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RADIONUCLIDES IN U.S. COALS AND THEIR IMPLICATIONS WITH RESPECT TO ENERGY DEVELOPMENT

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ABSTRACT

The current state of knowledge regarding radionuclide concentrations in U.S. coals is discussed. Emphasis is on the levels of uranium in coal (and lignite) which may represent a concern resulting from coal combustion; areas of the U.S. where such levels have been found; and implications of high radionuclide levels in coal to energy technologies (e.g., new vs. existing coal-fired power plants and coal-based synthetic fuel facilities). The paper reviews relevant studies and also presents new data derived from a computerized search of radionuclide content in about 3800 coal samples collected throughout the conterminous U.S.

1. INTRODUCTION

The central question of this paper concerns the fate of certain highly radioactive coals surveyed in the 1950s. Most studies on the impacts of fossil-fuel power plants appear not to have taken these coals into consideration. In light of recent EPA pronouncements, another look at these coals is in order.

On 27 December 1979, the Administrator of the U.S. Environmental Protection Agency (EPA) announced in the Federal Register the decision to list radionuclides as hazardous air pollutants under Section 112 of the Clean Air Act. This announcement contained a summary of the impacts of radioactive emissions from a variety of facilities (sources) including coal-fired power stations. In terms of fatal cancers to a regional population (within a 50-mile radius), the summary indicated that "new" coal-fired power plants resulted in twice the effects attributable to the second highest contributor (the phosphate industry) and that the effects were at least an order of magnitude more than any of the remaining contributors of radioactive air pollutants.

In the background document [1] to this announcement, it was shown that the fatal cancers from older "existing" facilities was yet another order of magnitude higher than for the "new" plants. Therefore, it is not unreasonable to infer from the 1979 announcement or the 1979 background document that coal-fired power plants were considered a major, if not the major, source of the several that were mentioned.

On 6 April 1983, the Administrator of EPA announced in the Federal Register that radionuclide emission standards were being proposed for four categories of sources: (a) Department of Energy (DOE) facilities;

(b) Nuclear Regulatory Commission licensed facilities (excluding facilities that are part of the uranium fuel cycle) and non-DOE Federal facilities; (c) underground uranium mines; and (d) elemental phosphorous plants. Of particular interest was the fact that standards were not proposed for coal-fired boilers, neither industrial nor utility boilers.

However, in the 1983 announcement, EPA provides a caveat recognizing that "there could be a subcategory of coal-fired boilers for which it would be appropriate to issue an emission standard," since there is "the possibility that boilers may be using coal with radionuclide content that is significiantly above average or that existing boilers may be operating in a manner that causes elevated emissions of radionuclides."

The apparent shift in emphasis between EPA's 1979 and 1983 positions on radionuclide releases from coal-fired power plants gives the above caveat special importance. This paper discusses two features of the caveat, namely, an emissions standard and coal with high radionuclide content.

2. BACKGROUND

Prior to World War II, uranium had little commercial value save minor use in the ceramic industry where uranium was employed to impart green and yellow coloring to glassware and fired clay products [2]. With the advent of nuclear power, uranium acquired a tremendous importance, and the search for new deposits led to the discovery of low-rank coals containing appreciable concentrations or uranium.

In the late 1940s, deposits of radioactive coal were discovered by the U.S. Geological Survey (USGS) in Wyoming and the Dakotas, resulting in a general reconnaissance search for uranium-bearing, coaly carbonaceous rocks in several western states by USGS in cooperation with the U.S. Atomic Energy Commission (AEC) during the years 1951-1954 [3, 4].

Although there were several more interesting discoveries of coaly, lignitic, and carbonaceous shales as well as impure coals in Idaho and New Mexico, it was not until a 1954 discovery of 1000 ppm (0.1 percent) uranium in thin beds of impure lignite in the Cave Hills and Slim Buttes areas of South Dakota that a wave of prospecting and land acquisition in the Dakotas and Eastern Montana began [4, 5]. In 1957, several shipments as large as 500 tons each of impure lignite and lignitic shale containing more than 1000 ppm were made for metallurgical testing by the AEC and the U.S. Bureau of Mines [6].

Six years later, commercial uraniuim recovery operations began at four locations in southwestern North Dakota with a cutoff concentration of 1300 ppm uranium. At two of these plants, the lignite was roasted in rotary kilns under controlled conditions with subsequent leaching of the uranium from the ash at another location. At the other two operations, the process was less complicated with open burning conducted in the puts themselves. For commercial reasons, none of these operations lasted more than three or four years. Until two years ago, a uranium mill in Karnes County, Texas had a roasting operation for burning uranium-bearing (300 ppm U) lignites for the primary purpose of uranium recovery.

The concept of extracting uranium from coal ash has remained of interest and continues to be studied [8, 9, 10, 11]. To ensure profitability, present economics require that the coal would be first burned for its heat content, with mineral extraction as a secondary benefit.

In 1964, Eisenbud and Petrov published an article regarding the relative radiological impacts of airborne releases from coal-fired and nuclear power plants [12]. Based on maximum permissible concentrations of radionuclides in airborne releases, it was argued that coal-fired power plants could be more hazardous radiologically than nuclear power plants. This controversy continues and several studies have provided refinements and modifications over the years. Two of these studies [13, 14] indicate that the radiological impacts from a coal-fired plant may be as large, if not more so, that those for a comparably sized nuclear power plant. Another study [1], while not making a direct comparison between the two types of power plants, provides sufficient information for the reader to readily draw a similar conclusion regarding nuclear and coal-fired power plants.

