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ENVIRONMENTAL IMPACT OF USING
FLY ASH IN CONCRETE

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TABLE OF CONTENTS

	<u>Page</u>
NOTICE.....	<i>ii</i>
TABLE OF CONTENTS.....	<i>iii</i>
LIST OF FIGURES AND TABLES.....	<i>iv</i>
SUMMARY.....	<i>vi</i>
I. INTRODUCTION.....	I-1
II. CHEMICAL COMPOSITION OF COAL, FLY ASH, AND FLY-ASH LEACHATE.....	II-1
A. Coal Composition.....	II-1
B. Ash Composition.....	II-1
III. COST OF TESTING FLY ASH-FILLED CONCRETE FOR ENVIRONMENTAL HAZARD.....	III-1
A. Measurement of Total Radioactivity of Fly Ash.....	III-1
B. Testing Fly Ash for Radium-226.....	III-2
C. Elemental Composition of Fly Ash.....	III-3
D. Organics in Fly Ash.....	III-4
E. Environmental Risks.....	III-4
IV. ESTIMATION OF ENVIRONMENTAL IMPACTS.....	IV-1
A. Multimedia Environmental Goals and Source Analysis Models.....	IV-1
B. Estimation of the Relative Hazard Offered by Individual Inorganic Pollutants.....	IV-3
C. Organic Pollutants.....	IV-15
D. Radiation.....	IV-16
E. Legal Requirements.....	IV-32
REFERENCES	

LIST OF FIGURES

<u>Number</u>		<u>Page</u>
IV-1	Decay Series for Naturally Occurring Uranium and Thorium Isotopes.....	IV-18

LIST OF TABLES

<u>Number</u>		<u>Page</u>
II-1	Commonly Determined Trace Elements in Coal..	II-2
II-2	Trace Elements in Coal That Are Not Commonly Determined.....	II-4
II-3	Summary of Trace Elements in Coal.....	II-5
II-4	Composition of Fly Ashes From Different (Unspecified) Locations Across the United States.....	II-9
II-5	Concentrations and Concentration Trends With Decreasing Fly Ash Particle Size for Selected Elements.....	II-10
II-6	Concentration of Trace Elements in Coal and Fly Ash in Different Geographical Locations.....	II-11
II-7	Enrichment Factors for Fly Ash/Coal From Unspecified Geographical Locations.....	II-13
II-8	Summary of Enrichment Factors.....	II-14
II-9	Estimated Elemental Composition of Fly Ash..	II-16
IV-1	Syndromes Produced on Humans by Various Toxic Elements.....	IV-4
IV-2	Syndromes Produced on Non-Human Organisms by Various Toxic Elements.....	IV-5
IV-3	Hittman Ranking System for Potential Toxicity for Various Elements.....	IV-6
IV-4	Comparison of the Absolute Toxicity Potential of Trace Elements as Estimated by the Hittman System and the MEG System and Estimation of the Relative Toxicity of These Materials in Fly Ash.....	IV-7

LIST OF TABLES (continued)

<u>Number</u>		<u>Page</u>
IV-5	Amount of Elements Extracted from Midwestern Fly Ash by Distilled Water at 25°C for 48 Hours.....	IV-11
IV-6	Degree of Hazard Which May be Associated With Leachate from Fly Ash-Filled Concrete.....	IV-13
IV-7	Estimated Concentration of Uranium and Thorium in U.S. Coals.....	IV-17
IV-8	Uranium and Thorium Coal/Fly Ash Enrichment Factors.....	IV-19
IV-9	Expected Average and Maximum Concentrations of Uranium and Thorium in Any U.S. Fly Ash..	IV-19
IV-10	Radioactivity Expected Due to Decay of the Uranium and Thorium Series Associated with One Cubic Yard of Fly Ash-Filled Concrete Using the Most Radioactive U.S. Fly Ash (Made from Iowa Coal).....	IV-21
IV-11	Estimate of the Maximum Amount of Radon Associated with One Cubic Yard of Fly Ash- Filled Concrete.....	IV-26
IV-12	Amount of Radon Produced and Expected to be Present in One Hour from 18 Cubic Feet of Concrete Containing 200 Pounds of Iowa Coal Fly Ash.....	IV-28
IV-13	Radiation Protection Guides.....	IV-29
IV-14	Legal Requirements and Guidelines Which May Apply to the Leachate from Ash-Filled Concrete.....	IV-33

