175
6-29-84 JS (1)

DR# 0154-6

DOE/ET/13800-7
(DE84008562)

Energy

F
O
S
S
I
L

RADIONUCLIDES IN U. S. COALS

By
C. A. Bisselle
R. D. Brown

March 1984

Work Performed Under Contract No. AC01-80ET13800

The MITRE Corporation
Metrek Division
McLean, Virginia

Technical Information Center
Office of Scientific and Technical Information
United States Department of Energy

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report has been reproduced directly from the best available copy.

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Printed Copy A05
Microfiche A01

Codes are used for pricing all publications. The code is determined by the number of pages in the publication. Information pertaining to the pricing codes can be found in the current issues of the following publications, which are generally available in most libraries: *Energy Research Abstracts (ERA)*; *Government Reports Announcements and Index (GRA and I)*; *Scientific and Technical Abstract Reports (STAR)*; and publication NTIS-PR-360 available from NTIS at the above address.

Radionuclides in U.S. Coals

C. A. Bisselle
R. D. Brown

March 1984

MTR-83W234

SPONSOR:
U.S. Department of Energy
Office of Fossil Energy
CONTRACT NO.:
DE-AC01-80ET13800, Task 29

The MITRE Corporation
Metrek Division
1820 Dolley Madison Boulevard
McLean, Virginia 22102

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

ABSTRACT

The current state of knowledge with respect to radionuclide concentrations in U.S. coals is discussed. Emphasis is placed on the levels of uranium in coal (and lignite) which are considered to represent a concern resulting from coal combustion; areas of the U.S. where such levels have been found; and possible origins of high radionuclide levels in coal. The report reviews relevant studies and presents new data derived from a computerized search of radionuclide content in about 4,000 coal samples collected throughout the coterminous U.S.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

TABLE OF CONTENTS

	<u>Page</u>
LIST OF ILLUSTRATIONS	vi
LIST OF TABLES	vii
EXECUTIVE SUMMARY	ix
1.0 INTRODUCTION	1
2.0 BACKGROUND	5
3.0 LEVELS OF CONCERN	11
4.0 FACTORS RELEVANT TO THE DEVELOPMENT OF A STANDARD	13
4.1 Radionuclides of Interest	13
4.2 Heating Value of Coal	18
4.3 Origin of Uranium in Coal	19
4.4 Organic Binding	21
4.5 Reserve Classification System	22
4.6 Secular Equilibrium	24
4.7 National Average	25
5.0 LITERATURE SEARCH	27
5.1 Procedure	27
5.2 Results	27
6.0 COMPUTER SEARCH	43
6.1 Procedure	43
6.2 Results	43
7.0 COMPARISON OF LITERATURE AND COMPUTER SURVEYS	57
8.0 TEXAS LIGNITE	61
9.0 SUMMARY	65
APPENDIX A: BIBLIOGRAPHY	A-1
APPENDIX B: INFORMATION NEEDS	B-1

LIST OF ILLUSTRATIONS

	<u>Page</u>
FIGURE 1: LOCATIONS OF HIGH-URANIUM COALS (NON-USCHEM)	39
FIGURE 2: DISTRIBUTION OF URANIUM IN COAL SAMPLES FROM USCHEM DATA BASE (0 - 14 PPM)	44
FIGURE 3: DISTRIBUTION OF URANIUM IN COAL SAMPLES FROM USCHEM DATA BASE (10 - 140 PPM)	45
FIGURE 4: URANIUM IN COAL: READINGS OVER 10 PPM (USCHEM DATA)	55
FIGURE 5: URANIUM IN COAL: READINGS OVER 20 PPM (USCHEM DATA)	56

LIST OF TABLES

	<u>Page</u>
TABLE 1: RELATIONSHIPS AMONG THE VARIOUS RADIONUCLIDES IN COAL	16
TABLE 2: URANIUM IN COAL (NON-USCHEM DATA)	28
TABLE 3: LOCATIONS OF HIGH-URANIUM COALS (NON-USCHEM)	40
TABLE 4: STATISTICAL INFORMATION ASSOCIATED WITH THE USCHEM PRINTOUT	47
TABLE 5: URANIUM IN COAL (USCHEM DATA)	50

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

EXECUTIVE SUMMARY

During the past 40 years, interest in the uranium content of coal has changed considerably. At one time, the uranium content was thought of as a valuable resource. Now, it is considered a potentially hazardous impurity. With the advent of nuclear power in the late 1940s and early 1950s, uranium acquired a tremendous importance and the search for new deposits of uranium led to the discovery of appreciable concentrations of uranium in the low-rank coals of several western states.

Implications for future energy development 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. for both direct combustion and use in synthetic fuel conversion; western coal is highly desirable 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; and, most of the reported findings of high uranium content in coal are in western states.

A reasonable 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 be true. Several studies 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. However, these studies were based on coals containing only a few ppm uranium unlike some of the high uranium coals discovered in the 1950s.

On April 6, 1983, the U.S. Environmental Protection Agency (EPA) proposed national emission standards for radionuclides (48 FR 15076). Although coal-fired boilers were placed in the category of sources for which standards were not proposed, "EPA did consider the possibility that boilers may be using coal with radionuclide content that is significantly above average..." and that "there could be a subcategory of coal-fired boilers for which it would be appropriate to issue an emission standard." An emission standard could be based on the uranium content in the coal.

A prerequisite to the determination of such a standard is a knowledge of the extent of radionuclides in coal throughout the country. This report discusses the current state of knowledge with respect to radionuclide concentrations in coal with emphasis on the

levels and locations of uranium in coal which may represent a concern with respect to the combustion of coal. It presents new data derived from a computerized search (the USCHEM data base maintained by the U.S. Geological Survey) of uranium content in approximately 3,800 coal samples collected throughout the coterminous U.S. The report also summarizes information contained in early documents (from the 1950s and the 1960s) wherein are noted potentially extensive quantities of uranium-bearing coal in various western states.

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 ranging from 5 to 30 ppm, which are essentially based on such a concept.

The results of the literature and computer searches for uranium-in-coal information indicate that many of the coals with high uranium content may not be of significance relative to hazardous radioactive emissions from coal combustion at power plants for a variety of reasons, including: low uranium content in most of a seam, too few samples, deposits too deep, beds too thin, minor or few occurrences, impure coal, low heating value, and high ash content.

If a standard of uranium in coal were established within the range mentioned above, 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.

It should be noted that this report represents only one component of reviews which are necessary to understand the subject of radionuclide emissions from coal-fired facilities. Other topics which require review and additional information are health effects assessment; exposure assessment; source terms; and mass balance within coal preparation, cleaning, and combustion processes. Additional information is also needed to clearly understand the nature and extent of radionuclide concentrations in economically mineable coals. Appendix B contains a listing of information needs and related research and development activities identified during the preparation of this report.

1.0 INTRODUCTION

On April 6, 1983, the U.S. Environmental Protection Agency (EPA) proposed national emission standards for radionuclides (Federal Register, Vol. 48(67): 15076-15091). Although coal-fired boilers were placed in the category of sources for which standards were not proposed, "EPA did consider the possibility that boilers may be using coal with radionuclide content that is significantly above average..." and that "there could be a subcategory of coal-fired boilers for which it would be appropriate to issue an emission standard."

There are several different forms that an emission standard could take: mass or activity* of a particular radionuclide emission per unit time (e.g., grams or curies per day); mass or activity of emission per unit heat input (e.g., grams or curies per joule); concentration of a radionuclide in the stack (e.g., curies per cubic meter); dose to an off-site individual or population per unit time (e.g., millirem per year); efficiency of pollution control equipment (e.g., 99.9 percent collection efficiency of an electrostatic precipitator); or concentration of a radionuclide(s) in the coal to be burned (e.g., curies or grams per gram per unit heat input).

A prerequisite to the determination of a radionuclide standard for emissions from coal combustion (especially one based on the

*The activity of a radionuclide may be expressed either as curies (Ci) or becquerels (Bq) per unit mass, where:

1 Ci = 3.7×10^{10} (exp 10) disintegrations per second;

1 Bq = 1 disintegration per second.

radionuclide content in the fuel) is a knowledge of the extent of radionuclides in coal throughout the country. This report discusses the current status of radionuclide concentrations in coal with emphasis on the levels and locations of uranium in coal (including lignite). The report also reviews relevant documentation and 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.

This report summarizes information contained in early documents (from the 1950s and the 1960s) wherein are noted potentially extensive quantities of uranium-bearing coal in various western states. Also reviewed are more recent analyses, indicating that the problem of radionuclides in coal is minimal. Differences between these two outlooks are discussed.

Also contained in this report are brief discussions of the history of searching for uranium in coal, the origins of uranium in coal, the reserve/resource classification system as it relates to the potential mineability of uranium-bearing coals, and the cleanability of coal relative to uranium.

A number of information needs and related research and development activities were identified during the preparation of

this report. They relate to the categories of existing data, new data, measurement and monitoring, fuel processing and combustion, and health effects assessment. These categories are discussed in Appendix B.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

2.0 BACKGROUND

During the past 40 years, the nature of the interest in the uranium content of coal has changed considerably. At one time the uranium content was thought of as a valuable resource, while more recently it has generally been considered as a potentially hazardous impurity.

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 (Mattson, 1970). 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 of uranium.

In the late 1940s, deposits of radioactive coal were discovered by the U.S. Geological Survey (USGS) in the Red Desert of Wyoming and the Fort Union Formation of North and South Dakota. The result of these discoveries was 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 (Denson, 1959; Vine, 1962). Emphasis was placed on finding coal in beds of mineable thickness, depth, and grade that could be used as fuel and from which uranium could be extracted as an ash byproduct.

Although there were interesting discoveries of coaly, lignitic, and carbonaceous shales as well as impure coals in the areas of Fall Creek and Goose Creek in Idaho, La Ventana in New Mexico, and Pumpkin Buttes in Wyoming, 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 (Vine, 1962; Miller and Gill, 1954). 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 (George, 1966).

Six years later, commercial uranium recovery operations began at four locations in southwestern North Dakota with a cutoff concentration of 1500 ppm U_3O_8 .^{*} 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 pits themselves. Because of the low heating value of the lignite "ore" (on the order of 5000 BTU per pound), it was sometimes necessary to augment the burning by tossing rubber tires onto the smoldering piles (Mitchel,

^{*}Since uranium comprises 88% of U_3O_8 by weight, this cutoff concentration, below which commercial operations were considered not worthwhile, is 1320 ppm U.