In reviewing such studies, two key factors should be considered:

- These studies compared the impacts due to the operation of the power plants alone and did not consider the variety of impacts associated with the remainder of the respective fuel cycles (e.g., mining, processing, transportation, waste disposal). Consideration of such additional factors could alter the conclusions based solely on the power plant portion of the fuel cycle.
- Pollution control devices, especially those for particulate matter, on newer coal-fired plants may mitigate the impacts of such units.

It is primarily upon this latter contention that EPA has decided not to include coal-fired power plants in the radionuclide category of its proposed National Emission Standards for Hazardous Air Pollutants.

The previously mentioned comparisons between nuclear and coal-fired power plants were based on the use of coal with average uranium values, on the order of a few ppm of uranium in the coal. The question of how representative of future conditions these comparisons are may be raised in light of the following factors:

- Subbituminous coal and lignite coals are expected to play an increasingly important role in meeting the energy needs of the U.S.
- Western coal is highly desireable for its low sulfur content.*
- Western coal is abundant.
- Western coal, by virtue of being easily strip mined, is more accessible than the coals of many other regions in the country.
- Most of the reported findings of high uranium content in coal are in western states.

A possible inference from these factors is that releases of radioactivity could increase dramatically from coal-fired power plants as more western coal is burned. This inference has not necessarily proven to

*Although revised New Source Performance Standards (NSPS) for sulfur emissions from coal-fired power plants may tend to reduce the need for low-sulfur coals at new or recently constructed plants, low-sulfur coal would still be desirable for many of the older plants (44 FR 33581).

be true. Several studies performed for or by the U.S. Department of Energy (DOE) show that, in general, the coals used in and/or the airborne pollutants released from western power plants are not significantly different with respect to radioactivity from those used or released elsewhere in the country [15, 16, 17]. However, it is important to note that none of these DOE studies considered coals with high radionuclide contents such as those reported by the USGS and the AEC in the 1950s.

An interesting development of relatively recent origin concerns the conversion of coals, lignites, and carbonaceous shales into synthetic fuels. Here too, the radionuclide content of the parent fuel has caused concern regarding its potential environmental impacts [18, 19, 20]. This concern may prove to be of greater importance than the radiological impacts of direct combustion of coal, since synthetic fuel development is expected to focus more on lower rank coals and coaly carbonaceous shales (wherein are found some of the higher uranium levels), rather than on anthracite or high-BTU bituminous coals (which are generally lower in uranium content).

3. EMISSION STANDARD

While there are several different forms that an emission standard could take, this study focuses on a standard based on the radionuclide content of the coal prior to combustion.

The most important radionuclides found in coal are uranium-238 and thorium-232 (plus their daughters) as well as potassium-40. For many samples (particilarly from early surveys), the presence of uranium is the only determination made. Measurements for thorium are less frequently made and potassium data are seldom reported.

The overall health risk of the radioactivity in coal depends upon the individual health risks of the many radionuclides potentially present in coal. However, it could be cumbersome to base a concentration standard on a number of isotopes. It would be much easier (and likelier to be done as well as more enforceable) if the standard were based on a single species if that species were shown to be representative, relatively easy to measure accurately, and it is possible, for example through correlation and other relationships, to account for the other isotopes.

Several of the lignites reported in the literature had heating values in the 3000-5000 BTU per pound range with a few samples as low as 1000 BTU per pound [21]. Although some of these ores are generally regarded as lignites, they are for the most part not of fuel grade and some will not support combustion [6]. Some specimens of the uraniferous lignite outcrops in the Cave Hills (South Dakota) region would not burn under a blowtorch flame [22].

Lignite coals are defined as having a heating value up to 8300 BTU per pound while subbituminous coals range from 8300 to 11,500 BTU per pound. The higher rank coals--bituminous and anthracite--have greater heating value although, strictly speaking, these coals are more properly descirbed in terms of fixed carbon and volatile matter limits rather than heating value [23]. Because different amounts of these fuels would be required to produce the equivalent heat input (and electrical output) in a power plant, any standard for uranium in coal should be established on a heating value basis.

Several authors [14, 24, 25, 17] refer to "national averages" for the uranium and thorium contents in coal. The referenced values of 1.8 ppm U and 4.7 ppm Th are based primarily on the work of Swanson who measured approximately 800 samples of coal from different parts of the country [26]. Strictly speaking, the values are simply the arithmetic averages of the 800 samples without any implications of how representative of the coal reserves the values are. Trace element concentrations, particularly uranium, can vary an order of magnitude or more between nearby seams and even laterally or vertically within a given seam [27]. Moreover, there is no indication of the tonnage or mineability associated with the samples. Nevertheless, these values have gained wide acceptance.

While there is no scientifically established level of uranium in coal which would be considered hazardous to health if the coal were burned in a power plant, several authors have estimated values, shown below, which are essentially based on such a concept.

Uranium Concentration	Reference
5 ppm	Van Hook, 1978 [28]
6 ppm	Greiner, 1983 [29]
10 ppm	Hardin, et al., 1982 [30]
20 ppm	Greiner, 1981 [31]
30 ppm	Wagner and Greiner, 1982 [25]

All of the authors qualify their estimates in one way or another. Van Hook states that "atmospheric releases of radionuclides from increased coal combustion do not represent a significant public health problem unless coal containing greater than 5 ppm U comes into general use." It is not clear whether "general use" implies one plant burning such coal over an extended period of time or most plants burning such coal over an extended period.* The latter condition is quite unlikely while the former may reasonably happen.