SUMMARY

This report addresses the environmental impacts of using fly ash-filled concrete. Since the chemical composition of fly-ash samples is not readily accessible in the available literature and an exhaustive literature search was outside the scope of this work, this report attempts to estimate the chemical composition of fly ash using the known chemical composition of coals from numerous regions of the country and the known behavior of elements in a limited number of coal and fly-ash samples. This technique assumes that each element in every piece of coal in the United States partitions itself into fly ash to the same extent and leaches from fly ash at the same rate. Using these limited data, enrichment factors were then calculated by dividing the composition in the fly ash by the composition in the corresponding coal samples. These enrichment factors were then applied to all of the coal samples for which chemical compositions were available to estimate the chemical composition of the fly ash.

The environmental impacts of using fly ash-filled concrete were considered from the following aspects:

- In all of these estimates, only the fly ash which contained the largest amount of the component in question was considered.
- The toxicity of water in contact with the concrete was considered from the standpoint of leaching of trace elements.

- The possibility of volatilization of organic compounds which had been sorbed onto the fly ash was discussed.
- The possibility of radiation damage from using the most radioactive fly ash likely to be encountered in the United States was analyzed considering the total radiation absorbed dose (rad) and roentgen equivalent man (rem) and comparing these values to background values as well as accepted standards.
- The amount of radon likely to be encountered was also considered.
- The likelihood of exceeding accepted standards was considered.

In order to perform this preliminary assessment of the environmental impact of fly ash in concrete, several assumptions were made. These assumptions include:

- Each element in every piece of U.S. coal or fly ash acts like that same element in every other piece of U.S. coal or fly ash.
- No element in fly ash is more soluble than manganese (the most soluble element in the fly ash samples studied).
- Only materials in the first two millimeters of any concrete surface will be subject to leaching.
- The density of fly ash-filled concrete is 120 pounds per cubic foot.

- The standard man absorbs all of the radiation to which he is exposed.
- Only one-fourth of the radiation associated with fly ash in a concrete house will reach the interior of the house.
- One-half the radon gas produced by the fly ash diffuses into the house.
- Basement seepage in such a house will not be hazardous to the environment.
- A 10X dilution of leachate from concrete products may be expected in the environment.

These assumptions, taken together, constitute the worst-possible-case assessment of hazard to the environment.

Analysis of the likely composition of water which may be in contact with the concrete showed that the leaching of trace elements from the concrete would probably not produce any further environmental harm over that produced by those trace elements contacting the environment through other sources. In this analysis, the U.S. Environmental Protection Agency's Multimedia Environmental Goals (MEGs), particularly the Minimum Acute Toxicity Effluent (MATE), were used to predict the concentration which would cause environmental damage. It was determined that none of the trace elements for which analysis was performed, with the possible exception of germanium, would cause environmental harm solely by its presence in leachate from fly ash, used as a filler in concrete.

The possibility of environmental damage by the volatilization of organic compounds sorbed onto the fly ash was considered. The most hazardous organic compounds appear to be the carcinogenic polynuclear aromatic hydrocarbon compounds (PAH). However, the analysis showed that neither these nor any other organic compounds would cause a problem by virtue of their sorption onto fly ash particles.

The radiation resulting from the use of fly ash which contained the highest concentration of uranium and thorium to be expected in the United States was considered. The radiation exposure to a man spending all of his time in a concrete house without any furnishings to reduce the radiation dosage was considered. The radiation exposure due to the uranium and thorium decay series in the fly ash-filled concrete was considerably less than background radiation. The exposure to radon of the abovementioned man was also considered. The radiation resulting from the use of fly ash containing 10 pCi Ra²²⁶ per gram (twice the amount proposed by EPA as the threshold level for determining a material to be "hazardous") was also considered.

The possibility that legal requirements would be exceeded by the leachate from fly ash-filled concrete was considered. These legal requirements include current and proposed drinking water standards; "Acceptable Level in Fresh Water, Critical Concentration;" Effluent Standards (One Day Maximum); "Acceptable Level in Marine Water, Critical Concentration;" Water Quality Criteria, Federal Water Pollution Control Administration, Derived Standards EPA Proposed Basis; EPA Public Water Supply Intake; the most stringent state standard; standard as Critical Concentration in Potable Water; and Maximum Acceptable Concentration for Livestock Drinking Water. These requirements originate in various federal and state agencies.

