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THIRD ANNUAL REPORT RADIOACTIVE EMISSIONS FROM COAL PRODUCTION AND UTILIZATION, OCTOBER 1, 1980-SEPTEMBER 30, 1981 - (USED AS A REFERENCE I OU2 RI REPORT)

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Third Annual Report Radioactive Emissions from Coal Production and Utilization

October 1, 1980—September 30, 1981

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THIRD ANNUAL REPORT

RADIOACTIVE EMISSIONS FROM COAL PRODUCTION AND UTILIZATION
OCTOBER 1, 1980--SEPTEMBER 30, 1981

by

Paul Wagner and N. Ray Greiner

ABSTRACT

Radiochemical analyses of the uranium series nuclides were done on coals and waste products from 21 coal-fired power plants. Leachability and radon-222 emanation measurements were done on the solids. The radioactivity found and reported in this series of reports was very close to the literature values for radioactivity in soil, water, and air. Coals (median 1.6 ppm U) were found to be about one-third as radioactive as soils (median 4.2 ppm), ashes were about twice as radioactive as soils, and the leachates and liquids were similar to well waters (median 0.8 ppb U). The radioactivity added to the air by fly ash is very small compared to the radioactivity already present on natural airborne dust. Consequently, the radiologic impact and concomitant health and environmental impacts from coal-fired power production appears to be generally quite minute.

I. EXECUTIVE SUMMARY

For nearly two decades the question of the nature and magnitude of radioactivity resulting from coal extraction and utilization has been the source of health and environmental concerns that have been discussed often in the public forum. This project was undertaken at the request of DOE to broaden the data base relating to the radioactivity in coal and to provide a basis for evaluation of the potential impact on the environment. We conclude that the radioactivity in coal and the waste from a coal-fired power plant differ very little from the radioactivity in ordinary substances like soil, water, and air.

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Reports of high uranium assays in some western coal samples and the fact that at one time certain lignite deposits were mined for their uranium content have given rise to the perception that lignites and western coals are very radioactive. While it is true that some samples of coal with high uranium content can be found extensive geochemical surveys performed by the USGS show that the average uranium content in US coals is probably close to 2 ppm (average crustal abundance is 4-5 ppm). The 3C coals in our sample inventory show the same average uranium content and the same distribution about the average as in the larger surveys.

When coal is burned, there is the possibility of increased solubility of the radioactivity due to chemical alteration of the mineral matter, of redistribution of volatile radionuclides, and of the release of radon gas. All of these things happen to some extent, but our data, and the reports from other scientific investigations, reveal that the resulting radioactivity in the solid wastes, the leachates, and the combustion gases is still within the range of radioactivity found in ordinary soil, water, and air.

Our conclusions are based on radiochemical analysis of the coals, ashes, and other power plant effluents provided by the EPA* sampling program, and by leaching and radon emanation measurements made on these samples. Data from the literature on radioactivity in soil, water, and air are also presented in the text of this report. This provides a background from which our data can be put into a broad perspective.

Because this area of research has a nationwide impact, we felt that it would be appropriate to convene a conference and workshop with scientists expert in this area and government representatives, in order to determine the overall degree of agreement or disagreement with the conclusions that we had reached. This workshop resulted in the publication of a document that contains the consensus. Our position and the conclusions we report here as the result of our research are in complete accord with these judgements.

Although it appears clear from our research and from the research of others that the radiologic impact from most US coal-fired power plants will be

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*These samples were provided to us by the Office of Radiation Programs, US Environmental Protection Agency, Washington, D.C.

minute, there are certain concerns about which not enough is known, and which need a reliable data base in order to form sound judgements. It is recommended that surveys of the uranium content in US coals be continued, and if it is determined that coal with 30 ppm or more of uranium is being burned extensively in a single locality, a study be made of that radiation environment. We recommend further that an investigation be made of the radiologic safety of coal combustion products incorporated in building materials where they are in close and prolonged contact with people.

II. INTRODUCTION

This is the third report on our evaluation of radioactivity from coal use in electric power production. The samples we have examined are coals, ashes, slurries, and other materials from power plants operating in the US. This report describes the most recent set of samples and gives some general information on radioactivity in nature, whereas the two previous reports[1,2] describe data from earlier sample sets. They also discuss the procedures, the precision of the data, and the task breakdown of the program.

In September of 1981 a workshop on radioactivity from coal use was sponsored by us in Santa Fe, NM. Our work and the work of other investigators were discussed, and proceedings have been published.[3] Some of the data presented in this report were not available at that time; however, the new data serve only to strengthen the conclusions drawn during the workshop. For a broad in-depth discussion of radioactivity in coal by a number of recent investigators in the field, we urge the reader of this report to refer to the workshop proceedings.

In this report we conclude on the basis of the data in this and the previous two reports that the radioactivity in the samples we studied is not much different from radioactivity present in common materials such as soil, water, and air. Even if the average radioactivity from coal were 10 times greater than it is now, hazards from other aspects of coal use probably would still be overriding. The major coal-related hazards we are referring to derive from mining, power plant operations, toxic nonradioactive chemicals, SO_2 releases, and NO_x releases.

