sampling, testing and data analysis. The passage of the Resource Conservation and Recovery Act of 1976 (RCRA, PL 94-480) and, subsequently, the attendant Codes of Federal Regulations (CFR) covering solid and hazardous wastes (i.e., subtitles D and C, respectively) formalized the requirements for ground-water monitoring at tens of thousands of facilities (40 CFR 257 and 264). The Comprehensive Environmental Response, Compensation, and Liability Act of 1983 (CERCLA, PL 96-510)

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and the subsequent Superfund Amendment and Reauthorization Act (SARA) in 1984 were promulgated to provide a trust fund for cleanup of abandoned or orphan sites. They did not specify monitoring requirements, but because of the required subsurface characterization, further increased the number of monitoring well installations in the United States. Related regulations have been generated as a result of the Safe Drinking Water Act of 1976, the Underground Injection Control program, the Surface Mining Control and Reclamation Act of 1977 and the Toxic Substance Control Act of 1983. Some states have taken primacy or control over these federal program(s) and, in selected areas, adopted regulations stricter than the federal government. Most states also have a licensing or registration program, which regulates drilling, construction, abandonment, and reporting of water and/or monitoring wells activities.

OVERVIEW

Monitoring wells are constructed for a variety of reasons. During the siting of new facilities, they are used to define baseline or preproject conditions. At existing or closed facilities they may be installed to determine if there is subsurface contamination at the site. If contamination is detected, additional monitoring wells may be required to characterize the extent and/or to monitor the performance of a facility or a remediation program.

The primary goal in monitoring well construction is to obtain samples representative of site specific subsurface conditions. During drilling this may include soil sampling, as well as periodic sampling of soil gases and groundwater. Great care must be taken to ensure that cross contamination does not occur between samples and that the potential for drag down or smearing contamination either up or down the borehole is minimized. Cross-contamination is also a major concern in collecting groundwater samples. In a regulatory environment that sets toxicological based standards in the parts per trillion concentrations, cleanliness akin to surgical procedures is sometimes required. Some sites with highly toxic contaminants in their soils, soil gas and/or groundwater may require specialized personnel protective equipment (PPE) and procedures.

Drilling Hazards

There are numerous hazards associated with the drilling of a borehole for the installation of a monitoring well. The proper development of a site specific sampling and analysis plan (SAP) and a health and safety plan (HASP) can minimize many of these hazards. All hazardous waste sites require an HASP in

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order to be in compliance with 29 CFR 1910.120, see Chapter 16 for more details. Personnel engaged in, or directly overseeing field activities at hazardous waste sites must complete Hazardous Waste Operations and Emergency Response (HAZWOPER) training, and have the appropriate medical surveillance before beginning fieldwork, (see Chapters 12 and 7, respectively). There are numerous hazards associated with well drilling, but the greatest dangers at drilling sites are associated with the mechanical operation of heavy equipment.

Mechanical Hazards

A number of standard drilling methods are available for installing monitoring wells: auger, cable tool, air or mud rotary and coring. Other drilling methods that are a takeoff or refinement of these basic approaches are also available. Driscoll [1986] has provided a comprehensive description of a wide variety of drilling techniques. Whatever drilling method is selected, it typically involves a combination of heavy machinery, overhead equipment, moving cables, pressurized hoses, loud compressors and pumps, rotating pipes, climbing masts, heavy lifting, and welding. Many times workers are required to complete tasks in the rain, mud, or snow wearing a range of work clothing and personal protective equipment. The most common problems include hearing impairment, burns/cuts, slips/falls, and back strains. Most lethal accidents on drill rigs involve drill rig masts coming in contact with overhead power lines, or drilling into underground utilities.

Increased Hazards from Wearing PPE

What is unique to drilling monitoring wells is their location at known or potentially contaminated sites. This added dimension increases the potential hazard, not only because of the risk of exposure to toxic materials, but also due to the added requirement for personnel protective equipment. Maslansky and Mailonsky [1997] provides a good overview of the various levels of PPE required, as well as general hazards of drilling at waste sites:

- Level D, generally includes a field suit (Tyvek, coveralls or rain gear), appropriate gloves for handling soil or groundwater, hard hat, eye protection, and steel-toe boots;
- Level C, generally includes the addition of a cartridge purifying respirator;
- Levels B and A, generally increase the respiratory protection to either a supplied airline or self-contained breathing apparatus.

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Although each increase in PPE level decreases the risk from a chemical hazard, it increases the risk from other physical hazards. Typically there is a decrease in mobility, reaction time, ability to communicate, and vision of a worker as well as an increase in physical and mental stress levels.

In hot or humid weather, PPE increases the likelihood of hyperthermia or heat prostration. Workers should be required to take frequent rest periods and drink sufficient fluids. Some recommended procedures to reduce the potential for heat stress include

- Acclimate to high humidity and/or heat by beginning with lighter work and shorter work periods during the startup phase of a project.
- Take frequent rest breaks.
- Remove as much of the PPE as possible to cool down and drink water during rest periods.
- Air condition the cool down room or trailer.

Further discussions on heat stress are included in Martin, Lippitt, and Prothero [1992] and in Chapter 10 of this book.

At some residential areas, site workers may not want to wear the appropriate PPE to prevent alarming the neighborhood. This has happened when placing monitoring wells in a ball park or at some gas stations. Not wearing the appropriate PPE as specified in the SAP can be hazardous to the site workers, and would be a citable offense under 1910.120.

Explosion/Fire Hazards

Explosive gases are a potential problem at solid and hazardous waste sites. Methane generation at solid waste landfills is well documented [Pacey, 1982]. When drilling in, or adjacent to, older landfills it is possible to tap gas pockets and release trapped methane gas. Numerous cases have been documented where methane gas from landfills has migrated off site to accumulate under slabs, buildings, or in basements, and later exploded. Other gases can be explosive when mixed with sufficient oxygen during the drilling process. The most common problem arises when welding in the presence of explosive gases. However, an unexpected ignition can occur from any spark. The result is a "blue flash" at the borehole, which can result in burns, a fire, and/or other accidents.

Drilling within or adjacent to dumps and/or landfills can create a fire hazard. As heat is generated during waste decomposition, it sometimes results in spontaneous combustion. The process of drilling can supply sufficient oxygen to the waste to change a smoldering fire to a free burning state. Some

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sites have smoldered for years, resulting in subterranean cavities in the waste. These cavities can become gas traps, or they can become unsupported caves much like karst sinkholes common in the Southeast. Accidents have occurred when heavy equipment working over one of these "garbage sinkholes" causes a collapse.

Select industrial, mining, and UST (gas station) sites have other fire and/or explosion hazards. Free-phase product or dissolved product at high concentrations can cause explosive conditions when provided air from the drilling operation. Some industrial and mining products are self-igniting when air is encountered, causing considerable potential for fire or explosion when drilling in this environment. Few industrial sites have as-built plans that provide an accurate location of all underground utilities. Drilling operations on sites as young as 3 years old have encountered buried lines or structures. These structures that were not identified on the plans can include pipes carrying flammable fluids, liquids that are hazardous to the environment, or high-pressure liquids or gases, utility lines (power, phone and sewer or underground storage tanks). Drilling through any of these pipes can cause a significant health and/or safety problems. All drill sites should be cleared by a utility locator prior to drilling. When possible, it is good practice to hand auger the first 5 to 15 feet of the borehole to ensure that there are no "invisible" buried lines.

Chemical Exposure Hazards

Toxic chemicals found at nearly all waste sites present another hazard. These chemicals range from the relatively benign to extremely dangerous. The exposure can result from contact, ingestion, and/or inhalation. The synergistic effect of chemical mixing at a site can result in an increased adverse effect relative to any single constituent. Mixtures of chemicals may also increase the mobility of an otherwise immobile contaminant.

Several precautions are emphasized at drilling sites to reduce exposure via the dermal and ingestion pathways, including

- Set up exclusion and personnel decontamination areas.
- Minimize the potential for hand to mouth transfer of toxic chemicals by not eating, drinking, or taking medications within the exclusion or decontamination areas.
- Do not chew gum or tobacco or smoke within the exclusion area.
- Wash hands after handling contaminated equipment and before using the restroom.
- Do not rub eyes or lick lips.

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- Do not take contaminated clothing to your vehicle, or home for laundering.
- Avoid wearing contact lenses, even under a respirator, as they tend to concentrate organic matter around the eyes.
- Record and report all potential exposures, including unusual odors, drill cuttings or vapors.

Specialized Hazards

Medical and biological wastes can pose special and unexpected hazards. Drill cuttings can include numerous "sharps," which may be infected. Exotic bacteriological and viral materials may be present that can be introduced to the breathable working environment. There are no air monitoring devices that can distinguish these contaminants. Drilling into areas of potential medical wastes should be avoided. If it cannot be avoided, review the HASP with a suitable professional to clarify PPE, reporting, and accident response procedures.

Radioactive wastes pose unique problems at some sites. Unexploded ordinance can present a high risk at military waste sites. Confined space entry presents another unique situation. These situations require specialized HASPs with appropriate review.

Equipment Loss

Although not a physical hazard, it is more typical than not for tools and instruments to be accidentally dropped down the borehole during the drilling process. Occasionally these tools and instruments are recovered. Considerable time and effort is spent trying to recover some of these tools and instruments.

Hazards of Containing Waste

Collection and containment of drill cuttings, drill fluids, and decontamination fluids is typically necessary when wells are being installed at a site where contamination is known or suspected. This typically involves filling and handling drums and tanks. The exposure of a worker to the waste is typically increased. Handling of drums and other containers is covered in more detail in Martin, Lippitt and Prothero, [1992]. Final disposition of these materials may be made following receipt of testing data from the well, or in some cases may require additional sampling of the drummed waste.

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Decontamination Hazards

The decontamination of drilling equipment typically includes steam and/or high-pressure washing of all equipment in a contained area. Many times the contained area consists of plastic sheeting, which becomes slippery when wet and muddy. Use of this equipment can cause danger from burns and slips/falls. Chemical decontamination may be required for small equipment, for example, the use of acids and/or solvents. Chemical decontamination increases the potential for dermal stress (burns) and respiratory exposures.

Engineered Controls to Reduce Hazards

Engineered controls should be used, whenever possible, to prevent the need to upgrade PPE and reduce contact with subsurface vapors/drill cuttings. A common engineering control is the use of industrial fans to dilute and remove gaseous contaminants or obnoxious fumes emanating from a borehole. Engineered controls are discussed in more detail in Chapter 8 of this book. **The importance of engineering controls cannot be overemphasized.**

Access Hazards

Monitoring wells are typically located at remote or highly industrialized sites. At remote sites, the access is usually difficult and can be dangerous, especially at night or under inclement conditions. Remote sites can have other natural dangers, such as venomous snakes and spiders. At industrial sites, there may be small access areas or heavy machinery that must be maneuvered around.

Environmental Hazards

Environmental hazards are the "hidden" hazards of drilling monitoring wells. These may impact the environment but not the site worker. One such environmental hazard consists of introducing contaminants to the subsurface during the drilling process. This may be caused by equipment failures (such as a break in a hydraulic hose) or accidents (such as overfilling a fuel tank at the drill site). Another more "hidden" environmental hazard may be "cross-connecting" aquifers via the drilling and well construction process. This impact may take a long time, if ever, to detect.

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Monitoring Well Installations

Installation presents effectively all the same hazards as the drilling, since it is typically done with the same equipment. This section summarizes monitor well construction, but does not repeat the list of hazards.

Well Construction

The use of 2- and 4-inch monitoring wells is common, and occasionally 6-inch wells are installed. Two-inch wells are the most frequently used. The benefits of the 2-inch wells are ease of installation through drill pipe, and the relatively low volume of water that must be purged before sampling. On the other hand, the use of 2-inch wells makes development of wells difficult, and can result in turbid samples that are not chemically representative of aquifer water. In deeper wells, it is sometimes preferable to use 4- or 6-inch casing and screen. These larger casings can accommodate larger pumps, which improve development and speed up the well purging process prior to sampling. It should also be noted that an adequately developed or efficient well with a dedicated purge and sampling pump reduces the sampling hazards relative to the manual purging and sampling with a bailer.

Selection of the screened zone is dependent on the monitoring purpose and the contaminants of concern. Most wells are installed with 2- to 10-foot screened sections. This allows for depth specific sampling from within a selected hydrogeologic unit. One exception is the placement of longer screens that rise above the water table to allow for the direct measurement of light non-aqueous phase liquids (LNAPL), such as petroleum hydrocarbons. Over the past two decades there have been thousands of these monitoring wells installed at service stations throughout the U.S. in order to identify leaking underground storage tanks (USTs). Where highly volatile contaminants are encountered, a screen rising above the water table can increase the risk of fire or explosion.

Another area requiring special design considerations is the presence of dense non-aqueous phase liquids (DNAPL). Many of the common chlorinated solvents are included in this family of immiscible-phase chemicals, and they can pose unique problems in monitoring and remediation [Cohen and Mercer, 1993; Pankow and Cherry, 1995].

The screened section of a monitoring well is designed to facilitate passage of water from the saturated zone of interest into the casing. A filter pack, generally a commercially washed and sized sand, is used to fill the annulus of the borehole. Matching the screen and filter pack sizes to the formation to obtain representative groundwater samples is not as critical as for a supply well. Driscoll [1986] provides detailed discussions of the considerations and

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design parameters commonly employed in the construction of water wells, with a discussion of the limitations specific to smaller diameter monitoring wells.

The vast majority of the modern monitoring wells are constructed of PVC. Demand for a material that is relatively low cost, readily available, light and easily handled has resulted in the manufacture of specialized screens, square threaded joints, o-ring seals, and various tips. At most installations these materials do not significantly interfere with the sampling and testing of the contaminants of concern. In order to ensure that there is minimal interference or introduced contamination from the well casing, it is always decontaminated prior to installation.

Well seals are placed in the annulus of the borehole above the filter-pack to prevent short circuiting or direct percolation of contaminants from the surface or upper soils and hydrogeologic units to the screened zone. After the screen and casing has been set, the filter-pack is typically placed to a height of at least 2 feet above the screen. A fine-grained sand pack material may be placed on top of the filter-pack to reduce the potential for any seal material infiltration. Typically, a bentonite clay seal is placed above the filter-pack, generally using pellets (below the water level) or chips (above the water level). Bentonite or cement grout is placed above the pellet or chip pad. This well seal is integral to the protection of the aquifer from the environmental contamination or hazards mentioned above.

The well installation is completed with a security or protective casing. These are typically set in concrete. It consists of an above-the-ground steel casing with a locking cap or a traffic-rated flush-mount water-tight box. Aboveground installations should be tall enough to be highly visible, but not so high that it makes access for sampling difficult. Aboveground installations may include barriers to protect them from traffic. The importance of the security casing is not just to ensure that there is no tampering with the monitoring well. It can also greatly extend the life of the well. Most wells are lost to service because of physical damage or loss. In many cases, they are run over by heavy equipment or vehicles, or bent or lost due to burial. Protective casings are typically locked and not painted.

Well Development

Well development refers to any of a number of processes used to remove drilling fluids or residues from the filter-pack and the adjacent geologic materials [Driscoll, 1986]. In the classic case, the well is pumped at a rate greater than its designed capacity. This results in increased entrance velocities through the filter-pack and the screen, and the evacuation of finer-grained particles. Common 2-inch PVC monitoring wells present a number of problems for well development. The diameter of the well precludes the use of high

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capacity pumps, and in most cases the well hydraulics will not support pumping more than a few gallons per minute. In many cases the simple use of surge blocks to loosen the fine-grained material followed by bailing to remove that material is the only solution. This water must typically be captured and contained until testing determines its quality and final disposition, presenting the typical health and safety problems:

- Risk of back strain during equipment installation and/or bailing;
- Heat prostration during hot weather; and
- Increased dermal exposure.

Groundwater Sampling

The goal of groundwater sampling is to collect a representative sample of the aquifer water from the hydrogeologic unit of interest for testing. This is a time consuming, routine and tedious job. The nature of the work can lead to fatigue and inattention to detail. As with all aspects of the monitoring process, avoidance of introduced or cross-contamination is a major obstacle to be overcome. Cleanliness and decontamination of sampling equipment is typically more stringent than that employed during drilling and installation of the monitoring well.

The initial task in sampling is to locate the monitoring well. This may be difficult, as it could be covered with weeds, under water, under a vehicle, or under stored supplies. The sampler should inspect the locking security casing for damage to the casing or well seal. A broken lock or hasp may indicate a potential safety hazard. Once located, opening a rusted lock or cleaning the dirt from a flush mount can be difficult. Gloves should be worn while carefully removing covers and caps to minimize dermal contact or infecting cuts. Entry should be made with caution, as the inside of the protective casing is a good place for spiders and snakes to get out of the weather. Once open, the depth-to-water in the well is measured using a suitable device, for example, steel tape, electric water level indicator or interface probe (appropriate for LNAPL), or reading a dedicated indicator such as a transducer. If the presence of a DNAPL is suspected, the bottom of the well is also checked with a single check valve bailer [ASTM, 1995] or other suitable sampler. The depth of the well is also recorded to check for any in-filling, caving, or obstructions. These conditions are noted and the measurements used to estimate the volume of water standing in the casing. It is recommended that the portion of the water level detector that enters the water (the tip) and a minimum of a 5-foot section above that portion be decontaminated before its use in any subsequent well.

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Prior to the collection of the groundwater sample, the standing water in the casing must be removed. It is assumed that this water is not representative of the groundwater, since it has been standing in the casing and subject to chemical and/or biochemical alterations. Purging of the monitoring well is generally accomplished by bailing or pumping. When the monitoring well hydraulics allow, pumping is the preferred method of purging.

Pore volume removal requirements can range from a specified number of pore volumes, commonly 3 to 10, to stabilization of field parameters. Field measurements of selected parameters, such as temperature, pH, specific conductance, turbidity, and/or dissolved oxygen, are obtained until they have reached some level of stabilization, commonly within 10 percent of the previous pore volume. These measurements can be made from periodic grab samples, or in some cases with the use of a flow through cell. Containment of the purge water is required at most sites with known or suspected contamination. Handling of drums and other containers is covered in more detail in Martin, Lippitt, and Prothero [1992].

Following the completion of the well purging, the groundwater sample is collected. Consideration equal to that for the selection of well construction materials is given to the selection of the sampling equipment. This includes an understanding of the contaminants of concern and their susceptibility to interference via leaching, sorption and/or geochemical alteration. Glass, stainless steel, Teflon, PVC, Tygon, and other materials are available. The use of disposable sampling equipment is common. Reusable sampling equipment will require decontamination. A common chemical decontamination sequence includes the use of tap, distilled and/or deioinzed water, a non-phosphatic detergent, and acid (pH < 2), and methanol.

Typical descriptions of sample collection procedures are as follows:

- Groundwater samples are collected directly from the dedicated pump discharge line or with a double-check valve Teflon or disposable bailer, as appropriate. (Note: monofilament line is recommended for the bailer line, as it is can be decontaminated much easier than a braided line.) Samples are transferred from the sampling equipment to a container specifically prepared for certain parameters. A bottom-drain-control valve is used to transfer the VOC sample from the bailer to the appropriate container. The sample is poured down the sides of the sample bottle, not splashed into its base. Samples collected for VOC analysis must be filled completely so there will be no headspace, thus minimizing will have no headspace to minimize the loss of VOCs by volatilization.
- Samples that will be analyzed for dissolved metals and anions may be filtered during collection with disposable 0.45-micron in-line filters, which

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will be attached directly to the pump discharge line or, when bailed, run through a peristaltic pump to facilitate filtration. Each filter will only be used once. (Note: field filtering is only necessary when turbidity biases the testing results due to sorption of contaminants to the fine-grained materials OR when acidic preservation and laboratory digestion elute "natural" metals from the fine-grained materials.)

- Each disposable bailer will be used for only one well and appropriately disposed. Other equipment (e.g., reusable bailers, bailer lines, discharge lines, and pumps), used for water sample collection will be decontaminated both before use at the facility and after each sample is collected.
- Quality control samples are typically collected.

These directions are a general example of field procedures. There are a wide variety of potential modifications or additions to the procedures that are designed to meet specific site or contaminant detection needs. Examples include the collection of petroleum hydrocarbons or LNAPLs from the top of the saturated zone, and the collection of DNAPL from the bottom of the monitoring well [Cohen and Mercer, 1993].

Access Hazards

The access hazards are the same as described in the monitoring well drilling section. Locating a monitoring well can cause auto or personnel accidents. Most above-grade monitoring wells are at a height of about 2 feet and not painted. These can be difficult to see from a vehicle, resulting in running off the road while looking, running into buildings or posts while looking, or running into the monitoring well itself. Once located, cuts and bruises are typical injuries related to opening "stuck" protective casings. Bites and stings are common from critters residing in the protective casings. In addition, when opening the well cover, there may be respiratory hazards associated with vapors emanating from the wellhead. Wherever the contaminants of concern, and the site conditions warrant, or the HASP requires, a worker should measure the VOC vapors and take the appropriate protective action, (see Chapters 5 and 13).

Sampling Procedures Hazards

Sampling involves the storage, transport and use of equipment and chemicals from the office to the field and from well to well. These must be carefully packed and transported in a clean, dust-free environment. The need for cleanliness has been emphasized throughout this discussion. Safety and

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hazardous working conditions parallel to those encountered in laboratories often exist. First aid, eye wash, and decontamination materials should be readily available to field samplers.

The primary hazard associated with sampling is splash and dermal contact. A sampler will inevitably be in contact with the groundwater being sampled. The proper PPE should be used both to protect the sampler and to avoid contamination of the sample. The use of gloves and splash protection while at the well are common, not just for personal protection, but to keep clothing clean and to make it easier to decontaminate the sampling equipment.

Vapors trapped in the protective casing or within the well casing are a concern during the sampling process. Safety measures to minimize these hazards include well head monitoring, when suspected gases are present, and the judicious implementation of engineering controls (sample from the down wind side) and/or wearing appropriate respirators.

Although not a physical hazard, it is all too common for tools and instruments to be accidentally dropped down the boring during the sampling process. Occasionally these tools and instruments are recovered. They should be treated as contaminated material until they have been thoroughly decontaminated. Considerable time and effort is spent trying to recover some of these tools and instruments.

Decontamination and Waste Handling Hazards

This generally involves washing or steam cleaning, but may include the use of surfactants, selected solvents, and/or acids for specific applications. There should be caution when trying to steam clean small groundwater sampling equipment. The handling and disposal of purge water, solvents and acids presents the same safety issues as discussed earlier.

Environmental Hazards

The proper construction and long-term stability of most monitoring wells cannot be verified. Thus, it is possible that a monitoring well is or can become a rapid pathway for contaminants to reach an aquifer. In addition, access to a monitoring well by a worker or the public allows direct access to the aquifer, with a potential for direct contamination. In a few extreme cases, early generation, unmarked, flush-mount protective casings were mistaken for fill ports for fuel tanks, resulting in significant direct contamination to an aquifer.

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CONCLUSION

Groundwater monitoring is ubiquitous in industrial solid and hazardous materials operations. It is required by law at thousands of facilities throughout the United States. Attention to detail in the placement, construction, and sampling of monitoring wells results in the highest quality of subsurface information. In turn this information provides the basis for the determination of need, and in many cases, the rational selection of remediation procedures. The nature of the sites being monitored determines the level of protection necessary for worker safety. While this can never be reduced to "zero exposure" it can and must be managed by taking into consideration site specific conditions, contaminants of concern and the goal(s) of the investigation, while remembering the limitations of the trained worker.

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17

TRANSPORTATION SAFETY

Richard Montgomery, Ph.D.
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INTRODUCTION

Transportation of hazardous waste from the generator or source to intermediate destinations and to final disposition has frequently been involved in major threats to the environment and public safety. In pre-RCRA times, small, locally based, solid waste haulers provided immediate and cheap removal of hazardous waste accumulations on a "no questions asked" basis. Truckers could remove unwanted wastes and dispose of them without permits or manifests.

In the late 1970s to early 1980s, federal regulations started restricting waste disposal operations. The RCRA program closed many land fills and municipal dumps that did not meet minimum EPA pollution control standards. During this same time, the Department of Transportation was tightening its regulations on hazardous materials haulers. During the 10-to 20-year period of transition between very limited enforcement of hazardous waste hauling and disposal up to the early 1990s when RCRA was fully enforceable, sizable portions of the nation's hazardous waste was not tracked. It was later learned that some haulers outfitted tankers with dumping valves so that liquid waste could be dumped while driving along back roads. Trailers loaded with waste drums were abandoned in unsecured locations. Rural areas and vacant lots were littered with all manner of hazardous wastes.

As the manifest system began to function, these practices were brought under better control. Regulatory agencies gained recognition and experience, most of the marginal transporters were "weeded out," and transportation became a vital link in the cradle-to-grave management strategy. Although illegal transportation activities continue to require the attention of law enforcement agencies, much of the regulatory focus has shifted to accident prevention, emergency response activity, surveillance of import-export activity, and tracking of wastes from source to ultimate disposition [Blackman, 1996].

The handling and transportation of hazardous materials has increased greatly during recent years. The increased use of chemicals in our daily lives,

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many of which are hazardous materials, poses an additional challenge to the safe handling, packaging, storing, or transporting of these materials. In 1997, about 10 to 15 percent of all tankers and other trucks on the highway carried hazardous materials, according to government estimates. This adds up to hundreds of truck shipments each day. One great fear is an accident greater than any yet experienced. Safety experts have calculated that single truck explosion on a crowded city street could kill several thousand persons; a ship accident in a port city like New York or San Francisco could kill and injure tens of thousands.

Rail shipments account for about 8percent of mile tonnage of hazardous materials transported annually, with about 3000 carloads shipped daily. The portion of these shipments that are hazardous *wastes* is not known. Capacities for tank cars carrying hazardous materials are limited to 34,500 gallons or 263,000 pounds gross weight [49 CFR 179].

The highway transport mode is regarded as the most versatile. Tank trucks can access most industrial sites and treatment, storage, and disposal facilities (TSDFs), while rail shipping requires expensive sidings and is suitable only for large quantity shipments. Cargo tanks are the main carriers of bulk hazardous *materials* [Office of Technology Assessment, 1986, Chapter 3]; however, large quantities of hazardous *wastes are* shipped in 55-gallon drums. Cargo tanks are usually made of steel or aluminum alloy, but can be constructed of other materials such as titanium, nickel, or stainless steel. They range in capacity from about 2000 to 9000 gallons, depending upon road weight laws and the proper ties of the materials to be transported.

Accident and transportation release statistics from the late 1970s and early 1980s provide insight to the relative hazards posed by the highway and rail modes of hazardous *materials* transportation. These data indicate that highway transport experienced twelve times the number of incidents involving hazardous materials, four times the number of fatalities, and twice the number of injuries as occurred in rail transport. However, rail accidents released approximately 50 percent greater quantities than did highway accidents involving hazardous *materials* [Blackman, 1985, Chapter 2]. Total transportation incidents involving hazardous wastes show significant increases from 1989 to 1993 (Table 17-1). However, numbers of hazardous waste incidents involving accidents or derailments show no particular trends. No transportation incident-related deaths were reported during the period. Hazardous *materials* incidents are shown for comparison.

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Table 17-1 Transportation Incidents Involving Hazardous Waste-Rail and Highway

Incidents		Accidents/Derailments		Deaths	
Year	Hazwaste	Hazwaste	Hazmat	Hazwaste	Hazmat
1989	149	15	342	0	8
1990	194	10	299	0	8
1991	202	13	303	0	10
1992	413	17	284	0	15
1993	575	7	264	0	15

"Incidents" do not equate with "accidents." A release incident can occur without an accident, and, conversely, an accident can occur without a release.
Source: Chemical Waste Transportation Institute, 1994.

Hazardous materials transportation incidents tend to be spectacular, dangerous, freakish, and unpredictable. Rail accidents, as noted, involve containers of up to 34,500 gallons or 130 tons vs. the 9000 gallon/40 ton limits for highway transportation. The greater quantity per container, chemical incompatibilities between rail tank car shipments, and the difficult accessibility encountered in rural locations leads to unmanageable fires which are frequently allowed to "burn themselves out." Incidents involving truck shipment of hazardous materials, when they occur in urban areas, are more likely to endanger human lives and property. Fires in populated areas typically must be controlled expeditiously in order to limit exposure and property damage. A 1981 report, prepared for the EPA, estimated that 96 percent of the 264 million tons of hazardous wastes generated each year were disposed of at the site where they were generated and that most of the hazardous waste shipped offsite was transported by truck [Westat Inc., 1984]. These shipments were usually over routes of 100 miles or less [ICF Inc., 1984]. By 1989, the National Solid Wastes Management Association (NSWMA) stated that trucks traveling over public highways moved 98 percent of the hazardous waste that is treated offsite. Rail freight moved the remainder [NSWMA, 1989]. By 1993, the EPA counted 20,800 transporters of hazardous waste [U.S. EPA 1993]. Shipments of hazardous waste by inland waterways and by air have been infrequent to date.