1965). For commercial (but not necessarily environmental) 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 lignites for the primary purpose of uranium recovery. A uranium content of 300 ppm was reported to be in the lignite (Cooper et al., 1979), but further evaluation reveals that this "lignite" was impure, being mixed with sandstone and shale (Zingaro, 1983).

The concept of extracting uranium from coal ash has remained of interest and continues to be studied (Wright and Roffman, 1976; Hurst, 1980; Toth et al., 1980; Vanderborgh, 1982). To ensure profitability, economics require that the coal in recent analyses would be, unlike the 1963-1967 experience in North Dakota, 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. Based on the concept of 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 (Martin et al., 1969; McBride et al., 1977) indicate that the radiological impacts

from a coal-fired plant may be as large, if not more so, than those for a comparably sized nuclear power plant. Another study (U.S. EPA, 1979), 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 the above studies, two important 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 with regard to 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 desirable 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 reasonable 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 be true. Several studies performed for or by the U.S. Department of Energy 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 (Facer, 1979; Beck et al., 1980; Abbott et al., 1983). The studies dealing with emissions did not specify the level of control technology in use at particular plants. However, the western coals cited in the studies were generally of moderate rank and not from seams identified in this report as having relatively high uranium levels. The reader should note that particulate emissions from new utility boilers (independent of location) will be controlled largely by electrostatic precipitators or fabric filter systems, resulting in a

substantial reduction in radionuclide emissions compared to the absence of such controls (U.S. EPA 1983).

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 (Lee et al., 1977; Koester and Zieger, 1978; U.S. EPA, 1983b). Although beyond the scope of this study, 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).

Thus, it can be seen that over the past four decades uranium in coal has shifted from being a valuable constituent extensively searched for as a commodity to being an impurity regarded as a potential hazard.

3.0 LEVELS OF CONCERN

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.

<u>Uranium Concentration</u>	<u>Reference</u>
5 ppm	Van Hook, 1978
6 ppm	Greiner, 1983
10 ppm	Hardin et al., 1982
20 ppm	Greiner, 1981
30 ppm	Wagner and Greiner, 1982

All of the authors qualify their estimates in one way or another. Van Hook (1978) 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 et al., (1976), as quoted in Styron (1980) noted that some deposits with U-238 concentrations as high as 44 ppm (before cleaning) are being used by electric power utilities in

*One may infer from Patterson's (1983) quotation 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.

the United States. 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.

4.0 FACTORS RELEVANT TO THE DEVELOPMENT OF A STANDARD

4.1 Radionuclides of Interest

The number of coal seams perceived as having "high" concentrations of radionuclides is inversely related to the value of the criterion used to protect human health. The scientific basis for the establishment of a regulatory standard based on uranium in coal should be well founded with respect to the concentration itself, the radionuclide or radionuclides upon which it is based, and health effects implications, both nationwide and near the site of combustion.

Since the values (5, 6, 10, 20, and 30 ppm of uranium in coal) mentioned earlier 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 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 a 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).

The most important radionuclides found in coal are uranium-238 and thorium-232 (plus their daughters) as well as potassium-40. For many samples (particularly 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. Both uranium and thorium data appear as trace elements in the USCHEM coal data base developed by USGS while potassium is listed as the oxide. Of the dozens of documents reviewed for this study, relatively few (e.g., Wagner and Greiner, 1982; Kary and McKlveen, 1981; Coles et al., 1978; Barber and Giorgio, 1977; Lee et al., 1977; Miller and Beck, 1981; and Bluskoter et al., 1977) even acknowledge the possibility of a potassium-40 contribution, and only the last three-mentioned documents provide any data.

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.

The most commonly measured radionuclide in coal is uranium-238. Some of the earlier concentrations resulted from chemical measurement of the element uranium, but this effectively has the same concentration (in ppm) as U-238 since the latter comprises over 99.2 percent of the former. Assuming that the measurement procedure for U-238 is no more complicated than for any of the other radionuclides present in coal, this isotope could be selected as the basis for the standard.*

To account for the other isotopes requires knowledge of two kinds of relationships--the geneology of individual decay series and the correlations between uranium, thorium, and potassium. As shown in Table 1, there are several relationships which can be traced to U-238. Within each of the decay series, any daughter radionuclide can be related to its original precursor. Furthermore, Th-232 and K-40 concentrations in coal can be related to those of U-238 via correlation factors or other parameters associated with least squares fitting procedures.

Gluskoter and his colleagues (1977) examined 114 Illinois coal samples for approximately 60 elements and calculated linear regression (least squares) correlation coefficients among the elements found including uranium, thorium, and potassium. While the

*If it is determined that another radionuclide is easier, less expensive, or more practical to monitor, then this other isotope may be used as the basis.

TABLE 1
RELATIONSHIPS AMONG THE VARIOUS
RADIONUCLIDES IN COAL

<u>CORRELATION C1</u>		<u>CORRELATION C2</u>	
<u>URANIUM</u> <u>SERIES</u>		<u>THORIUM</u> <u>SERIES</u>	<u>POTASSIUM</u>
<div style="display: flex; align-items: center;"> <div style="writing-mode: vertical-rl; transform: rotate(180deg); margin-right: 5px;">DECAY SERIES D1</div> <div style="flex-grow: 1;"> U-238 Th-234 Pa-234 U-234 Th-230 Ra-226 Rn-222 Po-218 Pb-214 Bi-214 Po-214 Pb-210 Bi-210 Po-210 Pb-206 </div> </div>		<div style="display: flex; align-items: center;"> <div style="writing-mode: vertical-rl; transform: rotate(180deg); margin-right: 5px;">DECAY SERIES D2</div> <div style="flex-grow: 1;"> Th-232 Ra-228 Ac-228 Th-228 Ra-224 Rn-220 Po-216 Pb-212 Bi-212 Po-212 Tl-208 Pb-208 </div> </div>	K-40

- NOTE: • Based on 114 Illinois coal samples, the correlation coefficient between uranium and thorium (C1) is 0.18 while that for uranium and potassium (C2) is 0.12 (Gluskoter et al., 1977).
- According to Coles et al. (1978), the radionuclides in the uranium decay series (D1) appear to be in secular equilibrium. Abbott et al., 1983 indicate that for western coals, both the uranium (D1) and thorium (D2) series daughters are in secular equilibrium with their respective parent isotopes.

isotopes U-238 and Th-232 comprise 99.3 percent and 100 percent, respectively, of their naturally occurring elements, K-40 is less than 0.2 percent of naturally occurring potassium (U.S. Public Health Service, 1970). Thus, on the basis of percentage composition, the correlation between the elements uranium and thorium also represents the correlation between the isotopes U-238 and Th-232. Since the natural abundance of K-40 at 0.118 percent is a constant factor, the correlation between the element potassium and the isotope potassium is unity. Therefore, the correlation between uranium (or U-238) and potassium is the same as the correlation between uranium (or U-238) and K-40. A similar argument based on the constancy of U-238 in uranium, as opposed to the nearness of 99.3 percent to 100 percent, could also have been used to establish that U-238 correlates with thorium the same as the element uranium.

The correlation coefficients between uranium and thorium (or U-238 and Th-232) and between uranium and potassium (or U-238 and K-40) are 0.18 and 0.12, respectively. They are both positive correlations, but neither is very strong. Of the elements compared, the strongest correlation with uranium was the element vanadium, with a correlation coefficient of 0.55. Moreover, they apply only to the 114-sample set of Illinois coal.

If a regulatory standard were to be based on the uranium content of coal, it would be appropriate to provide additional correlations (to determine correlation coefficients as well as proportionality

factors) perhaps using the USCHEM data base of the USGS. Thorium concentrations are presented as trace elements, but potassium-40 values would have to be determined from the listing of potassium oxide (K_2O) data.

The assumption of secular equilibrium within each of the two decay series appears applicable in general (at least for western coals), but interpreting correlations between the elements may be more problematic, because the leaching and migration of trace elements into coal are highly dependent on local conditions. For example, correlations derived from the USCHEM data base generally consider fairly low uranium or thorium contents. A separate correlation analysis should be performed for coal samples with very high (hundreds of ppm and above) uranium levels since the peculiar local conditions (e.g., acidity in overlying strata) which caused the large uranium migration may not have had a similar effect regarding thorium. Very few of the large uranium measurements made in the 1950s are accompanied by reported thorium analyses. Thus, it may be difficult to perform the statistical analyses until further chemical analyses are performed.

4.2 Heating Value of Coal

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 (Mitchell, 1965). 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 (George, 1966). Some specimens of the uraniferous lignite outcrops in the Cave Hills (South Dakota) region would not burn under a blowtorch flame (King and Young, 1956).

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, anthracite coal and some bituminous coals are more properly described in terms of fixed carbon and volatile matter limits rather than heating value (Wood et al., 1983). 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.

4.3 Origin of Uranium in Coal

Basically, there are three hypotheses relating to the occurrence of trace elements such as uranium in coal (Pipiringos, 1961):

Syngenetic--the uranium accumulated before or during the early stages of coal formation. It was introduced into the swamps by ground and surface water or by direct uranium-bearing ash falls.

Diagenetic--the uranium accumulated during or shortly after the formation of the coal, but before the hardening of the coal and the surrounding sediments.

Epigenetic--the uranium accumulated after the coal beds and surrounding rocks were formed, hardened, folded, and eroded. Uranium was introduced into the coal by circulating groundwater.

The main difference among these hypotheses is one of timing of the uranium deposition relative to the process of coalification. These three hypotheses have been refined and expanded upon (White et al, 1983), but the essential concepts still apply. The epigenetic theory is believed to pertain to most western coals (Pipiringos, 1961; Lee et al., 1977, Mohan et al., 1982), although combinations of all three hypotheses may account for the present distribution of uranium in coal (Pipiringos, 1961).

Geochemical studies suggest that the uranium entered the coal in aqueous solution, probably as a complex alkali or alkaline earth uranyl carbonate. The slightly acidic environment of the coal decomposed these complexes and the uranium was absorbed by the coal and subsequently reduced to uranite (Ergun, 1968). Alternatively, if sufficient silica is present in solution, the mineral coffinite can form instead (Breger, 1958).