III. RADIOACTIVITY IN THE US COAL SUPPLY

Almost all the radioactivity in the US coal supply comes from K-40 (potassium-40) and the decay series derived from the heavy elements Th-232 and

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U-238. The characteristics and significance of each of these sources of radioactivity have been discussed in earlier reports.[1,2] The behavior of the U-238 series radioelements will have the largest effect on the environment, so we have looked at those elements and their chemistry in the greatest detail.

Figure 1 shows how U-238 is distributed in 800 coals from a variety of US coal mines.[4] These data look very much like those taken in a survey of 2000 US coals.[5] Some samples are included in both reports.[4,5] The mean concentration of U-238 in these coals is 1.8 ppm or 0.6 pCi/g, with 70% of the coals falling in the range 0.3 to 3 ppm U-238. Coals containing larger than usual amounts of U-238 are of particular environmental interest. We note that only 4 of these 800 coals (0.5%) contain 30 ppm or more U-238. This characteristic of the histogram, that is, the fraction of the population in the high-uranium tail of the distribution, is similar in the other survey.[5]

On the right side of the coal histogram are some coals that contain 30-100 ppm U-238. The ash from these coals (assuming 10% ash content) would contain 300-1000 ppm uranium, which is high enough to be of concern. Because these coals represent a small fraction (0.5%) of the total supply, it is unlikely that more than a few plants would burn coal of this type for long periods of time, but there is a significant probability that one or two plants might. It therefore seems advisable to us (see Sec. VIII, Recommendations) to identify these high-uranium coal sources and to look carefully at how they are utilized.

The distribution of uranium in the coals in our collection is what one would expect if 20 samples were taken randomly from the distribution shown in Fig. 1.

IV. BEHAVIOR OF THE U-238 SERIES IN COAL, COAL COMBUSTION, AND COAL-RELATED WASTE.

Careful radiochemical analyses usually show that in coal the U-238 decay series is in secular equilibrium. Secular equilibrium means that all radioactive elements derived from U-238 in a given sample decay at the same rate and thus have the same activity. The first report of this series shows the U-238 decay series and the half-lives of the radionuclides.[1] Exposure of the coal to leaching, high temperatures, or the open air can disturb the secular equilibrium by dissolution of soluble elements, by volatilization, or by escape of radon gas. Leachates usually are not in secular equilibrium due to differences in solubility. Ashes generally are close to secular equilibrium, but