Leachate considerations were complicated by the dilution of the leachate before contact with the regulated bodies of water. However, this study found that all elements except selenium, thallium, and vanadium are unlikely to exceed the standards when using fly ash-filled concrete. The information for selenium, thallium, and vanadium is incomplete at present, which renders unsure any estimates of the probability that these elements will exceed the standards.

I. INTRODUCTION

The projected dependence of the nation on coal-produced electrical energy necessitates a thorough study of coal-associated environmental risks. By 1980 there will be 600 million tons of coal consumed annually in coal-fired generating plants only. This consumption will generate 50 million tons of fly ash per year. This amount of fly ash will pose a major disposal problem. To date, the only viable disposal methods are landfills and minefills (1).

Coal-produced fly ash is composed of small spherical particles somewhat similar to carbospheres. Material such as this is considered to be a good filler because of the reactive sites of the spheres, and can be either incorporated into blended cements or added to portland cement. The insolubility and leachability of fly ash components when mixed with cement is of particular importance. Cement and concrete systems containing fly ash will probably end up in buildings and roadways. There is limited information on the fate of the toxic trace metals, organics, and radionuclides released from the concrete systems. It will be worthwhile to study the leachability and release of toxic trace metals and radionuclides from construction materials specifically mixed with coal-produced fly ash.

Organic compounds may reach the environment by being sorbed on the fly ash during combustion and subsequent volatilization. Since the concentration of the organics introduced into the environment by this mechanism will be considerably less than in the gaseous emission streams, and since the organics in the emission streams are not toxic (they may be asphyxiants), the only organics which are

likely to cause any environmental harm are the carcinogenic polynuclear aromatic hydrocarbons (PAH*).

Fortunately, in the last few years, increased awareness of environmental impacts of new technologies has caused the public to desire an estimate of these impacts before the technology is widely used. It is hoped that these estimates can be used to prevent the further deterioration of the environment. This report attempts to estimate the health and ecological impacts of using fly ash as a filler in concrete.

Since the quantity of trace elements varies from one coal to another, Section II of this report attempts to estimate the quantity of trace elements in fly ash from various locations in the United States. Whenever possible, the actual composition of fly ash from various coals is given. When this is not possible, the composition of the coal is given, and the probable composition of the fly ash of this coal is estimated using enrichment factors calculated by dividing the concentration in the fly ash produced from a specific coal by the concentration in that coal. Obviously, the use of enrichment factors assumes that each element acts in an identical manner in each piece of coal. In addition, the concentration of leachate which has been in contact with the fly ash-containing concrete is estimated. Since very little information is available on the leaching of materials from fly ash, and no information is available on the leaching of materials from fly ash contained in concrete, these estimates are also based on numbers, called "partitioning factors," which are calculated

**In other reports, PAH are also called PNA or POM.*

using a formula similar to that used to calculate enrichment factors. They are based on a similar assumption, i.e., that each element in each piece of fly ash acts in an identical manner.

Section III of this report deals with the cost of conducting the actual experiments which will allow a better estimation of the environmental impacts which can be expected from using fly ash-filled concrete. These experiments include determining the quantity of radioactive pollutants which are found in fly-ash samples and the trace element and organic composition of leachate and volatiles from fly ash-filled concrete. These experiments will be applicable to fly ash from any source and can be used to estimate the environmental impact of using as cement fills fly ash from different geographical locations in the United States.

Section IV of this report will attempt to deal with the environmental impacts of using fly ash as a filler in concrete. In this report, Multimedia Environmental Goals (MEGs) and Source Analysis Models (SAMs) will be used extensively. The MEGs and SAMs are methodologies which have been developed by the U.S. Environmental Protection Agency (EPA) to predict the concentrations of pollutants in the environment which will cause no environmental damage. Since the volume of leachate will be impossible to quantify in this short study, only that part of the SAM known as the "Degree of Hazard" will be calculated. For those pollutants which are not covered by the MEGs, the probable MEG will be estimated. The health damage due to radiation will also be estimated. The relative degree of environmental impact for the trace elements will be estimated using both the MEG methodology and the "Hittman Number." This approach will

consider both the absolute toxicity of each individual element as well as its relative concentrations in the fly ash. Legal restraints and possible radiological hazards will also be assessed in this section.