The less extensive metamorphosis of lignite influences the geochemistry of inorganic constituents. Because of the greater number of available bonding sites in lignites, ion-exchange reactions (uranium has a very high ionic potential) are much more common than in higher rank coals (White et al., 1983). Experiments by Moore (1954) showed that low rank coals (lignite and subbituminous) are more effective in extracting uranium from solution than are anthracitic or bituminous coals. No significant deposits of uranium in bituminous or anthracitic coals are known in

the U.S.; deposits in excess of 50 ppm uranium rarely exceed a few tons in size (Vine, 1962). In fact, the uranium content of higher rank coals rarely exceeds 10 ppm (Abernathy and Gibson, 1963).

Uranium is often concentrated in the top or bottom few inches of thick beds of lignite or subbituminous coal near the contacts of the coal seam with sandstone or shale (Vine, 1962; Lacy et al., 1979; Mohan et al., 1982).

4.4 Organic Binding

The way in which uranium is bound to the coal has particular significance with regard to the cleanability of coal. It has been estimated that between 15 percent (Vanderborgh, 1982) and 50 percent (Beck et al., 1980) of the coal used annually by electric utilities undergoes some form of cleaning. Uranium has been found to be both inorganically and organically associated in coal (Cahill and Shiley, 1981).

However, the uranium in western coal typically occurs as an organo-uranium complex and distinct uranium minerals are rarely present (Abernathy and Gibson, 1963). In samples of Texas lignite, Mohan et al., (1982) found that a considerable portion of the uranium is associated with the organic phase. Gluskoter and his colleagues (1977) developed an organic affinity index for coal as a measure of its washability. Mixed results were obtained using five samples from Illinois, but, by and large, the uranium was determined to be bound organically, indicating that routine washing would not

remove the uranium. Finkelman (1980) notes that, while the mode of occurrence of uranium is variable, at least 80 percent of the uranium is organically bound in Appalachian coals. However, he also notes that in one sample of a Missouri coal all the uranium was inorganically bound in the form of micron-sized grains of uraninite.

4.5 Reserve Classification System

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 (Wood et al., 1983). Within the category of identified resources are the subcategories of reserves, marginal reserves, and subeconomic resources.

In the context of uranium concentration in coal, the present discussion focuses on subbituminous coal and lignite because abnormally high uranium concentrations are rare in anthracite or bituminous coals.

While a detailed explanation of the current classification system is beyond the scope of this study, it is sufficient to note that five feet is the minimum thickness for a subbituminous coal or lignite bed to be classified as either reserve or marginal reserve, with 30 inches as the minimum thickness for subeconomic resources. This bed thickness criterion applies to demonstrated, inferred, and

hypothetical situations (the one situation not involving a thickness criterion is for "speculative resources" where the only criterion is that the resource be less than 6000 feet deep). This is not to say that thin beds have not been and are not being mined; only that, as a general rule, such thin beds would not appear to be economically worthwhile at this time.

A number of criteria, both engineering and economic, are involved in determining the classification of a particular coal bed including depth of bed, thickness of bed, rank and quality of coal, spatial distribution of samples, recoverability factor, price of coal, cost of equipment, labor and transportation costs, taxes, supply and demand, weather conditions, and environmental/regulatory restrictions (Wood et al., 1983).

The category of prime interest relates to those resources which are economically obtainable in light of the several parameters mentioned above. This category was termed "recoverable, identified reserves" in 1972 (Theobald et al., 1972), "recoverable reserves" in 1974 (Averitt, 1974), and "economic demonstrated reserves" today (Wood et al., 1983). In the two earlier documents, the recoverable reserves amounted to approximately 10 percent of the estimated total resources.

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 is questionable.

4.6 Secular Equilibrium

For most coal samples, it may be assumed that the uranium-238 and the thorium-232 are in secular equilibrium with their respective daughter products (Abbott et al., 1983). This is a condition which occurs when a parent radionuclide has a much longer half-life than its daughters and all of the nuclides in a given decay series remain relatively stationary. In other words, radionuclides do not leave or enter the coal sample by gaseous diffusion (e.g., radon gas has great mobility under certain circumstances) or by leaching. The effect of this secular equilibrium condition is that all of the radionuclides in a given series have the same specific activity (as measured by curies or becquerels per gram). They do not have the same ppm values, however; this straight-forward determination further involves the atomic weight and half-life of the radionuclide. Thus, specific activities of all the members of a decay series can be estimated by measuring only one or two members.

4.7 National Average

Several authors (McBride et al., 1977; National Research Council, 1979; Wagner and Greiner, 1982; and Abbott et al., 1983) 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 (1976) who measured approximately 800 samples of coal from different parts of the country. 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 (NGPRP, 1974). Moreover, there is no indication of the tonnage or mineability associated with the samples. Nevertheless, these values have gained wide acceptance. Values of 1.7 ppm U and 4.5 ppm Th are reported by Beck et al. (1980) on the basis of 910 samples (including the 800 samples from Swanson). Van Hook (1978) considers 1 ppm U and 2 ppm Th to be "reasonable national averages." With the application of screening and weighting factors (thickness and BTU rating) Greiner et al. (1983) have attempted to apply some measure of economic worth to the coal associated with the samples within the USCHEM information base. The results of their analysis indicate a national average of 1.3 ppm U.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

5.0 LITERATURE SEARCH

5.1 Procedure

At the beginning of this study, a computerized literature search was performed using the NTIS Data Base and Georef Data Base accessed through the DIALOG system (operated by the Dialog Information Services, Palo Alto, California) as well as the Energy Data Base and Research-in-Progress Data Base accessed through the RECON system (operated by Oak Ridge National Laboratory, Oak Ridge, Tennessee for the U.S. Department of Energy). Using keywords such as coal, lignite, uranium, thorium, and several variations of the word "radioactivity" (e.g., radioisotopes, radiochemicals), a total of 435 titles with abstracts were printed. Of these, approximately 60 primary documents were ordered. Together with other secondary articles and reports obtained from the primary reference listings, approximately 110 documents were reviewed for this study.

5.2 Results

The results of a literature search for uranium-in-coal information are summarized in Table 2, where information on approximately one hundred sampling programs (from single samples to dozens and even hundreds of samples per program) in some 22 states (see Figure 1 and Table 3) is provided. As can be seen from Table 2, the thorium content of the coal frequently was not measured. From the comments column, one can infer that many of the coals associated with these findings may not be of significance

TABLE 2
URANIUM IN COAL
(NON-USCHEM DATA)

Location	U(ppm)	Th(ppm)	Comments
ALABAMA			
---	0.9 - 2.9	5.4	Kuhn, et al., 1980; two samples, INAA.
ARIZONA			
---	10.7	1.4	Kuhn et al., 1980; one sample, INAA.
Black Mesa Mine	10.2 - 1.1	2.1 - 4.6	{ Kary and McKlveen, 1981.
McKinley Mine	0.85	---	
Cholla	0.58 - 1.19	---	{ Southwestern Energy Study Group, 1972 as reviewed in Wright and Raffman, 1976.
Navaho	0.68 - 0.77	---	
CALIFORNIA			
Los Angeles Co.	200	---	{ Moore and Stephens, 1953 as reviewed by Kehn, 1957; thin beds, "minor occurrences".
San Benito Co.	50	---	
Amador Co.	40	---	
Alameda Co.	30	---	
COLORADO			
---	1	5	Kessler et al., 1973; one sample, SSMA.
Jefferson Co.	1000 - 5000	---	Gude and McKeown, 1953, as reviewed in Kehn, 1957; small lenticular bodies.

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

USCHEM is a U.S. Geological Survey Data Base.

Coal tonnages are in short tons or millions (M) of short tons.

TABLE 2 (Continued)

Location	U(ppm)	Th(ppm)	Comments
Hayden	0.58 - 1.12	---	Southwestern Energy Study Group, 1972 as reviewed in Wright and Roffman, 1976.
Canon City Field	0.5 - 2.9	13.0 - 10.8	<div> <div>6 samples</div> <div>3 samples</div> <div>17 samples</div> <div>21 samples</div> </div> <div> Boreck et al., 1977; U values G5ppm include 5.4, 5.8, 10.5, 11.4, 12.5, and 23.7, all in North Park Field. </div>
Boulder/Weld Field	0.4 - 0.7	13.0	
Yampa Field	10.2 - 2.3	13.0 - 10.2	
North Park Field	10.2 - 23.7	13.0 - 34.8	
arith. mean	4.1	6.1	
geo. mean	1.6	4.5	
IDAHO			
Goose Creek area (Cassia Co.)	max. 1100	---	Schopf and Gray, 1954; Hole 2, impure coal, 245 ft. deep, 4 ft. thick.
Cassia Co.	max. 970	---	Mapel and Hall, 1959 as reviewed in Abernathy and Gibson, 1963.
Fall Creek Area (Bonneville Co.)	max. 1300 avg. 200	---	Vine and Moore, 1952 as reviewed in Kehn, 1957; impure coal, "possible commercial deposit".
ILLINOIS			
Herrin No. 6 bed	0.8 - 7.5 avg. 2.2	1.37 - 3.9 ---	Kuhn et al., 1980; 15 samples, INAA.
Sahara Coal Co. Mine No. 6	85	---	Vine, 1962; 2 samples, 1 ft. thick bed.
Southern	1.18 - 1.22	---	Carter, 1975; 4 samples, TEMS, coal.
Herrin No. 6	0.5 - 4.5 avg. 1.6 ± 1.1	1.2 - 3.3 2.01 ± 0.47	Gluskoter, 1976; 25 samples, INAA.

TABLE 2 (Continued)

Location	U(ppm)	Th(ppm)	Comments
ILLINOIS (continued)			
Herrin No. 6	0.2 - 28	---	Gluskoter, 1976; bench sample K, 7 ft. thick seam, top 3 or 4 inches has 28 ppm U, while rest of sample has no more than 1 ppm.
---	0.3 - 4.6 mean 1.5 ± 0.9	0.7 - 5.1 2.1 ± 0.9	Gluskoter, 1977; 56 samples.
INDIANA			
Linton	20	---	Vine, 1962; 0.7 ft. thick.
Gentryville	12	---	Vine, 1962; 1.2 ft. thick.
---	10	---	Snider, 1954 as reviewed in Abernathy and Gibson, 1963.
IOWA			
Cherokee Group	6.1	1.7	Gluskoter, 1977; grab sample, high volatile C bituminous.
Harrisburg Herrin No. 6	110 - 80	---	Patterson, 1954 as reviewed in Kehn, 1957; "minor occurrences".
KANSAS			
NE of Fort Scott	70	---	As reviewed in Vine, 1962; 0.9 ft. thick
KENTUCKY			
---	1.29 - 1.39	4.24 - 4.74	Koester and Ziegler, 1970; fluorimetric analysis for U, colorimetric analysis for Th.
Providence	10	---	Vine 1962; 8 ft. thick.