Another important perspective can be gained from the statistics for hazardous *materials* transportation. Rail transportation moves about *8 percent* of hazardous materials shipped, but 57 percent of the *ton-miles* of hazardous materials shipped [Office of Technology Assessment, 1986]. Moreover, the

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student should have clearly in mind the fact that most "hazardous materials" become hazardous *wastes* when released to the environment. At that occurrence, the hazardous waste regulations of RCRA, CERCLA, and the state and local jurisdictions apply.

Enactment of the Hazardous and Solid Waste Amendments of 1984 (HSWA) brought more than 100,000 new small quantity generators (SQGs) under regulation. Most of the SQGs have had no alternative to shipment of their hazardous wastes offsite for disposition. Thus, HSWA may have caused some increase in transportation of wastes to treatment, storage, and disposal facilities. The addition of 25 new chemical constituents to Table I, 40 CFR 261.24, in 1990, is said to have brought 17,000 new generators under RCRA regulation. In 1993, the EPA counted 266,000 generators, of which approximately 240,000 are SQGs [EPA, 1993]. Thus, large numbers of generators have no options other than to transport hazardous wastes offsite for ultimate disposition. Reliable current statistics on quantities treated onsite are difficult to obtain. Superfund and RCRA site remediation activities involve more onsite treatment of hazardous wastes. In general, ever-tightening regulatory control, liability concerns and availability of commercial treatment options have tended to cause wastes to be shipped offsite for treatment.

All those charged with responsibility in handling, packaging, storing or transporting hazardous materials have a tremendously important duty to perform. It is essential that workers be familiar with proper procedures in identification, storing, stowing, handling, and transporting of these sensitive materials.

Training Requirement

This chapter will provide initial training to ensure that HAZMAT employees are familiar with the general provisions of DoT CFR 49 and EPA CFR 40, have knowledge of specific requirements applicable to functions performed, and have knowledge of emergency response information.

In general, the DoT regulations deal with container and equipment specifications, packaging, categorization of wastes, training and the determination of proper shipping descriptions. The EPA regulations provide the tracking mechanisms that are intended to maintain the cradle-to-grave management system.

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The DoT regulations dealing with transportation of hazardous materials are found in 49 CFR 171 thru 179 and are referred to as the HM 181, "Performance Oriented Packaging Standards." The DoT, as do other agencies, assigns a "docket number" to new regulatory proposals. The proposed regulations are referred to by docket number throughout the promulgation process. Upon final publication of the rule package, the DoT continues to refer to the implemented program by that number. Thus, the implementation of the Performance Oriented Packaging Standards continues to be referred to as HM 181.

The content and detail of these regulations greatly exceed the scope of this chapter, but the general thrust can be understood by examining the column headings of the 49 CFR 172.101 Hazardous Materials Table (see Table 17-2). The elements pertaining to transporters of hazardous materials focus on emergency response information and requirements, training of the "HAZMAT employee" and specialized training for drivers. The training requirement of 49 CFR 172, Subpart H, is referred to as "the HM 126F training."

The transporter must maintain the emergency response information contained on the manifest in a manner that ensures that it is immediately accessible to emergency responders. For example, drivers of cargo tank vehicles must keep the manifest on the seat adjacent to the driver's seat or in the "pocket" of the door on the driver's side of the cab. Similar requirements apply to train crews and bridge personnel on vessels. If the transporter makes use of a transfer facility, the emergency response information must be maintained in a location that is immediately accessible to the personnel operating the facility.

The, DoT immediate notification requirements for hazardous materials incidents are applicable to discharges of hazardous wastes. Notice is given by calling the National Response Center, operated by the U.S. Coast Guard [800 424 8802). Specifically, the National Response Center must be notified when:

- A person is killed or injured to the extent that hospitalization is required;
- The estimated damage exceeds $50,000;
- The fire, spill, breakage, or contamination involves disease-causing agents radioactive material;
- There is an evacuation of the general public for 1 hour or more;
- The spill exceeds a Superfund reportable quantity; and
- A life-threatening situation exists [49 CFR 17 l. 15].

The HM 126F HAZMAT employee training requirement is prescribed in 49 CFR 172, Subpart H. The training is required for any employee who performs any function having to do with the safety of a hazardous material

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Symbols	Hazardous Materials descriptions and proper shipping names	Hazard class or Division	Identification Number	PG	Label	Special Provisions	(8) Packaging (§173.***)			(9) Quanity limitations		(10) Vessel Stowage	
							Exceptions (8A)	Non-bulk (8B)	Bulk (8C)	Passenger aircraft/rail (9A)	Cargo aircraft only (9B)	Location (10A)	Other (10B)
(1)	(2)	(3)	(4)	(5)	(6)	(7)							
	Acetic anhydride	8	UN1715	II	8, 3	A3, A6, A7, A10, B2, T8	154	202	243	1 L	30 L	A	40
	Acetone	3	UN1090	II	3	T8	150	202	242	5 L	60 L	B	
	Acetone cyanohydrin, stabilized	6.1	UN1541	I	6.1	2, A3, B9, B14, B32, B76, B77 N34, T38, T43, T45	None	227	244	Forbidden	30 L	D	25,40, 49
	Acetone oils	3	UN1091	II	3	T7, T30	150	202	242	5 L	60 L	B	
	Acetonitrile	3	UN1648	II	3	T14	150	202	242	1 L	60 L	B	40
	Acetyl acetone peroxide with more than 9 percent by mass active oxygen	Forbidden											
	Acetyl benzoyl peroxide, solid or with more than 40 percent in solution	Forbidden											
	Acetyl bromide	8	UN1716	II	8	B2, T12, T26	154	202	242	1 L	30 L	C	40

Table 17-2
Hazardous Materials Table

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shipment (see 49 CFR 171.8 for the definition of "HAZMAT employee" and "HAZMAT employer"). The required training consists of three categories, which are

1. *General Awareness/Familiarization Training*--The hazards associated with hazmat transportation, the hazard classes of HM 181, and hazard communication requirements.
2. *Function-Specific Training*--The packaging, labeling, marking, and placarding of hazardous materials shipments, that is the Performance Oriented Packaging Standards.
3. *Safety Training*--Including the emergency response, personal protective clothing and equipment, and methods and procedures for avoiding accidents and exposure.

The standards also include driver training requirements and specialized training for drivers of vehicles transporting explosives, radioactive materials, or cryogenic gases. The HAZMAT employee must repeat the training at 2-year intervals: drivers must be trained annually.

EPA-RCRA Regulations for Hazardous Waste Transporters

The RCRA transporter regulations [40 CFR 263] define "transporter," provide the packing mechanisms that are intended to maintain the cradle-to-grave management systems for hazardous waste management and impose cleanup and reporting requirements that apply in the event of the discharge of hazardous waste(s) during transport.

The transporter is defined as any person engaged in the off-site transportation of hazardous waste within the United States if such transportation requires a manifest. This definition covers transportation by air, highway, rail, or water. The transporter regulations do not apply either to the onsite transportation of hazardous waste by generators who have their own treatment or disposal facilities nor to TSDFs transporting wastes within a facility [EPA, 1990, p. III-26]. *However,* both generator and TSDF owners and operators must avoid transporting wastes over public roads that pass through or alongside their facilities

Under some circumstances, transporters can become subject to the generator regulations by importing hazardous waste into the United States, by mixing hazardous wastes of different DoT shipping descriptions or by being responsible for cleanup of a discharge of hazardous wastes or commercial chemical product that occurred during transport. In such circumstances, the transporter must comply with the generator regulations [40 CFR 263.10].

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A transporter may store hazardous wastes at a transfer station for up to 10 days without being subject to other than the transporter regulations. If the storage time exceeds ten days, the transporter becomes a storage facility and must comply with the regulations pertaining to such a facility, including the requirements for obtaining a permit.

Transporters must comply with RCRA Subtitle C regulations, which require

- Obtaining an EPA identification number;
- Complying with the manifest system; and
- Handling hazardous waste discharges.

EPA ID Number

The EPA ID number is essential to the EPA and the primacy states in tracking transporter activity. Without this unique number, the transporter is forbidden to handle hazardous waste. Moreover, a transporter may not accept hazardous waste from an SQG or generator nor transfer hazardous waste to a TSDF unless they have EPA ID numbers. A transporter obtains an ID number by "notifying" the EPA of hazardous waste activity using a standard EPA notification form.

The Manifest

The RCRA Subtitle C regulations prohibit transporters from accepting hazardous waste shipments from shippers without a manifest. The function of the manifest system was described in the previous chapter. The transporter who accepts manifested hazardous wastes is required to sign and date the manifest and return a signed copy to the generator or previous transporter. The transporter is responsible for the shipment until the manifest is signed by the owner or operator of the receiving facility.

The transporter is required to deliver the entire quantity of waste accepted from either the generator or another transporter to the facility listed on the manifest or to the alternate facility if one is listed on the manifest. If the waste cannot be delivered as the manifest directs, the transporter must inform the generator and receive further instructions. The transporter must have the owner or operator of the TSDF sign and date the manifest at the time of delivery to the TSDF. The transporter retains Copy 4 of the manifest and gives the remaining three parts of the manifest to the TSDF owner or operator. The transporter must retain a copy of the manifest for 3 years from the date the hazardous waste is accepted by the *initial transporter*.

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CFR 49-The Department of Transportation (DoT) has regulatory responsibility for safety in the domestic transportation of hazardous materials (HM) by all modes except military air. The DoT regulation on the transportation of hazardous materials is published as Code of Federal Regulation (CFR) Title 49, Parts 100-199.

AFJMAN 24-204-For military air shipments of hazardous materials, there is a joint publication AFJMAN 24-204/TM 38-250/NAVSUP Pub 505/MCO P4030.10/DLAM 4145.3 which is based on the DOT regulation. AFJMAN 24-204 describes additional details required for transporting hazardous materials aboard military aircraft.

IATA-The International Air Transport Association (IATA) publishes the "Dangerous Goods Regulations" for the transportation of hazardous materials by international air. This document says that the successful application of the regulations is dependent on personnel trained by a properly planned and maintained program. U.S. shippers and certifiers need to study the IATA regulations since they fully comply with the requirements of Annex 18 of the Chicago Convention of International Civil Aviation and the International Civil Air Organization (ICAO). "Technical Instructions for the Safe Transport of Hazardous Goods by Air." The ICAO Technical Instructions contain detailed technical material needed to support the United Nations Committee of Experts' desire for all nations to use standard regulations for the international shipments of dangerous goods.

IMDG - The International Maritime Dangerous Goods (IMDG) Code sets forth description, classification, packaging, marking, labeling, placarding, and vessel stowage requirements. It establishes a unified international code for the carriage of dangerous goods at sea. The "Dangerous Goods" definition includes hazardous waste.

Example of Shipment Using CFR 49.

To get a better idea of how these regulations work, let's trace a single hazardous material, "Acetone" (a flammable liquid) through various phases of its preparation for shipment by commercial air. A current edition of the CFR 49 should be obtained to supplement this exercise.

When a request comes into the hazardous materials warehouse for a shipment, it must be screened for accuracy. The proper shipping requirements for acetone, hazard Class 3 with its corresponding ID number [UN1090], are checked in the alphabetical listing of hazardous materials. Proper shipping names are limited to those shown in Roman-type letters. It is also important to remember the mode(s) of transportation to the ultimate destination, as the requirements for each mode must be followed. Within the continental United States, the CFR 49 provides that information.

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When packing items for shipment, the paramount consideration is safety. To ensure safety, packers are required by the regulation to receive special training in the handling of hazardous materials. For obvious reasons, hazardous materials are stored in segregated areas-often a separate warehouse - where they are handled with extreme care.

Compatibility is a key factor in every phase of packing, shipping, and storing hazardous materials. Incompatible materials-like corrosives (Class 8) and flammable solids (Class 4, Division 4.1)-must be separated from one another all along the line.

Hazardous materials must be packed only in containers that meet specified shipping requirements. Containers are not chosen for convenience or style, but for sturdiness and durability in transit. In our example of acetone, we can tell where to locate the types of packaging that are to be used for acetone (column 8 of the Hazardous Materials Table). Note, column 8 is divided showing paragraphs for bulk packaging, nonbulk packaging, and exceptions. Since all the packaging paragraphs (or packaging authorizations) are found in Part 173 of CFR 49, the 202 under nonbulk packaging for acetone really indicates 173.202. So 173.242 is where to find packaging authorizations for bulk packaging, and 173.150 is an option for packaging relatively smaller amounts of our example. The choice of containers may depend on the container's availability or the amount of hazardous materials to be shipped.

Our sample material, acetone, is a Class 3 (flammable liquid). The third column, under hazard class, indicates that acetone might be extremely harmful in the event of a spill, so it must be packed with great care. Our packaging paragraph for nonbulk packaging for this substance (assuming this is a non-bulk shipment) indicates quite a few choices for combination packaging, single packaging, composite packaging, and even cylinders that are authorized to secure the material.

Specifications for these and other containers are designed with safety in mind. The containers are constructed firmly, with appropriate cushioning and secure closures to prevent accidental leakage or breakage as a result of changes in temperature, humidity, and altitude during air transportation.

Once material has been packaged, anyone who handles the container during shipment must be warned about the hazards (e.g., predictable dangers and potential catastrophes). This is accomplished by the use of required marking, labeling, and placarding on the mode of transportation.

Regulations require that each package be marked with the proper shipping name and identification number (i.e., UN or NA), as well as the name and address of the shipper and receiver.

Packaging markings may also provide other information. For instance, liquid hazardous materials shipped in packages with an inner container-like our

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acetone-must be marked on the top with "THIS END UP" or "THIS SIDE UP" and have arrows pointing to the top of the container.

Labeling is another source of essential information. Labels provide a warning to those who handle hazardous material packages of the hazards present in the container. Other labels give special instructions, such as shipping by cargo aircraft only.

All shipments of hazardous materials must have a certification document. The shipper must certify that the materials being shipped are properly classed, described, packaged, marked and labeled, and in proper condition for transport. Before a shipment is released for transport, documentation is carefully checked for compliance with applicable regulations. Failure to follow the regulations may result in "frustrated" cargo (slowed or stopped during shipment). Packages are palletized and loaded onto surface vehicles with strict regard to the properties of each item.

Compatibility and other safety considerations are crucial in the process of loading hazardous materials. On an aircraft, the pilot must be notified of where the hazardous materials are stored on the plane so that safety can be assured during the transportation process.

Another source of safety information is the material safety data sheet (MSDS). The MSDS should be provided by the manufacturer of the hazardous material, and must be made available to personnel who work with or around hazardous materials. It is your right to know. Information on the MSDS includes sections on health hazards, spill or leak procedures, special precautions, and any special protection requirements.

The DoT booklet "North American Emergency Response Guidebook" is an excellent source for emergency response actions. Our example, acetone with ID #1090, has emergency response procedures under Guide #127 which identifies acetone as a flammable liquid, polar/water-miscible. The DOT booklet gives advice under the following topics: Fire or Expolsion, Potential Hazards, Health, Public Safety, Protective Clothing, Evacuation, Emergency Response, and First Aid.

CLASSIFICATION OF HAZARDOUS MATERIALS DURING TRANSPORT

The proper classification of hazardous materials influences the packaging, hazard markings, shipping paper entries, emergency response, and any other instructions governing the material. With the wide range of hazardous materials being transported in the United States, it is reasonable to assume that many materials possess similar properties, and thus can safely be packaged and handled in a similar manner. It is, therefore, essential that the appropriate

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classification be made, as improper classification could result in a dangerous situation.

The following information should give you a general understanding of the DoT hazard classes, so that you will be more aware of the dangers which they may present and become familiar with the appropriate terminology.

The Nine Classes

The Department of Transportation divides hazardous materials into nine different classes. The hazard classifications (classes) and a brief description of each class are as follows:

Class 1: Explosives

Part 173.50 of CFR title 49 defines an explosive as any substance or article, including a device, which is designed to function by explosion (i.e., an extremely rapid release of gas and heat) or which, by chemical reaction within itself, is able to function in a similar manner even if not designed to function by explosion, unless the substance or article is otherwise classed under the provision of CFR 49.

- Division 1.1 consists of explosives that have a mass explosion hazard. A mass explosion is one which affects almost the entire load instantaneously. Example: Black Powder.
- Division 1.2 consists of explosives that have a projection hazard, but not a mass explosion hazard. Example: Mines.
- Division 1.3 consists of explosives that have a fire hazard and either a minor blast hazard or a minor projection hazard or both, not a mass explosion hazard. Example: Fuses.
- Division 1.4 consists of explosive devices that present a minor explosion hazard. Example: Fireworks.
- Division 1.5 consists of very insensitive explosives. This division is comprised of substances which have a mass explosion hazard, but are so insensitive that there is very little probability of initiation or of transition from burning to detonation under normal conditions of transport. Example: Explosive, Blasting, Type E.
- Division 1.6 consists of extremely insensitive articles that do not have a mass explosion hazard. The risk from these articles is limited to the explosion of a single article. Example: Articles, explosive, extremely insensitive.

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Class 2: Gases

1. Division 2.1 (flammable gas). "Flammable gas" means any material that is a gas at 20C (68F) or less and 101.3 kPa (14.7 psi) of pressure (a material that has a boiling point of 20°C (69°F) or less at 101.3 kPa (14.7 psi)) which is ignitable at 101.3 kPa (14.7 psi) when in a mixture of 13 percent or less by volume with air; or has a flammable range at 101.3 kPa (14.7 psi) with air of at least 12 percent regardless of the lower limit. Gases, Liquefied. Example: Petroleum.
2. Division 2.2 (non-flammable, non-poisonous compressed gas). A "non-flammable, non-poisonous compressed gas" means any material (or mixture) which exerts in the packaging an absolute pressure of 280 kPa (41 psi) at 20°C (68°F), and does not meet the definition of Division 2.1 or 2.3. Example: Carbon Dioxide.
3. Division 2.3 (Poisonous gas). "Poisonous gas" means a material which is a gas at 20C (68F) or less and a pressure of 101.3 kPa (14.7 psi) (a material which has a boiling point of 20C (68F) or less at 101.3 kPa (14.7 psi)) and which is known to be so toxic to humans as to pose a hazard to health during transportation or, in the absence of adequate data on human toxicity, is presumed to be toxic to humans based on tests on laboratory animals. Example: Methylchlorosilane.

Class 3: Flammable Liquid

A "flammable liquid" means any liquid having a flash point of not more than 60.5C (141F) with certain exceptions listed in CFR 49. Example: Benzene.

Class 4: Flammable Solids

Flammable solids include spontaneously combustible material; dangerous when wet material

1. Division 4.1 (flammable solid). A "flammable solid" means any of the following three types of materials: Certain wetted explosives; Self reactive material; and readily combustible solids. Example: Calcium Resinate.
2. Division 4.2 (spontaneously combustible material). "spontaneously combustible material" is either pyrophoric or self-heating. A pyrophoric material is a liquid or solid that, even in small quantities and without an external ignition source, can ignite within 5 minutes after coming in contact with air. A self-heating material is a material that, when in contact with air

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and without an energy supply, is liable to self-heat. Example: Calcium Hydrosulfite.

Class 5: Oxidizers, Organic Peroxides

1. Division 5.1 An "Oxidizer" is a material that by yielding oxygen, causes or enhances the combustion of materials. Example: Lead Dioxide.
2. Division 5.2 (organic peroxide). "Organic Peroxide" means any organic compound containing oxygen (O) in the bivalent-O-O-structure and which may be considered a derivative of hydrogen peroxide, where one or more of the hydrogen atoms have been placed by organic radicals, with certain exceptions. Example: Organic Peroxide Type B, Liquid.

Class 6: Toxic (Poisonous) Material; Infectious Substances

1. Division 6.1 (poisonous material). A "poisonous material" means a material, other than a gas, which is known to be so toxic to humans as to afford a hazard to health during transportation, or which, in the absence of adequate data on human toxicity, is presumed to be toxic to humans. Example: Sodium Cyanide.
2. Division 6.2 (infectious substance). An "infectious substance "means a viable microorganism, or its toxin, that causes or may cause disease in humans or animals, and includes those agents listed in CFR 42, part 72.3, of the regulations of the Department of Health and Human Services or any other agent that has the potential to cause severe, disabling or fatal disease. Example: Infectious Substances, Affecting Humans.

Class 7: Radioactive Material

"Radioactive Material" means any material having a specific activity greater than 0.0002 microcuries per gram. Example: Cesium 137.

Class 8: Corrosive Material.

A "corrosive material" is defined as a liquid or solid that causes visible destruction or irreversible alterations in human skin tissue at the site of contact, or a liquid that has a severe corrosion rate on steel or aluminum when certain tests are performed. Example: Sulfuric Acid

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Class 9: Miscellaneous Hazardous Material

"Miscellaneous hazardous material" means a material that presents a hazard during transport, but which is not included in any other hazard class. This class includes: any material that has an anesthetic, noxious or other similar property which could cause extreme annoyance or discomfort to a flight crew member so as to prevent the correct performance of assigned duties, or Any material that is not included in any other hazard class, but is subject to the requirements of CFR 49 because it meets the definition for an elevated temperature material, a hazardous substance, a hazardous waste, or a marine pollutant. Example: Ammonium Nitrate Fertilizers. (Note: Refer to CFR 49 for exact definitions.)

Classification of Material Having More Than One Hazard Class

If a material or substance is not listed in 172.101 of Hazardous Materials Table in CFR 49, but meets the definition of different classes, what should be done? For example, if a material has both flammable liquid and corrosive material (liquid) properties under packing group 1, what is its hazard classification? Material not specifically listed in the Hazardous Materials Table, but which meets the definition of more than one hazard class or division, shall be classed according to the highest hazard class of the following hazard classes which are listed in descending order of hazard:

Class 7 (radioactive materials, other than in limited quantities)
Division 2.3 (poisonous gases)
Division 2.1 (flammable gases)
Division 2.2 (nonflammable gases)
Division 6.1 (poisonous liquids, Packing Group 1, poisonous by inhalation only) A material that meets the definition of a pyrophoric material
(Division 4.2) A material that meets the definition of a self-reactive material (Division 4.2)
Class 3 (flammable liquids)
Class 8 (corrosive materials)
Division 4.1 (flammable solids)
Division 4.2 (spontaneously combustible materials)
Division 5.1 (oxidizers)
Division 6.1 (poisonous liquids or solids other than Packing Group 1, poisonous-by-inhalation)
Combustible liquids
Class 9 (miscellaneous hazardous materials)

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The precedence of hazards for a material meeting more than one of these hazards shall be determined using the Precedence of Hazard Table. (Table 17-3) [Source 49CFR 173].

Table 17-3
Precedence Of Hazard Table
(Hazard Class and Packing Group)

		4.2	4.3	5.1 [1]	5.1 II [1]	5.1 III [1]	6.1 I dermal [1]	6.1 I oral	6.1 II	6.1 III	8 I liquid	8 I solid	8 II liquid	8 II solid	8 III liquid	8 III solid
3	I	.....	.....	.....	.....	.....	3	3	3	3	3	(2)	3	(2)	3	(2)
3	II	.....	.....	.....	.....	.....	3	3	3	3	8	(2)	3	(2)	3	(2)
3	III	.....	.....	.....	.....	.....	6.1	6.1	6.1	3 [3]	8	(2)	8	(2)	3	(2)
4.1	II [4]	4.2	4.3	5.1	4.1	4.1	6.1	6.1	4.1	4.1	(2)	8	(2)	4.1	(2)	4.1
4.1	III [4]	4.2	4.3	5.1	4.1	4.1	6.1	6.1	6.1	4.1	(2)	8	(2)	8	(2)	4.1
4.2	II	.....	4.3	5.1	4.2	4.2	6.1	6.1	4.2	4.2	8	8	4.2	4.2	4.2	4.2
4.2	III	.....	4.3	5.1	5.1	4.2	6.1	6.1	6.1	4.2	8	8	8	8	4.2	4.2
4.3	I	.....	.....	5.1	4.3	4.3	6.1	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
4.3	II	.....	.....	5.1	4.3	4.3	6.1	4.3	4.3	4.3	8	8	8	4.3	4.3	4.3
4.3	III	.....	.....	5.1	5.1	4.3	6.1	6.1	6.1	4.3	8	8	8	8	4.3	4.3
5.1	I [4]	.....	.....	.....	.....	.....	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
5.1	II [4]	.....	.....	.....	.....	.....	6.1	5.1	5.1	5.1	8	8	8	5.1	5.1	5.1
5.1	III [4]	.....	.....	.....	.....	.....	6.1	6.1	6.1	5.1	8	8	8	8	5.1	5.1
6.1	I, Dermal	.....	.....	.....	.....	.....	.....	.....	.....	.....	8	6.1	6.1	6.1	6.1	6.1
6.1	I, Oral	.....	.....	.....	.....	.....	.....	.....	.....	.....	8	6.1	6.1	6.1	6.1	6.1
6.1	II, Inhalation	.....	.....	.....	.....	.....	.....	.....	.....	.....	8	6.1	6.1	6.1	6.1	6.1
6.1	II, Dermal	.....	.....	.....	.....	.....	.....	.....	.....	.....	8	6.1	8	6.1	6.1	6.1
6.1	II, Oral	.....	.....	.....	.....	.....	.....	.....	.....	.....	8	8	8	6.1	6.1	6.1
6.1	III	.....	.....	.....	.....	.....	.....	.....	.....	.....	8	8	8	8	8	8

[1] There are at present no established criteria for determining Packing Groups for liquids in Division 5.1. for the time being, the degree of hazard is to be assessed by analogy with listed substances, allocating the substances to packing Group I, great; II, medium; or III, minor danger.

[2] Substances of Division 4.1 other than self-reactive substances.

[3] Denotes an impossible combination.

[4] For pesticides only, where a material has the hazards of Class 3, Packing Group III, and Division 6.1, Packing Group III, the primary hazard is Division 6.1, Packing Group III [49 CFR 173].

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COMPATIBILITY, EMERGENCY RESPONSE, AND THE MSDS

Many hazardous materials become even more dangerous when they are combined with other materials. It is important to know how to store hazardous materials in the warehouse. It is also important to know how to segregate incompatible hazardous materials in accordance with the compatibility requirements for each mode of transportation. Labeling and placarding are of primary importance in determining compatibility. If a package is improperly or incorrectly labeled or placarded, the compatibility of that package with others in the load cannot be clearly and correctly determined. Those responsible for handling hazardous materials must constantly be mindful of the possible hazards involved.

Labeling and placarding is required to segregate incompatible hazardous materials in accordance with the compatibility requirements for each mode of transportation.

Compatibility by Motor Vehicle and Rail (in the United States) is provided by 49 CFR 174 and 177. Table 17-4 shows the segregation and separation of hazardous materials for highway and rail transport. To read the table, find the class or division for any two different materials. Read vertically from one class or division number and horizontally from the other. The intersection of the two columns provides the segregation necessary for those two materials. The absence of any hazard class or a "blank" space in the table indicates that no restrictions apply. The letter "X" at an intersection of horizontal and vertical columns indicates that these articles must not be loaded or stored together. The letter "O" at an intersection of horizontal and vertical columns indicates that these articles must not be loaded, transported, or stored together unless separated by a distance of 2.2 meters (88 inches) in all directions. That at the intersection of the horizontal and vertical columns indicates segregation among different Class 1 materials.

When checking for compatibility, the table notes should be consulted at all times. Example, if you have a Class 3 flammable liquid and a Division 4.3 dangerous-when- wet material, the intersection of the two columns contains an "O." The "O" indicates that these articles must not be loaded, transported, or stored together unless separated by a distance of 2.2 meters (88 inches) in all directions.

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Table 17-4
Segregation Table For Hazardous Materials

Class or Division		Notes	1.1, 1.2	1.3	1.4	1.5	1.6	2.1	2.2	2.3 gas Zone A	2.3 gas Zone B	3	4.1	4.2	4.3	5.1	5.2	8.1 liquids PG I Zone A	7	8 liquids only
Explosives	1.1 & 1.2	A						x	x	x	x	x	x	x	x	x	x	x	x	x
Explosives	1.3							x	x	x	x	x	x	x	x	x	x	x	x	x
Explosives	1.4							o	o	o	o	o		o				o		o
Very insensitive explosives	1.5	A						x	x	x	x	x	x	x	x	x	x	x	x	x
Extremely insensitive explosives	1.6																			
Flammable gases	2.1		x	x	o	x				x	o							o	o	
Non-toxic, non-flammable gases	2.2		x			x														
Poisonous gas Zone A	2.3		x	x	o	x		x				x	x	x	x	x	x			x
Poisonous gas Zone B	2.3		x	x	o	x		o				o	o	o	o	o	o			o
Flammable liquids	3		x	x	o	x				x	o					o		x		
Flammable solids	4.1		x			x				x	o							x		o
Spontaneously combustible material	4.2		x	x	o	x				x	o							x		x
Dangerous when wet materials	4.3		x	x		x				x	o							x		o
Oxidizers	5.1	A	x	x		x				x	o	o						x		o
Organic peroxides	5.2		x	x		x				x	o							x		o
Poisonous liquids PG I Zone A	6.1		x	x	o	x		o				x	x	x	x	x	x			x
Radioactive materials	7		x			x		o												
Corrosive liquids	8		x	x	o	x				x	o		o	x	o	o	o	x		

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Emergency Procedures

The best way to know the emergency response procedures during transportation is to read and understand your emergency response plan. Remember, "No person may offer for transportation, transfer, store or otherwise handle during transportation a hazardous material unless EMERGENCY RESPONSE INFORMATION is immediately available and the EMERGENCY RESPONSE TELEPHONE NUMBER is immediately available to any person who, as a representative of a federal, state or local government agency, responds to an incident involving a hazardous material, or is conducting an investigation which involves a hazardous material."