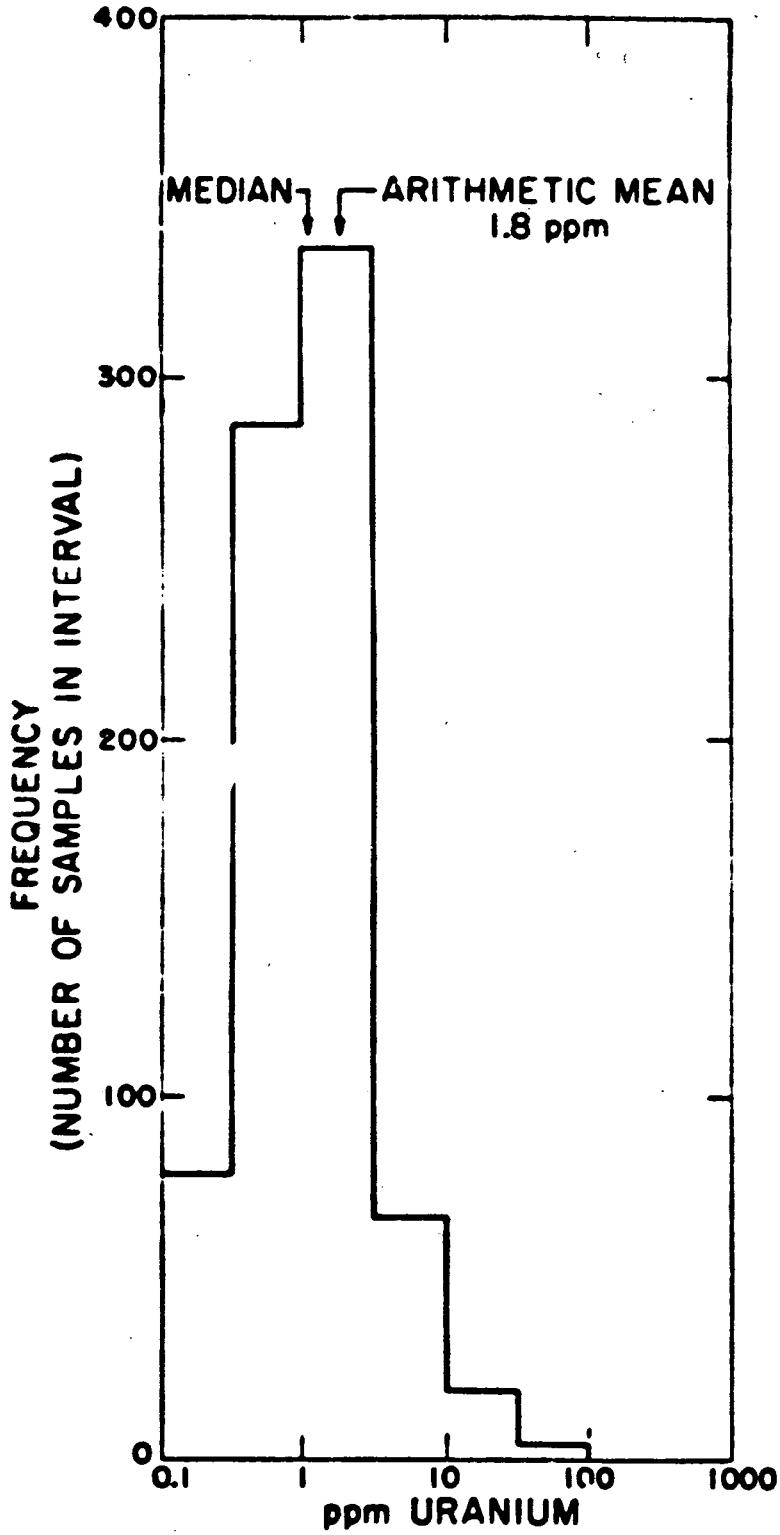

Fig. 1. Distribution of U-238 in 800 US coals.

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occasionally the volatile elements Pb-210 and Po-210 can be vaporized from heavier ash particles and deposited on lighter particles carried in the combustion gas stream. Some fly ashes and some coals can lose as much as 10-30% of their Rn-222 gas if exposed to the open air. Details of these processes are discussed with the data in this report and in the previous reports.[1,2]

V. URANIUM-238 AND ITS DECAY PRODUCTS IN SOIL, AIR, AND WATER

Radioactivity from K-40, U-238, and Th-232 is present not only in coal, but in virtually everything else, too. Some information on the natural radiation environment is presented in Table I. In this section we will present a summary of the knowledge of the U-238 series radionuclides in soil, water, and air to serve as a comparison to the radioactivity found in coal-related materials.

A. Soil

The distribution of U-238 in coal and coal ash is similar to the distribution in soils. An extensive data base on U-238 distribution in soils and natural waters is being generated by the National Uranium Resource Evaluation (NURE) program. We chose a set of 11 NURE reports,[9a-k] combined the data, and constructed histograms for the soils and well waters sampled in these areas. The soil samples numbered 8257, and they represent the topsoil in a total area of ~80,000 sq. mi. Each report covers a 1° x 2° quadrangle of the continental US that includes metropolitan as well as agricultural areas. The data do not necessarily represent the US as a whole, but the areas sampled are highly populated, are widely distributed geographically, and cover a significant area. Some areas that would have been desirable to sample either were not included in the NURE program, or the data were not yet reported in convenient form.

The histogram for the 8257 soil samples is given in Fig. 2. The width of the peak is the same as in the coal histogram, and the soil peak is at 4.2 ppm U, a uranium concentration three times greater than the coal peak. Therefore, on the average, the coal data base shows three times less radioactivity than the soil data base.

These histograms show that large and small values of uranium content are found in coal and soil. They show the probability of finding each range of values, and they show the most likely values. It is useful to be aware of these features of the histograms.

TABLE I

RADIOACTIVITY IN SOME COMMON NATURAL MATERIALS

Material	Nuclide	Activity	Remarks	Ref.[a]
Rock[b]	U-238	2.8 pCi/g	Same activity for daughters	157
Rocks[b]	Th-232	1.1 pCi/g	Same activity for daughters	157
Rocks[c]	U-238	0.8 pCi/g	Same activity for daughters	157
Rocks[c]	Th-232	0.3 pCi/g	Same activity for daughters	157
Beach sands[d]	U-238	0.6 pCi/g	Same activity for daughters	87
Beach sands[d]	Th-232	0.6 pCi/g	Same activity for daughters	87
Rainwater	Pb-210	1 pCi/ℓ	6 month av, various world locations	391
Air[e]	Pb-210	0.008 pCi/m^3	6 month av along 80th meridian	388
Air[e]	Rn-222	300 pCi/m^3	Yearly av, Cleveland, Ohio	374
Carbonate rocks[f]	U-238	0.4 pCi/g	Same activity for daughters	556
Sand	U-238	0.3 pCi/g	Same activity for daughters	557
Cement	U-238	0.4 pCi/g	Same activity for daughters	562
Rocks[g]	U-238	1.5 pCi/g	Same activity for daughters	29
Rocks[g]	Th-232	2.3 pCi/g	Same activity for daughters	29
Soil	U-238	0.6 pCi/g	Same activity for daughters	h
Soil	Th-232	1 pCi/g	Same activity for daughters	h
Drinking water	Ra-226	10 pCi/ℓ	Average for 17 communities in Iowa and Illinois	248
Well water	Ra-226	5.1 ± 3.9 pCi/ℓ	Average and std. deviation for well water from 25 Illinois communities	232
Surface water	Ra-226	0.14 ± 0.27 pCi/ℓ	Average and std. deviation for 22 Illinois surface water supplies	231
River water[i]	U-238	0.19 pCi/ℓ	Average for 10 Japanese Rivers	221
River water[i]	Ra-226	0.08 pCi/ℓ	Average for 10 Japanese rivers	221
River water[i]	Th-232	0.003 pCi/ℓ	Average for 10 Japanese rivers	221
Air[j]	Rn-222	1700 pCi/m^3	Cellars, geometric mean	k
Air[j]	Rn-222	830 pCi/m^3	First floors, geometric mean	k

[a] Numbers are page numbers in Ref. 6.

