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IV.1

The changing face of environmental monitoring

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IV.1.1. Introduction

During the past 30 years, analytical chemists have witnessed fundamental changes in both the technology and the policies of environmental monitoring. This chapter will look at two types of changes. We will first examine the changes taking place in monitoring policy, and second at the efforts being made to shift from laboratory analysis to field analysis.

The policy shift that will be looked at is the movement from a reference method system to a performance-based system. In this chapter, we will look at why regulatory agencies and the public initially adopted the reference method or technology approach to monitoring, the benefits and drawbacks of this decision, and the changes that are now taking place to eliminate the problems. We will highlight what the current movement to change from a technology to a performance-based approach to monitoring will have on the scientific community, the laboratory community, the consulting companies who serve government and private sector clients, the regulated community, and the regulatory agencies who are responsible for implementing the environmental programs.

The second area that will be addressed in this chapter are the efforts being made to improve monitoring quality while reducing data gathering costs by emphasizing field analysis. In addition to eliminating the costs and problems associated with preserving and shipping samples to the laboratory, the almost real-time nature of on-site analysis offers the data user tremendous potential savings. We will highlight some recent developments in the areas of field sampling and analysis and look at how these developments are impacting environmental monitoring and what additional changes we might expect to see.

IV.1.2. Monitoring policy

IV.1.2.1. Reference method approach

Beginning in the 1960s, the Congress of the United States enacted a series of laws to protect the nation's air, water, and land. Among the most important of these statutes, from the standpoint of monitoring, were the Clean Air Act (1963), the Clean Water Act (1973), the Safe Drinking Water Act (1974), the Resource Conservation and Recovery Act (1976), and the Comprehensive Environmental Response, Compensation, and Liability Act (1980).

These laws required the Environmental Protection Agency (the Agency or EPA) to establish criteria and procedures to assure the safety of the air we breathe, the water we drink, and the land we use for recreation and as a source of food.

In carrying out its mandates under these laws, the Agency recognized the need to be able to monitor the various environmental media. Such monitoring was needed to quantify the type and magnitude of the problems and to monitor compliance with the controls that would be needed to correct the problems and prevent future problems.

As it began to implement the air and water programs, the Agency realized that appropriate methodology for measuring the pollutants of interest at the levels of concern was generally not available. New techniques were needed and scientists in EPA, the private sector (e.g. instrument manufacturers), and academia responded with the development of many new measurement techniques. Many, such as quadruple mass spectrometers as detectors for gas chromatography and inductively coupled argon plasma emission spectrographs, required a fairly high level of sophistication and expertise if one wanted to be confident of the validity of the results. However, it was recognized early on that if the environmental programs were to be successful, one could not depend on having cadres of experienced analytical chemists gathering the monitoring data. For example, the drinking water programs require each of the many hundreds of public water supply systems in the United States to conduct periodic monitoring of the quality of the water that they distribute. Many of these systems are small and cannot afford to always employ highly sophisticated chemists conducting the analyses. Often, the systems would have to make use of well-trained technicians rather than chemists. A similar situation presented itself in the air monitoring arena. Here the vast majority of the monitoring is performed by local government agencies. Some of these agencies face the same staffing constraints as their drinking water counterparts.

It was not only the Agency that was concerned with this situation. The companies, the federal, state and local government agencies, and the laboratories and other organizations that assist the regulated community in complying with the regulations issued to implement the statutes were also concerned. They were especially apprehensive since, under the law, the regulated entity is criminally and civilly responsible for the quality of the data used to demonstrate compliance. The regulated entities wanted requirements that were clearly described so that they could be certain that they were correctly complying with the regulations, enforcement agencies needed clearly defined requirements so that they could easily determine if a regulated entity was in compliance, and the various supporting organizations (e.g. the engineering companies, the commercial laboratories, the instrument manufacturers) needed clear monitoring requirements in order to make it easier to bid on work and to deal with clients that often had only limited expertise in the field of environmental monitoring.