As a minimum, an emergency response plan must contain information on the following:

- The basic description and technical name of the hazardous material;
- Immediate hazards to health;
- Risks of fire or explosion;
- Immediate precautions to be taken in the event of an accident or incident;
- Immediate methods of handling fires;
- Initial methods for handling spills, leaks, or other releases; and
- Primary first aid measures.

All information required for hazardous material in shipment must be

- Printed in English;
- Available for use away from the package containing the hazardous material; and
- Presented on a document, other than the shipping paper, that includes both the basic description and technical name of the hazardous material, and the EMERGENCY RESPONSE INFORMATION required (e.g., a material safety data sheet); or related to the information in a manner that cross-references the description of the hazardous material on the shipping paper with the EMERGENCY RESPONSE INFORMATION contained in some other document.

Each carrier who transports a hazardous material shall maintain the EMERGENCY RESPONSE INFORMATION. This information must be immediately available and accessible in the event of a hazardous material incident. The DoT booklet, "North American Emergency Response Guidebook," is often used for this emergency response information.

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A person who offers a hazardous material for transportation must provide a 24-hour EMERGENCY RESPONSE TELEPHONE NUMBER for use in the event of an emergency involving the hazardous material. The telephone number must be

- Monitored at all times the hazardous material is being transported, including storage incidental to transportation;
- Entered on the shipping paper immediately following the description of the hazardous material or entered once on the shipping paper in a clearly visible location; and
- The telephone number required must be the number of the person offering the hazardous material for transportation or the number of an agency or organization capable of, and accepting responsibility for, providing detailed information concerning the hazardous material.

Hazardous Material Information System (HMIS)

An automated reference data base has been established to provide extensive data for those engaged in the safe transportation of hazardous materials. The system is administered for the Department of Defense by the Defense General Supply Center (DGSC-STF), Richmond, VA 23297. It provides compact disc and microfiche listings by NSN for most hazardous material used by DoD. It is available to users in DoD Regulations 6050.5-L and 6060.5-LR.

Material Safety Data Sheets (MSDS)

The Occupational Safety and Health Administration (OSHA) established a Hazard Communication Standard under CFR 29, Part 1910.120, to ensure the "worker's right-to-know." The standard was written in an effort to reduce injuries or illnesses caused to personnel working with or exposed to chemicals. Workers need to know the chemical hazards they are exposed to in the work-place and the safe practices linked with those chemicals.

CFR 29 assists workers in understanding chemical safety. Employers must meet three requirements in communicating chemical identification and hazards:

- Containers of hazardous materials must be properly labeled.
- Training programs must be established to assist employees in using chemicals safely and to enable them to respond to an emergency by containing or neutralizing a spill.

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- An MSDS must be available at all times.

An MSDS identifies chemical substances or mixtures by trade name and chemical name. It also names the hazardous properties of the chemical. An MSDS contains procedures for safe handling of hazardous materials and responding to an emergency, including first aid procedures. The MSDS is a legal requirement as well as a source of efficient information in a safety program. One section of the MSDS includes information on health hazards, spill or leak procedures, special precautions, and special protection requirements.

A safety training program not only transmits the potential hazards of chemicals to employees, but also explains appropriate protective measures against those risks. The training also emphasizes the recognition of chemicals, their appearance and odor. Safety training provides an introduction to protective measures and a demonstration of safety equipment.

After a hazard communication (HAZCOM) program has been developed, employers must put the program in writing. The program should include: chemicals in the workplace, work practices, a medical program, and a description of container labeling.

Labels identify the hazardous contents of containers and give the name and address of the manufacturer. Because labels alert handlers to the hazards present, they are not to be defaced or removed. Proper labeling ensures the right product is used in the right application. The Department of Transportation hazard class labels are separate labels used when containers of hazardous materials are transported.

Marking, Labeling, Placarding, and Forms

It is most important that personnel handling hazardous materials understand certain facts concerning those materials. This important information should include, but is not limited to, such items as

- The hazard class;
- The hazard posed by the material; and
- The proper shipping name of the material.

When this information is known, safety is enhanced and the possibility of an "incident" or spill is greatly reduced. In the event of an accident, emergency personnel responding to a spill are able to quickly assess the situation and take appropriate action. This is a significant part of the hazard communication (HAZCOM) requirements when telling the public and potential responders of hazards involved.

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The most common reasons for "frustrating" (delaying or stopping shipment) hazardous materials are improper marking and labeling. Persons responsible for the application of required marking and labeling must be familiar with the information contained in Subparts D and E of Part 172 of CFR 40.

Marking

The following information is general in nature and requirements may vary somewhat from one mode of transportation to another. It is recommended that you review the latest regulations prior to marking hazardous materials for transport.

Packages containing hazardous materials must be marked with the "proper shipping name" as determined from the regulations. The proper shipping name is used to provide universal understanding of the contents of the package, since it may be different from the item nomenclature. A four-digit identification number is also applied for this reason, and is located below or beside the identification marking information. Proper shipping names and identification numbers may be found in the Hazardous Materials Table of Part 172.101 of CFR 49 and in various international documents (e.g., IMO, ICAO). When a multipack contains hazardous materials, the proper shipping names and identification numbers, where assigned, shall be marked for each container comprising the multipack.

All markings must be clear and durable, and on a contrasting background to facilitate reading. Hazardous material packages will be marked with the name and address of the consignee or consignor. Only authorized abbreviations, such as "w" for "with" and "w/o" for "without," and "ORM" for other regulated materials may be used. The following descriptions and uses of markings and labels are provided:

- "This Side Up." Shown as arrows, this marking/label is used for each non-bulk combination package having inner packages containing liquid hazardous materials.
- See CFR 49 for exceptions. Note: CFR 49 refers to the "This side up" arrows as a mark, IATA refer to it as a label.
- "Marine Pollutant." A hazardous material listed as a marine pollutant requires a "marine pollutant" marking when shipped by vessel.
- "Inhalation Hazard." Each package containing a material which is poison by inhalation shall be marked with the words "Inhalation Hazard."

Unit packs and intermediate and exterior shipping containers packed below 141^{0}F or 60.5^{0}C shall be marked with a flash point of the material. Flash point

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markings shall be applied on the identification marked side by means of labeling, stamping, stenciling, or machine printing. Flash point markings may be shown in degrees Fahrenheit, Celsius or both. The size of lettering shall be proportionate to the available marking space on the container. The flash point shall be determined by using the testing methods prescribed in CFR 49.

Labeling

Labeling is required for hazardous material which meets one or more hazardous class definitions, in accordance with Column 6 of Table 172.101 of CFR 49

Additional Labeling Requirements. Each package containing a hazardous material which has a subsidiary hazard shall be labeled with primary and subsidiary hazard labels as specified in Column 6 of the Hazardous Materials Table.

No hazard label will be used on a package if the material is not hazardous, and no label that looks similar to a hazard label should be used.

In addition to hazard class labels, there are other labels that give important information about the contents of the hazardous material package. The "cargo aircraft only" warns handlers not to place that package of hazardous materials on a passenger-carrying airplane. There are also requirements for the use of an "empty" label.

Placement of Labels. Labels are generally required to be placed on the surface(s) of the package bearing the proper shipping name. When more than one hazardous material is packaged in a container, more than one kind of label may be needed. CFR 49 paragraph 172.404 states, "When hazardous materials having different hazard classes are packed within the same packaging, or within the same outside container or overpack the outside container or overpack must be labeled as required for each class of hazardous material contained therein."

When two or more different labels are required, they must be displayed or affixed next to each other. One hazard label is required on a package for each hazard class, except for radioactive materials which requires two labels, one on each side of the package.

Radioactive Labels. There are three categories of radioactive labels: White I (lowest category); Yellow II; and Yellow III (highest category, most dangerous).

Dangerous Placard. If a freight container, railcar or motor vehicle contains two or more classes of hazardous materials requiring different placards specified in Table 2 of CFR 49, Part 172.504, the DANGEROUS placard may be used in place of the separate placards specified for each class.

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When 2268 kg (5000 lbs) or more gross mass of one class of hazardous materials is loaded at one loading facility, the placard for that class must be applied.

Where to Place Placards

The shipper is responsible for furnishing the required placard to the carrier. The placards are required on each end and side of transporting motor vehicles or railcars. Placarding requirements on freight containers vary according to their size and the mode of transportation.

Each placard on a motor vehicle and each placard on a railcar must be readily visible from the direction it faces, except from the direction of another motor vehicle or railcar to which the motor vehicle or railcar is coupled. The requirement to placard the front of a motor vehicle may be accomplished by placarding the front of the tractor instead of the cargo body to which it is attached, or you may placard both the truck-tractor and the cargo body. Each placard, when practical, must be located so that dirt or water is not directed to it from the wheels of the transport vehicle.

Certificate Forms

Hazardous materials regulations require that most shipments be certified by the shipper as being properly prepared for shipment and in compliance with the appropriate regulations. This certification will take many forms, depending upon the mode of transportation involved.

A shipper's certification on the "Shipper's Declaration for Dangerous Goods" is required for all air shipments of hazardous materials. Currently, there is no government/military number assigned to the form.

Instructions for Completing the Shipper's Declaration for Dangerous Goods (Nonradioactive Shipments):

1. Shipper. Enter the address and telephone number where the hazardous material was certified.

2. Consignee. Enter the geographical location of the ultimate consignee (if known).

3. Air Waybill Number. The aircraft manifest number to which the Shipper's Declaration for Dangerous Goods will be attached may be entered. This number need not be entered by the shipper. It may be entered by the accepting operator at the time it is assigned. This may also be left blank.

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4. Page__of__Pages. Enter the page number and total number of pages of the Shipper's Declaration for Dangerous Goods form. Enter "Page 1 of 1 Pages" or leave blank if there are no extension pages.

5. Shipper's Reference Number. Enter the 17-character Transportation Control Number (TCN).

6. Optional Block. Leave blank.

7. Shipment Within Passenger Aircraft and Cargo Aircraft Limitations. If the shipment is acceptable for movement on both passenger and cargo aircraft, delete "Cargo Aircraft Only. "If the shipment is allowed on cargo aircraft only, delete "Passengers and Cargo Aircraft."

8. Airport of Departure. Enter the three-digit Port of Embarkation (POE) and/or the in-the-clear geographical location of the airport of departure.

9. Airport of Destination. Enter the three-digit Port of Debarkation (POD) and/or the in-the-clear geographical location of the airport of destination.

10. Shipment Type. Delete "RADIOACTIVE" since the shipment contains no radioactive material.

11. Proper Shipping Name. Enter the Proper Shipping Name (PSN) as it appears in the Hazardous Materials Table of CFR 49. Enter the following information if applicable, in association with the basic description:

- When a technical name is required, enter it in parenthesis immediately following the PSN when marking and certifying the shipment.
- Show the letters "RQ" (Reportable Quantity) after the PSN
- When the quantity of material in one package equals or exceeds the RQ found in Appendix A to CFR 49, 172.101.
- The word "POISON" for liquid or solid Class 6.1 Packing Group (PG) I or II material if the PSN does not identify the material as a poison.
- For materials which are poisonous by inhalation, enter the words POISON-INHALATION HAZARD" and "ZONE A, ZONE B," "ZONE C, "ZONE D" for gases, or "ZONE A" or "ZONE B" for liquids, as appropriate. If already identified, the word "POISON" need not be repeated. Enter "INHALATION HAZARD" and the appropriate zone.

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- The words "Dangerous When Wet" when a material meets the definition of a dangerous-when-wet material.

12. Class and Division. Enter the hazard class and division number given in Column 3 of Table A4.1 of CFR 49. For Class 1 Material, include the compatibility group letter and the inhabited building distance (if applicable). For a single item with more than one hazard, enter the hazard class number of the item's highest or primary hazard.

13. UN, NA, or ID Number. Enter the United Nations (UN), North American (NA), or identification number (ID) given in the Hazardous Materials Table of CFR 49). Include the UN, NA, or ID prefix and the number.

14. Packing Group. Enter the applicable Packing Group (PG) given in Column 5 of the Hazardous Materials Table of CFR 49

15. Subsidiary Risk. When more than one hazard label is required, enter the subsidiary risk hazard class and division number corresponding to the subsidiary risk label(s) required. Do not enter the hazard class and division number of the primary hazard in this space. Only list the hazard class and division number of additional (subsidiary) labels required. If a "Cargo Aircraft Only" label is required, DO NOT annotate it in this space.

16. Quantity and Type of Packing. Enter the following:

- The number of packages (of same type and content) and their type of packaging (e.g., fiberboard box, metal drums). If applicable, enter the specifically named self-propelled vehicle and mechanical apparatus.
- The weight (e.g., lb., oz, g,kg,), volume (e.g., pint, quart, cc, liter), or measure of the actual hazardous material (per package). Do not include nonhazardous content of the shipment. The net quantity must be entered in metric measure units. The equivalent English units of measure may be entered in parenthesis immediately following the number and type of package (e.g., wooden boxes x 4.5 kg (10 lb); 1 fiberboard box x 5 L (1.3 gallons). For explosives, Class 1.1, 1.2, and 1.3, enter the "Net Explosive Weight" (NEW) in kilograms (pounds) per package or per pallet (e.g., 3 wooden boxes x 120 kg 264.6 pounds NEW; 5 metal boxes x 200 kg F441 pounds NEW). Unless otherwise required by statute, either N/A or the NEW may be entered for Class 1.4, 1.5, and 1.6 explosives. Italy and the United Kingdom require the NEW for all explosives entering their country.

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Annotate kilograms (pounds) in association with the NEW (abbreviations may be used).
- Express in kilograms (pounds), not pounds per square inch, the quantity of compressed gas unless otherwise specified in this instruction.

17. Packing Instructions. The package for shipment. Enter the paragraph used to prepare

- If the packaging has been approved by separate letter, message, or other instructions, cite that and the date of the letter or message
- If a Performance Oriented Package (POP) certified package is overpacked to meet air eligibility requirements, cite A3.1.10 and the applicable packaging paragraph for the material. Cite the applicable packaging paragraph for the material when packaging inner containers into a 1A2 drum to meet air eligible and POP configuration requirements.

18. Authorization. Enter the special provision number from the Hazardous Materials Table of CFR 49 ONLY if it pertains to the packaging. When applicable, enter the words "Limited Quantity" or "LTD QTY."

19. Additional Handling Information. Enter:

- The PSN, hazard class, and net quantity of each additional hazard for items with multiple hazards.
- Handling instructions, when specified by a packaging paragraph.
- The name and quantity of nonhazardous fuel contained in tanks of vehicles or equipment. Include statement "nonhazardous battery installed," if applicable.
- The flash point in degrees Fahrenheit or Celsius when shipping flammable liquids or for any fuel identified in vehicle or equipment tanks. Show the letters "FP," the number, the degree symbol, and either "F" or "C" corresponding to the unit used. When known, enter the method of determining the flash point (e.g., Tag CC, Seta Flash, Pensky-Martins).
- The packing paragraph reference if required.
- The 24-hour Emergency Response number for the hazardous material listed on the Shipper's Declaration for Dangerous Goods. Enter the words "EMERGENCY CONTACT:" followed by the telephone number.

20. Name/Title of Signatory. Enter the name and title of the official signing the form.

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21. Place and Date. Enter the place and date the material was certified (e.g., Redstone Arsenal, AL, 6 Sep 97, Yakota Japan, 15 Nov 97).

22. Signature. The official who certifies that the shipment complies with the requirements of this instruction must physically sign the form.

Complete and sign an original and at least one copy of the certification form. An original signature is required on the original Shipper's Declaration for Dangerous Goods. The original certification form is attached to the copy of the manifest that is placed on the aircraft. Attach a copy to the station file manifest. The original attached to the aircraft manifest and the copy attached to the station file manifest must have the vertical red hatch border. Additional copies may be placed in a waterproof envelope and attached to the number one piece of the shipment.

Commercial Air Shipments.

The International Air Transport Association (IATA) prescribes a particular format for those hazardous items which are subject to their regulations. In addition to a signature of certification, the format requires the proper shipping name; class or division number; UN, NA or identification number; packing group; subsidiary risk; quantity and type of packaging; packaging instruction number used; and authorization documents when required.

Domestic Rail, Highway, and Vessel Shipments

A certification is required for domestic rail, highway and vessel shipments. This certification must appear on the shipping papers and indicate the proper hazard class, markings, labels, and what packaging have been used. A variety of forms may be used as shipping papers.

International Water Shipments

Another format for certification is prescribed for international water shipments of dangerous goods (another name for hazardous materials). . These requirements are a part of the International Maritime Organization's (IMO) Dangerous Goods Code.

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Performance Oriented Packaging (POP) and Handling Requirements

Safe packaging and handling practices are two important functions in the safe movement of hazardous materials. Not just any old box or bag will do when the cargo is a hazardous material. Proper containers are prescribed and must be used to safely contain hazardous material, and thus prevent an injury or damage to people and property.

Rough or improper handling may impose greater stress than the container can withstand and cause even the best container to fail. A general understanding of hazardous material container requirements and good handling practices are necessary to ensure incident- and accident-free shipment to the user.

If you suspect a package is leaking or seriously damaged, report it to your supervisor immediately. The following represents only a few of the general packaging requirements that exist for hazardous materials.

- Containers should be designed and constructed to avoid significant release of the hazardous material into the environment.
- There must be no mixture of gases that could increase heat or pressure that would reduce the effectiveness of the package. Containers labeled "Empty" must be entirely free of any hazardous material.
- Non-bulk packaging must be properly marked and meet all specification requirements, including performance testing, when required.
- Containers should be made of materials that do not react with the hazardous material inside.
- Containers being reused must have old markings removed or obliterated.

Performance Oriented Packaging (POP) Computer Program for Hazardous Materials

The POP standardized system is a program for hazardous materials shipment and contains POP test reports. The program aids in proper marking and selection of specification containers required for POP certified shipments of hazardous material.

United Nations Manufacture/Design Requirements

The United Nations has instituted performance oriented packaging (POP) requirements for the transportation of hazardous materials. Unlike U.S. Department of Transportation (DoT) specification containers, the UN does not

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describe the construction requirements in minute detail, but rather describes tests the container must pass successfully.

Performance Testing-A series of tests are prescribed: the drop test, leakproofness test, internal pressure (hydraulic) test, and stacking test. The International Maritime Organization and the DoT require a cooperage test for bung-type wooden barrels. DoT also requires containers to undergo vibration testing.

Packing Groups (PG)-Except for gases, etiological agents, and radioactive material, the UN classes have, for packaging purposes, been divided into three groups according to the degree of danger the material represents. The three groups are:

- Great Danger-Packing Group I (PGI)
- Medium Danger-Packing Group II (PGII)
- Minor Danger-Packing Group III (PGIII)

The tests for containers that will carry PGI materials are more stringent than for containers carrying PGIII materials. For example, the height for the drop test for PGI (great danger) solid hazardous material is 1.8 meters, while the height decreases to 1.2 meters for PGII (medium danger) material and to 0.8 meters for PGIII (minor danger) material.

UN Container/Design Markings-All markings must be durable and legible, and show the UN packaging symbol. Additionally, a code beside the UN packaging symbol indicates the packaging is a successfully tested design type and complies with manufacture provisions of the international requirements.

The manufacturer shall mark every package that is required to conform to a UN standard. These markings must be stamped, embossed, burned, printed or otherwise marked on the packaging to provide adequate accessibility, permanency, contrast and legibility so as to be readily apparent and understood.

The UN POP markings for hazardous materials shall be placed on the side of the container opposite the identification and markings. In packing drums, markings must not be applied to removable heads.

The UN packaging symbol certifies that the packaging complies with international requirements and performance tests. The capital letters "UN" may be applied in lieu of the symbol for embossed metal packagings.

The codes for designating UN containers consist of an Arabic number indicating the type of packaging, followed by one or more capital letters in Latin characters indicating the nature of the material used; and, when necessary, an Arabic numeral indicating the category of packaging.

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General Handling Requirements

- Explosives-Safety in handling explosives and standard operational procedures vary with types of explosives, see AFI 91-201 (Air Force), TM 9-1300-206 (Army), and NAVSEA OP5 (Navy).
- Compressed Gases-These materials, in general, must be stored in a cool, well-ventilated area away from fire hazards, sources of heat, ignition, or sparks. Do not drop, jar, or slide containers.
- Flammable Liquids-These materials should be stored in cool, well-ventilated areas. They must be stored away from sources of heat, flames, sparks, combustible materials or oxidizing agents. Containers must be kept tightly closed. In the event of leakage or spillage, rubber gloves, goggles, aprons and respirators must be used.
- Flammable Solids-Spontaneously combustible material and dangerous-when-wet materials must be stored in cool, well-ventilated areas away from moisture. They must not be stored near corrosives. All containers must be tightly and securely closed.
- Oxidizers, Organic Peroxides-These materials must be stored in a cool, well-ventilated area away from moisture. Do not store near corrosives.
- Poisonous (Toxic) Material; Infectious Substances-Keep cool and away from direct sunlight and high temperatures. Store away from sources of ignition, oxidizing materials, and acids. Avoid direct contact with the materials. Wear a gas mask or breathing apparatus, as instructed by safety personnel, during exposure.
- Radioactive Materials-Handling requirements for these materials can be complex and involved. Personnel handling these materials should take precautions to minimize exposure. Containers should not be opened except for good reason, and then only under the direct supervision of radiological protection personnel.
- Corrosive Materials-Corrosives must be stored in a cool, well-ventilated area away from sources of heat and oxidizing agents. Gas masks, respirators, rubber gloves, goggles, and other protective clothing should be available for use in the event of leakage.

Adherence to handling requirements and markings (e.g., This Side Up, Fragile) on hazardous materials containers is absolutely necessary to avoid risk to health and the environment.

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Handling Hazardous Waste Discharges

In the event of a discharge of hazardous waste during transport, special requirements established by the EPA and DoT must be followed by the driver/transporter. A discharge of hazardous waste is defined as "the accidental or intentional spilling, leaking, pumping, pouring, emitting, emptying, or dumping of hazardous waste into or on any land or water" [40 CFR 260.10].

EPA and DOT regulations pertaining to hazardous waste release events include provisions authorizing federal, state, or local government officials, acting within the scope of their official duties, to permit the immediate removal of hazardous wastes by transporters who do not have EPA ID numbers and without a manifest. Within 15 days following the incident, the transporter must obtain a temporary ID number and file a report, including a manifest, with the DOT. The EPA has also exempted all persons involved in treatment or containment actions during an immediate response to the discharge of hazardous wastes or materials from permitting requirements. All regulations for the final disposition of wastes must be followed after the emergency has been concluded.

EPA regulations similarly require transporters to clean up any discharges that occur during transport or take actions required or approved by appropriate government officials to mitigate human health or environmental hazards [Office of Technology Assessment, 1986, p. 247]. Such cleanups are characteristically hazardous, not only to those doing the cleanup work, but to nearby residents, to other users of the transportation system, and to the environment. It is rarely possible to achieve a totally satisfactory cleanup. Liquid wastes, liquid-borne solid wastes, and water from fire-fighting operations are often dispersed through storm drains and the soil, to the extent that they cannot be retrieved. Atmospheric releases are rarely controlled in a timely manner.

Import-Export Activity

International movement of hazardous wastes is a matter of growing interest and concern to responsible officials in the United States, Mexico, Canada, and other nations [Wells, 1993]. Documented shipments to and from Mexico and Canada are a small, but growing fraction of the quantities generated and managed in each nation. Table 17.5 summarizes those quantities for the years 1987 through 1994 [Blackman, 1996].

Significant effort on the part of U.S. (state and federal) and Mexican officials has been committed to improvement of tracking and accountability for hazardous wastes in the border areas. Indeed, the "increases" in U.S.-Mexican shipments indicated in Table 17-5, may reflect some combination of improving awareness, surveillance, inspection, documentation, and enforcement pertaining

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to hazardous waste shipments. Nevertheless, much of the waste generated on the Mexican side is never accounted for, and an occasional U.S. shipper attempts illegal movement of wastes to Mexico.

Table 17-5
Transborder Shipments of Hazardous Waste-U.S., Mexico, and Canada (Metric Tons)

Year	From Mexico	To Mexico	From Canada	To Canada
1987		10,710	43,203	129,476
1988	990	15,615	66,304	144,613
1989	1,940	28,101	107,707	154,304
1990	3,261	39,209	136,752	143,411
1991	5,795	57,091	223,079	135,161
1992	6,806	72,178	174,682	123,998
1993	11,146	71,593	229,648	173,416
1994	7,108			

Note: Canadian definition of "hazardous waste" includes recyclable, gases, and biomedical wastes which are not included in the U.S. definition.

Researchers of the UCLA School of Public Health have documented border area industrial waste management problems since 1989. They report that, EPA records for 1988 show that only 1percent (7 of 748) of the duel country industries operating in northern Baja California and Sonora requested shipment of hazardous wastes to the United States [Perry et al., 1990]. The Baja industries are estimated to generate 100,000 tons of hazardous waste per year. By the end of 1990, the Mexico federal agency found that only 14.5 percent of the duel country industries legally recycled or returned their residues to the United States [Castillo and Perry, 1992].

Two federal criminal prosecutions (US vs. Rodriquetastro & US vs. W) growing from the attempted shipment of waste polychlorinated biphenyl's (PCBs) to Mexico, confirm the necessity for vigorous monitoring and enforcement of waste management statues in the border area. The EPA provides technical and enforcement training to the U.S. Customs Service personnel, and the two agencies conduct joint training exercises at border patrol facilities. County, state, and federal environmental and law enforcement agencies have greatly improved cooperation and coordination of border area investigative activity.

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CONCLUSION

Transportation safety is a critical link in the handling and disposal of hazardous waste. Transportation regulations include hazardous waste under the broader category of hazardous materials.

Originators or initiators of the shipment of hazardous waste have the responsibility by federal regulation to identify and package the material for safe transport. This responsibility includes the training of all personnel that must handle the hazardous waste. The selection of qualified transporter, disposal site and/or ultimate destination must be accomplished with informed employees.

Any handler of hazardous waste must make sure that all papers are adequately filled out, containers labeled and marked, MSDS provided, and emergency procedures understood before the trip is started. It is the shipper's responsibility to determine the fitness of a package for the transport use intended. However, each person along the way must be trained to recognize the hazards associated with the transportation of hazardous waste and familiar with emergency procedures to protect health and environment.

The transportation industry has maintained a good record in the transporting of hazardous waste but the potential for disaster is still very great. With adequate training, information and resources, hazardous wastes can be transported safely.

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18

ISO 9000 AND 14,000 FOR HAZARDOUS WASTE OPERATIONS

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David T. Dyjack, C.I.H., M.S.P.H., Dr.P.H.

INTRODUCTION

Over the past several years there has been increased attention given to the development and use of quality assurance, environmental, and occupational health and safety management systems [Dyjack and Levine, 1996]. Relevant to the protection of personnel at hazardous waste operations is the use of occupational health and safety management systems (OHSMS). OHSMS approaches have evolved and can be observed in use in a variety of settings, including commercial, industrial, medical/health care, and government. The OHSMS approach can add value to OHS management at hazardous waste operations. This chapter will explore these issues

- OHSMS Background;
- The Systems Approach;
- A Universal OHSMS for use at Hazardous Waste Operations; and
- Section-by-Section Review of a Universal OHSMS.

Interest in an OHSMSs in the United States has grown with the need for a global approach to OHS, current management theory, and the influence of International Organization for Standardization (ISO) standards for quality and the environment. First, most major companies in the industrially developed world are multinational and need a standardized approach to safety and health. Japan, for example, has been manufacturing products and dealing with safety concerns around the world for a considerable period of time. Most companies recognize the need and benefits of meeting world standards or best practices for OHS while striving to meet local requirements of the host country. Second, current management science theories suggest that performance in all areas of business, including OHS, is measured and continuous improvement sought in an organized fashion. Third, central to the ISO approach is to harmonize existing standards or create new ones that promote free trade. Two of ISO's

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recent standards, developed by the world community, address areas somewhat analogous to OHS. They are the ISO standards for quality (ISO 9000 series) and environmental management (ISO 14,000 series). Both standards integrate these functions within a business (management) framework. One of the advantages to an OHSMS approach is resolution of the common criticism that OHS is rarely integrated into business systems but rather is typically a stand alone adjunct in most companies. Perceived key advantages of a management-systems approach for OHS are

- Alignment of OHS objectives with business objectives;
- Integration of OHS programs/systems into business systems;
- Establishment of a logical framework upon which to establish an OHS program;
- Establishment of a universal set of written procedures, programs, and goals;
- Essentially transparent to country differences;
- Establishment of a continuous improvement framework; and
- Provide an auditable baseline for performance worldwide.