TABLE 2 (Continued)

Location	U(ppm)	Th(ppm)	Comments
MONTANA			
Townsend Valley	220	—	Becraft, 1958; locality F, lignite, 2 in thick.
—	1.0 - 1.5	2.5 - 3	Kuhn et al., 1980; 3 samples.
Ekalaka Hills	G50	—	As reviewed in Vine, 1962; G1000 tons estimated reserves.
Eklalka Hills	10 - 340	—	Denson and Gill, 1965; 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	—	Denson and Gill, 1965; "only small amounts of uranium".
—	Max. 130	—	Hall and Gill, 1953 as reviewed in Abernathy and Gibson, 1963.
NEVADA			
Mohave	0.68 - 0.77	—	Southwestern Energy Study Group, 1972, as reported in Wright and Roffman, 1976.
Esmeralda County	30	—	Moore and Stephans, 1954 as reviewed in Abernathy and Gibson, 1963.
Gamma Property, Churchill County	60 - 520 avg. 283	—	Staatz and Bauer, 1951; 10 samples, mostly thin beds, clayey lignite with high ash content.
Churchill County	590	—	Lovering, 1954 as reviewed in Abernathy and Gibson, 1963.

TABLE 2 (Continued)

Location	U(ppm)	Th(ppm)	Comments
NEW MEXICO			
La Ventana Mesa, Sandoral County	10 - 6200	—	Backman et al., 1957 as reviewed in Kehn, 1957.
La Ventana Mesa	up to 6200 avg. 1000	—	Denson, 1959; small deposits.
Four Corners San Juan	2.10 - 3.70 1.40 - 1.70	— —	{Southwestern Energy Study Group, 1972 as reviewed in Wright and Roffman, 1976.
Four Corners Farmington	1.9 - 2.1	5.8 - 6.2	Kay and McKlveen, 1981.
---	0.4, 0.7, 2.6	1.7, 6.1	Wagner and Greiner, 1980.
NORTH DAKOTA			
---	1.0	2.7	Kuhn et al., 1980; 1 sample.
---	1.5	—	Mesich et al., 1975; Lignite, fluorescence analysis.
Mercer County Indian Head Mine	mean 4	mean 4	22 samples } Sommerville et al., 1976 as reviewed in
Dunn County Dunn Center bed	3.15 ± 1.79	3.64 ± 2.36	12 samples, } Schock et al., 1979. SSMA
Sentinel Butte Flat Top Butte Bullion Butte Chalky Buttes Medicine Pole Hills	650	—	As reviewed in Vine, 1962; 61000 tons estimated reserves each.
Little Badlands			Denson and Gill, 1965; 0.5 ft. thick, small amounts.

TABLE 2 (Continued)

Location	U(ppm)	Th(ppm)	Comments
NORTH DAKOTA (continued)			
Chalky Buttes	avg. 170		Denson and Gill, 1965; 2 ft. thick, average ash = 30%, estimated 15 M tons, most is overlain by less than 300 ft. overburden.
---	max. 450	---	Moore et al., 1959 as reviewed in Abernathy and Gibson, 1963.
---	max. 1400	---	Bergstrom, 1956 as reviewed in Abernathy and Gibson, 1963.
OHIO			
Crescent	30eU	---	Snider 1953 as reviewed in Kehn, 1957; "minor occurrences".
---	10	---	Snider, 1954 as reviewed in Abernathy and Gibson, 1963.
Latrobe	10	---	Vine, 1962; 0.5 Ft. thick.
PENNSYLVANIA			
---	0.3 - 0.5	1 - 3	Kessler et al., 1973; 6 samples, SSMA.
---	0.4	2.4	Kuhn et al., 1980; 1 sample, INAA.
Darlington, Beaver County	100	---	Fern, 1955 as reviewed in Kehn 1957; bottom 6 in. of coal, "minor occurrences".

TABLE 2 (Continued)

Location	U(ppm)	Th(ppm)	Comments
PENNSYLVANIA (continued)			
Dora, Jefferson County	30 - 40 eU	—	Fern, 1955 as reviewed in Kehn, 1957; "minor occurrences".
—	410	—	Vine, 1962; bituminous, lower Freeport bed, 0.1 ft. thick.
Beaver County Clearfield County Jefferson County }	10 - 70	—	Vine, 1962; 0.25 - 0.5 ft. thick.
Beaver County Clearfield County Jefferson County }	20 - 140	—	Fern, 1959 as reviewed in Abernathy and Gibson, 1963.
—	1.55, 2.10, 2.65	—	Chow and Earl, 1970; anathracite.
—	10 - 140	—	Caldwell et al., 1970.
—	max. 190	—	Patterson, 1954 as reviewed in Abernathy and Gibson, 1963.
—	10	—	Welch, 1953 as reviewed in Abernathy and Gibson, 1963; anthracite.
SOUTH DAKOTA			
Harding County	50 - 300	—	Deul and Annell, 1956; 6 samples.
Billy Dale Group, North Cave Hills	avg. 64400 620 - 11,300	—	King and Young, 1956; "E" bed is 9-10 in. thick near surface, several thousand tons combustible with abundant smoke.

TABLE 2 (Continued)

Location	U(ppm)	Th(ppm)	Comments
SOUTH DAKOTA (continued)			
Lodgepole area and Johnson outliers	G50	---	{ As reviewed in Vine 1962; G1000 tons estimated reserves.
Northern Slim Buttes	G50	---	
Slim Buttes, Olesrud Bed	1 - 150	---	Schopf and Gray, 1954; hole SD-10, lignite, 5 ft. thick, 381 ft. deep.
Slim Buttes Mendenhall rider bed	4 - 92	---	Schopf and Gray, 1954; hole 16, 8 ft. thick, 333 ft deep.
Slim Buttes, Mendenhall rider bed max.	900	---	Schopf and Gray, 1954; hole SD-8, 3 in. thick.
Slim Buttes, Mendenhall area	avg. 50	---	{ 5.4 ft. thick } Denson and Gill, 49 M tons 1965;
Slim Buttes, other than Mendenhall	avg. 70	---	
			340 M tons } 5800 BTU, impure lignite.
Mendenhall area, Harding County	avg. 50	---	Gill et al., 1959 as reviewed in Abernathy and Gibson, 1963.
TEXAS			
Karnes County	2300	---	Huang, 1978; Whitsett formation, delayed neutron activation analysis.
---	1 - 7	---	{ Wilcox lignite } Huang and Yegua-Jackson Chatham, 1978 Upper Jackson
	4 - 70	---	
	1 - 7800	---	
Karnes County	950 - 2450	---	Mohan et al., 1982; Jackson formation, 3 samples, lignite, intrusions into shale.

TABLE 2 (Continued)

Location	U(ppm)	Th(ppm)	Comments
TEXAS (continued)			
---	5.7	---	Radian sample
---	6.0, 6.2	---	Texas Railroad Commission
---	6.0	---	Texas Air Control Board
			White et al., 1983; 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			
---	10.1	10.1	Kessler et al., 1973; 1 sample, SSMA.
Kaiporowits	0.31 - 0.48	---	{ Southwestern Energy Study Group, 1972 as reviewed in Wright and Roffman, 1976.
Huntington Canyon	0.14 - 1.00	---	
---	20	---	Zeller, 1955 as reviewed in Abernathy and Gibson, 1963.
VIRGINIA			
---	0.2 - 5.6 mean 1.61 ± 0.97	3.0 - 14.0 5.62 ± 2.97	Henderson et al., 1981; 134 samples, whole coal, 5.6 ppm U sample from Dickenson County was only sample greater than 5 ppm, delayed neutron activation analysis.
---	0.4 - 1	1 - 5	Kessler et al., 1973; 3 samples, SSMA.

TABLE 2 (Continued)

Location	U(ppm)	Th(ppm)	Comments
WEST VIRGINIA			
—	10.6 - 1	2.1 - 6.2	Kuhn et al., 1980; 3 samples, INAA.
—	0.4 - 1	2 - 3	Kessler et al., 1973; 2 samples, SSMA;
—	110 - 30	—	Patterson, 1954 as reviewed in Abernathy and Gibson, 1963.
WYOMING			
—	0.6	0.7	Kuhn et al., 1980; 1 sample.
Naughton Jim Bridger	0.09 - 0.41 1.30	— —	{ Southwestern Energy Study Group, 1972 as reviewed in Wright and Roffman, 1976.
—	0.89 - 1.3	—	Mesich et al., 1975; 2 samples, subbituminous, fluorescence analysis.
Pumpkin Buttes	40 - 1000	—	J.D. Love, 1952 as reviewed in Kehn, 1957; "minor occurrences";
Sweetwater County Red Desert	10 - 470	—	Masursky and Pipiringos, 1957 as reviewed in Kehn, 1957; 163 M tons.
Sweetwater County Lumen Bed No. 2 Lumen Bed No. 1 Lumen, Battle, Monumount, Tierney and "E" beds	55, 90, 120 60, 80 10 - 40	— — —	{ Pipiringos, 1961; deduced from ash content and U in ash.

TABLE 2 (Concluded)

Location	U(ppm)	Th(ppm)	Comments
WYOMING (continued)			
Red Desert	4 - 100 avg. 30	—	Masursky, 1962; nine principal coal beds, 690 M tons at 30 ppm or more, 20% estimated to be strippable (160 ft overburden), beds from 2 in. to 42 ft. thick, subbituminous B, up to 510 ppm in impure-coal beds.
Sweetwater County	20 - 70	—	Wyant et al., 1956 as reviewed in Abernathy and Gibson, 1963.