[b] Florida rocks, including black sands and phosphorites, average values.

[c] Florida rocks, excluding black sands and phosphorites, average values.

[d] US Atlantic and Gulf Coasts, average values.

[e] Ground level air. This is a little high. Continental locations are typically 50-150 pCi/m^3, while regions near the oceans are typically 20-40 pCi/m^3. Oceanic locations and polar regions are even lower.

[f] Average for 28 samples.

[g] Colorado front range, average weighted by area.

[h] See Ref. 7, p. 59.

[i] Similar values are found for continental rivers around the world.

[j] Indoor air from 21 New York and New Jersey dwellings; outdoor air in the same locations had a geometric mean of 180 pCi/m^3.

[k] See Ref. 8, p. 1272.

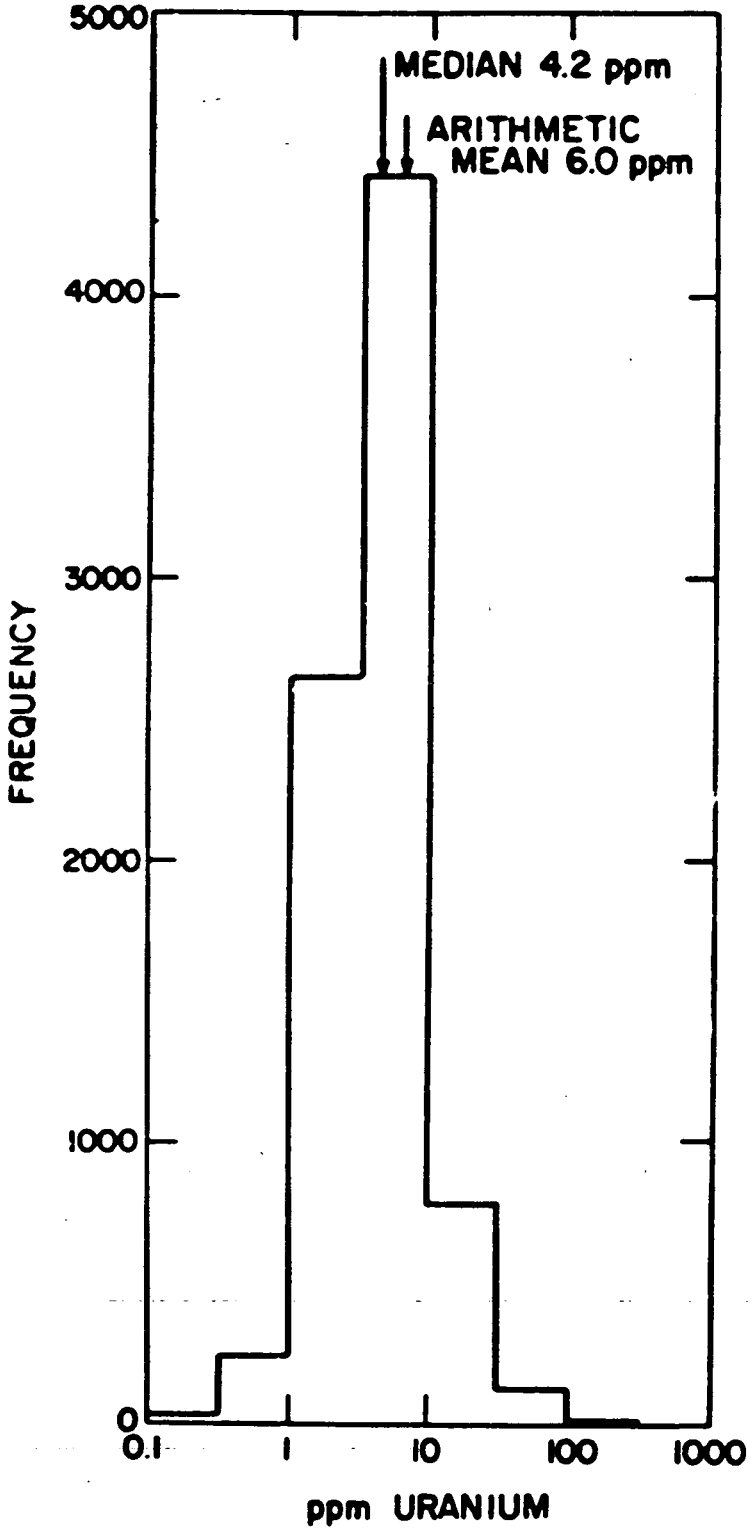

Fig. 2. Distribution of U-238 in 8257 soil samples from selected quadrangles.