In fact, Swanson as quoted in Styron noted that some deposits with U-238 concentrations as high as 44 ppm (before cleaning) are being used by electric power utilities in the United States [32]. While the value of 44 ppm is not an average and the duration of use is not mentioned, the inference can be taken that in some cases use of coal with above average uranium concentrations is not unlikely. Furthermore, it has not been established whether typical coal cleaning processes can remove substantial amounts of uranium.

For the three values associated with Greiner, it was suggested that any boiler extensively using coal with such uranium concentrations be evaluated with regard to its radiation environment.

Hardin and his co-authors at the U.S. Environmental Protection Agency concluded that the use of coal with 10 ppm uranium is a possibility and could lead to elevated population risks associated with radionuclide doses to lung and bone.

Since the values (5, 6, 10, 20, and 30 ppm of uranium in coal) are not based on rigorous analysis, such an analysis would be necessary before any regulatory standard could be established. Based on acceptable dose risk to

*One may infer from Patterson's quotation [33] of Van Hook's comment that the term "general use" refers to the entire utility industry, while the original quotation seems to have been made on the basis of a single power plant.

nearby individuals and populations, one could work backwards to an acceptable level for uranium in coal. In addition to the usual stack, meteorological, and demographic parameters involved in such calculations, conditions regarding the combustion process and the presence of other radionuclides must be considered. How much of a particular radionuclide remains with the bottom ash relative to the amount associated with fly ash and what particle size distributions are involved are two areas under investigation. Moreover, if the standard were to be promulgated on uranium in coal, other radionuclides often present in coal must be taken into account, particularly those which are highly volatile (e.g., various isotopes of lead, radon, and polonium).

4. RADIONUCLIDES IN COAL

A prerequisite to the determination of an emission standard based on radionuclide content in the fuel is a knowledge of the levels and locations of uranium in coal. This report presents new data derived from a computerized search (the USCHEM data base maintained by the U.S. Geological Survey) of uranium content in approximately 3800 coal samples collected throughout the coterminous U.S. Also summarized is information from a literature search of documents (mostly from the 1950s and the 1960s) wherein are noted potentially extensive quantities of uranium-bearing coal in various Western states.

4.1 Literature Search

The results of a literature search for uranium-in-coal information are summarized in Table 1, where information on approximately 65 sampling programs (from single samples to dozens and even hundreds of samples per program) in some 20 states (see also Figure 1) is provided. As can be seen from Table 1, the thorium content of the coal frequently was not measured. One can also infer that many of the coals associated with these findings may not be of significance relative to hazardous radioactive emissions from coal combustion at power plants for a variety of criteria, including:

- too few samples
- deposits too deep
- beds too thin
- minor or small occurrences
- impure coal
- low heating value
- high ash content

A coal sample with a low uranium content is defined in this report to be one having a uranium content of the same order of magnitude as the national average (i.e., 1.8 ppm U). When only a few samples are provided for a given area, one cannot be certain that the values recorded can represent the coal deposit with any statistical significance. In the case of grab samples, they are usually considered as being "rarely representative" [23]. Furthermore, a deposit that appears to have been examined only once (particularly where only low concentrations were found) would indicate that the find is of little interest. The early geologists (1950s and 1960s) were looking for commercially exploitable uranium which just happened to be in coal. Those deposits which were examined more than once for uranium and have a large amount of usable coal are the deposits which are of potential concern to environmentalists today.

The depth of a bed, its thickness, and its areal extent are indicators of the economic feasibility of extracting the coal. The desirability of extracting the coal may also depend upon the presence of impurities in the coal (e.g., trace metals, sandstone, shale), the BTU content of the coal, and the percentage of ash in the coal.

It must also be noted that since World War II, the coal resource classification system has undergone radical change. Recently, the USGS published a standardized system designed to lessen individual geologic and engineering judgments in the interpretation of data and methods and to provide reproducible and comparable estimates [23]. Under the present reserve classification system (depth, thickness, etc.), the extent of some of the earlier coal discoveries may no longer be considered quite as optimistically.

Moreover, since uranium ore was the mineral of primary interest, less attention was paid to the quality of the host medium. Substances identified as coal were sometimes misnamed (i.e., they may have been coaly carbonaceous shale or lignitic shale) or impure, being mixtures of coal, sandstone, and shale. In either case their suitability for direct combustion may be questionable.

Most of the listings in Table 1 appear to be relatively inconsequential on the basis of one or more of the criteria discussed above. There are four areas, however, which may warrant further analysis as potential sites of high-uranium coal or lignite: (a and b) Sweetwater County and North Park Field in Colorado; (c) Slim Buttes in South Dakota; and (d) Karnes County in Texas. Although the information in Table 1 does not conclusively imply that these four areas are potential trouble spots (in fact, one or two of the locations may not have met all the criteria discussed above), there does not appear to be enough information to rule them out at this time.

4.2 *Computer Search*

The USCHEM file, containing geochemical and trace element data, is part of the computer-based National Coal Resources Data System developed by the U.S. Geological Survey. In September 1983, the file was queried regarding measureable uranium and thorium concentrations in coal throughout the United States. The output, involving more than 3800 samples, was arranged in ascending order of uranium content. Average values were also determined.

The distribution of concentrations of uranium in the coal samples is such that more than 93 percent of the samples have concentrations less than 5 ppm U, while fewer than 2 percent have values greater than 10 ppm U. The concentrations appear to be normally distributed with a peak (modal value) between 0.61 and 0.7 ppm. The average concentration of uranium in coal for this distribution is 1.90 ppm while the corresponding value for thorium is 4.67 ppm.