FIGURE 1
LOCATIONS OF HIGH-URANIUM COALS
(NON USCHEM)

TABLE 3
LOCATIONS OF HIGH-URANIUM COALS
(NON-USCHEM)

1. Alameda County, CA
2. Amador County, CA
3. San Benito County, CA
4. Los Angeles County, CA
5. Churchill County, NV
6. Goose Creek, ID
7. Fall Creek, ID
8. Townsend Valley, MT
9. Ekalaka Hills, MT
10. Long Pine Hills, MT
11. Pumpkin Buttes, WY
12. Sweetwater County, WY
13. North Park Field, CO
14. Jefferson County, CO
15. La Ventana Mesa, NM
16. Sentinel Butte, ND
17. Belfield, ND
18. Little Badlands, ND
19. Chalky Buttes, ND
20. North Cave Hills, SD
21. South Cave Hills, SD
22. Slim Buttes, SD
23. Johnson Outlier and Lodgepole area, SD
24. Fort Scott, KS
25. Karnes County, TX
26. Cherokee Group, IA
27. Harrisburg, IL
28. Gentryville, IN
29. Dickenson County, VA
30. Crescent, OH
31. Darlington, PA
32. Dora, PA

Note: Numbers correspond to locations found in Figure 1. USCHEM is a U.S. Geological Survey Data Base.

relative to hazardous radioactive emissions from coal combustion at power plants for a variety of reasons, including:

- Low uranium content
- 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" (Wood et al., 1983). 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.

Most of the listings in Table 2 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: (1 and 2) Sweetwater County and North Park Field in Colorado; (3) Slim Buttes in South Dakota; and (4) Karnes County in Texas. Although the information in Table 2 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.

6.0 COMPUTER SEARCH

6.1 Procedure

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 measurable 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.

6.2 Results

The distribution of concentrations of uranium in the coal samples is shown in Figures 2 and 3. 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. Figure 2 displays the majority of samples on a scale up to 14 ppm in increments of 0.1 ppm and Figure 3 presents data from 10 to 140 ppm in increments of 1 ppm. The scale changes between the two graphs can be compared in the 10-14 ppm range where the two graphs overlap. The increments were chosen to include data greater than the lower bound up to and including the upper bound (e.g., from 0.51 up to 0.60 ppm). The information in Figure 2 appears to be normally distributed with a peak (modal value) between 0.61 and 0.7 ppm. Of the 412 values listed between 0.11 and 0.2, some 396 values were listed as less than 0.2 with no further information as to how they were

FIGURE 2
DISTRIBUTION OF URANIUM IN COAL SAMPLES
FROM USCHEM DATA BASE (0 - 14 PPM)

FIGURE 3
DISTRIBUTION OF URANIUM IN COAL SAMPLES
FROM USCHEM DATA BASE (10 – 140 PPM)

distributed. However, it is believed that they are normally distributed (Simon, 1983).

Statistical information derived from the computer run is presented in Table 4. There are several different ways of evaluating the data set depending upon whether one includes or excludes all lignite data and whether one includes or excludes qualified data (where entries are either zero or listed as "less than"). By the nature of the computer request, all uranium values are non-zero, but there are almost 400 data points with a reading of less than 0.2 ppm U. For thorium there are both zero and "less than" entries. Wherever qualified data are included, the value for computation is the same as if the "less than" sign were ignored.

The value assumed to best represent the uranium average is 1.90 ppm from the Full Set where lignite and "less than" data are included (there were no zero values for uranium). The corresponding Full Set value for thorium is not believed to be representative, because of the large number of zero values included. The value assumed for the thorium average is 4.67 ppm from Partial Set II although this may not be quite as good a representation as the uranium value. By excluding the approximately 900 thorium qualifiers, the zero values were ignored which is advantageous since most of the thorium zeros represented chemical analyses where thorium was not even sought. However, some of the zeros represent thorium sought for but not detected, and these should have been

TABLE 4

STATISTICAL INFORMATION ASSOCIATED WITH THE USCHEM PRINTOUT

CONDITIONS	URANIUM (ppm)	THORIUM (ppm)
● Full Set		
- with lignite	$A = 1.90 \pm 3.71$	3.53 ± 4.54
- with qualifiers	$N = 3838$	3838
● Partial Set (I)		
- without lignite	$A = 1.80 \pm 3.06$	3.35 ± 4.39
- with qualifiers	$N = 3533$	3533
● Partial Set (II)		
- with lignite	$A = 2.09 \pm 3.88$	4.67 ± 5.02
- without qualifiers	$N = 3443$	2916
● Partial Set (III)		
- without lignite	$A = 1.98 \pm 3.19$	4.41 ± 4.87
- without qualifiers	$N = 3156$	2414

NOTES:

USCHEM is a U.S. Geological Survey data base.

Qualifier samples are those whose entry is either zero or a "less than" value.

A = Arithmetic mean.

N = Number of samples.

included. Moreover, the "less than" values should have been included, but were not.

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.

By comparing Partial Set I with the Full Set and Partial Set III with Partial Set II, one can see that the inclusion of lignite data raises the average concentrations of uranium. This finding is in keeping with the earlier statement that uranium concentrations tend to be higher in lower rank coals.

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 5 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.

TABLE 5
URANIUM IN COAL
(USCHEM DATA)

STATE County	CONCENTRATIONS OF URANIUM IN COAL (ppm)				
	5	10	15	20	30
ALABAMA					
Choctaw	● *	--	--	--	--
Fayette	● *	--	--	--	--
ARIZONA					
Graham	● *	--	--	--	--
Pinal	● *	--	--	--	--
ARKANSAS					
Saline	● *	--	--	--	--
COLORADO					
Arapahoe	● X	● *	--	--	--
Elbert	● *	--	--	--	--
Jackson	● *	● *	--	--	--
Mesa	● *	--	--	--	--
Moffat	● *	--	--	--	--
Routt	● *	--	--	--	--

NOTES:

There are two sets of symbols associated with this Table. The first set, ● and --, signifies (based on the data in the USCHEM file) whether or not a mine in a particular county may be affected should a uranium-in-coal standard be established at a given level. For example, a mine in Arapahoe County, Colorado may be affected if the standard were set at either 5 or 10 ppm.

The second set, * and X, is related to the numerical distribution of data and indicates whether or not at least one sample value in this interval (as defined by the value in the column heading in question and the next higher column heading value) was reported for the given county. For example, Sweetwater County, Wyoming has coal samples in the 5-10 ppm range, the 10-15 ppm range, the 15-20 ppm range, and above 30 ppm, but not in the 20-30 range. Mahaska County, Iowa has coal samples in the 5-10 ppm and above 30 ppm ranges, but not in the 10-15 ppm or 15-20 ppm ranges. Wapello County, Iowa has coal samples in all of the ranges.

TABLE 5
(Continued)

STATE County	CONCENTRATIONS OF URANIUM IN COAL (ppm)				
	5	10	15	20	30
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	● *	--	--	--	--
MARYLAND					
Anne Arundel	● *	--	--	--	--
MASSACHUSETTS					
Nantucket	● *	● *	--	--	--

TABLE 5
(Continued)

STATE County	CONCENTRATIONS OF URANIUM IN COAL (ppm)				
	5	10	15	20	30
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	● *	--	--	--	--
Otoc	● 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	● *	● *	--	--	--

TABLE 5
(Concluded)

STATE County	CONCENTRATIONS OF URANIUM IN COAL (ppm)				
	5	10	15	20	30
OHIO					
Belmont	● *	--	--	--	--
Muskingom	● X	● *	--	--	--
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

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 county 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 the data is provided in Figures 4 and 5, showing those locations with at least one sample greater than 10 and 20 ppm, respectively. The symbols in Figure 5 further delineate those four locations with uranium concentrations in coal above 30 ppm, namely Wapello County, Iowa (34.6, 35.9, 40.7 and 42.9 ppm U); Adair County, Missouri (59.5 ppm U); Sweetwater County, Colorado (75.4 ppm U); and Churchill County, Nevada (129.5 ppm U).

FIGURE 4
URANIUM IN COAL: READINGS OVER 10 PPM
(USCHEM DATA)

FIGURE 5
URANIUM IN COAL: READINGS OVER 20 PPM
(USCHEM DATA)

7.0 COMPARISON OF LITERATURE AND COMPUTER SURVEYS

This section provides a comparison of the literature survey and the computer results; noting the similarities and differences and providing an overview based on the two approaches.

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. Moreover, the data in the literature review involving fairly recent samplings by State Geological Surveys (e.g., Gluskoter et al., 1977 for Illinois and Henderson et al., 1981 for Virginia) or consultants (e.g., White et al., 1983) have been screened by MITRE against the computer printout so as to reduce double counting. Such double counting is not always possible to detect since different authors may report the same results in different ways. For instance, a given sampling may be listed from a particular mine as a range of values by one author while another report may have the data reported as an average value for the county in question. However, for the most part, the two data bases are believed to be mutually exclusive.

From Tables 2 and 5, it can be seen that many of the same states are involved. Table 2 contains information from 22 states while 27 states are represented in Table 5 with a total of 30 states altogether. Figures 1 and 4 depict a similar situation although the comparison is not quite the same since Figure 4 presents only a

subset (uranium concentrations greater than 10 ppm) of the data in Table 5, while Figure 1 shows all of the locations, regardless of uranium concentration, listed in Table 2.

A notable difference between the two surveys is the lack of data from Texas and South Dakota in Table 5 (adapted from the USCHEM file) compared to the amount of information presented in the literature survey for these two states (see Table 2). 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 either Table 5 and Figure 4.

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:

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 (Lee et al., 1977). Toth et al. (1980) 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."

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. (Tukenmez and Paull, 1982). A new coal-fired utility boiler of 1000 MWe capacity is estimated to consume 3 million short tons of coal annually (U.S. EPA, 1979). Thus, it is conceivable that these deposits could supply several moderately sized power plants for many years.

8.0 TEXAS LIGNITE

With the renewed optimism regarding the future use of lignite as an energy source in Texas (Mannon, 1978), reports of extremely high uranium concentrations in Texas lignite (Altschuler and Johnston, 1976; Huang and Chatham, 1978; and Lacy et al., 1979) need examination. Parks (1979) notes that "in Texas" economic (i.e., greater than 200 ppm U) uranium deposits are often associated with lignite.