In response to these concerns, a two-pronged approach was adopted by EPA's air and water programs. They consisted of a combination of detailed, rigorously defined protocols for carrying out the required monitoring coupled with quality control and documentation requirements to ensure that the required procedures were being followed. Alternative methods approval systems were established by each regulatory program (e.g. drinking water, waste water, air emissions) to provide a mechanism for the regulated community (and for the innovation industry to get approval for their new products) to be allowed to use a monitoring technique or methodology other than one of the ones published by EPA.

Changes to this approach began in the early 1980s with implementation of the hazardous waste (RCRA) program. While the Agency continued to develop and publish methods for use in complying with the RCRA monitoring requirements, it attempted to build flexibility into the system by not mandating that the promulgated methods be used. For most of the regulatory program, monitoring requirements specified what parameters were to be determined and regulatory action levels specified, the regulations did not mandate use of any specific method(s). However, this philosophy of flexibility did not take hold in the monitoring community. A number of the states and many of the permit writers and compliance officials, when implementing the RCRA program required the regulated community and its supporting laboratories to use the methods that EPA published in its RCRA testing methods manual "*Test Methods for Evaluating Solid Waste*" (SW-846).

The next major milestone took place with the establishment of the EPA program to clean up abandoned, contaminated sites under the Comprehensive Environmental Response, Compensation, and Liability Act. The Agency's Superfund program, as it is commonly called, found itself in the position of needing to analyze a tremendous number of samples to determine which sites were contaminated, the nature and extent of the contamination, and what priority should be assigned to cleaning up the site. The amount of sampling and analysis required overwhelmed the Agency's own laboratory capability. To address this problem, EPA established the Contract Laboratory Program (CLP).

The purpose of the CLP was and is to serve as a means for EPA to efficiently and effectively purchase laboratory services from the commercial laboratory community in a manner that ensures free and open competition. Because of the large number of samples that need to be analyzed and the wide variety of analytes that were of interest to the Superfund program, a two-component system was established. In the routine services component, the Agency determined that a relatively small menu of selected analytical techniques could be used to analyze the vast majority of the soil and water samples that formed the bulk of the samples that the program would have to be analyzed. Given the nature of the government procurement process and the need of the potential bidders for clearly defined requirements, the CLP program selected a number of analytical techniques and codified the techniques into rigidly defined methods. In addition, to ensure the utility of the resulting analytical data in any future legal action, detailed reporting and record keeping requirements were placed on participating laboratories. A fundamental construct of the CLP was the concept of laboratory interchangeability. For each type of analysis that was needed, identical contracts were awarded to several laboratories. As a sample was collected by one of the many sampling teams, a sample management office distributed samples with an eye toward evening out the workload in the various laboratories. Samples from the same site might, in fact, end up being sent to several different laboratories for analysis. The rigorous specification of how the laboratory was to conduct the analysis, which was inherent in the CLP methods and contracting process, ensured uniformity of results.

The reference method or technology-based approach came to be adopted for many EPA and state regulatory programs because it offered the Agency, the states, local regulatory agencies, the regulatory community, and the laboratory community a number of advantages.

The technology-based approach eased the burden on federal and state permitting staffs in several ways. By limiting the universe of potential methods to those that have been evaluated and approved by the national program, it simplifies the selection of appropriate testing methods. By having national program offices specify the applications for which a method was appropriate, it eliminates the need for the local permit issuing staffs to assess the suitability of proposed methods for each facility. In addition to reducing the level of expertise and experience needed by the regional and state personnel involved in the permitting and enforcement of permits and regulations, by issuing and requiring the use of detailed, relatively prescriptive monitoring methods it makes it possible for the laboratory community to use less experienced, less well-trained analysts in carrying out the analyses. Finally, from the viewpoint of the regulated community, the technology-based approach is much easier and less expertise intensive with respect to identifying appropriate testing methods, convincing regulatory agencies of the appropriateness and scientific validity of proposed compliance methods, and contracting for and overseeing outside analytical services.