II. CHEMICAL COMPOSITION OF COAL, FLY ASH, AND FLY-ASH LEACHATE

A. Coal Composition

Coal is a complex organic material including inorganic trace metals and metallic compounds, bound nitrogen and sulfur, inert earth-like gangue, and high molecular weight carbon-containing matrices. Tables II-1 and II-2 give typical concentrations of various elements in coal. The numbers in parentheses are the range of data. Table II-3 summarizes the data in Tables II-1 and II-2. This table gives the arithmetic and geometric mean of the average values found in the various surveys listed in Tables II-1 and II-2, as well as the standard deviations and range of the mean values using the averages from the various surveys.

B. Ash Composition

The ash residue resulting from the combustion of coal is primarily derived from the inorganic mineral matter in the coal. Generally, ash makes up from 3 to 30 percent of the coal (11).

During the combustion of coal, the products formed are partitioned into three categories: bottom ash, fly ash, and vapors. The bottom ash is that part of the residue which is fused into particles heavy enough to drop out of the furnace gas stream (air and combustion gases). These particles are collected in the bottom of the furnace. The fly ash is that

TABLE II-1. COMMONLY DETERMINED TRACE ELEMENTS IN COAL (PPM)

Element	53 Coals from the Eastern Interior Region	51 Coals from the Northern Great Plains Region	73 Coals from the Appalachian Region	Washington State Univ. Study	West Virginia	Penn.	East Ky.	Ala.	Va.	Tenn.	Ill.	West Ky.	Ind.	Mont.	Wyo.	New Mex.	Ariz.
Aluminum (Al)				3.2±1.3													
Antimony (Sb)				8.02±0.3	9	16	6	13	10	9	6	7	7	<6	1	2	2
Arsenic (As)				366±35	77	70	79	110	99	120	49	44	31	380	170	270	39
Barium (Ba)					1.2	0.8	1.5	0.74	1.1	0.58	1.3	1.4	1.7	1.5	2.4	0.94	0.97
Beryllium (Be)	2.5	1.5	2.5														
Boron (B)	96	116	25		20	15	19	30	13	24	81	70	85	60	36	43	49
Bromine (Br)				21.4±0.7													
Cadmium (Cd)											2.9			<0.1	0.46	<2.6	<0.54
Calcium (Ca)																	
Cesium (Cs)																	
Chlorine (Cl)				1020±90													
Chromium (Cr)	20	7	13	21±2	19	24	19	19	20	19	29	18	19	3	5.8	11	9.7
Cobalt (Co)	3.8	2.7	5.1	6.1±0.4	17	18	15	18	14	13	15	16	24	7.7	5.2	15	
Copper (Cu)	11	15	15		11	13	11	14	13	11	8.3	8.8	9.7	3.2	4.4	5.9	4.9
Europium (Eu)				0.33±0.04													
Fluorine (F)					70	90	30	90	50	120	59		50	70	160	160	70
Gallium (Ga)	4.1	5.5	4.9														
Germanium (Ge)	13	1.6	5.8														
Hafnium (Hf)				0.74±0.08													
Iodine (I)																	
Iron (Fe)				8920±40													
Lanthanum (La)	5.1	9.5	9.4	11.9±0.5													
Lead (Pb)					4.9	5.2	4	3.7	6.1	4.9	33	6.4	7.2	4.8	0.61	4.7	3.9
Lithium (Li)					44	64	78	75	34	36	45	16	24	27	19	16	19
Magnesium (Mg)																	
Manganese (Mn)					21	21	26	19	42	23	73	19	26	57	14	19	9.7
Mercury (Hg)					0.12	0.20					0.18		0.08	0.07	0.05	0.08	0.05
Molybdenum (Mo)	4.3	1.7	3.5		6.2	9.8	5.2	11	8.3	7.8	8.8	7.4	5.2	4.8	2.2	2.0	0.97
Nickel (Ni)	15	7.2	14	21±3	18	20	16	17	22	16	25	16	33	3.3	4.1	8.1	4.9
Phosphorus (P)																	
Potassium (K)				3300±1100													
Rubidium (Rb)				23±2													
Scandium (Sc)				3.98±0.38													
Selenium (Se)				3.66±0.4	3.4	3.7	3.1	5.1	4.4	4.9	2	3.1	4	3	0.8	2.0	2.1
Silicon (Si)																	
Sodium (Na)				424±19													
Strontium (Sr)				142±20													
Sulfur (S)																	
Tantalum (Ta)				0.33±0.05													
Thorium (Th)				3.3±0.2													
Tin (Sn)	1.3	0.9	0.4		1.5	1.1	4.6	2.2	2.3	1.8	2.6	2.5	0.74	1.1	1.4	1.9	0.97
Titanium (Ti)	450	591	350	1135±56													
Uranium (U)																	
Vanadium (V)	35	16	21	40±5	30	33	29	31	33	34	35	32	35	12	15	25	9.7
Yttrium (Y)	7.7	13	14														
Zinc (Zn)					17	22	15	22	23	23	140	48	73	42	37	19	9.7
Zirconium (Zr)	44	59	7.6		63	68	60	56	44	45	88	77	100	77	39	110	39
Reference	2	3	4	5	6	6	6	6	6	6	6	6	6	6	6	6	6