Published concentrations of uranium in Texas lignites vary considerably. Deal and Annell (1956) reported that the lignite from Milam County showed such a low radioactivity that uranium determinations were not made. Using coal and lignite samples from 12 counties (including Karnes County), Kohls (1962) looked for, but did not detect, either uranium or thorium. On the other hand, Huang and Chatham (1978) 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. Cooper et al. (1979) 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. (1982) analyzed several lignite samples from the Jackson formation in Karnes County and found uranium concentrations varying from 950 to 2450 ppm. Toth et al. (1980) mention 32 small

strip mines of uraniferous lignite in Karnes County containing 0.05 percent U_3O_8 , or 440 ppm U. Recently, White et al. (1983) 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.

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 (1980) remarks that many of the lignite beds are very thin.

In 1979, while studying the relationship between stratigraphy and uranium deposition, Chatham surveyed a 4-acre section of southwestern Karnes County, Texas. 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 (1983) notes that large concentrations (i.e., several thousand ppm) of uranium in Texas lignite are quite rare and occur in very localized small quantities. 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.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

9.0 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 a standard of about 20 ppm uranium in coal were established, 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 (1982) 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. 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 (1979) believe that over the long run, the blending and averaging of coal will be sufficient to mitigate any real problems, but some seams may have to be segregated.

APPENDIX A
BIBLIOGRAPHY

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

APPENDIX A: BIBLIOGRAPHY

- Abbott, David T. and Clarence E. Styron. 1981. Radionuclides in Western Coal Efforts at Mound. Mound Facility, Miamisburg, OH. In, Wagner and Greiner, 1981.
- Abbott, David T., Clarence E. Styron, and Vito R. Casella. 1983. Final Report: Radionuclides in Western Coal. September 23, 1983. Mound Facility, Miamisburg, OH. (Report MLM-3026; also available from NTIS). Prepared for U.S. Department of Energy.
- Abernathy, R.F. and F.H. Gibson. 1963. Rare Elements in Coal. U.S. Bureau of Mines Information Circular 8163, Washington, D.C.
- Altschuler, S.F. and J.E. Johnston. 1976. Coal Resources, A Continuing Assessment. In, Fourth National Conference on Energy and the Environment, October 5, 1976, Cincinnati, OH. Published by the American Institute of Chemical Engineers, Dayton, OH.
- Averitt, Paul. 1974. Coal Resources of the United States, January 1, 1974. U.S. Geological Survey Bulletin 1412.
- Barber, D.E. and H.R. Giorgio. 1977. Gamma Ray Activity in Bituminous, Subbituminous and Lignite Coals. University of Minnesota School of Public Health. In, Health Physics, Vol. 32 (February): 83-88.
- Beck, Harold L. and Kevin M. Miller. 1980. Some Radiological Aspects of Coal Combustion. U.S. Department of Energy Environmental Measurements Laboratory, New York, NY. In, IEEE Transactions on Nuclear Science, Vol. NS-27(1):689-694, February.
- Beck, H.L., C.V. Gogolak, K.M. Miller, and Wayne M. Lowder. 1980. Perturbations on the Natural Radiation Environment Due to the Utilization of Coal as an Energy Source. U.S. Department of Energy (DOE) Environmental Measurements Laboratory, New York, NY. In, Proceedings of Symposium on the Natural Radiation Environment III, [ONF-780422(DOE)].
- Becraft, George E. 1958. Uranium in Carbonaceous Rocks in the Townsend and Helena Valleys, Montana. U.S. Geological Survey Bulletin 1046-G. Reston, VA.
- Boreck, Donna L., David C. Jones, D. Keith Murray, Janet E. Schultz, and Denise C. Suek. 1977. Colorado Coal Analyses, 1975. Colorado Geological Survey, Information Series 7, Denver, CO.

- Breger, Irving A. 1958. Geochemistry of Coal. U.S. Geological Survey. In, Economic Geology, Vol. 53:823-841.
- Cahill, R.A. and R.H. Shiley. 1981. Forms of Trace Elements in Coal. Illinois State Geological Survey. In, Proceedings of the International Conference on Coal Science, September 7, 1981 in Dusseldorf, West Germany. Published by Verlag Glueckauf GMBH, Essen, Germany.
- Caldwell, R. D., R.F. Crosby, and M.P. Lockard. 1970. Radioactivity in Coal Mine Drainage. In, Environmental Surveillance in the Vicinity of Nuclear Facilities. Presented at a Symposium sponsored by the Health Physics Society. Published by Charles C. Thomas, Springfield, IL.
- Carter, J.A., R.L. Walker, and J.R. Sites. 1975. Trace Impurities in Fuels by Isotope Dilution Mass Spectrometry. Oak Ridge National Laboratory. In, Trace Elements in Fuel, pp. 74-83, American Chemical Society, Washington, D.C.
- Chatham, James R. 1979. A Study of Uranium Distribution in an Upper Jackson Lignite-Sandstone Ore Body, South Texas. Master's Thesis (Geology), May 1979, Texas A&M University, College Station, TX.
- Chow, T.J. and J.L. Earl. 1970. Lead and Uranium in Pennsylvanian Anthracite. Scripps Institution of Oceanography, La Jolla, CA. In, Chemical Geology, Vol. 6(1):43-99, Published by Elsevier Publishing Co., Amsterdam, Netherlands.
- Coles, David G., R.C. Ragaini, and J.M. Ondov. 1978. Behavior of Natural Radionuclides in Western Coal-Fired Power Plants. Lawrence Livermore Laboratory. In, Environmental Science and Technology, Vol 12(4):442-446, April.
- Colorado Energy Research Institute. 1981. Water and Energy in Colorado's Future: The Impacts of Energy Development on Water Use in 1985 and 2000. Published by Westview Press, Boulder, CO (303 pp).
- Cooper, Hal B.H., Jr., Prabhat Barghava, and Ghazi A. Dakik. 1979. Releases of Radioisotopes from Coal and Lignite Combustion. University of Texas at Austin. In, Proceedings of the 71st Air Pollution Control Association Annual Meeting, Air Pollution Control Association, Pittsburgh, PA.

- Denson, Norman M. and James R. Gill. 1956. Uranium-Bearing Lignite and Its Relation to Volcanic Tuffs in Eastern Montana and North and South Dakota. Professional Paper No. 300, U.S. Geological Survey, Reston, VA.
- Denson, Norman M. 1959. Uranium in Coal in the Western United States. Bulletin 1055, U.S. Geological Survey, Reston, VA.
- Denson, N.M. and J.R. Gill. 1965. Uranium-Bearing Lignite and Carbonaceous Shale in the Southwestern Part of the Williston Basin--A Regional Study. U.S. Geological Survey Professional Paper 463. Reston, VA.
- Deul, Maurice and C.S. Ansell. 1956. The Occurrence of Minor Elements in Ash of Low-Rank Coal from Texas, Colorado, North Dakota and South Dakota. Geological Survey Bulletin 1036-H, U.S. Geological Survey, Reston, VA.
- Eisenbud, Merrill and Henry G. Petrow. 1964. Radioactivity in the Atmospheric Effluents of Power Plants that Use Fossil Fuels. New York University Medical Center. In, Science, Vol. 144:288-289, April 17, 1964.
- Ergun, Sabri. 1968. X-Ray Studies of Coals and Carbonaceous Materials. U.S. Bureau of Mines Bulletin 648, Washington, D.C.
- Facer, J. Fred, Jr. 1979. Uranium in Coal. Report No. GIBX-56(79), May, also available from NTIS. U.S. Department of Energy, Grand Junction, CO.
- Finkelman, R.B. 1980. Chalcophile Elements and Uranium in Coal. U.S. Geological Survey Professional Paper 1175, p. 28, Reston, VA.
- George, D'Arcy R. 1966. Production of Uranium from Uraniferous Lignites. U.S. Bureau of Mines, Salt Lake City, UT. In, Proceedings on Technology and Use of Lignite, April 29, 1965, Bismark, ND.
- Gluskoter, H.J., R.A. Cahill, W.G. Miller, R.R. Ruch, and N.F. Shimp. 1976. An Investigation of Trace Elements in Coal. Illinois State Geological Survey. In, EPA Symposium on Environmental Aspects of Fuel Conversion Technology, pp. 39-46, December 15, 1975, Hollywood, FL.

- Gluskoter, H.J., R.R. Ruch, W.G. Miller, R.A. Cahill, G.B. Dreher, and J.K. Kuhn. 1977. Trace Elements in Coal: Occurrence and Distribution. Illinois State Geological Survey (available as NTIS No. PB-270922), prepared for Industrial Environmental Research Laboratory, Research Triangle, NC.
- Greiner, N. Roy. 1981. Radioactivity from Coal Use--Where are the Problems? Los Alamos National Laboratory, NM. In, Wagner and Greiner, 1981.
- Greiner, N. Roy. 1983. Written correspondence (as a private citizen) to U.S. Environmental Protection Agency, Docket A-79-11, May 18, 1983, regarding "Radionuclide Emissions from Coal-Fired Boilers."
- Greiner, N. Roy and Paul Wagner. 1983. Final Report--Radioactive Emissions from Coal Production and Utilization: The Typical Case Put into Perspective, June 30--September 30, 1982. LA-9747-PR, issued August 1983, Los Alamos National Laboratory, Los Alamos, NM.
- Greiner, N. Roy, M.D. Williams, and P. Wagner. 1983. Estimation of Radionuclide Releases from Specific Large Coal-Fired Industrial and Utility Boilers. Los Alamos National Laboratory, Los Alamos, NM. LA-9845-MS, August 1983.
- Henderson, James A., Jr., Charles S. Oman, and S. Lynn Coleman. 1981. Analyses of Coal Samples Collected 1975-1977. Virginia Division of Mineral Resources Publication 33 or available from NTIS as DE82-902504. Department of Conservation and Economic Development, Charlottesville, VA.
- Hardin, James, J. Tadmor, C. Amato, C. Nelson, and A.C.B. Richardson. 1982. The Radiological Impact of Coal-Fired Industrial Boilers, Bench Draft, December 30, 1982. Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, DC.
- Huang, Wen H. 1978. Geochemical and Sedimentologic Problems of Uranium Deposits of Texas Gulf Coast Plain. In, The American Association of Petroleum Geologists Bulletin, Vol. 62(6):1049-1062, June.
- Huang, Wen H. and James Chatham. 1978. Uranium in Lignite: I. Geologic Occurrences in Texas. Texas A&M University. Proceedings of the 10th International Conference on Sedimentology, July 9-14, 1978, Vol. I (A-L) p. 317, Jerusalem, Israel.