Many would argue that there are an equal number of disadvantages as well. Those most commonly cited include no need for change, social and legal barriers internationally that cannot be overcome by a standardized approach, bureaucracy and cost.

OHSMS BACKGROUND

Many of the industrially developed countries of the world have seen injury and illness rates decline drastically over the last 50 years. However, these rates have generally reached a plateau over the last decade and most noteworthy over the most recent years. Many new and novel approaches have been tried to further improve performance such as behavior-based-safety techniques, improved health and safety auditing concepts, and management systems schemes. There is no doubt that many other approaches will also be tried in the future. Nevertheless, one of the newer techniques is the use of a management-systems approach.

In the United States, since the passage of the Occupational Safety and Health Act of 1970, the incidence rate of occupational fatalities has been reduced by 76 percent, and total injury/illness case rates by 27 percent. Even with these positive changes, the frequencies of occupational health and safety (OHS) fatality and injury/illness incidents, coupled with a stubbornly high and unchanging total lost-work-day case rate, continue to affect adversely the lives

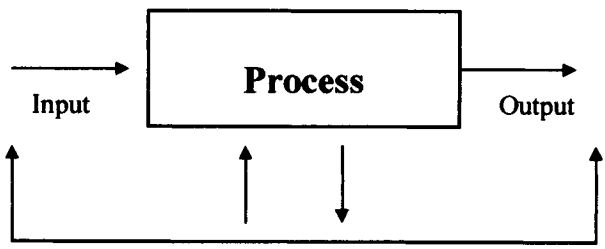
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of millions of workers and present a substantial burden on the cost of health care in the United States. This was recently confirmed in a comprehensive study which, among other things, found that approximately 6,500 job-related deaths from injuries, 60,300 deaths from disease, and 862,200 illnesses are estimated to occur annually in the American workforce. The total direct and indirect costs are estimated to be $171 billion, of which, injuries cost $145 billion and illnesses $26 billion [Leigh, 1997].

THE SYSTEMS APPROACH

The OHSMS approach to OHS management at hazardous waste operations is based on systems theories developed primarily in the natural and social sciences. The 4 basic elements of general system theories are:

- input;
- process;
- output; and
- feedback.



Feedback Loop

Figure 18-1

These system elements are depicted in Figure 18.1. Systems are further characterized as either open or closed systems. In the case of open systems, there are identifiable pathways whereby the system interacts-gaining information and energy-from its external environment. This phenomenon is readily observed in biological systems. Conversely, closed systems do not have such pathways, and thus limit their ability to respond to changing external conditions.

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In traditional OHS management approaches, the focus has been on outputs, such as illness, injury, and fatality incident rates. In a systems approach, regulatory compliance and trailing indicators (i.e. outcomes) are not neglected; however, there is a shift in focus towards performance variables and metrics from the input and process components of the system. These components can be thought of as being "upstream" from the system output [British Standards Institute, 1996].

Programs Versus Systems

An important distinction to make in an OHSMS approach is that between "programs" and "systems". The distinction is made here between traditional programmatic approaches and the newer systems approaches to OHS management. In the paradigm shift suggested by the development and implementation of OHSMSs, a program is operationalized as singular, vertical, and based on traditional command-control regulations. The focus is on compliance with the program standard/regulation, not the broader impact on OHS. In this conceptualization, programs do not have strong, if any, feedback or evaluation mechanisms whereby the program is adjusted or modified.

Conversely, a systems approach-while not losing sight of programmatic requirements and opportunities for improvement-broadens in perspective to address the manner in which the program affects other programs, and the extent to which the program may or may not improve worker health and safety. Furthermore, a systems approach focuses on OHS improvement, not exclusively on programmatic regulatory compliance. A key distinction of a systems approach is that there are clear feedback and evaluation mechanisms whereby the system responds to both internal and external events (Katz and Kahn, 1966; von Bertalanffy 1950).

In this context, an example of program compliance be with a single standard, would be the lock-out-tag-out (29 CFR 1926.417) standard for construction or the asbestos standard (29 CFR 1910.1001) for general industry. A systems approach integrates individual programs within the business operations and the external environment, and is thus more comprehensive than any single program. This is demonstrated by the universal OHSMS presented in Figures 18-2, 18-3 and 18-4.

One could argue that this program/system dichotomy is a weak distinction. That is, the programmatic approaches do in fact contain systems qualities vice versa. This observation is valid. However, the point of presenting the dichotomy is to elucidate the fact that programmatic OHS management approaches do not reflect or embrace systems concepts. Furthermore, such systems approaches potentially offer previously unrealized opportunities for enhancing OHS.

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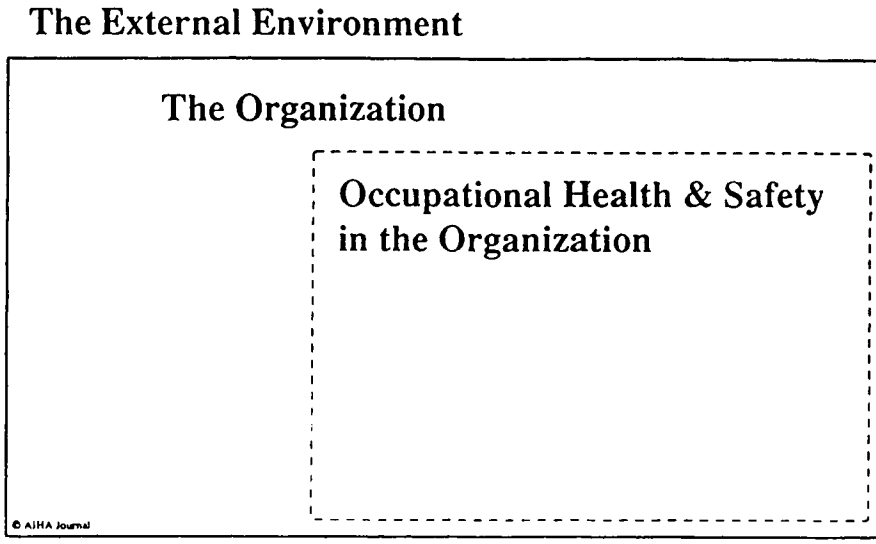


Figure 18.2 - Universal OHSMS Initial Construct

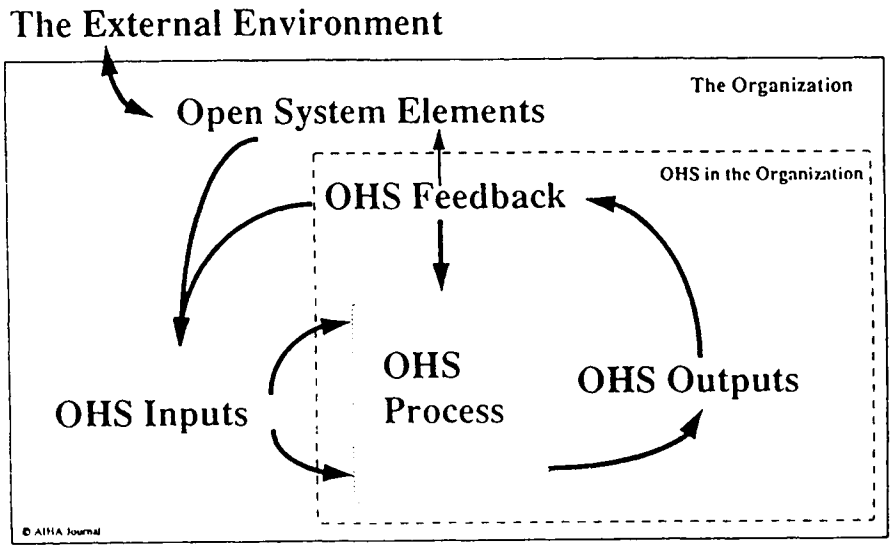


Figure 18.3 - Universal OHSMS Structure Development

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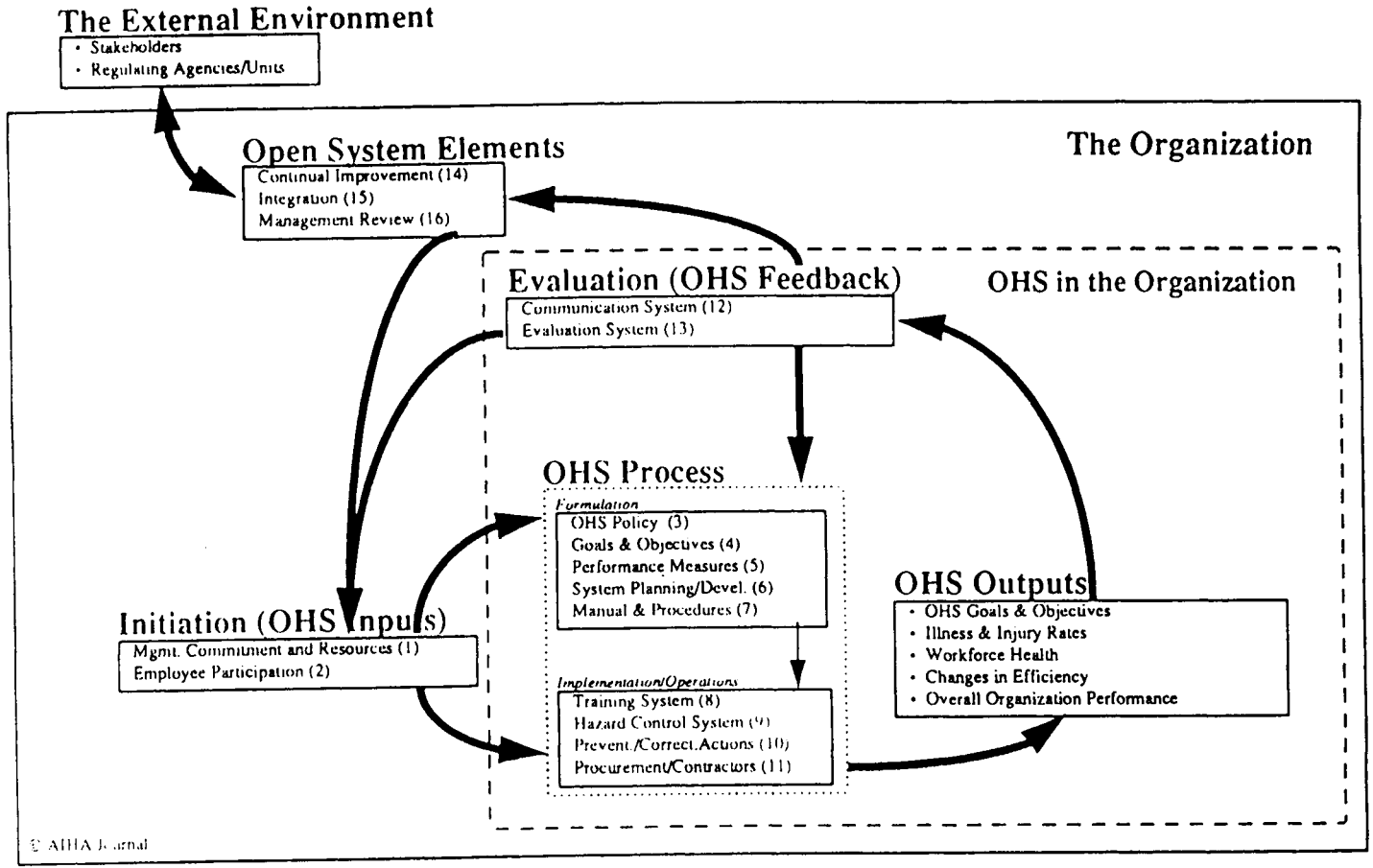


Figure 18.4 - Universal OHSMS Structure

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A UNIVERSAL OHSMS FOR USE AT HAZARDOUS WASTE OPERATIONS

Following the development of an ISO 9001-based OHSMS in 1995, researchers at the University of Michigan continued their work in this area with the development of a universal OHSMS and companion assessment instrument that can be applied in many settings, including at hazardous waste operations. (Levine and Dyjak, 1992). The assessment instrument was specifically developed (1) to measure the effectiveness of OHSMS, (2) to assist organizations in developing occupational health and safety performance variables and measurements, and, (3) to provide a means of discriminating between OHSMS models.

In order to develop the universal OHSMS 13 publicly-available management systems were reviewed, 7 of which were OHSMSs. The remaining 6 systems were quality assurance management systems (QAMS) or environmental management systems (EMS). Three OHSMS and 1 EMS models were selected for use in the development process. These 4 models were selected because they provided the most comprehensive management system approaches and contained the essential elements of all of the models reviewed. The four models are referred to herein as input models. These input models are

- **OSHA's Voluntary Protection Program (VPP).** The VPP represents the most comprehensive OHS management system approach within OSHA and encompasses elements of other systems approaches in OSHA, such as the 1989 Occupational Safety and Health Program Guidelines, Consultation's SHARP/form 33, the Performance Evaluation Profile (PEP), and the draft OHS program standard (initially identified as 29 CFR 1910.700).
- **The British Standards Institute's OHSMS, BS 8800:1996.** The British OHSMS was developed in 1996 and has been given considerable attention since other British standards have played a significant role in the development of both ISO 9000 and 14000. This OHSMS contains two approaches; one is based on ISO 14001 and the other is based on the British Health Safety Executives (HSE) OHS Guidelines HS(G) 65.
- **The American Industrial Hygiene Association's OHSMS.** The **AIHA's** OHSMS was developed by the Occupational Health and Safety Policy Group at the University of Michigan and the AIHA's OHSMS Task Force. This OHSMS is based on ISO 9001 and was designed to be easily integrated with this ISO model.

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- **ISO 14001:1996.** After several years of development, ISO 14001 was promulgated in late 1996. This environmental management system was developed to serve as a template for organizations in the improvement of their environmental management performance. While this is an environmental management system standard, many organizations are using it to develop their OHSMS, and thus it was used in the development of the universal OHSMS presented here.

Universal OHSMS Structure

The universal OHSMS structure can be summarized as containing 5 organizing categories and 27 sections (16 primary and 11 secondary). Considerable attention was given to the superstructure; that is, the 5 organizing categories and the manner in which the 16 primary sections are distributed among the 5 categories. The representation of this OHSMS (see Figure 18.4) could be presented in a number of ways. However, in an effort to create a more robust model, it was important to arrange the sections in such a way as to facilitate both OHSMS development and diagnostic activities. The 5 organizing categories are

1. Initiation (OHS inputs);
2. Formulation (OHS process);
3. Implementation/Operations (OHS process);
4. Evaluation (OHS feedback); and
5. Improvement/Integration (open system elements).

These categories are partially based on the policy analysis model developed by Brewer and deLeon [1993] and a simplified systems model, as depicted in Figure no. 18.1 [von Bertalanffy, 1950]. The sequence of steps followed is shown in Figures 18-2, 18-3, and 18-4. Figure 18-2 starts with a very basic construct showing the relationship between OHS management, the organization, and the external environment. Figure 18-3 develops the construct further showing how a systems model and a policy analysis model can fit in the construct. Finally, Figure 18-4 adds the universal OHSMS sections to the construct.

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With the universal OHSMS as presented in Figure 18-4, OHSMS developers and evaluators involved in hazardous waste operations can readily see how the sections relate to one another. This structure assists both the development and implementation of an OHSMS as well as facilitate diagnostic efforts. System evaluation functions are facilitated through this structure since the universal OHSMS components are clearly identified as needed for root-cause-analysis activities (Sec 13.2). That is, following preventive and corrective action (Sec. 10.0) and subsequent root cause analysis activities, evaluators will be able to identify the universal OHSMS sections which may need attention as result of the initial incident or system breakdown. This ability to identify clearly sections and make modifications will facilitate continual improvement (Sec. 14.0) goals.

Table 18-2 presents a summary of the number of OHSMS principles and measurement criteria found in each section. This table also shows the number of input-model clauses found in each section. Review of Table 18-2 reveals several interesting issues. One issue is that the universal OHSMS addresses medical surveillance more thoroughly than any of the input models (Sec. 13.3). While two of the input models do contain clauses that generally address medical surveillance, none does so to the degree that the universal OHSMS does. Based on the universal OHSMS developers' professional judgment and experience, emphasis in this area was increased. This emphasis strengthens the important linkage between industrial hygiene and occupational-medicine activities. Over their careers, the developers have observed numerous situations where this link was quite weak, or even non existent, in programs/systems purported to be comprehensive occupational health programs/systems.

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Table 18.1
A Universal OHSMS Outline

Initiation (OHS Inputs)

1.0 Management Commitment and Resources
    1.1 Regulatory Compliance and System Conformance
    1.2 Accountability, Responsibility, and Authority
2.0 Employee Participation

Formulation (OHS Process)

3.0 Occupational Health and Safety Policy
4.0 Goals and Objectives
5.0 Performance Measures
6.0 System Planning and Development
    6.1 Baseline Evaluation and Hazard/Risk Assessment
7.0 OHSMS Manual and Procedures

Implementation/Operations (OHS Process),

8.0 Training System
    8.1 Technical Expertise and Personnel Qualifications
9.0 Hazard Control System
    9.1 Process Design
    9.2 Emergency Preparedness and Response System
    9.3 Hazardous Agent Management System
10.0 Preventive and Corrective Action System
11.0 Procurement and Contracting

Evaluation (Feedback)

12.0 Communication System
    12.1 Document and Record Management System
13.0 Evaluation System
    13.1 Auditing and Self-Inspection
    13.2 Incident Investigation and Root Cause Analysis
    13.3 Medical Program and Surveillance

Improvement/Integration (Open System Elements)

14.0 Continual Improvement
15.0 Integration
16.0 Management Review

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Table 18-2
Universal OHMS principles and input clause summary

	OHSMS Assessment Instrument Sections	OSHA VPP	BSI BS 8800	AIHA OHSMS	ISO 14001	OHSMS Principles
1.0	Management Commitment and Resources	7	6	6	6	5
1.1	Regulatory Compliance and OHSMS Conformance	0	3	6	3	2
1.2	Accountability, Responsibility, and Authority	5	5	1	4	4
2.0	Employee Participation	7	2	3	0	6
3.0	Occupational Health and Safety Policy	1	1	3	3	2
4.0	Goals and objectives	1	1	4	5	6
5.0	Performance Measures	1	3	1	0	3
6.0	System Planning and Development	2	5	3	1	5
6.1	Baseline Evaluation and Hazard/Risk Assessment	2	6	2	2	3
7.0	OHSMS Manual and Procedures	4	0	2	2	3
8.0	Training System	6	2	9	7	7
8.1	Technical Expertise and Personnel Qualifications	1	3	5	1	4
9.0	Hazard Control System	1	1	11	2	4
9.1	Process Design	2	0	5	1	5
9.2	Emergency Response	0	1	1	2	5
9.3	Hazardous Agent Management	3	0	4	0	3
10.0	Preventive and Corrective Actions	3	1	11	2	4
11.0	Procurement and Contractor Systems	6	0	7	1	5
12.0	Communication Systems	4	2	8	2	5
12.1	Document and Record Management System	4	3	13	11	5
13.0	Evaluation System	10	0	16	4	7
13.1	Auditing and Self-Inspection	3	5	6	7	6
13.2	Incident Investigation	1	1	5	0	4
13.3	Medical Program and Surveillance	1	0	1	0	6
14.0	Continual Improvement	2	2	3	1	2
15.0	Intergration	2	5	2	3	2
16.0	Management Review	2	13	4	5	5
		85	13	142	75	118

Note: The number in each cell represents input clauses or OHSMS Principles, with the exception of the final column, where the numbers represent the number of Principles found in each section of the universal OHMS.

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System Components

When developing and implementing an OHSMS for hazardous waste operations, particular attention should be given to the following sections, hich are considered key performance variables for OHSMS success

1. Communication System/feedback channels (Sec. 12.0);
2. System Evaluation (Sec. 13.0), specially the development/measurement of Auditing/Self-Inspection (Sec. 13.1), and Root-Cause Analysis (Sec. 13.2);
3. Continual Improvement (Sec. 14.0);
4. Integration (Sec. 15.0); and,
5. Management Review (Sec. 16.0).

It is clear that all sections of the universal OHSMS are important to successful OHS management. For instance, many OSHA VPP participants would argue that management commitment (Sec. 1.0) and employee participation (Sec. 2.0) can be defined as the essential model components [OSHA, 1994]. The point of attempting to elucidate the components that are essential to a systems approach is that as future efforts are made to apply OHSMSs to smaller workplaces with limited resources, a thorough understanding of these key systems components will be necessary.

Communication System-Section 12.0

A well functioning communication system with defined feedback channels is essential for a successful OHSMS. As depicted in the systems model presented in Figures 18-1 and 18-3, this is a basic feature of a system, especially an open system. For the system to survive and potentially grow, there must be mechanisms whereby the system components receive feedback from each other and from the external environment.

This universal OHSMS section provides the means by which all other sections relate and interact. There are any number of ways that the communication system OHSMS principles can be operationalized. However, in its most basic form, a viable communication system should identify how, and to whom, information for the proper functioning of the OHSMS will be transmitted. The communication system should have mechanisms in place to confirm that information has been received by the intended party and in the prescribed time frame.

For example, universal OHSMS communication system principle, COMM01, states, "The organization shall ensure that the OHSMS has a

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clearly defined and functioning communication system whereby information, *data,* notifications, and other communications required by the OHSMS are transmitted in a timely manner to OHSMS personnel, employees, managers, and supervisors."

Performance Measures and Root Cause Analysis Sections 5.0 and 13.2

In the current OHS lexicon, terms such as "performance measures and metrics" are commonly used; synonyms for variables and measurements in the academic literature. In order to add more structure to these discussions, the broader context of scientific inquiry and measurement theory needs to be considered. That is, prior to identifying variables and measurements, it is necessary to identify the concepts and indicators with which they are associated.

Such a measurement hierarchy, from general to specific, can be summarized as follows:

1. It is first necessary to identify the construct to be measured (e.g., OHS performance);
2. This is followed by the identification of the indicator(s) associated with the construct(s) (e.g., Employee participation);
3. It is then necessary to identify the variable(s) associated with the construct(s) or indicator(s) (e.g., Continual improvement meetings); and
4. It is then necessary to quantify operational definitions for these variables (e.g., Number of team meetings per year).

Thus, in order to make valid and reliable performance measurements, the indicators, variables, measurement units, and their logical relationships must be established [Babbie, 1992; Pedhazur and Schmelkin, 1991].

In terms of the indicators to measure, the distinction has been made in the OHS literature between leading and trailing indicators. As in many disciplines, efforts are under way to identify leading indicators upon which management can rely on as predictors of emerging problems. This is seen in the economics field with an emphasis placed on leading economic indicators and in the environmental field with efforts to identify leading environmental health indicators from which environmental management decisions can be made.

Central to the identification of leading OHS indicators are the root-cause-analysis activities required in many OHSMSs. The use of root-cause-analysis techniques have been in use for many years in the health and safety field [Bird and Germain, 1990]. Root-cause analysis has been highlighted in the universal OHSMS because of its central importance in moving up the causal chain to the point of origin in the pursuit of leading OHS indicators. To achieve this, the

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input models, as well as OHSMSs and EMSs explicitly address root-cause analysis. In VPP and ISO 14001 training courses, root cause analysis is presented in several exercises titled "the four whys" and "follow the string" [Johnson, 1996; OSHA, 1994]. The point of these exercises is to show OHSMS evaluators several techniques on how to perform root-cause analysis. For example, an evaluator should always ask a set of four "why" questions when a nonconformity ordination is found, with each question based on the previous question.

Root-cause analysis may be considered a relatively minor component of an OHSMS, especially in entities in which there is full compliance is achieved with regulations and in which a numeric rating system is in place. However, compliance with regulations and high scores on a numeric system cannot replace the practice of following a line of inquiry from an unplanned incident, near miss, or regulatory citation to objective evidence that answers the question why? This is central to the philosophy of planning and operating an efficient, effective OHS management system. The lack of procedures for, or documentation of, the use of root-cause analysis may be traceable to, for example, nonconformance in clauses related to policy, management commitment, or training [Levine and Dyjak, 1997].

Continual Improvement-Section 14.0

Continual improvement is a key concept in the ISO-based OHSMSs and is the central concept reflected in the Deming/Shewhart Plan-Do-Check-Act cycle [Deming, 1986]. In an OHSMS context, continual improvement can be defined as the "process of improving the OHS management system to achieve enhancements in overall OHS MANAGEMENT performance through continuing reviews of appropriate OHS measures that are in line with the organization's OHS policy" [AIHA, 1996].

The basic notion embodied in this concept is that the organization continually seeks ways to improve the OHSMS and thus increase worker health and safety. Continual improvement focuses on problem prevention, corrective action, and performance improvement to affect worker health and safety. Continual improvement does not mean or imply a requirement to attain "better than compliance" conditions as measured against specification regulations or standards. While "better than compliance" may be a goal of an organization, it is not a requirement of the definition of continual improvement. There are numerous ways that an organization may operationally define continual improvement. However, the ultimate goal of continual improvement should be to reduce the potential for worker injury and illness.

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Integration-Section 15.0

A basic characteristic of OHSMSs is that they are integrated with other business functions and the external environment. As depicted in Figures 18-3 and 18-4, the OHSMS elements are connected through feedback channels. Also depicted in these figures is the manner in which the OHSMS is integrated with both the organization as a whole and the external environment. In order for an OHSMS to succeed, this open-system aspect must be understood and functioning. By definition, the implementation of an OHSMS requires that the OHSMS be connected, or related to other functions in the organization. This means that OHS issues and aspects of the OHSMS will be part of the organizational culture. Furthermore, at a fundamental level, this also means that worker health and safety will be an important value expressed by management and employees alike.

Management Review-Section 16.0

Management review is the means whereby the overall performance of the OHSMS is evaluated. It provides the link between the OHSMS, the organization, and the environment external to the organization. This involves evaluating the OHSMS's ability to meet the overall needs of the organization, its stakeholders, its employees, and regulating agencies. Management review is different from more specific system-evaluation efforts, which address specific aspects of the OHSMS elements.

The distinction between management review and system evaluation can be viewed in terms of how one would plan a long automobile trip. Using this metaphor, the ongoing monitoring of the fuel level, engine temperature, and general performance of the automobile corresponds with the functions performed during OHSMS system evaluation. Management review, on the other hand, corresponds with the ongoing evaluation of whether the car is on the correct highway to reach the intended destination. Continuing with the metaphor in terms of the program/system dichotomy discussed earlier, it can be said that, checking the tire pressure would correspond with and overall trip planning and vehicle performance would correspond with system evaluation.

Management review is the hallmark of a successful system and is a key attribute of strong management commitment to OHS. Without feedback, there can be no strategic planning or continual improvement. Management resistance to participate actively in the OHSMS review process would be a clear indicator of the lack of management commitment.

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SECTION-BY-SECTION REVIEW OF A UNIVERSAL OHSMS

A brief description of the universal OHSMS's five organizing categories and 27 sections follows.

Initiation (OHS Inputs)

OHSMS Initiation refers to the act of defining the necessary elements and conditions essential to OHSMS formulation, Implementation, and evaluation, These necessary elements Include strong management commitment, sufficient resources, and robust employee participation.

1.0 Management Commitment and Resources (COMMIT)

Management commitment to occupational health and safety may be operationally defined in several ways. Allocation of sufficient resources for the proper functioning of an OHS program or management system is a key variable to measure management commitment. Other variables, some of which are found in this section's OHSMS principles, are the establishment of organizational structures whereby managers and employees are supported in their occupational health and safety duties and the designation of a management representative who is responsible for overseeing the proper functioning of the OHSMS.

The importance of strong management commitment is reflected in OSHA's VPP and other OHSMSs. In fact, some occupational health and safety professionals assert that management commitment is the senaquanon of an OHSMS. The same maybe said about employee participation (Sec. 2.0). Therefore, these two input variables must be present for the development of a robust OHSMS.

1.1 Regulatory Compliance and System Conformance (REG)

Many governmental regulations and nongovernmental standards impose requirements on occupational health and safety management and, therefore, can affect the way an OHSMS is designed, implemented, and operated. Organizations need to understand the governmental regulations and nongovernmental standards that impact them. Striving for compliance or conformance with regulations and standards should be a top priority of the organization.

It is not the purpose of this section's OHSMS principles to identify for the organization the applicable regulations and standards. Rather, the purpose is to

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ensure that the organization has a system to identify, document, and implement applicable governmental and non-governmental requirements.

1.2 Accountability, Responsibility, and Authority (ACCOUNT)

OHSMS accountability, responsibility, and authority addresses the manner in which the organization defines the roles of personnel who are involved in OHSMS management, and the employees, supervisors, and managers who are affected by the system. Crucial to role definition is the manner in which occupational health and safety and OHSMS accountability, responsibility, and authority are defined, supported, and enforced by senior management. Having the director of OHS report directly to a high level manager would be an example of commitment.

In addition to defining these roles, the organization should ensure that potential discrimination against personnel who have OHSMS management responsibilities is prevented. Repeated and/or willful violations of occupational health and safety procedures should be subject to reprimand.