In assessing the efficiency of current regulations and permits and the desirability or need for the Agency to make changes in regulatory programs trend data is critical. In assessing the data on either a facility-specific, industry-specific, or area-specific basis, the issue of data comparability looms large. The fewer the methods that are employed in conducting the monitoring, the more rigorously defined and specified the analytical procedures that are used; and the more complete and consistent are the quality control and documentation procedures that are employed, the easier it is to compare and evaluate the monitoring data and to determine trends.

Just as the technology-based approach eases the process that a regulated entity needs to go through to select an appropriate outside laboratory, the use of uniform, detailed, measurement methods and quality control procedures and requirements simplifies the task of the federal and state inspectors in determining compliance with regulatory and permit requirements. It is much easier to determine if an analytical method was performed according to a specified procedure than it is to determine if the data meets a set of data quality objectives.

As mentioned earlier, the Superfund Contract Laboratory Program is basically a mechanism for the procurement of a large volume of relatively routine analytical services. In order for the laboratory community to accurately bid on such services, for EPA to be able to compare bids, and for EPA to be able to maintain a system of interchangeable suppliers a program with rigorously defined, consistently employed, and consistently performed analytical methods was deemed to be essential. A technology-based analytical methods program was selected when the program was initiated. The rigorousness of the approach was an advantage to the other federal agencies and the private sector organizations that were involved in contaminated site remediation. These organizations were able to use the EPA methods and procedures in implementing their own laboratory services procurement programs. A side benefit of the CLP adoption of the technology-based approach was the cost savings that resulted. These savings were due to the fact that the laboratories were able to redesign their internal procedures and dedicate instruments and staff to conducting large numbers of a particular type of analysis using the same steps and instrument conditions for all samples without regard to client or source. This resulted in a tremendous decrease in per sample analytical costs for analyses such as gas chromatography/mass spectrometry, atomic absorption spectroscopy, inductively coupled plasma atomic absorption spectroscopy, and high performance liquid chromatography.

In addition to the savings inherent in using fewer analytical methods, the higher volume per method encouraged and resulted in the automation of some more commonly used methods.

IV.1.2.2. ***Performance-based measurement system approach***

While, as just shown, the technology-based approach to regulatory monitoring specification offered many benefits, it also presented a number of serious disadvantages. These included: serving as a road block to the development and use of new monitoring technologies and often requiring the use by the regulated and enforcement communities of less efficient methods and approaches. Therefore, in addition to increasing the costs to the regulated and regulatory communities by promoting use of older, less efficient technologies, the technology-based approach serves as a major barrier to innovation. It should be pointed out that because of these disadvantages, the aforementioned CLP program has been moving away from the prescriptive, reference method approach. At this time, a significant percentage of the CLP work is done under a system whereby each user of analytical services specifies project-specific method requirements. This gives the laboratory greater flexibility in selecting the most appropriate method for a given situation.

EPA has initiated a number of complementary efforts to maintain the benefits of the technology-based approach while giving the monitoring community the flexibility it needs to improve the quality of the monitoring while, at the same time, lowering the cost of the required data gathering. These efforts include:

- streamlining EPA's various methods approval processes,
- integrating methods across programs,
- changing from a technology- to a performance-based system of monitoring specification,
- the Agency's XL Program (Excellence and Leadership) that offers the regulated community the opportunity to employ innovative approaches which improve the environment and reduce compliance costs,
- assisting the private sector in obtaining impartial evaluations of new monitoring technology and in promoting the results of the evaluations, and
- increasing the level of support provided to academia and other non-profit organizations involved in developing innovative monitoring technologies.