- Hurst, Fred J. 1980. Recovery of Uranium from Lignites. Oak Ridge National Laboratory. Presented at Western Regional Conference on Gold, Silver, Uranium and Coal. September 18-20, 1980, Rapid City, SD.
- Kary, R.E. and J.W. McKlveen, 1981. Radioactivity in Coal and Environs at the Cholla Power Plant, Joseph City, Arizona. Arizona Public Service Co. and Arizona State University. Presented at International Conference on Radiation Hazards in Mining: Control, Measurements, and Medical Aspects, October 4, 1981, Golden, CO. pp 1084-1091. Published by American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, NY.
- Kehn, Thomas H. 1957. Selected Annotated Bibliography of the Geology of Uranium-Bearing Coal and Carbonaceous Shale in the United States. U.S. Geological Survey Bulletin 1059-A. Reston, VA.
- Kessler, T., A.G. Sharkey, Jr., and R.A. Friedel. 1973. Analysis of Trace Elements in Coal by Spark-Source Mass Spectrometry. Report of Investigations No. 7714, U.S. Bureau of Mines, Washington, DC.
- King, John W. and Harry B. Young. 1956. High-Grade Uraniferous Lignites in Harding County, South Dakota. U.S. Atomic Energy Commission. U.S. Geological Survey Professional Paper 300, pp. 419-431. Reston, VA.
- Koester, Pamela A. and Warren H. Zieger. 1978. Analysis for Radionuclides in SRC and Coal Combustion Samples. Hittman Associates, Columbia, MD (September, available as NTIS No. PB-287179), prepared for U.S. Environmental Protection Agency, Research Triangle Park, NC.
- Kohls, Donald W. 1962. Reconnaissance of Trace Elements in Texas Coal and Lignite. Bureau of Economic Geology, Mineral Resource Circular No. 43, October, The University of Texas, Austin, TX.
- Kuhn, J.K., F.L. Fiene, R.A. Cahill, H.J. Gluskoter, and N.F. Shimp. 1980. Abundance of Trace and Minor Elements in Organic and Mineral Fractions of Coal. Illinois State Geological Survey. Environmental Geology Notes 88. August, Urbana, IL.
- Lacy, J.C. et al. 1979. An Integrated Assessment of Texas Lignite Development: Volume I--Technical Analysis. Radian Corporation April (available as NTIS No. PB80-178783). Prepared for Texas Energy Advisory Council, the U.S. Environmental Protection Agency, and the U.S. Department of Energy.

- Lee, Hong, T.O. Peyton, R.V. Steele, and R.K. White. 1977. Potential Radioactive Pollutants Resulting from Expanded Energy Programs. Stanford Research Institute, August (available as NTIS No. PB 272519), prepared for U.S. Environmental Protection Agency, Las Vegas, NV.
- Mannon, James H. 1978. Lignite Revival Takes Texas by Storm. In, Chemical Engineering, March 27, 1978, pp. 75-77.
- Martin, J.E., E.D. Harward, and D.T. Oakley. 1969. Comparison of Radioactivity from Fossil-Fuel and Nuclear Power Plants. Bureau of Radiological Health, U.S. Department of Health, Education, and Welfare. In, Environmental Effects of Producing Nuclear Power Part I, Appendix 14. Hearings before the Joint Committee on Atomic Energy, 91st Congress, pp. 773-809, November, 1969.
- Masursky, Harold. 1956. Trace Elements in Coal in the Red Desert, Wyoming. U.S. Geological Survey Professional Paper 300, pp. 439-444. Reston, VA.
- Masursky, Harold. 1962. Uranium-Bearing Coal in the Eastern Part of the Red Desert Area, Wyoming. U.S. Geological Survey Bulletin 1099-B. Reston, VA.
- Mattson, V.L. 1970. Uranium and Its Compounds. In, Kirk-Othmer Encyclopedia of Chemical Technology. Volume 21, John Wiley & Sons, Inc.
- McBride, J.P., R.E. Moore, J. P. Witherspoon, and R. E. Blanco. 1977. Radiological Impact of Airborne Effluents of Coal-Fired and Nuclear Power Plants. Oak Ridge National Laboratory (ORNL-5315, also available from NTIS), August, Oak Ridge, TN.
- Mesich, F.G., K. Schwitzgebel, R.A. Magee, F.B. Meserole, and R.G. Oldham. 1975. Coal Fired Power Plant Trace Element Study: A Three Station Comparison, Volume I. Radian Corporation (September, available as NTIS No. PB-257293). Prepared for U.S. Environmental Protection Agency, Denver, CO.
- Miller, Ralph L. and James R. Gill. 1954. Uranium from Coal. In, Scientific American, Vol. 191:36-39.
- Miller, Kevin M. and Harold L. Beck. 1981. Some Effects of Coal Combustion on the Radiation Environment. U.S. Department of Energy, New York, NY. In, Wagner and Greiner, 1981.
- Mitchel, Ronald J. 1965. Uranium-Bearing Lignite--North Dakota's Newest Industry. In, Metal Mining & Processing, March.

- Mohan, Mysore S., R.A. Zingaro, R.D. MacFarlane, and K.J. Irgolic. 1982. Characterization of a Uranium-Rich Organic Material Obtained from a South Texas Lignite. Texas A&M University, College Station, TX. In, Fuel, Vol. 61, September:853-858.
- Moore, George W. 1954. Extraction of Uranium from Aqueous Solution by Coal and Some Other Materials. In, Economic Geology Bulletin, No. 49, pp. 652-658. University of North Dakota, Grand Forks, ND.
- National Research Council. 1979. Redistribution of Accessory Elements in Mining and Mineral Processing. Part I: Coal and Oil Shale. National Academy of Sciences, Washington, DC.
- Northern Great Plains Resource Program (NGPRP). 1974. Northern Great Plains Resource Program: Mineral Resources Work Group Report. February. Available from NTIS as PB 243-151.
- Ondov, John M., R.C. Ragaini, and A.H. Biermann. 1979. Elemental Emissions from a Coal-Fired Power Plant. Comparison of a Venturi Wet Scrubber System with a Cold Side Electrostatic Precipitator. Lawrence Livermore Laboratory. In, Environmental Science and Technology, Vol. 13(5):598-607.
- Parks, Steven Louis. 1979. Distribution and a Possible Mechanism of Uranium Accumulation in the Catahoula Tuff, Live Oak County, Texas. Master's Thesis submitted to the Graduate College (Geology) of Texas A&M University, College Station, TX.
- Patterson, E.D. 1953. Uranium in Carbonaceous Rocks: Coal in Eastern States. In, Geologic Investigations of Radioactive Deposits: Semiannual Progress Report, June 1 to November 30, 1953. Report No. TEI-390, December. U.S. Geological Survey, Reston, VA.
- Patterson, Joel. 1983. Manager, Environmental Affairs, Middle South Services, Inc. New Orleans, LA. Written correspondence to U.S. Environmental Protection Agency, Docket No. A-79-11, July 14, 1983.
- Pipirngos, George N. 1961. Uranium-Bearing Coal in the Central Part of The Great Divide Basin. Bulletin 1099A, U.S. Geological Survey, Reston, VA.
- Ray, S.S. and F.G. Parker. 1977. Characterization of Ash from Coal-Fired Power Plants. Tennessee Valley Authority, January, prepared for U.S. Environmental Protection Agency (EPA-600/7-77-010, or available as NTIS No. PB-265374), Research Triangle Park, NC.

- Rubenson, David and Richard Pei. 1983. Oil Shale in the Piceance Basin: An Analysis of Land Use Issues. Report No. R-3040-RC, The Rand Corporation, Santa Monica, CA.
- Schock, Martin R., William W. Morrison, and Gene A. Christianson. 1979. The Long Term Effects of Trace Elements Emitted by Energy Conversion of Lignite Coal. North Dakota State Department of Health, July, prepared for Old West Regional Commission, Billings, MT.
- Schopf, James M. and Ralph J. Gray. 1954. Microscopic Studies of Uraniferous Coal Deposits. U.S. Geological Survey Circular 343. Reston, VA.
- Simon, Fred. 1983. U.S. Geological Survey, Reston, VA. Telephone conversation, October 31, 1983.
- Sommerville, M.H., J.L. Elder, R.G. Todd, A.P. Moran, and R.J. Peterson. 1976. An Environmental Assessment of a Proposed 250 mm scfd Dry Ash Lurgi Coal Gasification Facility Located in Dunn County, North Dakota--Volume IV, Trace Elements: Overburden, Plant Effluents, and Biological Activity. This is Reference 31 in Schock et al., 1979.
- Southwestern Energy Study Group. 1972. Composition of Trace Element Content of Coal and Power Plant Ash. Appendix JII, Coal Resources Work Group. This is Reference 11 in Wright and Roffman, 1976.
- Staatz, M.H. and H.L. Bauer. 1951. Uranium-Bearing Lignite Beds at the Gamma Property, Churchill County Nevada. U.S. Geological Survey Trace Elements Memorandum Report 226, June. Reston, VA.
- Styron, C.E. and B. Robinson. 1976. A Preliminary Radiological Impact Assessment of Western Coal Utilization. Monsanto Research Corporation (MLM-2470-OP) Miamisburg, OH.
- Styron, Clarence E. 1977. Preliminary Assessment of the Impact of Radionuclides in Western Coal on Health and Environment. MLM-2497(OP), Mound Facility, Miamisburg, OH.
- Styron, Clarence E., V.R. Casella, B.M. Farmer, L.C. Hopkins, P.H. Jenkins, C.A. Phillips, and B. Robinson. 1979. Assessment of the Radiological Impact of Coal Utilization: I. Preliminary Studies on Western Coal. Monsanto Research Corporation (MLM-2514, available from NTIS). Prepared for U.S. Department of Energy and the U.S. Environmental Protection Agency, Washington, DC.