2.0 Employee Participation (EMPLOY)

Employee participation in occupational health and safety management may be operationally defined in any number of ways. The key issue is that employees have input into occupational health and safety considerations, and that the input is meaningful, valued, and can affect policies and practices. Other important variables, some of which are found in this section's OHSMS principles, include employee participation in OHSMS formulation, implementation, and evaluation activities.

Many OHS professionals have identified employee participation in occupational health and safety management as the variable essential to successful OHS management and illness/injury reduction. Employee participation and management commitment (Sec. 1.0) are identified as two input variables that must be present in the development of a robust OHSMS.

Formulation (OHS Process)

OHSMS formulation refers to the act of designing the system. This starts with an OHS policy that expresses the organization's commitment to occupational health and safety. Goals, objectives and performance measures are used to immplement OHS policy.

Integral to OHSMS formulation is the planning and development of the system in terms of organizational structures. A baseline evaluation that

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identifies hazards and risks provides essential information. The OHSMS manual is used to present the policies and procedures that define the system.

3.0 Occupational Health and Safety Policy (POLICY)

The OHS policy represents the foundation from which OHS goals and objectives, performance measures, and other system components are developed. The OHS policy should be short, concise, easily understood, and known by all employees in the organization. It can be expressed in terms organizational mission or vision statements. It is a document that expresses the organization's OHS values.

The OHS policy should demonstrate senior management's commitment to occupational health and safety (Sec. 1.0), employee participation (Sec. 2.0), allocation of necessary resources, and continual improvement (Sec. 14.0). The policy should be evaluated periodically as part of the management review process.

4.0 Goals and Objectives (GOAL)

The development of OHS goals and objectives follows naturally from the OHS policy (Sec. 3.0) development activities. With the OHS policy established, there is a foundation upon which OHS goals and objectives can be generated.

The establishment of OHS goals and objectives represents the beginning of a progression from the conceptual realm of the OHS policy to an operational realm as expressed in the overall system structure/design (Sec. 6.0) and OHSMS manual (Sec. 7.0).

It is important that the organization give careful thought to the way it establishes and develops goals and objectives. They should be measurable and appropriate to the size, nature, and complexity of the organization's activities. The goals and objectives should reflect the organization's commitment to a safe and healthy workplace that is free of known hazards.

5.0 Performance Measures (PERFORM)

The ability to measure OHS performance over time is essential to eliminating occupational injuries and illness. To achieve this, the organization should develop performance measures that are consistent with the OHS variables expressed in the OHS policy (Sec. 3.0) and goals and objectives (Sec. 4.0). These measures should be considered, and possibly developed, at the same time that the goals and objectives are being created. Good correspondence between the goals and objectives and the performance measures will enhance in

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the organization's ability to perform the diagnostic functions of the evaluation system (13.0) and management review (16.0) components.

Traditional performance measures are trailing indicators of performance. Trailing indicators have been and should continue to be used to evaluate OHS performance. These indicators include, for example, citations for regulatory noncompliance, injury and illness statistics, lost workdays, and insurance costs.

Leading indicators may include percentage of safe behavior, exposure assessment data, employee observations, compliance with personal protection procedures and percentage of government-mandated training actually delivered. It is not the intent here to require the use of any specific indicators, but rather to provide principles from which the organization can specify, evaluate, and use such indicators. To the extent possible, the performance measures should be leading indicators of workplace health and safety as opposed to trailing indicators.

6.0 System Planning and Development (PLAN)

System planning and development activities address both initial OHSMS development and ongoing revision and modification of the system. This system component addresses the manner in which the overall structure and form of the OHSMS will be developed, implemented, and subsequently modified.

The performance-based nature of OHSMS standards can lead to a wide range of OHSMS structures when adapted and implemented in any given organization. This component is, therefore, one of the most crucial and this stage of the formulation process greatly affects the implementation and ongoing performance of the OHSMS. If this component of the OHSMS is not performed well, the probability of the occurrence of implementation problems will increase.

System planning and development activities represent the implementation of the preceding components in the OHSMS: OHS policy (Sec. 3.0); goals and objectives (Sec. 4.0), and performance measurement (Sec. 5.0). The planning and development activities must be informed by data from the baseline evaluation (Sec. 6.1), and the requirements of the hazard control system (9.0). The planning should identify the need for Occupational Health and Safety experts (see Figure 8-1).

6.1 Baseline Evaluation and Hazard/Risk Assessment (BASE)

A baseline evaluation of the organization's existing occupational health and safety management practices and OHS hazards is necessary before a robust OHSMS can be completely designed or implemented. The baseline evaluation needs to identify OHS hazards and their associated risks clearly.

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This information is essential to the development of numerous OHSMS components, including the training system (Sec. 8.0), hazard control system (Sec. 9.0), and the emergency preparedness and response system (Sec. 9.3).

The baseline evaluation can help establish the structure and methods to be used in other evaluation system (Sec. 13.0) functions, such as audits and self-inspections (Sec. 13.1).

7.0 OHSMS Manual and Procedures (MANUAL)

The OHSMS manual is the document where occupational health and safety and OHSMS policies and procedures are to be found. This document is a key part of OHSMS formulation activities because it compiles and presents the results of the formulation work.

OHSMS management is greatly enhanced by the presence of a written manual that contains OHS procedures to guide the system. It has been argued persuasively that the existence of such a manual is a necessary condition for maintaining a healthy and safe workplace. The OHSMS manual should be easily accessible to employees, taking into account levels of education and possible language barriers. It should be written in clear language and should use graphic illustrations where possible to communicate the intended information. It should also be reviewed periodically and updated as necessary.

Implementation/Operations (OHS Process)

OHSMS implementation represents the act of putting into practical effect the work done in the OHSMS initiation and formulation phases. Implementation involves the activities of the training, hazard control, preventive, and emergency response systems. Also addressed are procurement and contracting activities.

8.0 Training System (TRAIN)

The term training system is used broadly to reflect the importance of knowledge dissemination and skill development in a well-functioning OHSMS. Occupational health and safety training has been an integral component of OHS management for many years. It is universally recognized as an essential element in maintaining a healthy and safe workplace.

A successful training system must be based on an understanding of workplace hazards. The system needs to be integrated with the communication system (Sec. 12.0) feedback channels so that, as there are changes in the OHSMS, training efforts can be appropriately modified. A well-functioning

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training system includes a mechanism to identify training needs and track employee training-status in relation to the identified needs.

8.1 Technical Expertise and Personnel Qualifications (EXPERT)

Successful OHSMS operation requires qualified and competent personnel. This includes personnel in the organization who have direct OHSMS responsibilities as well as external consultants who may provide OHS services to the organization.

The organization can ensure the expertise of OHSMS personnel through preplacement review and post-placement training. In addition, the use of certified professionals can both improve performance and demonstrate an organizational commitment OHS. Taken from examples in the United States, such professionals could be certified industrial hygienists, certified safety pofessionals, licensed professional engineers, and board-certified occupational physicians and occupational health nurses.

It is not the purpose in these OHSMS principles to define the OHS qualifications required. Rather, the purpose is to ensure that the organization has a system to set criteria and document their use so that under qualified OHS persons can be identified and will not have an adverse impact on workplace health and safety.

9.0 Hazard Control System (CONTROL)

The hazard control system is broadly defined to include the various methods used to reduce or eliminate occupational hazards, and the methods through which the control system is modified as workplace conditions may change. Control methods are typically defined in terms of administrative controls, personal protective equipment (PPE), or engineering controls. The intent of these OHSMS principles is not to prescribe the type of OHS controls the organization should use. Rather, the intent is to provide the principles upon which such decisions may be made.

A successful hazard control system is informed by the evaluation (Sec. 13.0) and communication (Sec. 12.0) systems. The design of the hazard control system needs to be considered during system planning and development activities (Sec. 6.0).

A hazard control system goal should be to follow the widely accepted control hierarchy of (1) hazard elimination, (2) use of engineering controls, and, (3) use of PPE or administrative controls. For hazards that cannot be eliminated, engineering controls should be the first control option considered. Administrative and PPE controls may be considered and used if hazard

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elimination and engineering controls are not sufficient to protect worker health and safety.

9.1 Process Design (DESIGN)

This section addresses OHS concerns and issues associated with the installation of new processes or operations. The principles herein can also be applied to modification of existing processes or operations.

In this context, processes and operations represent a wide range of activities. Examples are: the installation of new office workstations, modifications made to an existing manufacturing process or development of a new medical waste disposal operation.

This system component does not address the overall design of the OHSMS, those activities are addressed in the system planning and development section (Sec. 6.0).

Successful process and operation design is informed by input from employees who will be assigned to the new process/operation. Such input should be sought, encouraged, valued, and able to affect the design process.

9.2 Emergency Preparedness and Response System (EMERG)

Emergency preparedness and response refers to the manner in which the organization prepares for and responds to OHS emergencies and accidents. As defined here, emergency preparedness and response system actions are initiated and conducted immediately when events occur that can cause serious illness, injuries, or even fatalities. Emergency response covers many possible hazard scenarios including, for example, evacuation of an office building, spill of a flammable liquid, release of a toxic gas, or incapacitation of workers by unknown agents.

Improper planning or execution of the plan can result in consequences that include life-ending, career-ending, or business-unit-bankrupting incidents. Details that may seem minor or innocuous, such as a leaky seal on a pump, improper calibration of an LEL meter, or lack of training for procedures to respond to an enunciator, can have catastrophic implications.

9. 3 Hazardous Agent Management System (HAZ)

The term hazardous agent refers to chemicals, biological agents, radioactive materials, and hazardous wastes. The hazardous agent management system is an important component of the more broadly defined hazard control system. The key issues addressed in these OHSMS principles are the

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identification of hazardous agents, understanding of their risks, control of the risks, and establishment of coordinating mechanisms.

Such hazardous agent management system practices typically include (1) an inventory mechanism, (2) labeling of containers/areas that contain hazardous substances, (3) notification of employees of potential hazards, and (4) employee training. It includes compliance with the OSHA Hazard Communication Standard and with state regulations.

The hazardous agent management system activities should be coordinated with the following OHSMS sections: system planning/development (Sec. 6.0); training system (Sec. 8.0); hazard control system (Sec. 9.0); and, evaluation system (Sec. 13.0).

10.0 Preventive and Corrective Action System (ACTION)

Preventive and corrective action refers to actions taken in response to, or in anticipation of, system breakdowns or high hazard/risk events. A key concept of this component is that actions should be as anticipatory as possible. That is, actions should be taken in advance to prevent an incident or other unplanned event that might adversely affect worker health, or that would require emergency or other response actions.

The identification of preventive and corrective actions should be an integral part of the organization's evaluation system (Sec. 13.0) efforts. Specifically, self-inspection (Sec. 13.1) efforts that are conducted on an ongoing basis, should identify potential hazards before they can cause losses. As new OHS hazards surface, or breakdowns/deficiencies in the OHSMS occur, preventive and corrective actions should be initiated to eliminate or reduce the effect that these findings may have on workplace health and safety.

11.0 Procurement and Contracting (BUYING)

Products and contractors can impact workplace health and safety. This system component addresses the need to be aware of such impacts and the need for mechanisms to control them.

A successful OHSMS will specify at least minimum requirements for the behavior of contractors while on the organization's premises. In some cases, it may be appropriate for contractors to follow all of the organization's safety rules. In other cases, it may be appropriate for the contractors to follow their own safety rules. Regardless of the approach, the contractor's safety record/history should be included as a selection/award criterion. Responsibility for auditing contractor performance by an OHS person should be delineated.

A mechanism should be in place to evaluate the manner in which all incoming products or items may affect workplace health and safety. In cases

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where this cannot be determined, a product or item should be restricted from use until its impact can be determined.

Evaluation (Feedback)

OHSMS evaluation represents the act of comparing expected and actual performance levels against established criteria, These findings are in turn communicated and used to improve the OHSMS and overall occupational health and safety performance.

12.0 Communication System (COMM)

The communication system may be defined and implemented in several ways. In its most basic form, a viable communication system should identify how, and to whom, information for the proper functioning of the OHSMS will be transmitted.

A well-functioning communication system with defined feedback channels is essential for a successful OHSMS. This system component provides the means by which all other system components relate and interact.

12.1 Document and Record Management System (DOC)

The document and record management system addresses the way the organization manages and organizes OHSMS documents and records.

A well-functioning document and record management system is essential in organizations that are pursuing OHSMS registration or certification. From a registrar's or auditor's perspective, the document and record management system provides one of the key indicators of whether the OHSMS is currently in conformance, and whether the probability is good that conformance will be maintained over time.

13.0 Evaluation System (EVAL)

The evaluation system is broadly defined and includes baseline evaluations (Sec. 6.1), auditing (Sec.13.1), self-inspection (Sec.13.1), incident investigation (Sec. 13.2), medical surveillance (Sec. 13.3), and management review (Sec. 16.0) activities.

In a systems framework these activities are fundamental to the system's ability to function and sustain itself over time. Each of the identified evaluation system activities is addressed in a separate section. General and methods-related evaluation system principles are presented in this section.

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13.1 Auditing and Self-inspection (AUDIT)

Occupational health and safety auditing and self-inspection are specific activities of the evaluation system (13.0) where information is gathered and assessed on individual OHS programs and systems. These activities include an assessment of changes in OHS hazards and the ability of the OHSMS to respond properly to the changes.

Auditing and self-inspection activities provide essential information to other OHSMS components, including the training (Sec. 8.0), hazard control (Sec. 9.0), and preventive and corrective action (10.0) systems. This section's OHSMS principles are distinct from management review (Sec. 16.0) functions which address the broader issue of the OHSMS structure in relation to changes in the regulatory environment and stakeholder expectations (e.g. employees, regulators, shareholder, community). Audits apply to both internal and contractor performance.

13.2 Incident Investigation and Root-Cause Analysis (ROOT)

Incident investigation and root-cause analysis refers to the activities conducted to determine the origin and cause(s) of accidents, near miss accidents, injuries, fatalities, or breakdowns in the OHSMS.

An important aspect of incident investigations is the performance of a root-cause analysis is to see at what point(s) the OHSMS failed. This includes establishing and moving up a causation chain from the incident backwards to the point(s) of origin. The important goal is to find the source(s) of the breakdown(s) in the OHSMS so that it (they) can be corrected.

13.3 Medical Program and Surveillance (MEDICAL)

Medical program and surveillance refers to the activities associated with providing medical services within the organization, and the development and operation of a medical surveillance program. An occupational medical surveillance program, when workplace hazards dictate, is a key component of an OHS systems approach.

This section's OHSMS principles do not require the presence of a medical surveillance program, only that the need is assessed. This is required for certain hazardous waste workers under 29 CFR 1910.120(f). In the case where a program is developed and implemented, the principles offer baseline guidance and criteria.

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Improvement/Integration (Open System Elements)

OHSMS improvement refers to the act of using evaluation and assessment findings to improve occupational health and safety performance. Integration refers to the act of integrating OHS with management systems and business functions in the organization, as well as the community. Management review provides the mechanism whereby OHSMS performance Is broadly assessed in terms of stakeholder expectations (e.g. employees, shareholders, regulators, community).

14.0 Continual Improvement (IMPROVE)

Continual improvement may be operationally defined and implemented in several ways. The basic notion here is that the organization should seek ways to achieve ongoing improvement of occupational health and safety performance. The ultimate goal of continual improvement activities should be to eliminate worker injury and illness.

Continual improvement does not mean or imply a requirement to attain better-than-compliance conditions as measured against specification regulations or standards. While better-than-compliance conditions may be a goal of an organization, it is not a requirement of the definition of continual improvement suggested here.

15.0 Integration (INTEGRT)

Integration refers to the actions the organization takes to integrate its occupational health and safety functions with other management system and business processes in the organization and in the community.

A successful OHSMS requires that the OHSMS be connected, or related, to all other key functions in the organization. This means that occupational health and safety issues and aspects of the OHSMS will be part of the organizational culture. In addition, at a fundamental level, this also means that worker health and safety will be an important value expressed by management and employees alike.

16.0 Management Review (REVIEW)

The overall performance of the OHSMS is evaluated through management reviews. It is through this activity that the OHSMS, the organization, and the environment external to the organization are linked. This involves evaluating the OHSMS's ability to meet the overall needs of the organization, its stakeholders, its employees, and regulating agencies. Management review is

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different from more specific evaluation system (Sec. 13.0) efforts that address specific aspects of the OHSMS elements.

Management review is a necessary condition for a successful system. Without consideration of feedback, there can be no meaningful planning (Sec. 6.0) or continual improvement (Sec. 14.0).

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APPENDIX A
ABBREVIATIONS

alc	alcohol
amorph	amorphous
anhyd	anhydrous
aq	aqueous
atm	atmosphere
autoign temp	autoignition temperature
bp	boiling point
BPR	Blood Pressure effects
b range	boiling range
bz	benzene
C	Centigrade/Celsius
carc(s)	carcinogen(s)
CARC	carcinogenic effects
cc	cubic centimeter
CL	ceiling concentration
compd(s)	compound(s)
conc	concentration, concentrated
contg	containing
corr	corrovise
cryst	crystal(s), crystalline
CUM	cumualitive effects
CVS	cardiovascular effects
d	density
D	Day
dba	decibel
decomp	decomposition
deliq	deliquescent
eth	ether
exper	experimental (animal)
expl	explosive
expos	exposure
eye	administration into eye (irritant)
EYE	systemic eye effects
F	Fahrenheit
fbr	fibroblasts
flamm	flammable
flash p	flash point
fp	freezing point
GIT	gastrointestinal tract effects
g/L	grams per liter
glac	glacial
GLN	glandular effects
gran	granular effects
hr	hour
hexag	hexagonal
hmn	human
H_2	hydrogen
htd	heated
htg	heating
im	intramuscular
incomp	incompatible
inhal	inhalation
insol	insoluble
intox	intoxication
ip	intraperitoneal
irr	irritant, irritating, irritation
IR	infrared
IRR	irritant effects (systemic)
itr	intratracheal
iv	intravenous
kg	kilogram
L	liter

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mem	membrane	PNS	peripheral nervous systems effects
min	minimum	ppb	parts per billion (v/V)
µg, ug	microgram	pph	parts per hundred (v/V) (percent)
µmol, umol	microgram	ppm	parts per million (v/V)
mg	milligram	ppt	parts per trillion (v/V)
mg/m3	milligrams per cubic meter	PROP	properties
mg/L	milligrams per liter	psi	pounds per square inch
misc	miscible	PSY	psychotrohic effects
ml	milliliter	PUL	pulmonary system effects
MLD	mild irritation effects	rbt	rabbit
mm	millimeter	refr	refractive
mod	moderately	resp	respiratory
MOD	mucous membrane effects	rhomb	rhombic
mol	mole	S, sec	second(s)
mp	melting point	scu	subcutaneous
mR	miliroentgen	SEV	severe irritation effects
mR/hr	miliroentgen per hour	SKN	systemic skin effects
MSK	musculoskeletal effects	slt	slight
µ, u	micron	sltly	slightly
mumem	mucous membrane	sol	soluble
MUT	mutagen	soln	solution
mw	molecular weight	solv(s)	solvent(s)
N	nitrogen	spont	spontaneous(ly)
NEO	neoplastic effects	subl	sublimes
nonflamm	nonflammable	susp	suspect
NTP	Notional Toxicology Program	SYS	systemic effects
o-	ortho	L_{re}	rectal temperature
ocu	ocular	ta	ambient air temperature
p-	para	ta adj	adjusted air temperature
par	parenteral	tech	technical
petr eth	petroleum	temp	temperature
pg	picogram	TER	teratogenic effects
pk	peak concentration	TFX	toxic effects
pmol	picmole	tox	toxic, toxicity

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uel	upper explosive limits
unk	unknown
UNS	toxic effects unspecified in source
UV	ultraviolent
vap d	vapor density
vap press	vapor pressure
visc	viscosity
v/V	volume per volume
W	week(s)
Y	year(s)
>	greater than
>	less than
<=	equal to or less than
=>	equal to or greater than

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Appendix B
ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
ALR	airline respirator
ANSI	American National Standards Institute
APR	air-purifying respirators
ASTM	American Society for Testing and Materials
CA	carcinogen
CAA	Clean Air Act
CAS	Chemical Abstracts Service
CC	closed cup
CDC	Center for Disease Control
CELDS	Computer-Aided Environmental Legislative Data System
CEQ	Council on Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act (also called Superfund)
CFR	Code of Federal Regulations
CGI	combustible gas indicator
CNS	central nervous system
COC	Cleveland Open Cup
CPC	chemical protective clothing
CPR	cardiopulmonary resuscitation
CRC	contamination reduction corridor
CRZ	contamination reduction zone
CWA	Clean Water Act
DNAPL	dense non-aqueous phase liquids
DoD	Department of Defense
DoE	Department of Energy
DoT	U.S. Department of Transportation
EKG	electrocardiogram
EPA	U.S. Environmental Protection Agency
ESCBA	escape-only self-contained breathing apparatus
ETA	equivocal tumorigenic agent
FEF	forced expiratory flow
FEMA	Federal Emergency Management Administration
FEV_1	forced expiratory volume in one second
FID	flame ionization detector
FIFRA	Federal Insecticide, Fungicide and Rodenticide Act
FIT	field investigation team
FRC	functional residual capacity
FVC	forced vital capacity
GC	gas chromatography

FOR REFERENCE PURPOSES ONLY

GI	gastrointestinal
GM	Geiger-Muller (Geiger Counter)
HAZMAT	Hazardous Material Response Team
HAZWOPER	Hazardous Waste Operations and Emergency Response (training)
HNU	name of company that manufactures a type of photoionizer used to detect organic gases and vapors (also applied to the device)
HR	hazard rating
HW	hazardous waste
IAR	International Agency for Research on Cancer
IATA	International Air Transport Association
ICAO	International civil air organization
IDLH	immediately dangerous to life or health
IMDG	International maritime dangerous goods
ISO	International Organization for Standardization
IUPA	International Union for Pure and Applied Chemistry
LEL	lower explosive limit
LFL	lower flammable limit
LNAPL	Light non-aqueous phase liquids
LOAEL	Lowest-observed adverse effect level
LOEL	Lowest-observed effect level
MMEFR	maximal midexpiratory flow rate
MSDS	Material Safety Data Sheet
MSHA	Mine Safety and Health Administration
MVV	maximal voluntary ventilation
NCRP	North Carolina Research Park
NEPA	National Environmental Protection Agency
NEW	net explosive weight
NFPA	National Fire Protection Agency
NGWA	National Groundwater Association
NIOSH	National Institute for Occupational Safety and Health
NOAEL	no observed adverse effect level
NOEL	no observed effect level
NORM	naturally occurring radioactive materials
NRC	Nuclear Regulatory Commission
OC	open cup
OHSMS	Occupational health and safety management
ORM	Other regulated materials
OSHA	Occupational Safety and Health Administration
OVA	organic vapor analyzer
PCB	polychlorinated biphenyl
PDS	personnel decontamination station
PEL	permissible exposure limit or published exposure limit
PG	Packing Group
PID	photoionization detector
PAH	polynuclear aromatic hydrocarbons
PPC	personal protective clothing

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PPE	personal protective equipment
POP	performance oriented package
PVC	polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
REL	recommended exposure limits
RV	residual volume
SAP	sampling and analysis plan
SARA	Superfund Amendments and Reauthorization Act
SCBA	self-contained breathing apparatus
SMAC23	Sequential Multiple Analyzer Computer
SOP	standard operating procedure
SQG(s)	small quantity generator(s)
SSO	site safety officer
STEL	short-term exposure limit
TAT	technical assistance team
TCC	taglibue closed cup
TD	toxic dose
THR	toxic and hazard review
TLC	total lung capacity
TLV	threshold limit value
TLV-C	threshold limit value-ceiling
TSCA	Toxic Substances Control Act
TSD	transportation, storage and delivery
TWA	time-weighted average
UEL	upper explosive limit
ULC	Underwriters Laboratory classification
UN	United Nations
USCG	U.S. Coast Guard

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APPENDIX C
CHEMICAL FORMULAS

Ag_2O	silver oxide	Fe_2O	iron oxide
Al	aluminum	F_2O	fluorine oxide
$AlCl_3$	aluminum chloride	H_2	hydrogen gas
BF_3	boron trifluoride	HCHO	formaldehyde
B_2O_3	boron oxide	HCl	hydrochloric acid
BO_x	boron oxides	HF	hydrofluoric acid
Br_2	bromine gas	HgF_2	mercuric fluoride
BrF_3	bromine trifluoride	HI	hydriodic acid
$CaCl_2$	calcium chloride	H_2O	water
$Ca(CN)_2$	calcium cyanide	H_2O_2 or HOOH	hydrogen peroxide
CaO_x	calcium oxides	HOAc	acetic acid
$Ca(OCl)_2$	calcium oxychloride	HOCl	hypochlorous acid
CCl_4	carbon tetrachloride	H_2S	hydrogen sulfide
CdO	cadmium oxide	H_2SO_4	sulfuric acid
$Cd(OH)_2$	cadmium hydroxide	$H_2S_2O_3$	trisulfuric acid
C_6H_6	benzene	IF_7	iodine hepta fluoride
$CHCL_3$	chloroform	$KClO_3$	potassium chlorate
CH_3OH	methanol	K_2CrO_4	potassium chromate
Cl_2	chlorine gas	KHC	potassium carbide
ClF_3	chlorine trifluoride	KOH	potassium hydroxide
ClO_2	chlorine oxide	LiH	lithium hydride
CN	cyanide	LiOH	lithium hydroxide
CO	carbon monoxide	$Mg(C_2H_5)_2$	magnesium ethyl
CO_2	carbon dioxide	MgO	magnesia
$COCL_2$	phosgene	Na_2C_2	sodium carbide
CoO_x	cobalt oxides	NaClO3	sodium perchlorate
CrO_3	chromium trioxide	NaK	sodium potassium alloy
Cr_2O_3	chromium oxide	NaN_3	sodium nitride
CS_2	carbon bisulfide	$NaNO_3$	sodium nitrate
Cs_2O	cesium oxide	Na_2O	sodium oxide
$CuFeS_2$	copper iron sulfide	Na_2O_2	sodium peroxide
EtOH	ethanol	NaOBr	sodium oxybromide
F_2	fluorine gas	NaOCl	sodium oxychloride

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NaOH	sodium hydroxide
NaPCP	sodium pentachlorophrnate
NF_3	nitrogen fluoride
NH_3	ammonia
NH_4+	ammonium radical
NH_4NO_3	ammonium nitrate
NH_4OH	ammonium hydroxide
N_2O_4	nitrogen dioxide
NO_x	nitrogen oxides
NOCl	nitrosyl chloride
O_2	oxygen gas
O_3	ozone
OF_2	oxygen fluoride
OsO_4	osmium tetroxide
PCl_3	phosphorus trichloride
P_2O_3	phosphorus trioxide
P_2O_5	phosphorus pentoxide
PO_x	phosphrous oxides
Rb_2C_2	rubidium carbide
SO_2	sulfur dioxide
SiO_2	silica
SO_2	sulfur dioxide
SO_x	sulfur oxides
2,3,7,8-TCDD	dioxin
TeO	tellurium oxide
$Tl(NO_3)_3$	thallium nitrate
Tl_2O	thallous oxide
VO_x	vanadium oxides
$ZnCl_2$	zinc chloride
$ZnCrO_4$	zinc chromate
$ZnCr_2O_7$	zinc dichromate
ZnO	zinc oxide

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APPENDIX D
GLOSSARY

absorbed dose The energy imparted by ionizing radiation per unit mass of tissue.

acute exposure Exposure to a substance in a short time span and generally at high concentrations.

alpha particle (alpha radiation) A positively charged particle having a mass and charge equal in magnitude to a helium nucleus (two protons & two neutrons). They are emitted by certain radioactive materials. They will travel only 10-60 mm through the air before being stopped by air molecules. They are most dangerous when they are inhaled or ingested.

alpha radiation A type of ionizing radiation consisting of alpha particles, which are two protons and two neutrons bound together, with an electrical charge of +2. An alpha particle is equivalent to a helium nucleus.

autoreactive A compound that is reactive under normal conditions without initiation by heat or other compounds or change in conditions,

becquerel (Bq) A unit of activity equal to one nuclear transformation or disintegration per second. The curie, is related to the becquerel according to 1 Ci = 3.7×10^{10} Bq.

beta particle (beta radiation) A charged particle emitted from the nucleus of an atom, with a mass and charge equal in magnitude to that of the electron. They are faster and lighter than an alpha particle.

breakthrough time The elapsed time between initial contact of the hazardous chemical with the outside surface of protective clothing material and the time at which the chemical can be detected at the inside surface of the material by means of the chosen analytic technique.

buddy system A system of organizing employees into work groups in such a manner that each employee is designated to be observed by at least one other employee in the group. The purpose of the buddy system is to provide rapid assistance to employees in the event of an emergency.

bulk container A cargo container, such as that attached to a tank truck or tank car, used for transporting substances in large quantities.

bung A cap or screw used to cover the small opening in the top of a metal drum or barrel.

canister A purifying device for an air-purifying respirator that is held in a haness attached tot he body or attached to the chin part of a face piece, is connected to the facepiece by a breathing tube, and removes particulates or specific chemical gases or vapors from the ambient air as it is inhaled through the canister.