Under EPA's current regulatory monitoring structure, review and approval of alternative or new monitoring technologies and methods are conducted by the various regulatory programs. For example, the Office of Air and Radiation is responsible for the methods used to comply with the Clean Air Act, the Office of Water with the Clean Water Act and the Safe Drinking Water Act, and the Office of Solid Waste with the Resource Conservation and Recovery Act. Each office has developed its own procedures for obtaining approval for a new technology and its own mechanism for making new methods available to the public. Beginning in 1994 with an effort by the Office of Solid Waste, the Agency began to remove regulatory requirements to employ specific methods when complying with Agency monitoring requirements and to streamline its methods approval processes in order to speed up the introduction of new measurement technologies (US EPA, 2000). The Office of Solid Waste effort resulted in a proposed rulemaking in 2002

(US EPA, 2002). On a parallel path, the Office of Water proposed to streamline its methods approval process (US EPA, 1995). The goals of the streamlining effort included:

1. decreasing the time and Agency resources required to approve new analytical techniques and improved methods,
2. provide for an increase in the number of methods that are approved for use each year,
3. increase participation of outside organizations in the method development process, and
4. improve overall program quality.

At the same time as EPA is moving to implement the performance approach (Crumbling, 2000; US EPA, 2000), the National Environmental Laboratory Accreditation Program (NELAC), the standards setting body for the United States' federal–state–tribal national environmental laboratory accreditation program, is working to change its accreditation standards to adopt the performance approach (NELAC, 2002).

However, success of the new approach will not be easy. A change of this magnitude will require major efforts by all members of the environmental community. Two areas where these efforts will be especially important are in education and in promoting risk taking.

A whole generation has grown up believing that the route to quality data is to follow methods and procedures issued by government and other standards setting organizations. Analysts have put aside the scientist's philosophy of critically examining the validity of suggested methods or approaches in light of the properties of the samples being tested. The education and re-education process will have to address this problem. It will have to train the analytical community in how to select the most appropriate, most cost-effective approach to obtaining the information needed to solve the problem while meeting the data quality objectives. Similarly, those members of the environmental community overseeing the studies need to learn how to evaluate analytical data quality against the data quality objectives rather than to look at whether a given method was used or whether all the steps of the published procedure were followed.

A second part of the problem deals with breaking down the aversion to risk that has been built into the system. How can the engineers who develop sampling and analysis plans for the regulated community and the permit officials who have to approve the plans be given an incentive to take risks? Trying new approaches will help the regulated community save money and offers government the potential for better environmental decision making. However, trying new and untried approaches presents risk. New methods and testing strategies do not always work out. Mistakes have negative time and cost consequences. Since in the long run, taking a creative approach to monitoring will save the regulated community and the public money and improve the quality of the decision making, clients must be understanding when a study has to be redone and government officials must be understanding when monitoring schemes are found not to yield the needed data.

In conclusion, the performance-based approach will help to:

1. streamline the adoption and use of new analytical technologies,
2. improve the comparability of data obtained from different studies,
3. help assure that methods used for gathering data actually work in the particular samples being analyzed,

4. simplify operations for laboratories analyzing similar types of samples but for different regulatory programs,
5. encourage innovation in environmental monitoring technology, and
6. result in more reliable, faster, and cheaper data monitoring.

IV.1.3. Field monitoring technology

While the changes taking place in monitoring policy are important, the changes taking place on the technology side will have no less of an impact. In this chapter, we will briefly look at one of the more active areas of environmental monitoring research – on-site analysis. The area of "field" or "on-site" analysis covers a number of areas. For purposes of this discussion, we can categorize the technology into three areas. These are: sample collection tools, measurement methods, and data communication. In this discussion, the author will touch on some of the more important developments in the areas of sampling and measurement methods.

Obtaining accurate data on subsurface soil or water contamination has long posed a difficult challenge to environmental scientists. Obtaining samples without contaminating or otherwise adversely affecting the soil or ground water is exceedingly difficult using conventional techniques. Several approaches to solving this problem have been under development for a number of years. These include development of non-drilling methods for obtaining subsurface samples and development of *in situ* techniques for detecting and measuring soil and water contamination. In the past few years these efforts have borne fruit with the development and commercialization of the cone penetrometer, and the adoption of remote sensors that can be used to identify and measure subsurface contaminants.