One conclusion from this exercise is that it would appear that the "national average" of 1.8 ppm U and 4.7 ppm Th in coal has not changed significantly since Swanson's analysis in 1976. It must be remembered that none of these "national averages" is anything more than an arithmetic average of a given set of samples; moreover, the samples were chosen because they were known to contain uranium. Samples known not to contain this element were not considered in the averaging.

Table 1. Uranium in Coal (Literature Data, Greater than 5 ppm)

Location	U(ppm)	Comments
CALIFORNIA		
Los Angeles Co.	200	Moore and Stephans, 1953
San Benito Co.	50	as reviewed in [34];
Amador Co.	40	thin beds, "minor
Alameda Co.	30	occurrences".
COLORADO		
Jefferson Co.	1000 - 5000	Gude and McKeown, 1953, as reviewed in [34]; small lenticular bodies.
North Park Field	L0.2 - 23.7	[35]; 21 samples, U values
arith. mean	4.1	G5ppm include 5.4, 5.8,
geo. mean	1.6	10.5, 11.4, 12.5, and 23.7, Th = L3.0 - 34.8ppm
IDAHO		
Goose Creek area (Cassia Co.)	max. 1100	[36]; Hole 2, impure coal, 245 ft. deep, 4 ft. thick.
Cassia Co.	max. 970	Mapel and Hail, 1959 as reviewed in [37];
Fall Creek Area (Bonneville Co.)	max. 1300 avg. 200	Vine and Moore, 1952 as reviewed in [34]; impure coal, "possible commercial deposit".
ILLINOIS		
Herrin No. 6 bed	0.8 - 7.5 avg. 2.2	[38]; 15 samples, INAA, Th = 1.37 - 3.9 ppm.
Sahara Coal Co. Mine No. 6	85	[4]; 2 samples, 1 ft. thick bed.

Note:
INAA = Instrumental neutron activation analysis
SSMA = Spark source mass spectrometry
TEMS = Thermal emission mass spectroscopy
Lx = Less than x
Gx = Greater than x
eU = Equivalent uranium
Coal tonnages are in short tons or millions (M) of short tons.

Table 1 (Continued)

Location	U(ppm)	Comments
ILLINOIS (continued)		
Herrin No. 6	0.2 - 28	[39]; bench sample R, 7 ft. thick seam, top 3 or 4 inches has 28 ppm U, while rest of sample has no more than 1 ppm.
INDIANA		
Linton	20	[4]; 0.7 ft. thick.
Gentryville	12	[4]; 1.2 ft. thick.
IOWA		
Cherokee Group	6.1	[40]; grab sample, high volatile C bituminous, Th = 1.7 ppm.
Harrisburg Herrin No. 6	L10 - 80	Patterson, 1954 as reviewed in [34]; "minor occurrences".
KANSAS		
NE of Fort Scott	70	[4]; 0.9 ft. thick
KENTUCKY		
Providence	10	[4]; 8 ft. thick.
MONTANA		
Townsend Valley	220	[41]; locality F, lignite, 2 in thick.
Ekalaka Hills	G50	As reviewed in [4]; G1000 tons estimated reserves.
Ekalaka Hills	10 - 340	[42]; mostly in Custer National Forest, up to 7 ft. thick, lignite, high ash (24-49%), up to 215 ft. deep.
Long Pine Hills	50 - 300	[42]; "only small amounts of uranium."

Table 1 (Continued)

Location	U(ppm)	Comments
NEVADA		
Esmeralda County	30	Moore and Stephans, 1954 as reviewed in [37].
Gamma Property, Churchill County	60 - 520 avg. 283	[43]; 10 samples, mostly thin beds, clayey lignite with high ash content.
Churchill County	590	Lovering, 1954 as reviewed in [37].
NEW MEXICO		
La Ventana Mesa, Sandoral County	10 - 6200	Backman et al., 1957 as reviewed in [34].
La Ventana Mesa	up to 6200 avg. 1000	[3]; small deposits.
NORTH DAKOTA		
Sentinel Butte Flat Top Butte Bullion Butte Chalky Buttes Medicine Pole Hills	G50	As reviewed in [4]; G1000 tons estimated reserves each.
Little Badlands	avg. 900	[42]; 0.5 ft. thick, small amounts.
Chalky Buttes	avg. 170	[42]; 2 ft. thick, average ash = 30%, estimated 15 M tons, most is overlain by less than 300 ft. overburden.
OHIO		
Crescent	30eU	Snider 1953 as reviewed in [34]; "minor occurrences."
Latrobe	10	[4]; 0.5 ft. thick.
PENNSYLVANIA		
Darlington, Beaver County	100	Ferm, 1955 as reviewed in [34]; bottom 6 in. of coal, "minor occurrences."
Dora, Jefferson County	30 - 40 eU	Ferm, 1955 as reviewed in [34]; "minor occurrences."