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carboy A bottle or rectangular container for holding liquids with a capacity of approximately 5 to 15 gallons; made of glass, plastic, or metal and often cushioned in a protective container.

cartridge A purifying device for an air-purifying respirator that attaches directly to the facepiece and removes particulates or specific chemical gases or vapors from the ambient air as it is inhaled through the cartridge.

chronic exposure Exposure to a substance over a long period of time, usually at low doses.

cleanup operation An operation where hazardous substances are removed, contained, incinerated, neutralized, stabilized, or in any other manner processed or handled with the ultimate goal of making the site safer for people or the environment.

closed-circuit SCBA A type of self-contained breathing apparatus (SCBA) that recycles exhaled air by removing carbon dioxide and replenishing oxygen. Also called a *rebreather SCBA.*

colorimetric tube An instrument for the chemical analysis of liquids by comparison of the color of the given liquid with standard colors.

CLO A unit of measure for CPC thermal heating values. Based on heat transfer rates through clothing at room temperature.

combustible Capable of burning.

contamination control line The boundary between the support zone and the contamination reduction zone.

contamination reduction corridor (CRC) The part of the contamination reduction zone where the personnel decontamination stations are located.

contamination reduction zone (CRZ) The area on a site where decontamination takes place, preventing cross-contamination from contaminated areas to clean areas.

continuous-flow respirator A respiratory protection device that maintains a constant flow of air into the facepiece at all times. Airflow is independent of user respiration.

controlled area A defined area in which the occupational exposure of personnel to radiation or radioactive material is under the supervision of an individual in charge of radiation protection.

crazing The formation of minute cracks (as in the lens of a facepiece).

cross-contamination The transfer of a chemical contaminant from one person, piece of equipment, or area to another that was previously not contaminated with that substance.

curie (Ci) See also Becquerel. (a) Formerly, a special unit of activity. One curie equals 3.7×10^{10} disintegrations per second exactly or 1 Ci = 3.7 x

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10^{10} Bq. (b) By popular usage, the quantity of any radioactive material having an activity of one curie.

decay, radioactive A spontaneous nuclear transformation in which particles or gamma radiation is emitted, or X radiation is emitted following orbital electron capture, or the nucleus undergoes spontaneous fission.

decontamination The removal of hazardous substances from employees and their equipment to the extent necessary to preclude the occurrence of adverse health effects or cross-contamination.

decontamination line A specific sequence of decontamination stations within the contamination reduction zone for decontaminating personnel or equipment.

degradation A chemical reaction between chemical and structural materials (in, for example, protective clothing or equipment) that results in damage to the structural material.

demand respirator A respiratory protection device that supplies air or oxygen to the user in response to negative pressure created by inhalation.

dermeal Pertaining to skin.

disinfection The application of a chemical that kills bacteria.

dose A general form denoting the quantity of radiation or energy absorbed. Most people receive between 150 and 200 millirems a year, and any level less than 5,000 millirems a year is considered low-level. Scientist have found that radiation doses of over 100,000 millirem will usually cause radiation sickness. Doses of over 500,000 millirems, if received in three days or less, will usually kill a person.

dosimeter An instrument for measuring doses of radioactivity or other chemical exposures based on collection media over a period of time.

dress-out area A section of the support zone where personnel suit up for entry into the exclusion zone.

emergency response A response effort by employees from outside the immediate release area or by other designated responders (e.g., mutual-aid groups or local fire departments) to a situation that results, or is likely to result, in an uncontrolled release of a hazardous substance.

escape-only SCBA (ESCBA) A type of self-contained breathing apparatus (SCBA) that is approved for escape purposes only. It does not carry the safety features necessary for longer work periods.

etioiogic agent A microorganism that may cause human disease.

exclusion zone The contaminated area of a site.

explosive A chemical that is capable of burning or bursting suddenly and violently.

facility Any site, area, building, structure, installation, equipment, pipe or pipeline (including any pipe into a sewer or publicly owned treatment

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works). well, pit, pond, lagoon, impoundment. ditch, storage container, motor vehicle, rolling stock. or aircraft where a hazardous substance has been deposited.

filter A purifying device for an air-purifying respirator that removes particulates and/or metal fumes from the ambient air as it is inhaled.

flammable Capable of being easily ignited or burning with extreme rapidity.

flammable gas Any compressed gas meeting the requirements for lower flammability limit, flan~mability limit range, flame projection, or flame propagation criteria as specified in 49 CFR 173.300(b).

flammable liquid Any liquid having a flash point below 100°F as determined by tests listed in 49 CFR 173.115(d). A *pyrophoric liquid* ignites spontaneously in dry or moist air at or above 130°F.

flammable solid Any solid material, other than an explosive, that can be ignited readily and when ignited burns so vigorously and persistently as to create a serious transportation hazard (49 CFR 173.150).

flash point The minimum temperature at which a liquid gives off enough vapors to form an ignitable mixture with the air near the surface of the liquid.

gamma radiation A type of ionizing radiation consisting of high-energy, short-wave length electromagnetic radiation. A type of radiation that is released in waves by unstable atoms when they stabilize. They are a very strong (range of energy from 10 keV to 9 MeV) type of electromagnetic wave. Gamma waves have no mass and travel even faster than alpha and beta radiation.

gamma-ray scintillation detector A gamma-ray detector consisting of a crystal, such as sodium iodide, thallium-activated, NaI(T1), and a photomultiplier tube housed in a light-tight container.

grappler An implement used to hold and manipulate objects from a distance.

Gray Gy The SI unit of absorbed radiation dose, one joule per kilogram.

hazardous materials response team (HAZMAT) An organized group of employees, designated by the employer, expected to handle and control actual or potential leaks or spills of hazardous substances requiring possible close approach to the substance.

hazardous substance Any substance designated by the following regulations: Sections 101(14) and 101(33) of CERCLA; 49 CFR 1172.101.

hazardous waste A waste or combination of wastes as defined in 40 CFR 171.6.

hazardous waste operation Any operation conducted within the scope of 40 CFR 261.3 or 40 CFR 171.6.

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health hazard A chemical, mixture of chemicals, or pathogen for which there is statistically significant evidence based on at least one scientific study that acute or chronic health effects may occur in exposed individuals.

health physics The science of radiation protection.

hot line The outer boundary of a site's exclusion zone.

health physics The science of radiation protection

immediately dangerous to life or health (IDLH) The maximum concentration from which one could escape within 30 minutes without any escape-impairing symptoms or any irreversible health effects.

incompatible Incapable of being combined without a dangerous effect (e.g., descriptive of two or more substances that produce an unfavorable chemical reaction if they come in contact).

injection The introduction of chemicals into the body through puncture wounds.

ionizing radiation High-energy radiation that causes irradiated substances to form ions, which are electrically charged particles.

LC_{50} Abbreviation for the median lethal concentration of a substances that will kill 50% of the animals exposed to that concentration.

LD_{50} Abbreviation for the median lethal dose of a substance that will kill 50% of the animals exposed to that dose.

manifest A list of cargo.

mixed waste Hazardous chemical waste that is also radioactive.

monitor, radiation A radiation detector the purpose of which is to measure the level of ionizing radiation (or quantity of radioactive material). It may also give quantitative information on dose or dose rate. The term is frequently prefixed with a word indicating the purpose of the monitor such as an area monitor, or air particle monitor.

monitoring, radiation (radiation protection) The continuing collection and assessment of the pertinent information to determine the adequacy of radiation protection practices and to indicate potentially significant changes in conditions or protection performance.

neutron A non-charged particle in the center of the atom. Together with the proton it forms the nucleus.

occupational dose (regulatory) Dose (or dose equivalent) resulting from exposure of an individual to radiation in a restricted area or in the course of employment in which the individual's duties involve exposure to radiation (see 10 CFR 20.3).

open-circuit SCBA A self-contained breathing apparatus (SCBA) in which the user exhales air directly into the atmosphere.

overpack 1. An oversized drum into which a leaking drum can be placed and sealed. 2. To overpack such a drum.

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oxygen deficiency The concentration of oxygen by volume below which atmosphere-supplying respiratory equipment must be provided. It exists in atmospheres where the percentage of oxygen by volume is less than 19.5 percent.

palletize To place on a pallet or to transport or store by means of a pallet.

particulate Formed of separate, small, solid pieces.

penetration The chemical penetration of protective clothing through openings such as seams, buttonholes, zippers, or breathing air ports.

percutaneous Effected or performed through the skin, stored, disposed of, or placed. Does not include any consumer product in consumer use or any waterborne vessel.

permeation Seepage and sorption of a chemical through a material (e.g., the material making up protective clothing or equipment).

permissible exposure limit (PEL) The exposure, inhalation, or dermal permissible exposure limit specified in 29 CFR 1910, G and Z. The Osha standard for an 8 hour time-weighted average exposure allowable for a working lifetime without adverse health effect.

postemergency response That portion of an emergency response performed after the immediate threat of a release has been stabilized or eliminated and cleanup of the site has begun.

pressure-demand respirator A respiratory protection device that supplies air to the user and maintains a slight positive pressure in the face piece at all times. it supplies additional air in response to the negative pressure created by inhalation.

protection factor The ratio of the ambient concentration of an airborne substance to the concentration of the substance inside the respirator at the breathing zone of the wearer. The protection factor is a measure of the degree of protection the respirator offers.

published exposure limit (PEL) The recommended exposure limits published in *Recommendations of Occupational Health Standards* (NIOSH 1986).

qualified person A person with specific training, knowledge, and experience in the area for which he or she has the responsibility and the authority to control.

rad A former unit of absorbed dose 1 rad = 10^2 Gy = 10^2 J/kg [see Gray (Gy)]. Radiation energy in the form of electromagnetic waves.

radiation hazard A situation or condition that could result in deleterious effects attributable to deliberate, accidental, occupational, or natural exposure to radiation.

radiation protection All measures concerned with reducing deleterious effects of radiation to persons or materials (also called "radiological protection").

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radioactive material A material of which one or more constituents exhibit radioactivity. NOTE: For special purposes such as regulation, this term may be restricted to radioactive material with an activity or a specific activity greater than a specified value.

radioactive waste: Unwanted radioactive materials obtained in the processing of handling of radioactive materials

reagent A substance used in a chemical reaction to detect, measure, examine, or produce other substances.

redress area A section of the exclusion zone where decontaminated personnel put on clothing for use in the support zone.

rem A former unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, the distribution factor, and any other necessary modifying factors (originally derived from roentgen equivalent man).

restricted area Any area to which access is controlled for the protection of individuals from exposure to radiation and radioactive materials.

roentgen (R) - A unit of exposure: 1 R = 2.58 x 10^4 C/kg.

scintillation counter A counter in which the light flashes produced in a scintillation by ionizing radiation are converted into electrical pulses by a photomultiplier tube.

self-contained breathing apparatus (SCBA) A respiratory protection device that supplies clean air to the user from a compressed air source carried by the user.

sievert (Sv) The special name of the unit of dose equivalent. It is given numerically by 1 Sv = 1 J x kg- 1 (= 100 rein).

site safety supervisor (SSO) The individual located on a hazardous waste site who is responsible to the employer and has the authority and knowledge necessary to implement the site safety and health plan and verify compliance with applicable safety and health requirements.

small-quantity generator A generator of hazardous wastes that in any calendar month generates no more than 2205 pounds (1000 kilograms) of hazardous wastes.

sorbent material A substance that takes up other materials either by absorption or adsorption.

staging area An area in which items are arranged in some order.

standard operating procedure (SOP) Established or prescribed tactical or administrative method to be allowed routinely for the performance of a designated operation or in a designated situation.

Superfund A common name for the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980.

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supplied-air respirator A respiratory protection device that supplies air to the user from a source that is not worn by the user but is connected to the user by a hose. Also called an *air-line respirator.*

support zone The uncontaminated area of a site where workers will not be exposed to hazardous conditions.

surfactant A contamination agent that reduces adhesion forces between contaminants and the surfaces being cleaned.

swab A piece of cotton or gauze on the end of a slender stick used for obtaining a piece of tissue or secretion for bacteriologic examination.

swipe A patch of cloth or paper that is wiped over a surface and analyzed for the presence of a substance.

threshold The intensity or concentration below which a stimulus or substance produces a specified effect.

uncontrolled hazardous waste site An area where an accumulation of hazardous waste creates a threat to the health and safety of individuals, the environment, or both.

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EXAMPLE

SITE HEALTH AND SAFETY PLAN

FOR

(name) HAZARDOUS WASTE SITE

(location)

CONTRACT #_____

NATIONAL PRIORITY LIST #_____

Submitted to:

_____
_____
_____

Prepared by:

_____
_____
_____

Date: _____

Revisions: _____

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Appendix F
INDUSTRIAL SITE HEALTH AND SAFETY PLAN

GENERAL

The following document specifies the health and safety requirements to be enforced during the performance of the work described in the Remediation Workplan proposed by Priester & Associates, Inc. (P&A) for the former creosote operation located at the Darlington Prison Farm facility, Darlington, South Carolina. General site specifications are as follows:

Site:	Darlington County, Prison Farm
Location:	Darlington South Carolina
Region:	EPA Region 4
SCDHEC Contact:	Phone # 555-5200
Objective:	Modified in-situ, bioremediation of contaminated soils, and testing of contaminated soils and groundwater. Excavation and stockpiling of soils will be required. Pumping and containment of potentially contaminated groundwater will be required.
Proposed start date:	November 1994

Facility Description: The former facility was located on an active prison. Inmates used a metal lined pit formerly filled with creosote to preserve wood. The site has been inactive since 1984. The former pit and it's contents were removed during previous cleanup activities. The only source of contamination is the presently contaminated soil and groundwater. The contaminated groundwater remains below ground, and has not reached the hydrologic short circuit, a slow moving creek bounding the southern perimeter of the subject site.

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APPLICABLE REQUIREMENTS

The publications listed below form a part of this specification to the extent referenced. The publications are referenced in this text by the basic designation only.

A. Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities, US Department of Health and Human Services, October, 1985.

B. Environmental Protection Agency (EPA), Standard Operating Safety Guidelines, Office of Emergency and Remedial Response, Hazardous Response Support Division, November, 1985.

C. US Army Corps of Engineers Safety and Health Requirements, EM 385-1-1, October, 1987.

D. American National Standards Institute (ANSI), American National Standard Practices for Respiratory Protection, 1980.

PUBLIC SAFETY

Priester & Associates shall provide temporary fencing, barricades, caution tape and/or guards, as required, to provide protection in the interest of public safety. Whenever P&A's operations create a condition hazardous to the public, they shall furnish at their own expense and without cost, such flagmen and guards as are necessary to give adequate warning to the public of any dangerous conditions to be encountered and shall furnish, erect, or maintain such fences, barricades, lights, signs and other devices as are necessary to prevent accidents and avoid damage or injury to the public.

WORK SITE SAFETY

Priester & Associates shall perform whatever work is necessary for safety conditions on the job site. These requirements do not supersede, but are in addition to any applicable federal, OSHA, state, or local regulations. If a conflict occurs between these requirements and current regulations, the more stringent shall apply.

Priester & Associates shall at all times provide proper facilities for safe access to the work by authorized personnel. It shall be the responsibility of

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P&A to be familiar with the required health and safety regulations in the performance of this work.

SITE HEALTH AND SAFETY OFFICER

Priester & Associates shall provide a Site Health and Safety Manager (SHSM) whose responsibility will be to implement, monitor, and enforce the Site Health and Safety Plan. The SHSM shall have working experience in the chemical industry and/or chemical waste remediation industry and shall have a sound working knowledge of federal and state occupational safety and health regulations and have formal educational training in occupational safety and health policies and techniques (40 hour OSHA plus 8 hour supervisors training, at a minimum).

The SHSM may implement requirements in addition to those specified herein and shall be included as necessary in the Appendix entitled "ADDITIONAL SITE-SPECIFIC HEALTH AND SAFETY INFORMATION".

Should any unforeseen or site-specific safety related factor, hazard, or condition become evident during the Performance of the work, P&A shall take immediate and prudent action to establish and maintain safe working conditions and to safeguard site personnel, the public and the environment. P&A shall also inform the contracting officer of such a condition within 24 hours or sooner.

HAZARD ASSESSMENT

Current Use Scenario

Darlington County operates an active prison on the site. However, the area of the site which is affected by creosote contamination is outside the prison fence. Consequently, while the inmates are confined, there is little chance of exposure to the creosote constituents. On those occasions when the few inmates at the facility are outdoors, potential exposures will be limited by the use of water mist sprayed over any ongoing excavation or stockpiling operations.

The formally excavated pit is roped off and marked with warning signs. Piles of firewood and an equipment shed are located to the south of the formally excavated pit. Some additional surficial contamination has been identified to the north and west of the shed, and the plume passes beneath this area. The Remediation and interception operations will require the use of some of the area currently covered by the wood pile. The shed and the wood piles

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will be removed from this area to reduce the potential for accidental exposure and provide space for upcoming operations.

After the wood piles and the shed have been removed, a remediation exclusion area will be roped off and flagged. Only people who have received the required training will be allowed within this exclusion area.

The creosote related constituents that have been detected at levels high enough to be a concern are polycyclic aromatic hydrocarbons (PAHs). PAH compounds are generally semi-volatile, have a low vapor pressure, and low solubility in water.

The following list of constituents summarizes the highest concentrations detected in any sample from the affected area. These are the "worst case" maximum values and are not representative of the contaminant levels present in most of the contaminated area.

The toxicity of individual PAHs is generally not well characterized. Many PAHs are carcinogenic or are potentially carcinogenic. The following list of PAHs detected in the soils and groundwater at the prison farm creosote pit in the concentrations shown. These substances are classified as potentially carcinogenic:

Substance	**Concentration (ppm)**
Benzo (a) anthracene	200.000
Benzo (b) fluoranthene	20.000
Benzo (k) fluoranthene	100.000
Chrysene	180.000
Dibenzo(a,h) anthracene	.....
Indeno (1,2,3-cd) pyrene	61.000
Benzo (a) pyrene; and	45.000
Carbazole	

There is evidence of potential carcinogenicity in animals for all the above compounds. There are no data that specifically link exposure to chrysene with human cancer; however, there are sufficient data to link exposure to chrysene to animal cancer. Toxicological data are limited for most PAHs except benzo(a) pyrene (BaP). No data could be found concerning studies on the potential effects of human exposure to individual PAHs, therefore these compounds are grouped for risk characterization.

Noncarcinogenic PAHs detected on the site include the following:

Substance	**Concentration (ppm)**
Acenaphthene	590.000
Acenaphthylene	98.000

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Anthracene	220.000
Benzo (g,h,i) perylene	.....
Dibenzofuran	0.460
Fluoranthene	1100.000
Fluorene	770.000
2-Methylnaphthalene	0.420
Naphthalene	2000.000
Phenanthrene	2300.000
Pyrene	880.000

Phenols and Chrysene are primarily contact hazards which affect the internal organs, especially the kidneys, liver, and gastro-intestinal systems. Cresols affect mainly the CNS and the respiratory system. Mist, dust, and/or fumes increase the respiratory hazards associated with these chemicals.

Additional Known Substances	**Concentration (ppm)**
Benzo (a) Pyrene	45.000
2,4-Dimethyl pheno	0.048
n-Propyl acetate	18.000
Acetone	0.960
Benzene	1.100
2-butanone	0.790
Isopropano	132.000
Toluene	0.120
Xylenes (total)	0.310

PERSONNEL PROTECTION PROGRAM

General

Priester & Associates shall establish and maintain a complete Personnel Protection Program for all personnel working on treatment of potentially hazardous waste at the subject site.

Priester & Associates shall be required to certify that all contractor, subcontractor, or service personnel entering the exclusion zone (Zone 1) or contaminant reduction zone (Zone 2), as defined hereinafter, for the purpose of performing or supervising the removal of potentially hazardous waste; for health, safety, security, or administrative purposes; for maintenance; or for any other function have met the training requirements specified by OSHA (29 CFR

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Part 1910.120 [e]). A valid, up-to-date Certificate of Training is acceptable documentation.

Priester & Associates shall be responsible for, and guarantee that, P&A's and subcontractor's personnel and all visitors who have not successfully completed the required training in accordance with 29 CFR 1910.120, are not permitted to enter Zones 1 and 2 for any reason during any contractor activities. P&A shall provide and require that all previously trained contractor, subcontractor, or service personnel assigned to or entering Zones 1 and 2 are capable of and familiar with the use of safety, health, and respiratory protective equipment, and with the safety and security procedures required for this operation.

Work Areas: For all field activities P&A shall organize the site into work areas. These work areas include but are not limited to the following areas:

Zone 1: The Exclusion Zone

The exclusion zone (Zone 1) is the zone where contamination does or could occur. All people entering the exclusion zone shall wear prescribed levels of protection. An entry and exit check point may be established at the periphery (hot line) of the exclusion zone to regulate the flow of personnel and equipment into and out of the zone and to verify that the procedures established to enter and exit are followed.

Zone 2: The Contamination Reduction Zone

The contamination reduction zone is the zone between the exclusion zone and the support zone, which provides a transition between contaminated and clean zones. Zone 2 serves as a buffer to further reduce the probability of the clean or support zone becoming contaminated or being affected by other existing hazards. It provides additional insurance that the physical transfer of contamination substances on people, equipment, or in the air is limited through a combination of decontamination, distance between exclusion zone and the support zone, air dilution, zone restrictions, and work functions.

At the boundary between the exclusion and contamination reduction zones, decontamination station(s) may be established, for personnel, small equipment and heavy equipment. A contamination reduction corridor through the contamination reduction zone may be established if the SHSM considers it to be warranted.

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Zone 3: The Support Zone

A support Zone is defined as being an area outside the zone of significant contamination. support zone shall be clearly delineated and shall be secured against active or passive contamination from the work site. The function of the area may include:

A. An entry area for personnel, material, and equipment to the area of removal operations.
B. An exit area for decontaminated personnel, materials, and equipment from the area of removal operations.
C. The housing of site services.
D. A storage area for clean safety and work equipment.

MEDICAL MONITORING

Priester & Associates shall utilize the services of licensed medical support to provide medical needs and examinations. The name of the physician and evidence of examination of on-onsite personnel shall be available as necessary and provided from contractor's headquaters location.

All on-site personnel involved in this project shall be provided with medical surveillance in accordance with 29 CFR 1910.120, and all other applicable state and federal laws and regulations. Medical monitoring shall be provided before the onset of work, at the conclusion of the project, and at any time there is suspected excessive exposure to toxic chemicals or physical agents.

Priester & Associates shall maintain all medical records.

RESPIRATORY PROGRAM

All personnel wearing an air-purifying respirator or air-supplied respirator, such as self-contained breathing apparatus (SCBA), as required by the SHSM, shall be fit-tested and properly trained and experienced in their use. All respiratory protection equipment shall be properly decontaminated and sanitized at the end of each workday. Other respiratory requirements shall be in accordance with EM 385-t-1, OSHA, and ANSI published standards.

INITIAL ON-SITE TRAINING

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Priester & Associates shall provide site-specific training to all on-site employees as specified by the SHSM in his Site Health and Safety Plan. This site-specific training will include the following items:

A. Names of personnel and alternatives responsible for site safety and health.
B. Safety, health, and other hazards present on-site.
C. Proper use of personnel protective equipment.
D. Work practices by which the employee can minimize risks from hazards.
E. Safe use of engineering-controls and equipment on the site.
F. Medical surveillance requirements including the recognition of symptoms and signs which may indicate overexposure to hazards.
G. The contents of the health and safety plan (e.g., air monitoring procedures, site control measures, emergency response plan, confined space entry procedures, etc.)

MONITORING PROCEDURES

The perimeter for the site has been identified as well as the zone of contamination (see attached site map). During excavation and sampling operations, monitoring of the breathing zone will be accomplished with Organic Vapor Analyzers, and Draeger tubes.

Based on the current site assessment, the relevant TLV/TWA are: Cresol (all isomers) - NIOSH 2.3 ppm (10mg/m^3), OSHA 5 ppm (22 mg/m^3-skin), IDLH 250 ppm

Phenol - NIOSH 5ppm (19 mg/m^3), C 15.8 ppm (60 mg/m^3 - 15 min.-skin), OSHA 5 ppm

Chrysene - ACGIH sets no numerical limits but simply lists chrysene as a suspected human carcinogen. A SCBA should be used for any exposure level.

Medical surveillance procedures for evidence of personal exposure:

Look for dizziness, tremors, excitement, vomiting, nausea, abdominal pain, incoherence, convulsions, and dermatitis, or unconsciousness.

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EMERGENCY AND FIRST AID REQUIREMENTS

Priester & Associates shall prearrange for emergency medical care services at a nearby medical facility and establish emergency routes. P&A shall establish communication links with health and emergency services to inform them of any emergency situations that may arise.

In the event of any emergency associated with or resulting from work at this site, P&A shall without delay cease work activity on the site, take diligent action to remove or otherwise minimize the cause of the emergency, render full assistance to local authorities to remedy any impact on local residents or property, and institute whatever measures are necessary to prevent any repetition of the conditions or actions leading to or resulting in the emergency.

Priester & Associates shall have at least one person skilled in First Aid on site at all times. This person may perform other duties, but must be immediately available to render first aid when needed.

At least one "industrial" first aid kit shall be contractor provided and maintained fully stocked at a manned location at or near each work area. First aid kit locations shall be specially marked and provided with supplies necessary to cleanse and decontaminate burns, wounds, or lesions.

PERSONNEL HYGIENE DURING OPERATIONS

Priester & Associates shall be responsible for, and ensure that all visitors, contractor, subcontractor, and service personnel performing or supervising remedial work within the exclusion zone (Zone 1) or contaminant reduction zones (Zone 2), or exposed or subject to exposure to hazardous chemical vapors, liquids, or contaminated solids, observe and adhere to the personal hygiene-related provisions of this section, the EPA Standard Operating Safety Guides, and all Federal and OSHA regulations and guidance.

Contractor, subcontractor, service personnel, and visitors found not to be following the protocols for the personal hygiene-related provisions of this section and all Federal, OSHA and EPA regulations and guidance will, be barred from the site.

Smoking, chewing, eating, and drinking shall be prohibited in Zones 1 and 2. Soiled disposable outerwear shall be removed before leaving Zone 2 to enter Zone 3, and before cleansing hands. Contractor, subcontractor, and service personnel shall be required to thoroughly cleanse their hands and other exposed areas before entering the lunch area.

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PERSONNEL PROTECTION EQUIPMENT

Priester & Associates shall be required to establish the level of personnel protection necessary to safely execute the work in this site health and safety plan. At present, the minimum requirements for personnel protection are: Poly-tyvec clothing, hard-hats, steel toe boots, and full face respirators, with hepa organic filter cartridges, if results from monitoring prove necessary.

P&A shall ensure that all safety equipment and protective clothing is kept clean and well maintained. All personnel protective equipment shall be decontaminated at the end of the workday. P&A, as part of this site health and safety plan, shall maintain, at his office or other well established place at the job site, safety equipment applicable to the work as prescribed by the governing safety authorities, all articles necessary for giving first aid to the injured, and shall establish the procedure for the immediate removal to a hospital or a doctor's care of any person who may be injured on the job site.

Priester & Associates shall provide a minimum level of personnel protection of level "D", including all of the following in compliance with an approved Site Health and Safety Plan:

Suitable disposable outerwear, gloves, hard-hats, and footwear on a daily basis for the use of on-site personnel.

Appropriate MSHA/NIOSH certified respirators, if required, in sufficient quantities for on-site personnel.

Contained storage and disposal for used disposable outerwear.

Handwashing facilities: a facility for changing into and out of and storing work clothing, separate from street clothing.

A lunch and/or break area that will be well separated from Zones 1 and 2.

Used disposable outerwear, shall be placed inside disposal containers provided for that purpose. P&A is responsible for their proper transport and disposal off-site.

Should any unforeseen or site-specific safety related factor, hazard or condition become evident during the performance of the work, P&A shall take immediate and prudent action to establish and maintain safe working conditions and to safeguard site personnel, the public, and the environment.

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The performance of all work and all completed remediation, particularly with respect to ladders, platforms, structure openings, scaffolding, shoring, sloping, lagging, machinery guards, and all other safety equipment shall be in accordance with the applicable governing safety authorities.

In addition to the above, P&A shall take steps to ensure that:

A. Safety equipment is available for contractor personnel and is properly maintained.
B. Use of protective equipment and clothing by personnel entering the site is enforced.

C. Communication with all team members, the contracting officer, and other personnel regarding safety matters is maintained.

D. Corrective actions are implemented in the event of an emergency or unsafe conditions as instructed in the event of an emergency or unsafe conditions as instructed by the site safety coordinator.

PERSONNEL DECONTAMINATION

Personnel exiting Zone 1 must be thoroughly decontaminated before entering Zone 3. Decontamination activities will be restricted to the contamination reduction corridor (CRC) located in the contamination reduction zone (zone2). The length of the CRC and the extent of decontamination will be established by the Site Manager.