The principle behind the cone penetrometer is relatively simple. A truck mounted, hollow lance equipped with a point that can be disengaged or opened, while in the ground, is pushed into the ground reaching depths of 30 m or more depending on soil characteristics. In order to be able to exert the forces needed to push the cone deeply into the ground, the trucks are normally quite heavy (40,000 kg) and can exert greater than 27,000 kg of hydraulic pushing force on a 30–50 mm diameter penetrating lance. The cone penetrometer offers a number of advantages. These include an ability to quickly locate areas of contamination at a site since driving the lance takes only minutes. It gives the scientist the ability to easily collect samples of soil, ground water, or soil gas at any desired depth. And the application with the most potential is its ability to make *in situ* measurements of the soil water or gas. The unit can serve to place one or more sensors at specific points in the subsurface to yield a profile of the soil and ground water contamination.

This last advantage of the cone penetrometer has not yet been fully realized. Among the sensors that have been successfully evaluated and are currently being used in the United States for such *in situ* analysis are optical sensors based on fluorescence and Raman spectroscopy (for location of chlorinated hydrocarbons and other non-aqueous phase liquids), chlorinated compound specific soil gas sensors, electrochemical sensors for detecting metals and other conducting species, as well as conventional geophysical logging devices that can be used to map the subsurface to allow a more accurate assessment of ground water flow pathways.

Two factors have been responsible for the rapid advances that field monitoring has seen take place in the last decade. These are:

1. the development of new measurement techniques or, in some cases, the adoption to environmental problems of techniques that have been used for other applications;
2. the miniaturization and ruggedization of conventional instrumentation to permit its use in a field setting.

One of the more important of the new technologies that have been made available to the environmental analyst have been the immunochemical-based methods. Also contributing important new tools to the analyst's toolbox has been the development of field screening kits, using conventional chemistries, for important environmental pollutants such as polychlorinated biphenyls and other chlorinated organic compounds that are based on conventional chemistry, and the development of solid state chemical sensors.

Immunochemical-based assays have gained widespread acceptance in the medical testing field. They have been found to accurately determine whether or not a woman is pregnant, and can be used with confidence to rapidly identify a number of illnesses. In the later part of the 1980s, a number of researchers began to adapt this technology to solving environmental problems. Among the first of the assays to be made available were kits to determine polychlorinated biphenyl, pentachlorophenol, and polyaromatic hydrocarbon contamination in water and soil. In addition, kits to identify the presence of unacceptable levels of residue pesticide on food and plants were developed.

Immunochemical-based assays offer several important advantages. They are fast, yielding results generally within 30 min. They are sensitive and can determine if contamination is present at the ppm and ppb level. They are selective and generally exhibit a relatively low level of both positive and negative interferences. More importantly, interferences are generally of a positive nature since compounds with a structure similar to that of the target analyte often exhibit a cross-reactivity. It is this relative freedom from negative interference and positive bias that can make these assays attractive to the environmental community. Because of this positive bias, the user has a high degree of confidence that, if the assay indicates an absence of contamination at the indicated level of sensitivity, the area is in fact clean. False positive results are generally of less concern since they can generally be eliminated by subjecting the suspected samples to conventional laboratory analysis.