Table 1 (Continued)

Location	U(ppm)	Comments
PENNSYLVANIA (continued)		
Beaver County		[4]; 0.25 - 0.5 ft. thick.
Clearfield County	10 - 70	
Jefferson County		
SOUTH DAKOTA		
Harding County	50 - 300	[44]; 6 samples.
Billy Dale Group, North Cave Hills	avg. G4400 620 - 11,300	[22]; "E" bed is 9-10 in. thick near surface, several thousand tons combustible with abundant smoke.
Lodgepole area and Johnson outliers	G50	As reviewed in [4]; G1000 tons estimated reserves.
Northern Slim Buttes	G50	
Slim Buttes, Olesrud Bed	1 - 150	[36]; hole SD-10, lignite, 5 ft. thick, 381 ft. deep.
Slim Buttes Mendenhall rider bed	4 - 92	[36]; hole 16, 8 ft. thick, 333 ft deep.
Slim Buttes, Mendenhall rider bed	max. 900	[36]; hole SD-8, 3 in. thick.
Slim Buttes, Mendenhall area	avg. 50	5.4 ft. thick, 49 M tons; [42]; 5800 BTU, impure lignite.
Slim Buttes, other than Mendenhall	avg. 70	340 M tons; [42]; 5800 BTU, impure lignite.
Mendenhall area, Harding County	avg. 50	Gill et al., 1959 as reviewed in [37].
TEXAS		
Karnes County	2300	[45];Whitsett formation, delayed neutron activation analysis.
---	1 - 7	Wilcox lignite
	4 - 70	Yegua-Jackson [46]
	1 - 7800	Upper Jackson

Table 1 (Concluded)

Location	U(ppm)	Comments
TEXAS (continued)		
Karnes County	950 - 2450	[46]; Jackson formation, 3 samples, lignite, intrusions into shale.
---	5.7	Radian sample } [48]
---	6.0, 6.2	Texas Railroad Commission } [48]
---	6.0	Texas Air Control Board } [48] data gathered on 163 samples of Texas lignite, 105 of which were associated with U determinations. Only the listed 4 values were greater than 5 ppm.
UTAH		
---	20	Zeller, 1955 as reviewed in [37].
VIRGINIA		
---	0.2 - 5.6 mean 1.61 $\pm$ 0.97	[49]; 134 samples, whole coal, 5.6 ppm U sample from Dickenson County was only sample greater than 5 ppm, delayed neutron activation analysis, Th = 3.0 - 14.0 ppm.
WEST VIRGINIA		
---	L10 - 30	Patterson, 1954 as reviewed in [37].
WYOMING		
Pumpkin Buttes	40 - 1000	J.D. Love, 1952 as reviewed in [34]; "minor occurrences."
Sweetwater County Red Desert	10 - 470	Masursky and Pipiringos, 1957 as reviewed in [34]; 163 M tons.
Red Desert	4 - 100 avg. 30	[50]; nine principal coal beds, 690 M tons at 30 ppm or more, 20% estimated to be strippable (L60 ft overburden), beds from 2 in. to 42 ft. thick, subbituminous B, up to 510 ppm in impure-coal beds.

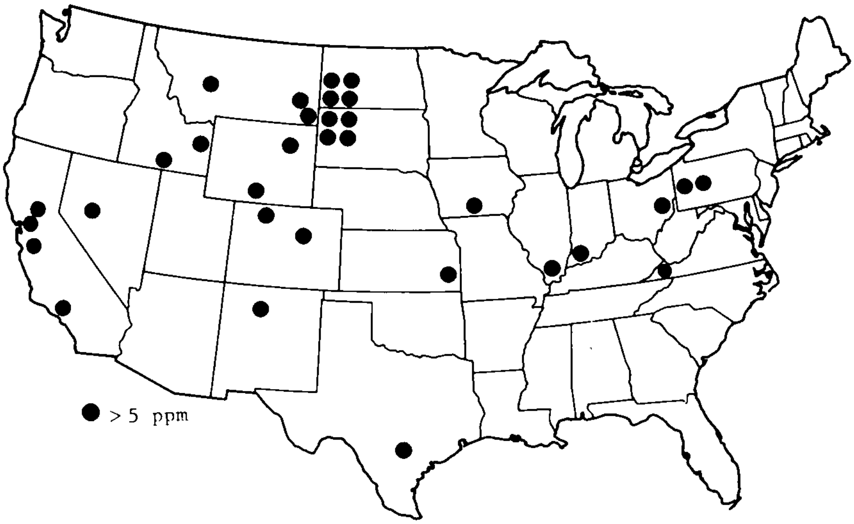

Fig. 1. Locations of High-Uranium Coals (Literature Data)

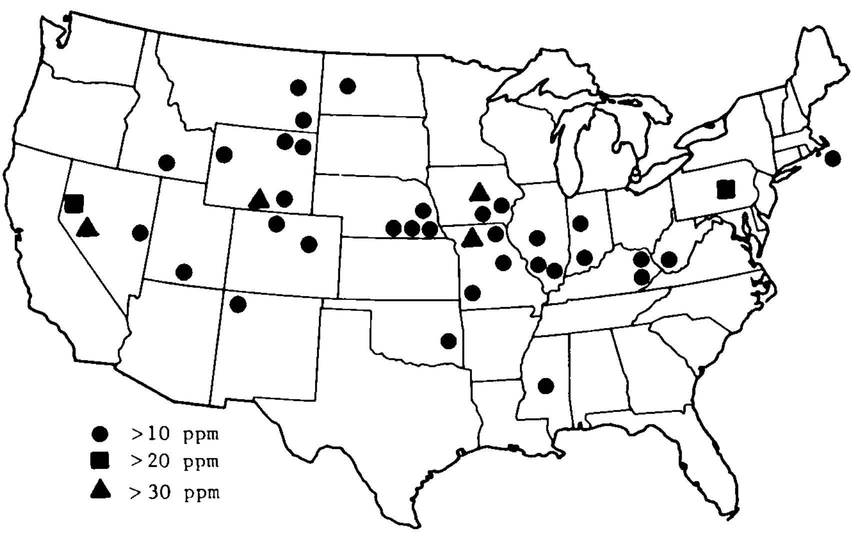

Fig. 2. Locations of High-Uranium Coals (USCHEM Data)