Personnel engaged in decontamination work shall wear the proper protective equipment designated for this activity. Personnel entering and exiting Zone 2 will be controlled by the Site Health and Safety Manager.

Decontamination fluids will be collected by P&A and stored on site until it is determined if they are contaminated.

EQUIPMENT DECONTAMINATION

Priester & Associates may provide an equipment decontamination station within the contamination reduction zone for removing contaminants from all vehicles and equipment leaving the work area. Washwater and other decontamination fluids shall be collected and stored until it is determined if they are contaminated. Personnel engaged in vehicle decontamination may wear protective equipment including disposable clothing and respiratory protection as determined by the Site Manager. Any item taken into the Exclusion Zone

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must be assumed to be contaminated and must be decontaminated before the item leaves the area.

AIR MONITORING

During the progress of the work, P&A shall periodically monitor the quality of the air in and around each active work location. Monitoring shall be conducted on a regular periodic basis, and additionally as required by special or work-related conditions. Any departures from general background shall be entered in the monitoring and project logs and reported through contractor's channel of communications.

Air monitoring equipment shall be calibrated daily for expected contaminants, and shall be operated by personnel trained in the use of the specific equipment provided. P&A shall maintain a log of the location, time, type, and value of each reading, including calibration reading. Copies of log sheet shall be included in the site report.

FIRE PREVENTION AND PROTECTION

Priester & Associates shall perform all work in a fire-safe manner and shall supply and maintain at each work area adequate fire-fighting equipment capable of extinguishing incipient fires. This equipment shall include, at a minimum, 20-pound ABC type dry chemical fire extinguishers at the Support and exclusion zones. P&A shall comply with all applicable federal, local, and state fire-prevention regulations.

OCCUPATIONAL SAFETY AND HEALTH ACT (OSHA) STANDARDS

The OSHA standards for Construction (Title 29, Code of Federal Regulations Part 1926 as revised from time to time) are applicable to this project.

ADDITIONAL SITE SPECIFIC HEALTH & SAFETY INFORMATION:

PERSONNEL EXPOSURE

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Skin Contact: Wash immediately, look for symptoms of exposure. Seek medical attention if necessary.

Inhalation: Artificial respiration if breathing stops, seek medical attention immediately. (There are no confined spaces on this site.)

Ingestion: Seek medical attention immediately, Do Not induce vomiting

POTENTIAL OR ACTUAL FIRE OR EXPOSURE:

Call Fire Department - Phone # 393-1111

Call Police - Phone # 398-4335

PERSONNEL INJURY:

Call Ambulance/Hospital - Phone # 398-4440

EMERGENCY NUMBERS:

Emergency System	911
Ambulance	398-4440
Fire Department	393-1111
Hospital Emergency Room	395-1155
Hospital General Info.	395-1100
Poison Control Center	765-7359
Police	398-4335
State Contact: (DHEC)	(803) 555-4335

Drilling: Overhead and underground utilities- call 1-800-922-0983 to locate underground cables. Heat generated during drilling may cause hazardous

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vapors to be released; Dust generated during drilling may be particulate hazard.

EMERGENCY CONTACTS:

Lawrence Stegner - Darlington County - 555-1111

Dr. Lamar Priester - Priester and Associates - 555-1112

Darlington County Emergency Management - 555-1113

Personnel assigned to handle materials (decontaminate, analyze samples, etc..)

Personnel Assignment

Dr. Lamar Priester	Project Director QA/QC
Kay Loyd	Professional Engineer
John Newman	Project Manager
Clyde Livingston	Professional Geologist

SITE ENTRY PROCEDURES

All personnel will receive clearance from Priester & Associates personnel prior to entering the zone of contamination. All unauthorized personnel will remain outside the zone of contamination. Any personnel entering the zone of contamination will:

1. Have current training per 29 CFR 1910.120
2. Have current medical surveillance per 29 CFR 1910.120
3. Will be outfitted in a minimum level of protective clothing as indicated by Priester & Associates personnel.

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EMERGENCY ROUTES

Darlington County EMS: One block at end of street on left.
Hospital: Highway 151/34 to Darlington. Follow Highway to Wilson Hospital once within the city limits.

REQUIRED FORMS

The forms required for reporting information regarding safety meetings, incidents, transgress and egress from the site, etc., are given in the following section.

DATE:

TIME:

INCIDENT LOCATION:

INCIDENT TYPE:

INCIDENT COMMANDER:

SAFETY OFFICER:

SAFETY PLAN

DESCRIPTION OF HAZARDS ANTICIPATED: (USE D.E.C.I.D.E., DECISION MAKING MODEL., DETECT, ESTIMATE, CHOOSE, IDENTIFY, DO BEST EVALUATE)

CURRENT WEATHER CONDITIONS:

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ANTICIPATED WEATHER CHANGES: (INDICATE TIMES IF AVAILABLE)

STEPS TO CONTROL INCIDENT:

DECRIBE LIKELY OUTCOMES

HOT ZONE:

CONTROL ZONE:

EXCLUISION ZONE:

COMMAND CENTER:

SITUATIONS WHICH WOULD CAUSE RE-EVALUATION OF THE ABOVE ZONES

EQUIPMENT CURRENTLY ON SITE:

EQUIPMENT TO BE BROUGHT ON SITE:

SAFETY MEETING TO ADDRESS:

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INITIAL MONITORING REQUIREMENTS:

WILL HEAT/COLD STRESS MONITORING BE REQUIRED:

EMERGENCY PROCEDURES:

ON-SITE MEDICAL PERSONNEL/FACILITIES:

LOCATION OF CLOSEST MEDICAL FACILITY:

EMERGENCY PHONE NUMBERS:

AGENCIES TO NOTIFY:

AGENCIES TO NOTIFY:

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SAFETY MEETING FORM

DATE: _____ **INCIDENT:** _____ **LOCATION:** _____
TIME: _____
ITEMS DISCUSSED: _____
_____
_____
_____

CONTRACTOR: _____
EMPLOYEES:

	PRINT NAME	SSN	SIGN NAME
1.			
2.			
3.			
4.			
5.			

CONTRACTOR: _____
EMPLOYEES:

	PRINT NAME	SSN	SIGN NAME
1.			
2.			
3.			
4.			
5.			

CONTRACTOR: _____
EMPLOYEES:

	PRINT NAME	SSN	SIGN NAME
1.			
2.			
3.			
4.			
5.			

CONTRACTOR: _____
EMPLOYEES:

	PRINT NAME	SSN	SIGN NAME
1.			
2.			
3.			
4.			
5.			

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INCIDENT AIR MONITORING FORM

DATE: _____ **INCIDENT:** _____ **LOCATION:**_____
TIME: _____

INCIDENT DEBRIEFING FORM

INCIDENT LOCATION:_____ **DATE:** _____
INCIDENT TYPE: _____ **TIME:** _____
INCIDENT COMMANDER: _____ _____
SAFETY OFFICER: _____

SITE PLAN

DATE: _____ **INCIDENT:** _____ **LOCATION:**_____
TIME: _____

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TRAINING MEETING FORM

DATE: _____ **INCIDENT:** _____ **LOCATION:** _____
TIME: _____

TRAINING CONDUCTED: _____
_____
_____

CONTRACTOR: _____
EMPLOYEES:

	PRINT NAME	SSN	SIGN NAME
1.			
2.			
3.			
4.			
5.			

CONTRACTOR: _____
EMPLOYEES:

	PRINT NAME	SSN	SIGN NAME
1.			
2.			
3.			
4.			
5.			

CONTRACTOR: _____
EMPLOYEES:

	PRINT NAME	SSN	SIGN NAME
1.			
2.			
3.			
4.			
5.			

CONTRACTOR: _____
EMPLOYEES:

	PRINT NAME	SSN	SIGN NAME
1.			
2.			
3.			
4.			
5.			

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INCIDENT TIME LOG

INCIDENT LOCATION:_____ **DATE:** _____

INCIDENT TYPE: _____ **TIME:** _____

TIME OF ARRIVAL: _____

TIME OF INITIAL SAFETY MEETING: _____

SAFETY TOPICS DISCUSSED: _____

_____

TIME WORK INITIATED: _____

TIME WORK COMPLETED: _____

TRAINING

RESPIRATORY: _____
SPECIFY TYPE

PERSONAL PROTECTIVE EQUIPMENT: _____
SPECIFY TYPE

ADDITIONAL SAFETY MEETINGS:

(1) DATE: _____ **TIME:** _____ **TOPICS(s):**_____

_____

(2) DATE: _____ **TIME:** _____ **TOPICS(s):**_____

_____

(3) DATE: _____ **TIME:** _____ **TOPICS(s):**_____

_____

(4) DATE: _____ **TIME:** _____ **TOPICS(s):**_____

_____

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Appendix G
HAZARDOUS WASTE MANAGEMENT OF DOE SITES

Michael Gochfeld M.D., Ph.D.

World War II, the Manhattan Project, beating Germany to "the Bomb" and National Security provide the historic foundation for the application of large-scale industrialization to the development of nuclear weaponry in the early 1940's and subsequently [Sanger, 1995]. Cloaked in secrecy, bomb development proceeded first at Chicago, Oak Ridge, Richland, and Los Alamos, culminating in the mid-1945 bombing of Hiroshima and Nagasaki. The subsequent expansion of nuclear weapon development, production, and testing in the late 1940's and 1950's, to meet the perceived needs of the Cold War, resulted in one of the World's largest industrial complexes, which in one way or another occupied hundreds of sites in dozens of states, with sixteen major and many minor industrial facilities, research laboratories, and mining and milling entities, which are today referred to simply as "The complex". The Atomic Energy commission (AEC) formed in 1946 was divided into the Energy Research and Development Administration (ERDA) and the Nuclear Regulatory Commission (NRC) in 1974. In 1977 ERDA responsibilities were transferred to the newly formed Department of Energy (DoE) [DoE, 1995].

Impelled by national security and a sense of urgency, and veiled by secrecy, the contractors who operated these sites for the AEC and its successors, disposed of untold quantities of hazardous materials, in a variety of ways, many of them suboptimal. Large quantities of radioactivity were released into air and water, and huge quantities are still stored on sites or remain in the ground or groundwater. Many of the lagoons, tanks, and containers were designed only for temporary storage, and in retrospect, the risks of storing radionuclides with very long half-lives in containers with relatively short ones, should have been foreseen [DoE, 1994].

Prior to 1990, public understanding of nuclear waste management had focused on spent nuclear fuel from commercial reactors (high level) and on medical and laboratory waste (generally low level) - although the magnitude of AEC/DoE wastes was not widely known, DoE was already involved in waste management at least by the mid-1970's, when plans for the Waste Isolation Pilot Plant (WIPP) were begun [Holden, 1984]. In 1983 the Defense Waste Processing Plant for vitrification of high level waste was begun at Savannah River.

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In 1989, with the Cold War winding down, and the Federal Bureau of Investigation raid on operations at the Rocky Flats Plant outside of Denver, still fresh, the production of nuclear weaponry came to a halt throughout the Complex. The production and separation of plutonium, and the fabrication of reactor fuel, stopped, often overnight, leaving many recently operating industrial facilities not designed for storage, highly contaminated.

At this point in late 1989 the Department of Energy began switching its mission from the development and production of nuclear weapons to the development and implementation of remediation technologies on the weapons Complex. DoE created an Office of Environmental Restoration and Waste Management (EM) which was empowered to carry out a mission whose magnitude had not yet been assessed.

By the early 1990's the magnitude of hazardous waste on the DoE sites was becoming apparent, and the first impressions of the funds needed to adequately control current and remove future hazards, was sometimes projected to exceed a trillion dollars. Subsequent estimates place the hazardous waste cleanup bill more modestly at between $100 and $400 billion dollars to be spent over up to 70 years, and the current annual budget is approximately $6 billion. Much of this budget is dedicated to maintaining current storage to prevent leaks or criticality events while awaiting definitive "cleanup" technology and disposal sites [DoE, 1998].

DoE lifted its historic veil of secrecy with a vengeance, and a large number of publications, mostly in the "grey literature" appeared describing the need for environmental remediation as well as the plans to accomplish this daunting task. The Waste Management: Programmatic Environmental Impact Statement, a multivolume work, details many of the problems on a site-by-site basis.

In a 1994 report to congress [O'Toole, 1994] DoE's Assistant Secretary for Environment, Safety, and Health, Tara O'Toole described aging buildings, containers not intended for long-term storage and materials loose in the environment with unknown locations and quantity. She reported that the "Weapon complex may pose more danger to workers and the public than it did during peak nuclear weapons production". Cleanup was identified as an "enormous task" even before restoration of polluted environments could be accomplished. In many cases the blueprints for buildings and the location of wastes remain undocumented, and the institutional memory for how things had been done or where they had been buried, was fast disappearing as site employees retired or died.

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CHALLENGES FACING DOE

The huge, far-flung industrial complex with its history of long-abandoned and perhaps forgotten processes and wastes, and changing administrative and funding climate, faces many challenges. The magnitude of the waste and the costs entailed in remediating them, will require new approaches to assessing risks, establishing priorities, implementing new technologies, and new social approaches to making value decisions and tradeoffs that will impact hazardous waste management at lesser sites elsewhere. The number of workers who will be involved in the cleanup and restoration is enormous, and cleanup is being managed on a site-by-site basis, which makes protecting these workers even more difficult.

We can categorize the DoE challenge by the number and locations of sites, the administrative responsibility (Waste Management, Environmental Restoration, Facilities Management), and the types of hazards. At each site, there may be many subsites and for each subsite there may be several projects required to deal with different wastes. Moreover, the available technology, budget, and expertise will change over time.

What makes this especially challenging is that each of the dozens of sites has different hazards in varying amounts, with different storage conditions, coupled with different levels of experience and expertise in managing toxic wastes. In many cases the technologies to definitively manage some wastes do not yet exist, and DoE is pioneering their development.

Number of DoE Sites: Estimates vary, but DoE's Environmental Management Program created in 1989, now has responsibility for at least 135 sites in 37 states. Even that number is misleading for the huge sites such as Nevada Test Site (1350 sq mi), Idaho National Engineering and Environmental Laboratory (INEEL 890 sq mi), Hanford (560 sq.mi), Savannah River (310 sq.mi), and Oak Ridge each have many discrete facilities, basins, tank fields, and contaminated areas that are as large or larger than most non-DoE hazardous waste sites on the National Priorities (NPL or "Superfund" list) [DoE, 1995]. Although some of these large sites were chosen for their remoteness, others such as Rocky Flats (16 mi from Denver) and Fernald (18 mi from Cincinnati) are close to major urban centers.

The number of sites varies as some are cleaned up completely and others are transferred from energy production to environmental management. More than half of the sites are Uranium Mill Tailings Remedial Action Projects (UMTRA) and Formerly Utilized Sites in the Remedial Action Program (FUSRAP) . Some of the latter sites are small and came to attention only when faced with development. For example, construction of a Jersey City, NJ, shopping center on the site of the World War II Kellex Industries uranium processing site, was delayed for weeks pending discussions of who would

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actually collect and transport the 100 barrels of radioactive soil. [Pensack, 1979].

Magnitude of Hazardous Waste: DoE estimates that a million cubic meters of radioactive waste with very long half-lives must be managed and maintained safely until permanent storage becomes available. Indeed, more than half of the "clean-up" budget actually involves in situ waste management and stabilization . This has been likened to payments on a mortgage, where most of the monthly check pays interest, and the principle is reduced only slowly. It may be unrealistic or impossible to completely reduce the "principle." In large measure, long-term cleanup is contingent on the availability of interim and permanent, subterranean storage, now being explored respectively at Yucca Mountain, NV and at the Waste Isolation Pilot Plant (WIPP) in New Mexico. Both sites face political opposition in their respective states. Thus much of the waste currently being cleaned up is being stored temporarily (or perhaps a better term is Semi-permanently) on the sites of origin. Indeed, the containers of vitrified material from the Defense Waste Processing or vitrification plant at SRS, originally destined for WIPP are now being stored at SRS.

DoE also is responsible for over 7000 contaminated buildings which must be stabilized, monitored and then decontaminated, decommissioned and dismantled. In addition to the chemical and radioactive hazards they contain, there is abundant asbestos in the walls, lead in the piping, and mercury in electric switches. Workers encounter unsuspected drums or tanks with unidentified chemicals including solvents and acids. All of this must be managed as hazardous waste as well. Ultimately whether and when this vast remediation challenge is completed depends on a National dialogue regarding acceptable levels of residual risk balanced against cleanup cost to the nation and future land uses for the sites.

HAZARDS TO WORKERS

The Hazards facing remediation workers at DoE sites can be categorized by the media in which they occur, and by their type: radioactive, chemical, biological, physical, and psychosocial Most attention has focused on the first two of these. In addition, the hazards can be understood in terms of: a) the categories of hazards, b) the media in which wastes occur, c) the organization of work. DoE divides its environmental management efforts into the following categories [DoE, 1994]: Nuclear Materials/Facilities Stabilization (NMFS), Waste Management (WM), and Environmental Restoration (ER).

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CONTAMINATED MEDIA

Hazardous materials may be present in air, soil, water, and artificial structures and may expose humans directly through ingestion, inhalation, or dermal contact, or indirectly through food chain contamination. At DoE sites chemicals and radionuclides are found in:

1. Contaminated soils;
2. Surface water and sediments;
3. Groundwater;
4. Loose contamination on the surface, subsurface, or on structures, may become airborne;
5. In tanks, drums, or containers of liquids and solids either indoors or outdoors and below or above the ground;
6. In equipment or system components;
7. In sealed or unsealed sources;
8. In areas near nuclear reactors including cooling waters;
9. As fissile materials; and
10. As materials such as targets and warheads waiting to be dismantled.

Soil and groundwater contamination by radionuclides, metals, and/or solvents occurs at many of the major DoE sites. However, some of the most serious problems are posed by contamination occurring within structures. These materials may be loose, in bags, drums, boxes, glove boxes, pails, or in tanks or process containers. In some cases the integrity of the buildings is in question. Many of the large storage vessels, including drums, and above or below ground tanks, are compromised or actually leaking. Many have outlived their intended lifespan. Maintenance activities are designed to repair them and prevent leakage. Great care must be taken in handling such materials. In hazard analyses, some of the most serious scenarios involve fires or explosions in contaminated structures or containers.

CATEGORIES OF HAZARDS RADIOACTIVE WASTE

The main categories of waste are:

1. High level liquid or sludge wastes (HLW): results from reprocessing spent nuclear fuel or fuel targets. It is liquid to begin with and is usually converted to solid form for permanent storage; mostly vitrified and stored in stainless steel cylinders under ground. Much of this waste is potentially

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explosive, and is stored in over 200 underground tanks holding about 100 million gallons.

2. Transuranic wastes (TRUW): Contains more than 100 nanocuries per gram of alpha-emitting transuranic isotopes (radioactive elements with a molecular weight greater than uranium) with half lives greater than 20 years. Treated by volume reduction.
3. Low-level radioactive waste (LLW): defined by the absence of high-level waste (HLW) or transuranic waste (TRUW). It is treated by compaction, and by allowing short-lived isotopes to decay
4. Low-level mixed wastes (LLMW): contain both chemical or hazardous wastes and radioactive contaminants derived from processing of nuclear materials and from energy research. There are approximately 82,000 m3 of LLMW identified, and additional amounts are being generated. Solidification and incineration are commonly used, but new technologies are needed

The following table, G-1 includes waste that will be generated over the next 20 years but does not include waste that will be generated over the next 20 years but does not include waste that will be generated during restoration process. Source: U.S. Department of Energy Programmatic Environmental Impact Statement [1994].

Table G-1

Estimated amounts of wastes on the DoE complex

	Current m^3	Future m^3
Low-level mixed waste	82,000	144,000
Low-level waste	114,000	1,370,000
High-level waste	399,000[a]	----------
Hazardous waste	----------	69,000

[a]An additional 29,000 HLW canisters are predicted from treatment process.

LLMW and LLW can be further categorized as non-alpha or alpha wastes, depending on whether there is less than or greater than 10 nanocuries (nCi) of alpha radiation per gram. LLMN, LLW, and TRUW with a surface dose rate of more than 200 mrem/hour are defined as "remote-handled" and require special shielding and remote-handling equipment. Lower level material, defined as "contact-handled", requires less protection, but is not benign.

Waste characterization can be complex. For example, the plutonium residue at Rocky Flats (the major plutonium storage site) includes salts,

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process sludge, ash, as well as contaminated fragments of glass, metal, and rags. There is also "scrub alloy" of plutonium, americium, aluminum, and magnesium, formed in the plutonium recovery process. Plutonium itself is not readily absorbed through the skin or intestine, but fine particulates generated during handling or recovery, can be absorbed by inhalation. Exposure can occur when workers cut or jab themselves on scraps of plutonium metal. Remote handling in closed systems and multiple layers of containment during transportation, are required to minimize worker risk.

CHEMICAL HAZARDS

Hazardous waste: A broad category referring primarily to chemical wastes as defined under the Resource Conservation and Recovery Act (RCRA) which "may (a) cause or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness or (b) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, disposed of, or otherwise managed."

DoE and its contractors traditionally paid much less attention to chemical exposures than to radiation Many of the radionuclides pose both toxic and radiation hazards. Huge quantities of solvents, acids, and other reactive compounds were used and are still present on the sites. One of the most challenging is beryllium exposure, which is primarily a problem at Rocky Flats where chronic beryllium disease was first recognized in a worker in the early 1990's, resulting in a screening program employing newly developed biomarkers such as a lymphocyte proliferation test [Kreiss et al., 1993]. Other examples include the large quantities of mercury at Oak Ridge as well as mercury contamination at SRS, carbon tetrachloride at Rocky Flats, and trichlorethylene at Paducah. One of the most widespread hazards is asbestos which was used extensively in construction, particularly in the form of "transite" wallboard.

BIOLOGICAL HAZARDS

Outside of health care facilities, biological hazards receive relatively little attention. However, workers on DoE sites must protect themselves against the widespread tick-borne, Lyme Disease, as well as against Rabies which is increasingly widespread in wild animals, particularly in the East. In the West Plague and Hanta virus are significant threats. In the South and West, poisonous snakes are a potential threat. Workers dismantling the C reactor at

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Hanford, have encountered many rattlesnake, using the foundation of buildings as den sites.

PHYSICAL HAZARDS

In the hazardous waste field we have focused almost exclusively on the chemical and radiation hazards facing remediation workers. New studies, however, emphasize that the greatest risks facing remediation workers are the same physical hazards likely to be encountered in any construction work. In setting priorities for cleanup DoE has attempted to estimate hazards to offsite populations from non-remediation balanced against the hazards to offsite populations, to non-involved workers, and to waste management workers, from remediation itself. Both cancer and genetic endpoints and physical injuries have been estimated .

Despite the emphasis on radiological and now on chemical hazards, the greatest risk of injury or death is from physical hazards such as falls, falling objects, crush injuries, equipment related injuries, electrocutions and vehicular accidents. Although less likely to be fatal, the hazards of noise and temperature stress must also be considered. The possibility of fires, explosions. or critical events (unexpected nuclear chain reactions), exists in many facilities.

From 1941 to 1994, 201 of the 384 fatalities in DoE facilities occurred among construction workers, including 4 of the 5 that occurred in 1993-1994. Radiation risks ranked after construction injuries, and burns and illness from chemical exposures.

As O'Toole predicted hazardous waste management at the DoE sites is proving more hazardous than during the weapons production phase. Assuming the statistics for both time periods are accurate, the lost workday rate at SRS from 1982 to1990 ranged from less than 0.1 to 3.3, while from 1991 to 1995 it ranged from 8.3 to 17.6 (Westinghouse Savannah River Corporation Data).

A special set of hazards is encountered in the training of security forces, where recent fatalities have been related to a climbing accident and a live ammunition accident.

Probably the most widespread physical hazard will be heat stress (see Chapter 10), for workers encumbered by chemical-protective suits working in direct sunlight. This hazard is not unique to DoE sites, but many of these sites are in southern latitudes where long summers and intense heat render workers more vulnerable to heat stress syndromes.

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PSYCHOSOCIAL HAZARDS

Although many of the workers with long experience on DoE sites feel themselves well-trained and able to protect themselves against any hazardous condition, this is not necessarily true for subcontract workers unfamiliar with radiation. Both initial training and reinforcement should provide adequate information and equip workers to protect themselves, thereby eliminating a major source of stress. Even hazardous waste workers with experience in managing chemically contaminated sites, may find dealing with radioactive waste unusually stressful.

An overall source of stress has been the "downsizing" that has occurred at many DoE sites, with job loss often exceeding 25 percent. Moreover, the change of mission has been perceived by many workers as a loss of purpose. This is coupled with a shift to integrating contractors who have less direct contact with the activities on site but mainly serve a procurement role.

TRANSPORTATION HAZARDS

Proposals to manage nuclear wastes at DoE sites include extensive transportation requirements. Some of the 42,000 kg of plutonium residues at Rocky Flats in Colorado may be shipped to South Carolina (SRS) for separation, before being shipped to New Mexico (WIPP) for final interment. During the period of weapons production, shipments of radioactive materials and bomb components in secured vehicles, was commonplace but secret.

Today the DoE's Transportation Safeguards Division is responsible for both the safe transport and security of shipments of radioactive material. DoE is responsible for the safety of the materials, the transportation workers, and communities en route. It provides eight regional Radiological Assistance Programs teams to respond to any emergencies. DoE also provides a Transportation Emergency Preparedness Program to train and equip emergency responders for dealing with transportation accidents.

ORGANIZATION OF WORK

Although often overlooked, the way in which hazardous waste work is organized and performed, significantly influences worker risk. The change from large corporations with long-term familiarity with a site, extensive training programs, and large health and safety staffs, to small sub-contractors, requires heightened awareness of the potential for injuries and exposures. In the early 1990's when DoE shifted its focus from weapons production to

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environmental management, its sites were managed by large corporations as Management and Operations (M&O) contractors. These large firms became responsible for maintaining the wastes and beginning the daunting remediation task.

In about 1995, faced by the need to justify its cleanup budget. DoE began a massive restructuring of its site operations, moving to what it called a "management and integrator" or M&I concept, in which the large firms that managed sites, would serve mainly to procure and manage remediation subcontracts which would be conducted by small, more specialized, and presumably more efficient contractors and subcontractors. This was accompanied by massive "downsizing" of its sites, and a shift from a few operating companies with large staffs in occupational medicine, radiation protection, and safety, to many small companies with small or non-existing health and safety staffs Although the responsibility for protecting worker health and safety, remains ultimately with DoE and its major contractors, the actual responsibility for implementation of health and safety is being fragmented. thereby increasing the need for vigilance on the part of all responsible for protecting the health of this very large hazardous waste force.

Registry of Workers: A major component of any health and safety program is the ability to evaluate its effectiveness. To do this requires accurate denominator data----the ability to know how many workers were engaged in various kinds of work. A registry of hazardous waste workers on DoE sites would include names, social security numbers, age, gender, job title, activity on DoE site, and duration, and could be cross-linked to hazards known to exist on the site.

Due to legislative history, federal agencies divide remediation work into two broad procurement categories "construction" and "service". The former is regulated under the Davis-Bacon Act, which requires, among other things, payment of prevailing wages and the weekly certification of payrolls. The latter does not require weekly payroll certifications. The existence of the certifications provides a ready means of identifying these remediation workers However, a large number of remediation contracts are defined as service, allowing payment of lower wages, and does not require certification.

An alternative DoE requirement is needed to develop a similar reporting system for the "service" contract workers, who may be performing the most hazardous work on sites.

The injury and illness rate of DoE's construction contractors are lower than the national construction average by 30 to 60% [Gochfeld and Mohr 1997]. This partly reflects the greater investment of large corporations in safety, and partly the oversight by DoE's office of Environment, Safety and Health These rates, cannot, however, be expected to apply to the many small contractors who will be doing the bulk of the work in the future.

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CORPORATE HEALTH AND SAFETY AT DOE SITES

At DoE sites radiologic hazards are relatively well identified compared with chemical hazards, and historically DoE has built much larger technical staffs in radiation protection than in industrial hygiene. In 1996 the staff for radiation protection at SRS exceeded 700 while the industrial hygiene staff was less than 40.

Many national firms that specialize in hazardous waste treatment, management, or removal, have their own corporate Health and Safety Plan as well as corporate employees, and/or outside contractors, who provide safety, industrial hygiene, and occupational medical expertise. Although these staff are often based at corporate headquarters far from the remediation site, these corporations can readily develop Site Specific Health and Safety Plans which mesh with their generic corporate HASPs. Their centralized staff can provide some health and safety oversight for field operations, but the training and experience of their onsite health and safety personnel will vary. For small construction firms that have little previous experience with hazardous waste, developing a sound HASP is daunting and requires outside expertise as well as cooperation from the contracting agency that will review the HASP.

DoE issued orders 5480.4 and later 440.1 to guide its contractors on compliance with occupational medical provisions both internal and those of OSHA, regarding hazardous waste management. DoE recognized its obligation to extend its coverage "to non-DoE employees/contractors who have a need to enter a DoE environmental restoration site as visitors." However, in a period of declining budgets, the primary site contractors must concentrate on providing services to their own employees, and generally do not provide much-needed services to outside contractors.