The chemical and immunochemical-based assays have three primary applications in environmental testing. The largest of these is in site characterization. When contamination is suspected, the test kits can be used to rapidly determine if contamination is present at a level of concern. If it is known that contamination has occurred, then the tests offer a means of determining the extent of contamination in a manner that saves both time and money compared to conventional sampling and laboratory analysis. Using these tests, one can quickly and inexpensively examine areas of suspected contamination and separate the areas that are in need of remediation from those that are clean. The third application is that of process control. During, for example, a site remediation where soil is being removed or a cleanup process is being employed to remove contamination, one often needs to monitor the level of residual contamination to determine if additional soil needs to be removed, or if the treatment process is no longer effective. Here use of field screening tests permits one to answer these questions on a real-time basis. Using the field tests eliminates delaying the cleanup while awaiting the laboratory results, eliminates lost productivity while the crew waits to find out if additional soil needs to be excavated, and eliminates the expenses of having to reactivate treatment beds or employ redundant processes in order to prevent unexpected exceedances of treatment targets.

The ability to drastically reduce the size and power requirements of conventional analytical instrumentation has led to some of the largest advances in recent years. For example, the development of portable X-ray fluorescence (XRF) instruments brought the benefits that immunoassays gave for organic contaminants to the heavy metals. Use of XRF has been of inestimable value to both the lead in paint cleanup program and to the site remediation efforts. Similarly, the organic arena has seen the commercialization of handheld organic compound vapor detectors based on the principles of gas chromatography; of field portable gas chromatographs employing both conventional detectors and even mass spectrometers; a wide variety of infrared spectrometers both long path length instruments for air monitoring and conventional Fourier transform infrared (FT-IR) instruments. We have even seen the introduction of portable time of flight mass spectrometers designed to determine the presence of specific, highly toxic organic compounds. Some of these new instruments were originally developed for military applications and have recently been adapted to environmental applications.

IV.1.4. Future trends

The environmental monitoring arena continues to change. New technology continues to be developed that promises both to improve our current ways of monitoring and to open up totally new approaches.

The rapid advances in microminiaturization continue to shrink analytical instrumentation with no end in sight. Research is underway that promises order-of-magnitude reductions in the size of today's instruments. Having a wider variety of instruments available for field analysis will continue and possibly accelerate the trend to on-site analysis. In addition, it opens up the possibility of, for the first time, obtaining real-time information on personal exposure to toxic chemicals. Analytical instruments that can be worn by individuals at home and at work can significantly improve the quality of the exposure information used in assessing risk, which are the basis for regulatory standards.

Remote sensing is another area receiving a great deal of attention on the part of the Agency and the research community. Environmental remote sensing can be subdivided into three major categories based on the distance between the sensor and the area being monitored.

The first category, satellite-based measurement systems are primarily employed to study the Earth and its changing environment. Observations of the oceans, atmosphere, land, and forests enable the study of environmental changes and to distinguish between natural changes and human activity-induced changes. Multispectral and hyperspectral land imaging systems of high and moderate spatial resolution, passive microwave imaging systems, and multispectral thermal imagery are areas of current research interest. Advances in this arena lead to improvements in areas such as land and water management, urban planning, and environmental monitoring.

The second major category of remote sensing encompasses aircraft-borne instruments. Moving the instruments closer to the Earth permits one to more accurately monitor both the atmosphere and the land. Advances in light detection and ranging (LIDAR) systems will permit better monitoring of important atmospheric species such as ozone, carbon monoxide, water vapor, hydrocarbons, and nitrous oxide as well as meteorological parameters such as atmospheric density, pressure, and temperature. Research is currently being sponsored to enable or to significantly expand the capabilities of LIDAR systems to the near ultraviolet through infrared regions of the spectra. In addition, advancing the capabilities of the optical techniques, research to develop radar instruments which are capable of sub-surface probing over soil, wetlands, or water to detect and profile the presence of subsurface minerals, water, and pollutants is being pursued.

The third, but by no means the least important, area is that of ground-based instruments. Here techniques such as long path length FT-IR can serve as valuable tools for monitoring facility and area emissions and for ensuring the safety of site remediation personnel. Advances in this area will be important to Agency efforts to take a more ecosystem and facility wide approach to controlling the release of hazardous pollutants. It will expand our ability to continuously monitor releases and to more accurately assess potential risk. It will also give the facility operator the tools and the information needed to more efficiently and effectively operate the facility.