Table 2. Uranium in Coal (USCHEM Data)

STATE County	CONCENTRATIONS OF URANIUM IN COAL (ppm) 5	10	15	20	30
ALABAMA					
Choctaw	● *	--	--	--	--
Fayette	● *	--	--	--	--
ARIZONA					
Grahm	● *	--	--	--	--
Pinal	● *	--	--	--	--
ARKANSAS					
Saline	● *	--	--	--	--
COLORADO					
Arapahoe	● X	● *	--	--	--
Elbert	● *	--	--	--	--
Jackson	● *	● *	--	--	--
Mesa	● *	--	--	--	--
Moffat	● *	--	--	--	--
Routt	● *	--	--	--	--
IDAHO					
Cassia	● X	● *	--	--	--
ILLINOIS					
Franklin	● X	● X	● *	--	--
Montgomery	● *	● X	● *	--	--
Perry	● X	● *	● *	--	--
INDIANA					
Dubois	● X	● *	--	--	--
Fountain	● X	● X	● *	--	--
Gibson	● *	--	--	--	--
Sullivan	● *	--	--	--	--
Vermillion	● *	--	--	--	--
Warrick	● *	--	--	--	--
IOWA					
Appanoose	● *	● X	● *	--	--
Davis	● *	--	--	--	--
Mahaska	● *	● X	● X	● *	--
Wapello	● *	● *	● *	● *	● *
KANSAS					
Bourbon	● *	--	--	--	--
Wilson	● *	--	--	--	--
KENTUCKY					
Breathitt	● *	--	--	--	--
Johnson	● X	● *	--	--	--
Lawrence	● *	● *	--	--	--
Leslie	● *	--	--	--	--

Table 2 (Continued)

STATE County	CONCENTRATIONS OF URANIUM IN COAL (ppm) 5	 10	 15	 20	 30
MARYLAND					
Anne Arundel	● *	--	--	--	--
MASSACHUSETTS					
Nantucket	● *	● *	--	--	--
MISSISSIPPI					
Scott	● X	● X	● *	--	--
MISSOURI					
Adair	● X	● X	● X	● X	● *
Audrain	● X	● *	--	--	--
Barton	● X	● *	--	--	--
Bates	● *	--	--	--	--
Henry	● *	--	--	--	--
Macon	● *	● *	● *	--	--
Putnam	● *	● *	● *	--	--
MONTANA					
Big Horn	● *	--	--	--	--
Garfield	● *	● *	● *	--	--
Powder River	● *	● *	--	--	--
Richland	● *	--	--	--	--
NEBRASKA					
Jefferson	● X	● *	--	--	--
Johnson	● *	--	--	--	--
Otoe	● X	● *	● *	--	--
Pawnee	● X	● X	● *	--	--
Richardson	● X	● *	--	--	--
NEVADA					
Churchill	● X	● X	● X	● X	● *
Esmeralda	● *	--	--	--	--
Washoe	● *	● X	● X	● *	--
White Pine	● X	● *	--	--	--
NEW MEXICO					
Colfax	● *	--	--	--	--
San Juan	● *	● *	--	--	--
NORTH DAKOTA					
Dunn	● *	● *	--	--	--
OHIO					
Belmont	● *	--	--	--	--
Muskingom	● X	● *	--	--	--

Table 2 (Concluded)

STATE County	CONCENTRATIONS OF URANIUM IN COAL (ppm) 5	 10	 15	 20	 30
OKLAHOMA					
Craig	● *	--	--	--	--
Haskell	● X	● *	--	--	--
Le Flore	● *	--	--	--	--
Nowata	● *	--	--	--	--
Pittsburg	● *	--	--	--	--
PENNSYLVANIA					
Northumberland	● X	● X	● X	● *	--
TENNESSEE					
Anderson	● *	--	--	--	--
Fentress	● *	--	--	--	--
Scott	● *	--	--	--	--
UTAH					
Kane	● *	● *	--	--	--
VIRGINIA					
Russell	● *	--	--	--	--
WEST VIRGINIA					
Harrison	● *	--	--	--	--
Raleigh	● *	--	--	--	--
Wyoming	● *	● *	--	--	--
WYOMING					
Campbell	● *	● *	● *	--	--
Carvon	● *	● X	● *	--	--
Johnson	● *	--	--	--	--
Sheridan	● *	● *	● *	--	--
Sweetwater	● *	● *	● *	● X	● *
Teton	● *	● *	--	--	--
TOTAL STATES AFFECTED	27	20	10	5	4
Total Counties	79	41	21	6	4

NOTES: There are two sets of symbols for this Table. The first set, ● and --, signifies whether a mine in a particular county may be affected should a uranium-in-coal standard be established at a given level; e.g., a mine in Arapahoe County, CO, may be affected if the standard were set at either 5 or 10 ppm. The second set, * and X, indicates whether at least one sample value is in this interval (as defined by the value in the column heading in question and the next higher column heading value); e.g., Sweetwater County, WY, has coal samples in the 5-10, the 10-15, and the 15-20 ppm ranges, and above 30 ppm, but not in the 20-30 ppm range. Mahaska County, IA, has coal samples in the 5-10 ppm and above 30 ppm ranges, but not in the 10-15 or 15-20 ppm ranges.