WORKER PROTECTION

Due to the novel hazards imposed by mixed radioactive and chemical waste they are regulated separately. DoE is spending large sums to develop remediation technology, much of which will eventually benefit remediation at all sites. As the mission of DoE has shifted from weapons production to waste management, DoE has also recognized the need to protect the workforce employed on its sites by the large industrial firms which operated the sites. Although not covered by OSHA, DoE quickly adopted OSHA's requirements for the training of hazardous waste workers [DoE, 1991].

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The Department announced its commitment to conducting work efficiently and in a manner that ensures protection of workers, the public and the environment. To some extent "efficiency" and "protection" may be inimical. Over the past three years, the Department has developed and implemented a number of systems that are designed to achieve an acceptable level of safety throughout departmental operations. These systems are designed to: "Enhance our ability to plan and execute work, identify the hazards associated with specific operations and activities, and control or eliminate such hazards in an appropriate and cost-effective manner."

When DoE reviews contractor Health and Safety Plans, it identifies some standard safety procedures such as pre-job briefings, lockout/tagout procedures, access to material Safety Data Sheets, and worker training.

WORKER/SUBCONTRACTOR TRAINING

OSHA mandates training for hazardous waste workers. DoE goes beyond that in providing additional levels of training. A typical sequence would include:

1. General employee training (for site safety and security)
2. Hazardous waste training (40 hour course as required by 29 CFR 1910.120)
3. Radiation training if needed
4. Prework briefings on site hazards and as conditions change
5. Daily safety briefings

In addition, the prime contractor must conduct a review of the submitted worksite Health and Safety Plan, before issuing radiologic work permits and work clearance and authorization, and must review a completed Hazard Assessment form and proposed Exposure Monitoring Strategies/Industrial Hygiene Survey Procedures.

DoE or the prime contractor provides written requirements to subcontractors regarding Safety and Health, and reviews the HASP to see that it conforms with the requirements. It requires an ongoing hazard communication program includes labels, signs, material safety data sheets, and other written materials as need arlses. The general safety rules provided to prospective subcontractors are exceedingly specific [DoE, 1996].

Other examples of health and safety concerns are embodies in the SRS safety rules for subcontractors [WSRC, 1995] and the *Handbook for Occupational Health and Safety* [DoE, 1995], both published by DoE. It is apparent that on paper, at least. DoE has substantial provisions to assure worker health and safety during remediation. On the other hand, with reduced

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staffing, it is apparent that at least at some sites, DoE and its major contractors will not be able to adequately monitor safety performance. Various groups have developed worker training materials with different levels of complexity regarding workingly safely with chemical and radiation hazards. Murray and Powell [Murray, 1994] provide a clear introduction to radiation hazards and the managment of radioactive waste, aimed at an educated lay person.

EMPLOYEE JOB TASK ANALYSIS

DoE is in the process of implementing the EJTA across sites which requires supervisors to formally analyze the tasks required of each worker, including both critical functions and potential hazards. More detailed than a job description, the EJTA allows the linkage of each worker with the appropriate level of medical clearance and surveillance (see Medical surveillance chapter). It identifies workers who may be doing the most hazardous work.

At the 500-square mile Hanford site (Richland, WA), occupational medical services are provided by an independent medical contractor. the Hanford Environmental Health Foundation. Experience there emphasizes the need for "rigorous occupational health and safety programs that can predict, characterize, and control the workplace exposures, and for innovative medical screening and surveillance that can help prevent occupational disease" [DoE, 1997].

The Department of Energy, Environmental Safety and Health Office has mechanisms in place for the quality assurance assessment of the occupational medical programs of its site contractors. The Worker Protection Order (440.1[19]) outlines requirements for protecting workers, but leaves the enforcement to the discretion of the local DoE field office. The "Review of Contractor Occupational Medical Programs" does not yet extend to reviewing the performance of the many lower tier contractors engaged in various aspects of the EM mission. Nor is it apparent, however, how the EJTA will extend to subcontractors. With the decentralization of the health and safety responsibility, there is a strong need to actually audit subcontractor performance closely, since there is substantial variability in performance [Udasin, 1991]

WORKER INVOLVEMENT IN HAZARD RECOGNITION

DoE's Office of Environment, Health and Safety plays the lead role in assuring that environmental management activities do not jeopardize worker

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health. It has a responsibility to "Improve worker protection by indicating ways to minimize radiological, physical, chemical and biological hazards and to reinforce the health, safety and radiological training completed by-hazardous waste workers." Recognizing the need to involve workers in hazard recognition, DoE/EHS issued a guide [DoE, 1993] for workers informing them of responsibilities and rights under the OHSA Hazardous Waste Operations and Emergency Response Standard (also known as the HAZWOPER standard; 29 CFR 1910.120).

The importance of worker recognition of hazards has long been recognized in occupational health and safety fields. In factories, management-worker safety committees are commonplace and work together to protect workers by identifying and correcting hazards. Shannon et al. [Shannon, 1996] surveyed 416 factories and found that involvement of workers in health and safety committees capable of solving problems and greater experience of the workforce were the major predictors of low lost-time injuries. It was very important that health and safety responsibilities were defined in every manager's job description and were important in their performance evaluations. A disadvantage of hazardous waste work is that the deployment of workers tends to be short-term and is not conducive to developing worker-management safety committees on each job site.

Workers are key participants in the Job, Task and Hazard Analysis. Although the original HAZWOPER standard does not specifically apply to DoE facilities, DoE has chosen to apply portions of the standard concerned with worker protection to:

- Facility deactivation;
- Decommissioning, decontamination, and dismantlement;
- Surveillance and maintenance;
- Non-RCRA permitted treatment, storage and disposal facilities;
- Construction;
- Laboratory activities;
- Research and development activities; and
- Satellite accumulation sites.

How the standard will be enforced at DoE sites is currently under negotiation between DoE and OSHA.

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WORKER EXPERIENCE

Many current workers on the Complex have many years of experience with the site and its hazards. They have had extensive training in radiation and safety. To the extent that they participate in environmental remediation, they provide a well-trained, experienced workforce. Experience is a major predictor of lower lost-time injury rates. The shift to subcontract workers unfamiliar with a site, requires close surveillance.

CONTRACT PROVISIONS

A major instrument for safeguarding the health and safety of subcontract workers is built into the DoE procurement process. Bids for construction and remediation activities must include a detailed health and safety plan (HASP) in response to the site description provided in the bid solicitation contractors are chosen mainly on the basis of price, but an inadequate plan may disqualify a bidder or they may be required to enhance their HASP. Before final approval contractors must fulfill several additional steps indicating how they will deal with specific hazards. They must verify that their workers have had all the required training. They must hold regular (usually daily) safety briefings before commencing work, and they must file reports on accidents or near accidents. They are required to identify an appropriately trained person as site Health and Safety Officer (HSO).

To assure that these systems are operable, the prime contractor must have adequate staff and incentive to assure that the requirements are met. Unfortunately this is not uniformly applicable around the Complex. Moreover, safety must be made a personal responsibility of managers and contractors at all levels.

NEW TECHNOLOGIES

In November 1989 DoE established an Office of Technology Development to develop new approaches to managing different toxic wastes in different media, and to bring these technologies to the application stage. These technologies are in varying stages of readiness, entail varying requirements for personnel and pose varying degrees of hazards to workers which have not been assessed. Some of these involve improved Landfill Characterization Systems designed to improve detection and tracking of pollutants in soil with minimal intrusion [OTD, 1994], including the incorporation of in situ analytic systems which reduce the exposure to samplers and laboratory personnel. Likewise new

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containment, stabilization, and extraction systems may reduce the need for excavating and transporting soil, thereby reducing or at least altering the hazard potential for workers. In any case the safety of workers and the public (not just those directly engaged with the technology) should be considered in the design, selection, and implementation of new technologies.

MISSION AND SECURITY

Traditionally many of the workers at DoE sites lived in communities close to the site and comprise a significant portion (although now usually a minority) of the community potentially exposed to off-site contamination. Yet the neighboring communities are still highly dependent on the site's employment and purchases. Therefore adjacent communities are likely to rank maintaining some mission for the site, more highly than cleaning up and closing it A second major concern for communities and for DoE is the security of radioactive material, particularly plutonium. As a greater diversity of subcontract employees gain access to the site for purposes of remediation, the need for vigilance is increased.

CONCLUSION

DoE's huge environmental management, cleanup, and restoration program imposes a major challenge for the agency and for society as a whole[NAPA, 1997]. The increasing involvement of outside contractors and subcontractors, may jeopardize the health of many workers unaccustomed to work at hazardous waste sites in general or at DoE sites in particular. The agency has adequate orders and provisions both nationally and site-specific, to protect workers. but the budget for implementation of these requirements and oversight of performance is shrinking Protecting the hazardous waste workers on these sites will be a major challenge and will provide valuable lessons for protecting hazardous waste workers on other, smaller sites, as well. Balancing the hazards they face with the hazards posed by contamination, and choosing the most socially desirable alternatives is a broader social challenge [NRC, 1997]. Maintaining safety in this relatively new venture will require close cooperation among occupational health disciplines and attention to adequate funding.

In addition to operating procedures manuals which vary from site to site, DoE has procedures in place to investigate accidents, including a Lessons Learned approach and an Operation Experience Analysis and Feedback (OEAF) approach to investigating the occurrence Reporting and Processing

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System data base (ORPS). Table G-2 shows the cause of 413 radionuclide release incidents in the data base.

Table G-2

Root Causes and Management problems leading to radionuclide release events in the Occurrence Reporting and Processing System data base (n=413).

Training Deficiency	5%
Design Problem	10%
Equipment / Material Problem	13%
Personnel Error	14%
Procedure Problem	16%
Management Problem	41%
Inadequate administrative control[a]	30%
Work organization/Planning deficiency	25%
Other management problems	15%
Policy not communicated or enforced	10%
Improper resource allocation	10%
Inadequate supervision	10%

[a] failure to follow established procedures

DoE has adopted by reference many OSHA safety standards including 1910.120 (HAZWOPER) AND 1910.146 (Confined Space).

Confined Space Entry: Some of the most tragic fatalities occur through violations of confined entry procedures resulting in asphyxiation's or serious exposure to high concentrations of materials. The OSHA Confined Space standard (1910.146)provides detailed requirements for both prime contractors (Section (c)(7)(iv) and subcontractors (c)(9). This includes testing of spaces before entry and continuous monitoring during operations.

DoE 5480.19 *Conduct of Operations Requirements for DoE Facilities* spells out in detail many procedural issues. It is not clear how readily this document is incorporated into new subcontracts.

Case Report: A subcontractor was filling abandoned below-ground tanks with grout as part of a closure required under the Resource Conservation and Recovery Act (RCRA). At the start of the last truckload, operators failed to

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check the water level in the tank. The grout displaced water which overflowed onto the surrounding ground, requiring emergency spill control measures and resulting in a spill of plutonium-238 and curium-243 in excess of 5 million decays per minute of alpha and 300,000 decays per minute of beta-gamma. The workers were in radiation contamination clothing and wore respirators and were not exposed. (Source: Occurrence Reporting and Processing System Report SR--WSRC-SLDHZD-1997-0005).

Case Report: A subcontract worker was pumping contaminated sludge from a tank which as a confined space required continuous air monitoring. Although a work clearance permit and radiation work permit had been obtained, a confined space permit had not. This violation potentially jeopardized the worker. The solution was to monitor future subcontractor training classes and to retrain all of the subcontractor's work force on confined space procedures. (Source: ORPS Report SR--WSRC-RMAT 1997-0003).

Case Report: A cutting torch used to remove equipment in a high-contamination area, produced sparks that ignited a welder's anti-contamination clothing. There was no "buddy" available to observe the fire and the welder did not detect that he was on fire until it was too late. The DoE investigation determined that although flame-retardant clothing is available at some DoE sites, there is no requirement that it be used. Similarly there was no requirement for a "buddy" for fire watch, which could have prevented this fatality.

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Appendix H
PROTECTING ECOLOGICAL WORKERS AT HAZARDOUS WASTE SITES

Joanna Burger, Ph.D.
Michael Gochfeld, M.D., Ph.D.

The number of hazardous waste workers has increased dramatically over the last 25 years, making it important to understand the diversity of such workers and the range of threats they face [Gochfeld, 1990]. Protecting workers on hazardous waste sites requires recognizing the full range of activities that may be performed, including some that are not traditionally recognized as hazardous waste work. This chapter describes the threats faced by ecological field workers and ecological risk assessors, a new class of "nontraditional" hazardous waste workers.

In the past decade, the increasing emphasis on Ecological Risk Assessment and on Resource Damage Assessment [NRC, 1993] has brought a new breed of workers to hazardous waste sites. Trained in biology and ecology, they do not consider themselves hazardous waste workers. Many who were formerly involved with conducting environmental impact assessments on relatively pristine lands [Burger, 1994], find themselves evaluating ecological risks on contaminated lands such as Superfund sites, Department of Defense lands, or Department of Energy facilities. They never dreamed of taking 40-hour training courses on hazardous waste, and their experience with personal protective equipment was limited to sunglasses, insect repellent, and perhaps snake boots. Increasingly such workers have had to become hazardous waste workers, and whether sampling water, soil, or biota, they are potentially exposed to biological, chemical, and radiation as well as physical hazards.

Ecological risk assessors are often ill-prepared to both recognize the dangers of a contaminated site, or understand how to protect themselves. For example, one of our first cases was an employee of the U.S. Fish and Wildlife Service, who was instructed to capture Canada Geese that had landed in a chemical waste lagoon and had become ill. Wearing hip waders, he entered the water, and with some splashing managed to capture two of the birds to be used for toxicologic analysis and criminal evidence. He developed skin rashes from contaminated water hitting his unprotected upper body and arms, and greatly feared that he might have inhaled carcinogens from the water. After a detailed clinical evaluation it was possible to provide him substantial reassurance, but also to caution him and his supervisors regarding the need for training and

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protection in the future. This is not an atypical scenario for a wildlife biologist becoming in effect a hazardous waste worker.

Conversely, some of the hazards that ecological workers regularly encounter may baffle other more traditional hazardous waste workers who may encounter a rabid Raccoon *(Procyon lotor)* or a den of Rattlesnakes *(Crotalus)* while remediating contaminated facilities. These could cause serious illness or injury [Auerbach and Geehr, 1989]. At Department of Energy's Hanford site in central Washington, workers demolishing an abandoned nuclear reactor proudly pointed out to us the locations where they had encountered rattlesnake dens, and explained how they had learned to contain the reptiles pending the arrival of a wildlife specialist.

Similarly, ecologists examining the effects of nuclear energy production on snake communities at the Idaho Engineering and Environmental Laboratory frequently traverse rocky areas frequented by rattlesnakes that are sunning themselves. These ecological risk assessors regularly work by themselves, many miles from any form of help. On the one hand, they may be capturing snakes and other organisms to assess their level of contamination, while on the other they may fall victim to serious bites.

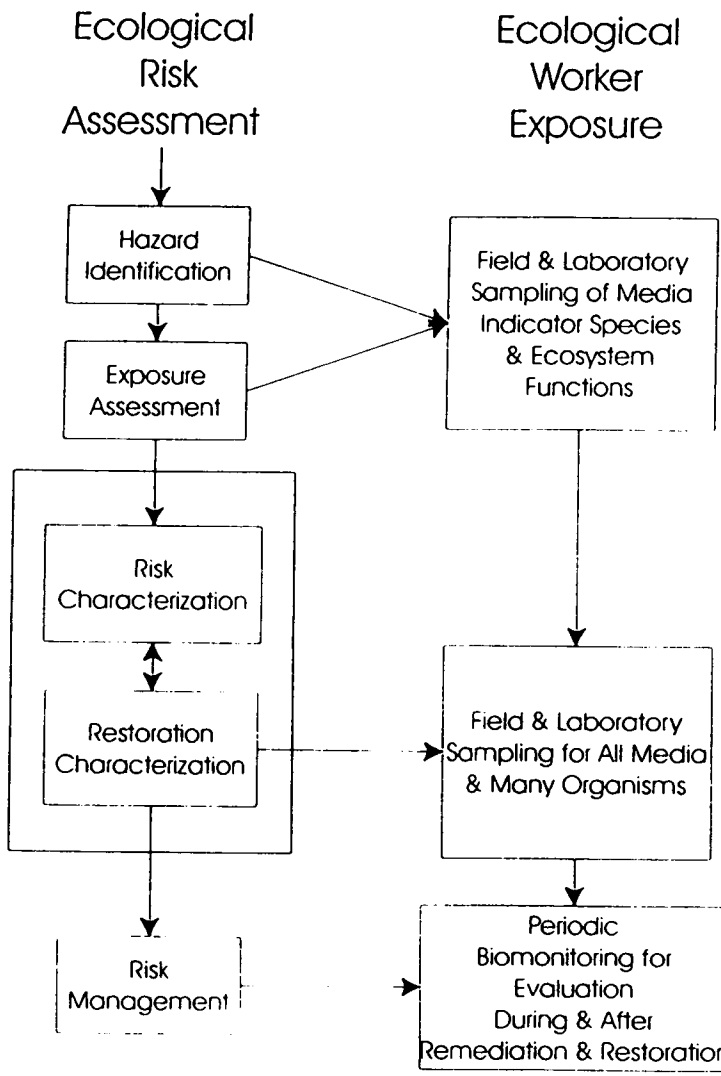
These and other examples make it clear that there are two different kinds of exposures resulting from ecological situations: (1) ecological workers face traditional hazardous waste situations without the proper background or training, and (2) traditional hazardous waste workers face ecological hazards without the proper background or training.

With the increase in the need to clean up Superfund sites, and lands belonging to the Department of Energy and the Department of Defense, it is clear that both ecological risk assessors and hazardous waste workers must be trained to deal with biological, chemical, physical and radiological risks to themselves and others while on the job. In our recent work for the Consortium for Risk Evaluation with Stakeholder Participation at Department of Energy sites it has become clear that ecological field workers are largely unaware of the typical hazards faced by hazardous waste workers and vice versa. The problem is exacerbated by a complete lack of interaction and management of the two groups of workers.

ECOLOGICAL RISK ASSESSMENT

The emerging field of ecological risk assessment has developed its own paradigms and serves a variety of functions including determining compliance, measuring baseline and changes in environmental quality, and quantifying damage for litigation [Burger, 1994; Suter, 1993; Bartell, 1992]. See Figure H-1.

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While ecological risk assessment uses as its basic paradigm the human health risk assessment model [NRC, 1983], there are significant differences that results in extensive exposure in the field [Burger Gochfeld, 1996]. Additional work is involved in ecological restoration or ecosystem rehabilitation [Jackson et al., 1995]. This requires baseline studies as well as follow-up studies, while remediated sites are being restored to more or less natural conditions [Cairns, 1995]. Once restoration is underway, continual monitoring is required and provides the potential for exposure, if sites have not been completely "cleaned up."

For more than two decades environmental scientists and ecologists have investigated natural organisms that can be used as bioassays for environmental contaminants [NRC, 1981]. Recently there has been increasing effort to develop animals and plants as bioindicators of environmental quality or lack thereof, and there are many studies of specific biomarkers that can be used to indicate pollution, both qualitatively and quantitatively [Peakall, 1992; Linthurst et al., 1995].

Ecological Risk Assessment encompasses a wide range of objectives, involving identification, inventories, collection of samples, and developing and validating models (See Table H-1).

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Table H-.1 Tasks performed by Ecological Risk Assessors That May Involve Exposure to Hazardous Chemicals

1. Identifying and inventorying terrestrial and or aquatic plants and animals to estimate the past effects of habitat loss or the future effects of remediation, or to evaluate the efficacy of remediation.
2. Identifying and periodically sampling bioindicator species.
3. Estimating chemical or radiation dose to certain species.
4. Estimating past or future damage to sensitive habitats or ecosystems.
5. Identifying any federally or state-listed endangered or threatened species or species of special concern.
6. Collecting biological data for compliance with regulatory affairs.
7. Collecting specimens for contaminant analysis.
8. Developing scenarios and models to analyze effects of spills.
9. Validating models by collecting environmental and biological samples in affected ecosystems.
10. Evaluation of restoration activities by continued censusing and sampling of populations.

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Unlike many other types of hazardous waste workers, many of these tasks involve many months of fieldwork and sampling to obtain information during all seasons of the year [Burger and Gochfeld, 1993]. For example, identifying and inventorying terrestrial or aquatic animals usually requires sampling throughout the year because different animal groups are active at different times. Migratory birds increase in the spring and fall, amphibians are most active in the early spring, reptiles are more active in the summer, and mammals may migrate from one habitat to another at different times of the year.

There are also daily variations in the activities of animals that make sampling at different times of day essential. Frogs usually call only at night, requiring night sampling. Birds may be most active early in the morning, and some mammals can be trapped only at night, requiring early morning checks of traps. All of these variations expose ecological field workers to hazards when others are not around. Since not all animals or plants can be sampled, it is essential to select indicators. The wide range of bioindicators [Hunsaker et al., 1990; Kreman, 1992] that are required to adequately evaluate a hazardous waste site, both before and after cleanup, results in an equally wide range of exposures, both to biological and chemical stressors. This increases the training task, both for the ecological risk assessors and the hazardous waste workers.

Often ecological workers are on sites that are not adequately controlled, and are likely to be there when there are no other workers on site who can provide guidance about personal protective equipment. Ecologists frequently have to collect data or samples early in the morning, late at night, or during weekends. In some cases ecological work may proceed on a site not yet identified as a hazardous waste site. Ecological workers are also accustomed to working alone with little supervision, and although they may have elaborate field study protocols, these traditionally do not cover health and safety relating to hazardous chemicals.

There are four broad categories of sampling that are essential to Ecological Risk Assessors (see Table H- 2), and all occur on contaminated sites. Soil, Water, Plants and Animals can all be evaluated with censusing, collecting of samples, and later analysis of the samples in the laboratory. For all three major sampling methods there can be a variety of hazards faced by workers.

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Table H- 2. The Activities That Ecological Risk Assessors Routinely Engage In On Hazardous Waste Sites. (Usually the same workers conduct all of the types of sampling.)

Major Media Sampling Air sampling Soil sampling Water sampling Plant sampling Animal sampling
Types of Sampling Censusing - inventory of presence and abundance Collecting - taking of biological material for later analysis of contaminants, pathologies or other abnormalities Laboratory analysis - measuring contaminants, disease rates, or abnormalities

The primary hazards faced by ecological workers include biological, infectious diseases, toxic agents, and physical hazards (see Table H-3). The usual problem is that ecologists are trained to face the biological and perhaps infectious disease hazards, but are not trained to deal with the toxic or physical hazards, whereas the hazardous waste workers may be trained to deal with the toxic agents, but not the other hazards.

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Table H-3 Hazards Routinely Faced by Ecological Workers

Typical Environmental Hazards
- Biological Hazards
  - Animal bites
  - Animal attacks
  - Cuts from vegetation
- Infectious Diseases
  - Tick-borne diseases (Lyme, Ehrlichiosis)
  - Viral diseases (Rabies, Hanta)
- Toxic Agents
  - Irritating plants (Poison Ivies, nettles, Saw Grass)
  - Toxic insects (Wasps, Blister Beetles)
  - Venomous animals (Snakes, Scorpions)
- Physical Hazards
  - Falls
  - Quicksand
  - Water Emergencies (drowning, frost bite, heat stroke)
- Typical Hazardous Waste Hazards
  - Chemical agents in air, water, soil, containers, and biota.
  - Radioactive agents in air, water, soil, containers, biota.

WHEN PRISTINE-APPEARING SITES ARE CONTAMINATED

There is an additional threat that ecological risk workers face that may not be immediately apparent. Many hazardous waste sites, particularly large ones such as the Department of Energy sites or Department of Defense sites, have highly contaminated sites that are surrounded by buffer zones. Many of these buffer zones are very large, involving thousands of acres, and they appear to be intact or pristine ecosystems. The relative pristine appearance of these sites may be misleading, resulting in a decrease of vigilance with respect to proper procedures. Both the ecological worker and the hazardous waste worker may be lulled into believing that the site is clean because it appears clean. However, many species of animals move great distances, both on a daily and a seasonal basis, and may transport contaminants to otherwise pristine-looking areas. For example, in one evening a Raccoon or White-tailed Deer *(Odocoileus virginianus)* may travel several miles, moving from a hazardous site to a pristine area. For this reason, it is always important to treat all animals on a

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site as potentially exposed, regardless of the relative distance from the center of the hazardous waste activities.

ECOTOXICOLOGY

Although the terms "ecotoxicology" and "ecological risk assessment" are sometimes confused, the former has a much stronger toxicologic and laboratory focus. It is defined as "toxicity testing on one or more components of any ecosystem" [Cairns, 1989]. In addition to traditional hazards of laboratory work, ecotoxicologists may encounter hazards specific to their trade, particularly if they work with species or assemblages that pose potential hazards. As an example, in the 1980's our laboratory conducted a multiyear study of the bioassay potential of a captive population of white-footed mice *(Peromyscus leucopus* [Burger and Gochfeld, 1992], a species that was subsequently shown to be a host for Hanta virus. Had these animals been infected, both the field workers who collected them and the laboratory personnel (including ourselves) who handled them, would have been in jeopardy.

Such laboratory work regularly entails capturing wild animals of various species, adapting them to the laboratory, raising them, and exposing them to hazardous materials including heavy metals, organics, radionuclides, and biohazardous materials [Hoffman et al., 1995]. Studies on such small-scale pens or aquaria can be considered microcosm studies. A substantial amount of ecotoxicology has been conducted on the mesocosm scale in outdoor ponds (usually smaller than an acre) by aquatic toxicologists. Such ponds may be treated with pesticides or other hazardous materials, and field workers then monitor various aquatic species on a regular basis [Suter, 1993].

Although ecotoxicologists normally work in the relatively controlled microcosm and mesocosm scale, there is an increasing number of scientists who are conducting controlled experiments in the field, using wild animals [Burger and Gochfeld, 1997b; Hoffman et al., 1990]. These types of experiments have the potential for exposure to nearly all of the hazards listed in Table H-3.

Laboratory workers are not immune to the hazards faced by the field workers, but because they work in the relatively sterile conditions of a laboratory they may be less aware of the dangers from working with wild specimens. For example, laboratory personnel working with biomarkers in Raccoons, Opossums *(Didelphus)* and other field-collected specimens can be exposed to rabies, Hanta virus or other infectious diseases.

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EDUCATION AND TRAINING REQUIREMENTS

Ecological field workers must be able to recognize hazards, to prevent exposure, and to deal with unpredictable events. They must learn to choose and use personnel protective equipment just as well as the remediation workers. They must also be prepared to deal with a variety of acute exposures, such as an insect bite, a snake bite, or a wound caused by an animal. The details of traditional hazardous waste programs are elaborated in many other chapters in this book. The unique feature of this chapter lies in recognizing the potential hazardous exposures in certain ecological work, and bringing such workers into conformity with the regulations aimed at protecting them. It also lies in the recognition by traditional hazardous waste workers that they can be exposed to threats from animals and plants while they conduct their normal hazardous waste work.

Ecological field workers are most likely to be drawn from backgrounds in wildlife management, ecology, or biology, less often from environmental science. Their undergraduate or graduate training is usually lacking in any focus on hazardous waste as a problem, much less on health and safety aspects of hazardous waste work. Yet hazardous waste management is a growing area of employment for people with such training, particularly as the focus of hazardous waste site remediation turns to restoration. Ecological field workers may work on an unsuspected contaminated site or on a known hazardous waste site prior to or after remediation. They may encounter unsuspected hazards on a site that appears pristine or at least non-contaminated.

Since the majority of ecological workers will spend little time on seriously contaminated sites, it is not likely that they will have 40-hour hazardous waste training courses. However, they do need to become familiar with principles of hazardous waste management and do need to know how to determine whether a site that they may be investigating (perhaps for real estate development or conservation purposes) is known to be contaminated. They also need to know how to recognize evidence that their site may be contaminated and what to do immediately, and how to report suspected contamination.

It would be reasonable to offer and recommend a course in hazardous waste management as an upper level undergraduate course in ecology and wildlife management programs. The course should focus not only on the problems of hazardous waste and environmental contamination, but on the health and safety issues of hazardous waste workers. It should include procedures for working at sites not yet known to be contaminated. We also suggest it may be useful for hazardous waste workers to undergo brief ecological training (at least site-specific training) in which they are made aware of the biological hazards wildlife on site may present.

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Beyond a basic educational component, there will be additional training requirements. Entry onto known contaminated sites will usually require the 40 hour HAZWOPER training as specified in OSHA's hazardous waste standard (29CFR 1910.120). Conversely, the typical generic training offered hazardous waste workers does not include biological hazards that may be encountered on certain sites. Site-specific training is required by specific employers or site managers, but is not a uniform requirement. We recommend uniform development of a site specific training program that would include identification of biological hazards encountered on sites. Some companies have already developed generic programs which they routinely modify for new sites.

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