IV.1.5. Conclusion

In conclusion, the author believes that the next decade will bring major changes to environmental monitoring. The laboratory community will split into two types of organizations. One type of laboratory will specialize in using EPA and other well-accepted, standardized methods to analyze well-characterized matrices (e.g. drinking water, surface waters, routine wastewater effluents, soils). These laboratories will be highly automated with rigid quality control/quality assurance systems in order to offer quality data and low price (similar to today's medical testing laboratory industry). The second type of laboratory organization will deal with non-routine monitoring problems. They will offer the client tailored approaches to monitoring problems. These organizations will use a mixture of conventional laboratory analysis, field screening, and field analysis tailored to the individual clients needs and designed to reduce data gathering costs while ensuring adherence to required data quality objectives.

In any case, the trend toward moving the analysis from the laboratory to the field will not only continue but will also accelerate. We can expect to see less laboratory analyses, more field analysis, more continuous analysis, and more remote sensing.

References

Crumbling, D.M., 2000. Improving the cost-effectiveness of hazardous waste site characterization and monitoring. Special Report #6. US EPA Technology Innovation Office, Washington, DC, Electronic J. *FAILSAFE*, p. 12. Web site: http://www.cluin.org/products/failsafe.htm.

NELAC, 2003. Quality Systems Standards, Proposed Changes, Chapter 5. Available on NELAC web site at: http://www.epa.gov/ttn/nelac/propstand/5qs-p20030602.pdf.

US EPA, 1995. 40 CFR Part 304(h). Streamlining approval of analytical methods; notice of availability of documents. Fed. Reg., 60 (176), 47325–47334 (September 12, 1995).

US EPA, 2000. Technology Innovation Office and Office of Solid Waste and Emergency Response. The Relationship Between SW-846, PBMS and Innovative Analytical Technologies, US EPA, Washington, DC, December 11, p. 14. Web site: http://www.clu-in.org/PRODUCTS/REGS/analyticalregs.htm.

US EPA, 2002. Waste management system; testing and monitoring activities; proposed rule: methods innovation rule. Fed. Reg., 67, 66251–66301 (October 30, 2002).

For further information

Performance-based monitoring

Friedman D. 1993 Debating performance-based methods Environ. Lab. Mag.52.

Friedman D. 2000 Update on PBMS activities at EPA New Technologies Session II – Business Ramifications. WTQA 2000, Proceedings of 16th Annual Waste Testing and Quality Assurance Symposium: "Environmental Sampling and Analysis in the 21st Century" WPI–US EPA Arlington, VA August 2000.

Lesnik B. 2000 Analytical strategy for the RCRA program: a performance-based approach (short course) WTQA 2000, Proceedings of 16th Annual Waste Testing and Quality Assurance Symposium: "Environmental Sampling and Analysis in the 21st Century" WPI–US EPA Arlington, VA August 2000.

Stevenson R. 1995 The time has come for performance-based systems Am. Environ. Lab. 794.

WEF 1995 EPA's Planned Performance Based Methods System, Water Environment Laboratory Solutions Water Environment Federation Alexandria, VA July 1995.

WTQA 1998 Proceedings of 14th Annual Waste Testing and Quality Assurance Symposium: "Using a Performance-Based Measurement System (PMBS)" ACS–US EPA Arlington, VA July 1998.

WTQA 1999 Proceedings of 15th Annual Waste Testing and Quality Assurance Symposium: "Preparing for Change Under PBMS" ACS–US EPA Arlington, VA July 1999.

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Field Analytical Chemistry and Technology. Wiley, New York (Print ISSN 1086-900X, online ISSN: 1520-6521) (Journal dealing with application of analytical chemistry outside of the conventional, fixed-site laboratory; published since 1996/97); Web sites: abstracts: http://www3.interscience.wile.com/cgi-bin/issuetoc?ID = 88510905, full text: http://lib.harvard.edu/e-resources/details/f/fianchte.html.