(continued)

TABLE II-1. COMMONLY DETERMINED TRACE ELEMENTS IN COAL (PPM) (Continued)

Element	Mean U.S. Coals	Utah Co. 1	Penn. Coal	N.E. Standard	Illinois Basin	Appalachian Coal Fields	Western U.S.	8 Seam King Mine Utah	Lower Dekoven Seam, Will Scarlett Mine, Ill.	Mining City Seam, Jerry Mine, Kentucky	Illinois	Forty-eight Coals from the Western and Southwestern Interior Region
Aluminum (Al)					12,000 (4,300-30,000)	17,000 (11,000-31,000)	10,000 (3,100-22,000)				13,000	
Antimony (Sb)		1.52	0.48	3	1.3 (0.1-8.9)	1.6 (0.25-7.7)	0.58 (0.18-3.5)				5	
Arsenic (As)	5	0.828	34.9	8	14 (1.0-120)	25 (1.8-100)	2.3 (0.34-9.8)				14	
Barium (Ba)	500			360	100 (5-750)	200 (72-420)	500 (160-1,600)					
Beryllium (Be)					1.7 (0.5-4.0)	1.3 (0.23-2.6)	0.46 (<0.10-1.4)	0.4	0.8	0.2	2	1.1
Boron (B)					110 (12-230)	42 (5.0-120)	56 (16-140)	12	25	7	102	33
Bromine (Br)		8.07	36.1	20	13 (0.6-52)	12 (0.71-26)	4.7 (0.58-25)				15	
Cadmium (Cd)		16.2	2.49		2.2 (<0.1-65)	0.24 (<0.10-0.60)	0.18 (<0.10-0.60)	0.2	4	1.4	3	
Calcium (Ca)	10,000	<2,000	4,300		6,700 (100-27,000)	4,700 (900-26,000)	17,000 (4,400-38,000)				8,000	
Cesium (Cs)		0.11	1.78		1.4 (0.5-3.6)	2.0 (0.40-6.2)	0.42 (0.01-3.8)					
Chlorine (Cl)				950	1,400 (100-5,400)	1,700 (100-8,000)	300 (100-1,300)				1,400	
Chromium (Cr)	13	4.13	39.4	20	18 (4.0-60)	20 (10-90)	9.0 (2.4-20)	25	25	<1.5	14	13
Cobalt (Co)	5	1.02	6.0	6	7.3 (2.0-34)	9.8 (1.5-33)	1.8 (0.6-70)	25	12	4	10	4.6
Copper (Cu)	15	5.85	23.2		14 (5.0-44)	18 (5.1-30)	10 (3.1-23)	12	25		15	11
Europium (Eu)				0.3	0.26 (0.1-0.87)	0.52 (0.16-0.92)	0.20 (0.07-0.80)					
Fluorine (F)					67 (29-140)	89 (50-150)	62 (19-140)				60	
Gallium (Ga)	7				3.2 (0.8-10)	5.7 (2.911)	2.5 (0.80-6.5)				3	2.0
Germanium (Ge)	5				6.9 (<1.0-43)	1.6 (<0.10-6.0)	0.91 (<0.14-3.0)				7	5.9
Hafnium (Hf)				0.8	0.54 (0.13-1.5)	1.2 (0.58-2.2)	0.78 (0.24-1.3)					
Iodine (I)					1.7 (<0.24-14)	1.7 (<0.33-4.9)	0.52 (<0.24-1.0)					
Iron (Fe)	10,000	2,890	24,300	8,700	20,000 (4,500-41,000)	15,000 (5,000-26,000)	5,300 (3,000-12,000)				20,000	
Lanthanum (La)	10	9.7	14.9	10	6.8 (2.7-20)	15 (6.1-23)	5.2 (1.8-13)					6.5
Lead (Pb)					32 (<0.8-220)	5.9 (<1.0-18)	3.4 (<0.74-9.0)	<0.02	<0.02	<0.02	35	
Lithium (Li)												