A national average of uranium concentration in coal would have more significance if it were feasible to include additional information. Weighting and/or screening factors relating to the mineability and economic worth of various deposits would indicate which uranium-in-coal samples should realistically be included in the computation and by how much. Moreover, samples for which uranium was sought but not detected should be considered since not all coal contains uranium. The nature of the computer request precluded the latter while the former was not feasible due to data gaps in the USCHEM file. Since the basic purpose of the computer request for this study was to determine where samples were which might cause problems if a standard were established at any of several levels, zero concentrations of uranium were not included.

The auxiliary information (e.g., depth, thickness, Btu content) is not uniformly represented in all of the uranium-in-coal samples. Depth-to-seam information is contained in a different information file (not USCHEM), and the identification numbers for samples in the two systems are not necessarily the same. This can create difficulties when trying to cross-reference data. The so-called "thickness" data in USCHEM is vague in the sense that it is not clear whether seam thickness, sample thickness, or bench thickness is implied for the different samples. One would have to review the original field notes to ascertain the type of thickness cited. There are few BTU values in the USCHEM data base. From a printout of samples where the uranium in coal is greater than 5 ppm, approximately half of the samples lacked BTU information.

A geographical/numerical distribution of the uranium concentration data is presented in Table 2 wherein two concepts are considered. One, noted by X and * symbols, provides an approximate distribution of the data by county and state. It is approximate in the sense that an asterisk (*) indicates that at least one data entry occurs in a given concentration interval (e.g., 5-10 ppm, 10-15 ppm). An X indicates no data in the interval.

The other set of symbols, ● *and --, relate to the establishment of a* threshold uranium concentration in coal. If a bullet (●) occurs, there is at least one coal sample in that county which has a higher value than the column heading, and the responsible mine may be affected if a standard is established. Bullets in the first two columns for a given conty do not necessarily mean that samples of 5 and 10 ppm U were found; a single value of 13 ppm U would result in both bullets since either standard (5 or 10 ppm) would be exceeded. At the end of the table is a count of the number of counties and states which might be affected if the value of the column heading were chosen as the standard.

A strictly geographical presentation of data is provided in Figure 2 showing those locations with at least one sample greater than 10, 20, and 30 ppm, respectively. The symbols in Figure 2 delineate those four locations with uranium concentrations in coal above 30 ppm, namely Wapello County, IA (34.6, 35.9, 40.7 and 42.9 ppm U); Adair County, MO (59.5 ppm U); Sweetwater County, CO (75.4 ppm U); and Churchill County, NV (129.5 ppm U).

4.3 Comparison of Literature and Computer Surveys

Information regarding uranium in coal entered into the USCHEM file has a cutoff date in the early 1970s which means that none of the very high (hundreds and thousands of ppm U) readings of the 1950s and 1960s appear in the computer printout.

From Tables 1 and 2, it can be seen that many of the same states are involved. Table 1 contains information from 20 states while 27 states are represented in Table 2 with a total of 30 states altogether. Figures 1 and 2 depict a similar situation although it should be recalled that the cutoff values (5 ppm U for Figure 1 and 10 ppm U for Figure 2) are slightly different.

A notable difference between the two surveys is the lack of data from Texas and South Dakota in the computer results compared to the amount of information presented in the literature survey for these two states. Relative to the literature survey, it is understandable why South Dakota is not represented in the USCHEM file (at least for concentrations greater than 5 ppm U), since most of this state's data appear to have been collected prior to 1970. However, the literature survey indicates high uranium levels in Texas coal samples collected during the 1970s, while the highest value in the USCHEM file is only 4.65 ppm and consequently does not appear in Table 2.

At the end of the discussion for each data set (literature review and computer analysis) several locations where potential impacts might occur were identified. One location is common to both data sets--Sweetwater County, Colorado. This area in the Red Desert was described in 1962 by Masursky as follows [50]:

> Coal reserves and uranium content were calculated for the nine principal coal beds, which range in thickness from a few inches to 42 feet and average about 7 feet. Estimates of uranium content are based on uranium analyses of 1,700 core and auger samples and 500 surface samples obtained in 60 core holes, 140 auger holes, and 79 surface sections. About 24,000 short tons of uranium is contained in 690 million short tons of coal at a grade of 0.003 percent or more uranium. An additional 1,600 million tons of measured and indicated coal contains less than 0.003 percent uranium. About 20 percent of the estimated coal is potentially strippable.
>
> In Battle Spring Flat, the area of highest uranium concentration, the Sourdough No. 2 bed averages 2.8 feet in thickness, underlies 428 acres, and contains 2 million tons of coal with an average uranium content of 0.010 percent; the coal ash averages 0.030 percent uranium. Locally, thin splits of this bed contain as much as 0.047 percent uranium and 0.140 percent uranium in the coal ash. The 103 proximate and 16 ultimate analyses of cores show that the coal contains an average of about 16 percent ash, 2.5 percent sulfur, and 21 percent moisture and has an average heating value of about 7,900 Btu on an as-received basis. The coal is subbituminous B in rank.
>
> Results of the investigation indicate that the large reserves of coal in the Red Desert are of interest primarily as a fuel resource and that uranium probably can be produced only as a byproduct.

Several features of this quotation are of interest: the large number of samples analyzed, the average uranium content of 30 ppm U or more, the large tonnages (approximately 140 million short tons) of potentially strippable coal, moderate ash content, somewhat high sulfur content, and subbituminous B rank. Other than the sulfur and ash contents, these deposits might be considered fairly attractive for direct combustion, gasification, or liquefaction.