Soils exhale Rn-222 as discussed in the following section. The long-lived decay product Pb-210 (21 yr half-life) falls out of the air on dust and collects at the surface of undisturbed soil. Levels of 7 pCi/g have been observed in surface soil.[10]

B. Air

Respirable and ingestible radioactivity in air comes principally from Rn-222 exhaled from the ground. Radon-222 is produced from the decay of Ra-226, a member of the U-238 decay series. The exhalation of Rn-222 from soil depends on a number of factors, among which are atmospheric pressure and dampness. Virtually no Rn-222 is exhaled by the oceans because most of the oceanic Rn-222 decays before it can diffuse to the surface. For this discussion the most important decay product of Rn-222 is Pb-210, which in turn decays to Po-210. Lead-210 collects on the dust in the air and is washed out in rainfall. Usually the Rn-222 content of continental air is assumed[7] to be 150 pCi/m^3. This decays to produce 0.07 pCi/m^3 of Pb-210. Rain collects the Pb-210 from a long column of air, so it is not surprising that rainwater samples containing Pb-210 at 3.3 to 7.5 pCi/ℓ have been collected.[11]

C. Water

NURE data for well and ground water are presented in Fig. 3. A histogram for domestic water sources (including well and surface waters) is presented in Fig. 4.[12] Our data for coal-related leachates (Fig. 5) and slurry liquids match the diagram for well waters. Surface waters derived from rainfall tend to contain very little U-238 and Ra-226, but they contain larger amounts of Pb-210 and Po-210, which are produced in the air from Rn-222. Analyses of some rainwaters reported in the literature show Pb-210 and Po-210 levels that generally exceed those of our leachates.[11]

VI. EXPERIMENTAL RESULTS AND DISCUSSION

A. Coals

Radionuclide content of the coals sampled in this series is listed in Table II. The radioactivity in these coals and the others analyzed by us in previous years corresponds to the distribution of uranium typical of a large number of US coals (Fig. 1). The highest U-238 activity found in our set of coals is 1.98 pCi/g, which is three times the median value. Radon emanation

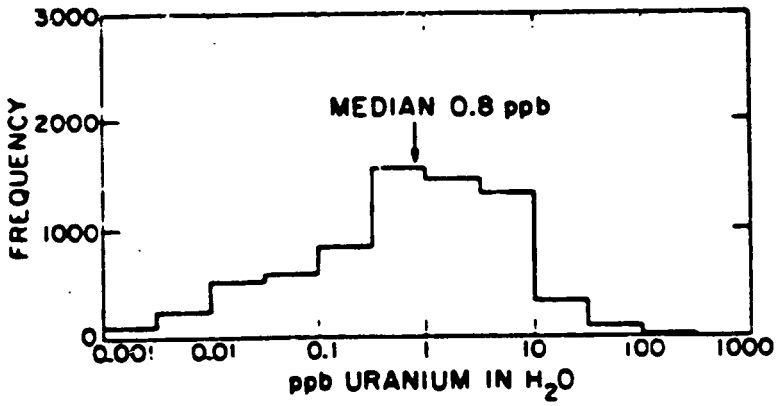

Fig. 3. Distribution of U-238 in well and ground water (NURE data).

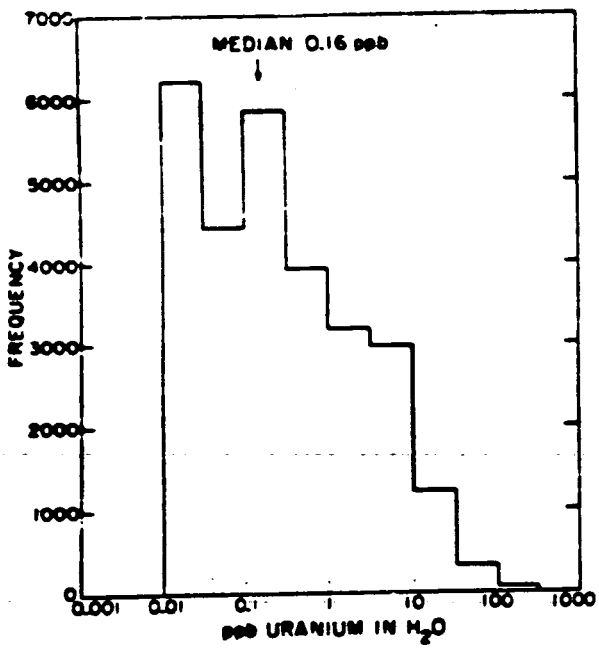

Fig. 4. Distribution of U-238 in domestic water sources (US).

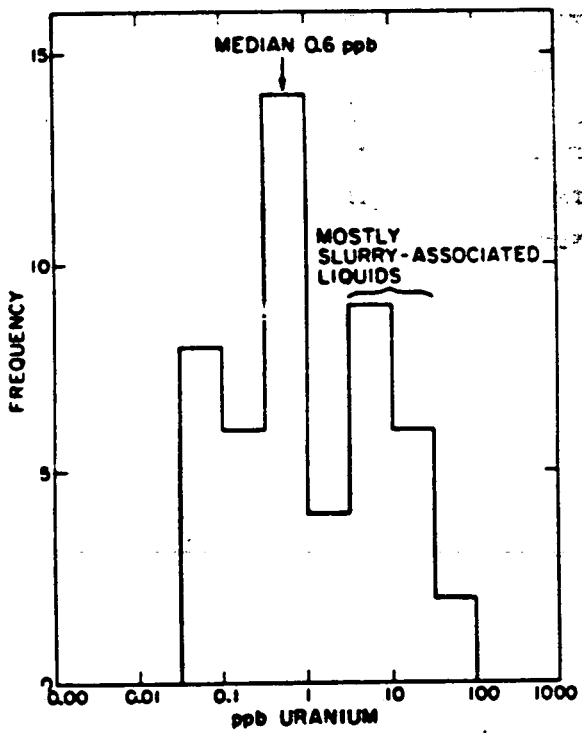

Fig. 5. Distribution of U-238 in coal-related leachates and slurry liquids.