Koglin, E.N., Poziomek, E.S., Krum, M.L. 1995 Emerging technologies for detecting and measuring contaminants in the vadose zone. Wilson, L.G., Everett, L.G., Collen, S.J., Handbook of Vadose Zone Characterization and Monitoring Lewis Publishers Boca Raton, FL 657–700.

Kounaves, S.P. (Principal Investigator), 1999. Electrochemical Sensor for Heavy Metals in Groundwater – Phase IV. Tufts University. Web sites: http://electrochem.tufts.edu/mars.html; http://es.epa/gov/ncerqa_abstracts/centers/hsrc/detection/det14.html.

Meuzelaar, H. 2001 Technological innovation in field analytical chemistry Field Anal. Chem. Tech. 5 213–214.

Rapid Optical Screen Tool (ROST), Innovative Technology Evaluation Report. Report Number EPA/540/R-95/519. US Environmental Protection Agency, Washington, DC, August 1995.

Russwurm, G.M., Childers, J.W., McClenny, W. 1996 FT-IR Open-Path Monitoring Guidance Document, Second Edition Report Number: EPA/600/R-96/040US Environmental Protection AgencyResearch Triangle Park, NCApril 1996.

Site Characterization Analysis Penetrometer System (SCAPS), Innovative Technology Evaluation Report. Report Number EPA/540/R-95/520. US Environmental Protection Agency, Washington, DC, August 1995.

Stepan, D.J. (Principal Investigator) 2000. Real-Time In Situ Detection of Organic Contaminants by Laser-Induced Fluorescence. Energy and Environmental Research Center EERC – University of North Dakota, North Dakota. Web site: http://www.eerc.und,nodac.edu/summaries/RTIS.htm.

US EPA1997 The Site Characterization and Analysis Penetrometer System (SCAPS) Laser-Induced Fluorescence (LIF) Sensor and Support System. Innovative Technology Verification Report EPA/600/R-97/019 National Exposure Research Laboratory Las Vegas, NV.

US EPA 2002 Dynamic Field Activities. Geophysical Methods US Environmental Protection Agency Washington, DC Web site: http://www.epa.gov/superfund/programs/dfa/geometh.htm.

US EPA 2002 Dynamic Field Activities. Field-Based Analytical Methods US Environmental Protection Agency Washington, DC p. 13. Web site: http://www.epa.gov/superfund/programs/dfa/fldmeth.htm.

US EPA – Office of Solid Waste 2002 4000 Series Methods (Immunoassay) SW-846 On-line – Test Methods for Evaluating Solid Waste. Physical/Chemical Methods 3rd edn US Environmental Protection Agency Washington, DC Web site: http://www.epa.gov/epaoswer/hazwaste/test/main.htm.

US EPA – Technology Innovation Office 2002 Using field analytical methods Characterization and Monitoring. Educational, Policy and Guidance Materials US Environmental Protection Agency Washington, DC p. 13. Web site: http://www.cli-in.org/char1_edu.cfm.

WTQA 2000 Where will we be in 2005? – New Technologies Session I WTQA 2000, Proceedings of 16th Annual Waste Testing and Quality Assurance Symposium: "Environmental Sampling and Analysis in the 21st Century" WPI–US EPA Arlington, VA August 2000.

WTQA 2001 Field/New Technologies Sessions I and II WTQA 2001, Proceedings of 17th Annual Waste Testing and Quality Assurance Symposium "Effective Environmental Information" WPI–US EPA Arlington, VA August 2000.

WTQA 2002 Managing uncertainty using field sampling and analysis. Technical Session Proceedings of 18th Annual Waste Testing and Quality Assurance Symposium "Sound Science Through Effective Project Planning" WPI–US EPA Arlington VA August 2002. WTQA Proceedings are available at web site: http://www.epa.gov/epaoswer/hazwaste/test/proceedingsdoclist.htm.