Many years later, the deposits in Sweetwater County are still receiving attention regarding the extent of the deposit and the uranium content [18]. Toth et al. note that this coal may be "more commercially desirable for direct combustion than the lower grade lignite in most states...(which) may be more amenable to coal conversion systems" [10].

The quantities of coal involved may be significant. For 1981 it was estimated that 600 million short tons of coal were consumed by all electric utilities in the U.S. [51]. A new coal-fired utility boiler of 1000 MWe capacity is estimated to consume 3 million short tons of coal annually [1]. Thus, it is conceivable that these deposits could supply several moderately sized power plants for many years.

5. TEXAS LIGNITE

With the renewed optimism regarding the future use of lignite as an energy source in Texas [52], reports of extremely high uranium concentrations in Texas lignite [53, 46, 54] need examination. Parks notes that economic (i.e., greater than 200 ppm U) uranium deposits in Texas are often associated with lignite [55].

Published concentrations of uranium in Texas lignites vary considerably. Deul and Annell reported that the lignite from Milam County showed such a low radioactivity that uranium determinations were not made [44]. Using coal and lignite samples from 12 counties (including Karnes County), Kohls looked for, but did not detect, either uranium or thorium [56]. On the other hand, Huang and Chatham report uranium concentrations in lignite ranging from 1 to 7 ppm in Wilcox lignite, 4 to 70 ppm in Yegua-Jackson lignite, and 1-7800 ppm in Upper Jackson lignite [46]. Cooper et al. [7] mention "unsubstantiated reports of uranium concentrations of as much as 80 to 300 ppm by weight in some South Texas lignite coals. . ." Cooper also refers to a roasting recovery operation in Karnes County for burning uranium-bearing lignites with 300 ppm U. Mohan et al. analyzed several lignite samples from the Jackson formation in Karnes County and found uranium concentrations varying from 950 to 2450 ppm [47]. Toth et al. mention 32 small strip mines of uraniferous lignite in Karnes County containing 0.05 percent U_3O_8, or 440 ppm U [10]. Recently, White et al. compiled a listing of uranium-in-lignite values from 102 samples with a mean of 1.8 ppm covering a range from 0.4 to 6.2 ppm [48].

Much of this apparent discrepancy in uranium content can be explained in terms of the quality and use of the lignite. Much of the lignite under consideration is impure being mixed with sandstone and/or shale and is not suitable for combustion use. Such impurities are not necessarily a disadvantage when the lignite is used for uranium extraction by roasting since the interspersed or contacting sandstones and shales are often high in uranium. Facer remarks that many of the lignite beds are very thin [15].

In 1979, while studying the relationship between stratigraphy and uranium deposition, Chatham surveyed a 4-acre section of southwestern Karnes County, Texas [57]. Nine vertical profiles in this area indicated two seams of lignite, each about one to two feet thick, separated by approximately one foot of mudstone, and lying within 60 feet of the surface. Most of the approximately 150 samples in the lignite contained in the range of 20 to several hundred ppm U while several samples, particularly near the lower contact of the lower seam, contained a few thousand ppm U. No information was provided regarding the quality (impurities or Btu content) of the lignite.

Zingaro notes that large concentrations (i.e., several thousand ppm) of uranium in Texas lignite are quite rare and occur in very localized small quantities [58]. He characterizes the sample yielding 7800 ppm U as a "freak inclusion" of lignite into a shale formation. He also notes that, while concentrations in the hundreds of ppm are not uncommon, the occurrences are widely dispersed and involve mostly impure lignites unsuitable for direct combustion purposes.

6. SUMMARY

Based on recent data from the USCHEM file, the "national average" for uranium in coal is essentially the same as that proposed by Swanson in 1976 (i.e., 1.8 ppm U). Although most of the early high-uranium samples have been omitted from either computation, these high values have largely been shown to be in coal which was either too impure, in a bed too thin or too deep, too low in heat content, or otherwise unsuitable as a fuel for a power plant. Because earlier geologists were looking primarily for uranium, they were not always careful in defining the host medium, often designating as coal those substances which might more properly be termed as coaly, lignitic, or carbonaceous shales.

If EPA should consider establishing a uranium-in-coal standard, it should be based on the isotope U-238 contained in coal and related to the coal's heat content. Moreover, the health effects of other radionuclides in coal should be taken into account. If the standard is approximately 20 ppm uranium in coal, most mines in the country would not be affected. However, there are a few areas in the country (e.g., in Wyoming, Colorado, Texas, South Dakota, Missouri, Nevada) where coal deposits may be of commercial interest and contain enough uranium to warrant further investigation.

Based on Swanson's 1976 data, Wagner and Greiner concluded that there was a significant probability that one or two power plants might burn coal with uranium content greater than 30 ppm for long periods of time [25]. Supplementing their data with information from the present literature review and the recent computer search, one might infer that a few more power plants could be involved--and this inference may possibly be extended if a standard were established at a lower concentration of uranium in coal.

Lacy and his colleagues believe that over the long run, the blending and averaging of coal for direct combustion will be sufficient to mitigate any real problems, but some seams may have to be segregated [54]. These discussions regarding the number of power plants possibly affected and the use of coal blending refer primarily to the smaller, older power plants not necessarily adhering to NSPS controls.

The potential for radionuclide releases from the development and utilization of synthetic fuels should also be of concern since the raw materials (often lower rank coals and/or carbonaceous shales) may have high uranium content.

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