TABLE II

RADIONUCLIDE CONTENT OF COALS

Plant	Activity (pCi/g)					
	Th-232	U-238	Ra-226	Pb-210	Po-210	Escaping Rn-222
M-15[a]	0.16	0.23	0.31	0.37	0.18	-
M-16	0.15	0.17	0.28	0.33	0.09	0.019
M-17	0.32	0.56	0.91	0.91	0.46	0.005
M-18	0.25	0.41	0.47	0.53	0.28	0.004
M-33	0.25	0.41	0.55	0.62	0.33	0.109
M-34	0.57	0.81	0.76	1.03	0.69	0.22
M-35	0.43	0.70	0.70	0.75	0.46	0.22
M-98	0.10	0.24	0.30	0.46	0.20	-
M-99	0.16	0.20	0.24	0.50	0.23	-
M-1[b]	0.38	1.98	1.6	2.1	1.4	-
M-1 Coke	0.03	0.09	0.14	0.48	0.16	0.001

[a]Av of 3 coal samples.

[b]M-1 Plant resampled in this series.

from these coals is less than that expected from typical soils. All the coal leachates would pass the drinking water standard for radioactivity[13] (Table VIII).

B. Solid Wastes From Coal Combustion

The solid wastes from coal combustion are fly ash, bottom ash, hopper ash, and slurry solids. Fly ash is the ash that passes through the pollution control device and escapes out the stack. We have not examined any fly ash samples. Bottom ash is the ash that is heavy enough to drop out of the combustion gas stream and fall to the bottom of the boiler. This ash often looks like glassy cinders. Small ash particles remain entrained in the combustion gas stream and must be removed to comply with air pollution regulations. The means for removing this ash is usually a cyclone, baghouse, electrostatic precipitator, or wet scrubber. The ash collected by the first three devices is usually a dry powder called hopper ash, and the ash collected by a wet scrubber is incorporated in a waste slurry that may contain other solids such as limestone or lime for sulfur removal.

In modern boilers the coal is pulverized and blown into the combustion zone. This method produces mostly entrained ash particles and a small amount of bottom ash.

The ashes and slurry solids in our sample collection are about twice as radioactive as the soils, and the width of the ash distribution is roughly equal to the width of the soil distribution. The new data for hopper ash (Table III), bottom ash (Table IV), and slurry solids (Table V) are presented Figure 6 is a histogram of the U-238 content of these wastes Most of these wastes show secular equilibrium in the U-238 series. Occasionally Pb-210 and Po-210 are enhanced in the hopper ash and depleted in the bottom ash

There are reasons to suppose that the volatile metals Pb-210 and Po-210 might be somewhat concentrated on the very fine hopper ash and the escaping fly ash. Not having any fly ash samples, we decided to sieve a $\leq$10-μm-diam fraction, when possible, from several of our hopper ash samples for Ra-226, Pb-210, and Po-210 analyses to compare with the bulk hopper ash samples The data are shown in Tables VI and VII. Lead-210 appears to be significantly more concentrated on the fine hopper ash. The ratio ranges from 1.05 to 2.5 with a mean of 1.60 and a standard deviation of the mean of 0.13. Radon-226 is not significantly concentrated on the finer ash. The variations in the Ra-226 ratios appear to be accounted for by the random errors in the individual analyses

Although we have data on Po-210 in these fine ashes, an adequate interpretation requires correction for Pb-210 decay, and therefore, a precise knowledge of the time of combustion. Generally we find that when Pb-210 is enhanced on the hopper ash Po-210 is also, and Po-210 is correspondingly depleted in the bottom ash. This is in accord with the fact that Po-210 is even more volatile than Pb-210 at typical combustion temperatures.

C. Leachates and Slurry Liquids

Figure 5 is a histogram of the U-238 data, which match those of the NURE well waters. Tables VIII-XII show additional data for the other nuclides. In most cases, the combined α and β activities reported here for undiluted leachates do not appear to exceed the EPA guide for drinking water.[13] Only one sample, M-98 hopper ash, had more Ra-226 than allowed ($\leq$5 pCi/ℓ). However, strict compliance with the guide would require measurement of gross α, gross β, and in some cases Ra-228.

TABLE III

HOPPER ASH

Plant	Activity (pCi/g) Th-232	U-238	Ra-226	Pb-210	Po-210	Escaping Rn-222
M-15[a]	1.56	2.31	2.22	2.07	0.86	-
M-16	2.35	3.09	3.2	5.0	2.6	0.039
M-17	2.3	3.2	3.44	4.6	1.9	0.018
M-18	4.12	6.44	5.65	9.28	5.32	0.079
M-33	2.25	3.45	1.06	6.3	5.0	0.011
M-35	2.41	3.78	3.72	4.4	3.1	0.025
M-98	0.87	2.42	3.00	3.12	2.06	-
M-99 ESP	0.73	1.20	1.37	12.7	10.6	-
M-99 Mech	1.41	2.23	2.27	2.53	0.94	-

[a]Av of 3 samples.