- Styron, Clarence E. 1980. An Assessment of Natural Radionuclides in the Coal Fuel Cycle. In, Proceedings of Symposium on the Natural Radiation Environment III, CONF-780422, U.S. Department of Energy.
- Styron, Clarence E., C.T. Bishop, V.R. Casella, P.H. Jenkins, and W.H. Yanko. 1981. Assessment of the Radiological Impact of Coal Utilization: II. Radionuclides in Western Coal Ash. (MLM-2810, also available from NTIS), Mound Facility, Miamisburg, OH.
- Swanson, Vernon E. et al. 1976. Collection, Chemical Analysis and Evaluation of Coal Samples in 1975. Open-File report 76-468, U.S. Geological Survey, Reston, VA.
- Theobald, P.K., S.P. Schweinfurth, and D.C. Duncan. 1972. Energy Resources of the United States. U.S. Geological Survey Circular No. 650. Reston, VA.
- Toth, G.W., C.K. Chase, N. Lewis, and W.L. Clem. 1980. U308 Production Analysis for Nonsandstone Uranium Deposits. NUS Corporation, prepared for Electric Power Research Institute, Palo Alto, CA.
- Tukenmez, Ercan and Mary K. Paull. 1982. Outlook for U.S. Coal. August 1982. Energy Information Administration (DOE/EIA-0333), U.S. Department of Energy, Washington, D.C.
- U.S. Environmental Protection Agency (U.S. EPA). 1979. Radiological Impact Caused by Emissions of Radionuclides into Air in the United States, Preliminary Report. August, EPA 520/7-79-006, or available as NTIS No. PB80-122336. Office of Radiation Programs, Washington, DC.
- U.S. Environmental Protection Agency (U.S. EPA). 1983. Background Information Document: Proposed Standards for Radionuclides. March, EPA 520/1-83-001. Office of Radiation Programs, Washington, DC.
- U.S. Environmental Protection Agency (U.S. EPA). 1983b. Environmental Monitoring Reference Manual for Synthetic Fuels Facilities. July (EPA-600/8-83-027, or available as NTIS No. PB83-251850), Office of Research and Development, Washington, D.C.
- U.S. Public Health Service. 1970. Radiological Health Handbook. Revised Edition, January 1970, U.S. Department of Health, Education, and Welfare, Rockville, MD.

- Vanderborgh, Nicholas E. 1982. Recovery of Minerals from U.S. Coals. Los Alamos National Laboratory (LA-UR-82-452 or available from NTIS as DE82-008173). Presented at Process Mineralogy Symposium, 1982 AIME Meeting, February 15-18, 1982, Dallas, TX.
- Van Hook, R.I. 1978. Potential Health and Environmental Effects of Trace Elements and Radionuclides from Increased Coal Utilization. ORNL-5367 or Environmental Sciences Division Publication No. 1117, Oak Ridge National Laboratory, Oak Ridge, TN.
- Vine, James D. 1962. Geology of Uranium in Coaly Carbonaceous Rocks. U.S. Geological Survey Professional Paper 356-D. Reston, VA.
- Wagner, Paul and N. Roy Greiner. 1980. Second Annual Report: Radioactive Emissions from Coal Production and Utilization, October 1, 1979 - September 30, 1980. Los Alamos Scientific Laboratory (LA-8825-PR), Los Alamos, NM.
- Wagner, Paul, D.R. Dreesen, E.M. Wewerka, and N.R. Greiner. 1980. Radioactive Emissions from Coal Production and Utilization: July 1, 1978-September 30, 1979, Progress Report. (LA-8618-PR) Los Alamos Scientific Laboratory, Los Alamos, NM.
- Wagner, Paul and N. Roy Greiner. 1981. Proceedings of the Workshop on Radioactivity Associated with Coal Use, September 15-17, 1981, Santa Fe, NM. (LA-9106-C, also available as DE82-007880). Sponsored by Los Alamos National Laboratory, Los Alamos, NM.
- Wagner, Paul and N. Roy Greiner. 1982. Third Annual Report: Radioactive Emissions from Coal Production and Utilization; October 1, 1980-September 30, 1981. Progress Report (LA-9359-PR), Los Alamos National Laboratory, Los Alamos, NM.
- White, D.M., L.O. Edwards, and D.A. DuBose. 1983. Trace Elements in Texas Lignite. Radian Corporation, August 31, 1983. Prepared for Texas Energy and Natural Resources Advisory Council, Austin, TX.
- Wood, G.H., T.M. Kehn, M.D. Carter, and W.C. Culbertson. 1983. Coal Resource Classification System of the U.S. Geological Survey. U.S. Geological Survey Circular 891. Reston, VA.

Wright, James H. and Haia K. Roffman. 1976. Coal Ash--A Potential Mineral Source. In, Environmental Technology '76, Proceedings of the Institute of Environmental Sciences, April 25, 1976, Philadelphia, PA, pp. 163-173. Published by Institute of Environmental Sciences, Mt. Prospect, IL.

Yuhnke, Robert. 1983. Environmental Defense Fund. Transcript of oral testimony to the U.S. Environmental Protection Agency hearing at Denver, CO, June 14, 1983. EPA Docket A-79-11.

Zingaro, Ralph A. 1983. Department of Chemistry, Texas A&M University, College Station, TX, November 1, 1983 and December 1, 1983. Telephone Conversations.

APPENDIX B
INFORMATION NEEDS

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

There are a number of information needs and related research and development activities which have been identified during the preparation of this report. These relate not only to the subject of this report (i.e., radionuclides in coal), but to all components of the topic of radionuclide emissions from coal-fired power plants, including health effects. The information needs are identified below within the categories of: 1. Existing Data; 2. New Data; 3. Measurement and Monitoring; 4. Fuel Processing and Combustion; and 5. Health Effects Assessment.

1.0 Existing Data

Most of the data on the radionuclide content of U.S. coals exist within the USCHEM data file maintained by the U.S. Geological Survey (USGS). The file was utilized for this report. A number of additional search routines and file expansion activities can provide further information which would be useful in understanding the extent of radionuclide levels in U.S. coals. These actions would not involve the collection of coal samples.

1.1 Zero Values

The search conducted for this report was limited (as have most other published searches) only to samples containing measureable amounts of radionuclides. Incorporation of zero values into the determination of a national average (e.g., by assuming near-zero values of approximately 0.01 ppm) would result in a lower value for the national average. This would not negate extant values for radionuclides in coal, but would present a more representative perspective with respect to the average concentration of radionuclides in the vast number of U.S. coal seams. Should this action result in a substantial lowering of the average, the number of high values (e.g., above 10 ppm) would appear to be relatively few and the use of alternative seams or blending could appear to be viable solutions to the problems of controlling radionuclide emissions where necessary.

1.2 Expanded Data File

The current search was limited to data within the USCHEM file which have been verified through a quality assurance program. As of the date of the search, about two-thirds of the 6,000 samples collected had been verified. The process of verification should be expedited in order that data from all collected samples can be examined for identification of the locations of relatively high concentrations of radionuclides.

1.3 Integration of Data Files

The USGS maintains a stratigraphic data file on the distribution, depth, thickness, and various physical characteristics of coal strata. Currently, this data file cannot be searched for data on particular samples contained in the USCHEM file. The data files should be cross-indexed to allow for the identification of both chemical and physical data on a particular coal sample. Searching of the integrated files could provide information useful in the identification of the mineability of coal seams characterized by high levels of radionuclides.

1.4 Mineability

Data from samples containing relatively high levels of radionuclides should be examined with respect to the mineability of the coal seams from which the samples were collected. Data on depth-to-seam, seam thickness, areal extent, BTU and ash content, and other parameters need to be considered. The USCHEM file is not clear whether seam thickness, sample thickness, or bench thickness is implied for particular samples. The original field notes should be examined to ascertain the type of thickness cited and other pertinent information relevant to the mineability of those samples identified as containing relatively high concentrations of radionuclides. Should such information be obtainable directly from the stratigraphic data file, examination of file notes may not be necessary.

1.5 Data Correlation

As discussed in Section 4.1, the leaching and migration of trace elements into and out of coal are highly dependent on local conditions. Further analyses of existing data are needed to establish a pattern with respect to the association between uranium and thorium, between the elements and the components of their decay series, and between the elements and non-radioactive elements (e.g., uranium exhibited a strong correlation with vanadium in a 114-sample set of Illinois coal). The establishment of such correlations would be useful in developing a relatively rapid, inexpensive, and reliable indicator of the radionuclide content of a coal sample.

2.0 New Data

A number of federal coal tracts are under consideration for possible lease. These are in the states of Wyoming,

Colorado, and Utah. Some seams near the possible lease sites appear to contain relatively high levels of radionuclides. However, the data cited in this report are too few with which to make definitive statements regarding the radionuclide content of the possible lease sites. Collected samples and new samples collected in representative locations may need to be examined to determine the relative abundance of radionuclides in western coals which may be developed in the next few years.

3.0 Measurement and Monitoring

A study needs to be made of the representativeness of a coal sample with respect to radionuclides. An optimum strategy needs to be developed to deal with the apparent accumulation of radionuclides in the top and/or bottom few centimeters of most coal seams. Determination of the vertical distribution of isotopes within a seam would provide information useful in mixing coal from a given seam or blending coals from different seams.

A Geiger counter, scintillation counter, or similar device should be tested to determine if existing off-the-shelf equipment can be used to quickly scan coal for relatively high values of radionuclides (e.g., above 20 ppm). Such devices, if necessary, could be installed on conveyors to scan coal during sizing and blending activities.

4.0 Fuel Processing and Combustion

Limited information suggests that radionuclides are organically bound to coal, making them difficult to remove during routine coal cleaning operations. More information is needed to confirm or refine this hypothesis.

The U.S. Environmental Protection Agency and the Utility Air Regulatory Group have conducted radionuclide emission sampling studies. The results of these tests are contained within the docket file (Docket No. A-79-11) in support of the proposed radionuclide standard. Further tests may be needed at a research combustor to sample emissions from the combustion of atypical coals and from particle fractionation of emissions to determine the levels of radionuclides in the fine particles capable of penetrating deeply into the air sacs (alveoli) of the lungs.

More information is needed with respect to the mass balance of radionuclides passing through coal cleaning and power plant combustion processes.

5.0 Health Effects Assessment

In various background information documents prepared by the U.S. Environmental Protection Agency, the potential fatal cancers estimated were "about one to two" for the entire industry to 1.5 per year from an existing coal-fired power plant in an urban location. No thorough, definitive risk assessment has been made of this problem. Until it is completed, a scientifically sound radionuclide standard based on the radionuclide content in coal cannot be determined. The risk assessment procedure needs to address the entire fuel cycle from the radionuclide content in the coal, through processing and combustion, to transport of emissions and eventual dose to humans.