TABLE IV

BOTTOM ASH

Plant	Activity (pCi/g) Th-232	U-238	Ra-226	Pb-210	Po-210
M-1	1.18	5.65	6.8	2.5	0.48
M-34	2.36	3.13	3.53	2.7	0.5
M-99	1.05	1.68	1.9	1.1	0.1

TABLE V

LIME, LIMESTONES AND SLURRY SOLIDS

Plant	Material	Activity (pCi/g) Th-232	U-238	Ra-226	Pb-210	Po-210
M-1	LS	<d.	0.91	1.22	1.45	0.75
M-1	SSB	0.35	2.94	2.70	6.1	4.1
M-1	SSA	0.32	2.81	2.7	6.2	3.6
M-15	SSB	1.52	2.04	2.08	2.91	3.0
M-15	SSA	1.32	1.78	2.06	2.92	2.0
M-34	LS	0.07	0.56	0.76	0.96	0.34
M-98	L	0.08	1.00	1.08	1.13	<0.3
M-98	SS	1.09	1.92	2.3	3.3	1.4

LS = limestone.
SSB = scrubber slurry before control device.
SSA = scrubber slurry after control device.
L = lime.
SS = scrubber slurry.

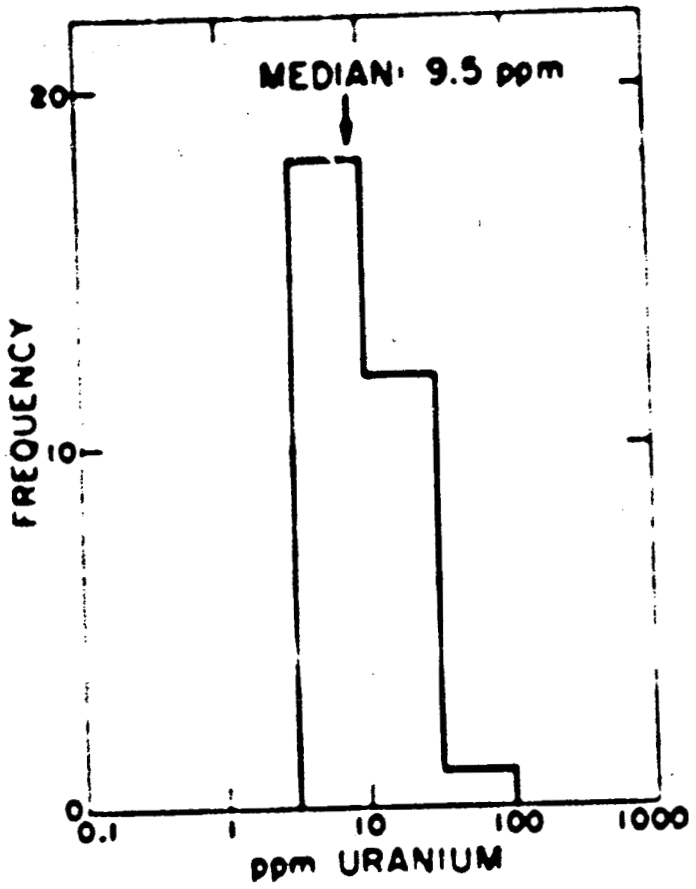

Fig 6 Distribution of U-238 in ashes and slurry solids.

TABLE VI

RADIOACTIVITY ON THE FINEST HOPPER ASH

Plant	Activity (pCi/g) Ra-226	Pb-210
#-2	5.19	12
#-3	4.74	8.8
#-4	9.1	35
#-5	7.7	11.9
#-6	-	2.9
A	4.09	7.96
#-10	1.95	3.33
#-17	4.69	7.03
#-33	4.08	8.51
#-35	2.94	9.18

TABLE VII

ENHANCEMENT OF RADIOACTIVITY ON FINE HOPPER ASH

Plant	Radioactivity (Fines) / Radioactivity (Bulk)		Size of Fines (μm)
	R-226	Pb-210	
M-2	1.10	1.05	-10
M-3	1.08	1.33	-10
M-4	1.21	1.17	-10
M-5	1.31	1.63	-10
M-6	-	1.71	-30
A	0.92	1.21	-20 + 10
M-10	0.78	2.50	-30
M-17	1.36	1.53	-10
M-4	1.25	2.0	-10
M-33	1.00	1.35	-10
M-35	0.79	2.09	-10
	mean 1.08 ± 0.06	1.60 ± 0.13	
	range 0.78 - 1.36	1.05 - 2.50	

TABLE VIII

COAL LEACHATES

Plant	Activity (pCi/ℓ)				
	Th-232	U-238	Ra-226	Pb-210	Po-210
M-1	-	3.3	4.0	0.88	<0.5
M-1 Coke	-	0.2	1.0	<1.0	0.61
M-15	-	<0.2	0.23	0.29	<0.3
M-16	<0.002	<0.1	0.5	0.56	0.24
M-17	-	<0.03	0.21	0.28	<0.1
M-18	<0.01	<0.2	1.1	1.94	0.17
M-98	-	0.03	0.47	0.79	<0.3
M-99	-	<0.1	-	-	-

TABLE IX

BOTTOM ASH LEACHATES OR SLURRY LIQUIDS

Plant	Activity (pCi/ℓ)				
	Th-232	U-238	Ra-226	Pb-210	Po-210
M-1[a]	-	-	0.41	-	-
M-15[b]	-	<0.1	0.08	1.34	<0.3
M-33[a]	-	0.2	0.15	0.63	<5
M-33[b]	-	0.2	0.23	<10	<5
M-34[b]	-	0.2	0.13	2.30	<0.3
M-99[b]	-	<0.1	0.06	0.83	<0.3

[a]Slurry liquid.

[b]Leachate.

TABLE X

HOPPER ASH LEACHATES

Plant	Activity (pCi/ℓ)				
	Th-232	U-238	Ra-226	Pb-210	Po-210
M-15	-	<0.1	-	0.75	<0.3
M-16	-	<0.2	0.62	0.33	<0.1
M-17	-	<0.03	0.5	0.66	<0.1
M-18	0.95	0.3	0.22	0.28	0.5
M-98	-	0.1	5.4	0.57	<0.3
M-99	-	<0.1	-	-	-

TABLE XI

SCRUBBER SLURRY LIQUIDS AND LEACHATES

Plant	Type	Activity (pCi/ℓ) Th-232	U-238	Ra-226	Pb-210	Po-210	pH
M-1	Makeup H_2O	-	-	0.47	1.0	<0.1	8.0
	Liq.[a]	-	-	3.3	0.86	0.14	7.5
	Leach.[a]	-	1.1	0.83	0.93	<10	7.9
	Liq.[b]	-	-	4.53	0.62	<0.1	7.6
	Leach[b]	-	1.5	0.59	0.432	<10	7.6
M-15	Liq.[c]	-	5.5	0.8	0.13	<0.3	6.9
	Liq.[d]	-	9.2	0.24	0.2	<0.3	8.0
	Makeup H_2O	-	1.1	0.53	1.94	<5	8.3
M-34	Makeup H_2O	-	1.2	0.17	0.33	<5	8.0
	Liq.[c]	-	-	0.33	0.17	<5	7.5
	Liq.[d]	-	0.1	-	-	-	7.7
M-98	Liq.	-	-	0.08	1.2	0.14	8.6

[a] Before cyclone
[b] After cyclone
[c] Feed
[d] Spent

TABLE XII

LIME AND LIMESTONE LEACHATES

Plant	Activity (pCi/ℓ) Th-232	U-238	Ra-226	Pb-210	Po-210	pH
M-1	-	1.0	-	-	-	8.1
M-34	-	0.6	0.07	2.01	<0.3	-

VII. CONCLUSIONS

From the data obtained in this and the other investigations, we draw the following conclusions.

- Coal is about one-third as radioactive as widespread soils and stream sediments.
- Coal ash is about twice as radioactive as these soils and sediments.
- Even hopper ash containing enhanced radioactivity from Pb-210 and Po-210 is no more than twice as radioactive as undisturbed topsoil.
- Radon-222 emanation from coal and ash is typically far less than from soils.
- In spite of some popular myths, coal is not very radioactive, western coal is no more radioactive than eastern coal, lignite is no more radioactive than other coals, and, compared to what is there naturally, very little radioactivity is added to the environment from coal use in power plants. See Table XIII.

TABLE XIII

RADIOACTIVITY IN AIR AT THE MAXIMUM IMPACT ZONE (MIZ)

	Activity (pCi/m^3)		
Nuclide	Natural Radioactivity	Added Radioactivity from Coal[a]	Enhancement[b]
U-238	1×10^{-4}	2×10^{-5}	2
Ra-226	1×10^{-4}	1×10^{-5}	1
Rn-222	1.5×10^{2}	1×10^{-3}	100% escape
Po-218[c]	1.5×10^{2}	1×10^{-3}	100% escape
Pb-210	2×10^{-2}	2×10^{-5}	2
Po-210[c]	2×10^{-3}	3×10^{-5}	10

[a]Assumed 1% escape of fly ash; dilution by factor of 5×10^4 (annual average dilution at MIZ).

[b]Enhancement on escaping ash vs collected ash due to volatility and other factors.

[c]About 90% of the radiologic dose to the lung is from Po-218, and 10% of the dose is from Po-210 in natural air. The other radionuclides contribute about 1% of the dose. The increased dose to the lung due to coal use is $\leq$ 0.5% by these estimates (see Ref.7).

VIII. RECOMMENDATIONS

One major concern remains at this time. We believe it advisable to identify any major coal supplies that contain 30 ppm or more uranium, to determine the tonnages involved, and to determine how that coal is distributed to the consumers. If coal containing 30 ppm or more uranium is burned consistently at one site, further investigation is be advisable to establish the radiologic safety of the site.

The workshop report also recommends the study of radioactivity in construction materials derived from coal-fired power plant wastes.[3] We agree with that recommendation.

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