Magnesium (Mg)	<2,000	<1,000	<10,000	4,300	503 (100-1,700)	600 (200-1,500)	1,400 (300-3,900)				500	
Manganese (Mn)	5	1.42	28.2		53 (6.0-210)	18 (2.4-61)	49 (<1.4-220)	12	125	4	50	
Mercury (Hg)	0.012	0.05	0.73		0.2 (0.03-1.6)	0.20 (0.05-0.47)	0.09 (0.02-0.63)				0.2	
Molybdenum (Mo)	5	1.65	3.73		8.1 (0.3-29)	4.6 (0.10-22)	2.1 (<0.13-30)	0.08	12	4	8	3.1
Nickel (Ni)	15	12	4,480	20	21 (7.6-68)	15 (6.3-28)	5.0 (1.5-18)	12	25	4	20	14
Phosphorus (P)					64 (<10-340)	150 (15-1,500)	130 (10-510)				70	
Potassium (K)	1,000	2,800	5,000	3,300	1,700 (400-5,600)	2,500 (600-6,800)	500 (100-3,200)				1,600	
Rubidium (Rb)	100	<5	28.8	23	19 (<2.0-46)	22 (9.0-63)	4.6 (<0.30-29)					
Scandium (Sc)	5	1.42	5.89	3.9	2.7 (1.2-7.7)	5.1 (1.6-9.3)	1.8 (0.50-4.5)					
Selenium (Se)	5	10.4	7.2	3	2.2 (0.4-7.7)	4.0 (1.1-8.1)	1.4 (0.40-2.7)				2	
Silicon (Si)					24,000 (5,800-47,000)	28,000 (10,000-63,000)	17,000 (3,800-47,000)				25,000	
Sodium (Na)	2,000	10,300	1,900	420	500 (1-2,000)	400 (100-800)	1,400 (100-6,000)	5,000	2,500	150	500	
Strontium (Sr)				150	35 (<10-130)	130 (28-550)	260 (53-500)					
Sulfur (S)					33,000 (5,600-64,000)	23,000 (5,500-50,000)	7,600 (3,400-19,000)					
Tantalum (Ta)				0.3	0.15 (0.07-0.3)	0.33 (0.12-1.1)	0.15 (0.04-0.33)					
Thorium (Th)				3	2.1 (0.71-5.11)	4.5 (1.8-9.0)	2.3 (0.62-5.7)					
Tin (Sn)					3.8 (<0.2-51)	2.0 (<0.20-8.0)	1.9 (<0.10-15)				5	1.3
Titanium (Ti)				100	600 (200-1,500)	900 (500-1,600)	500 (200-1,300)	75	400	450	700	250
Uranium (U)		1.07	2.03		1.5 (0.31-4.6)	1.5 (0.40-2.9)	1.2 (<0.30-2.5)					
Vanadium (V)	15			40	32 (11-90)	38 (14-73)	14 (4.6-43)	12	50	4	30	18
Yttrium (Y)												7.4
Zinc (Zn)	30	19.0	42.9		250 (10-5,300)	25 (2.0-120)	7.0 (<0.30-17)	25	125	<0.05	270	108
Zirconium (Zr)					47 (12-130)	45 (8.0-88)	33 (12-170)				70	
Reference	5	5	5	5	7	7	7	8	8	9	10	10

TABLE II-2. TRACE ELEMENTS IN COAL THAT ARE NOT COMMONLY DETERMINED (PPM)

Element	Illinois Basin	Appalachian Coal Fields	Western U.S.	Utah	Penn.	Wyo.	New Mex.	Ariz.
Cerium (Ce)	14 (4.4-46)	25 (11-42)	11 (2.8-30)					
Dysprosium (Dy)	1.1 (0.5-3.3)	2.3 (0.74-35)	0.63 (0.22-1.4)					
Gold (Au)				0.03	0.06			
Indium (In)	0.16 (<0.01-0.63)	0.23 (0.13-0.37)	0.10 (<0.01-0.25)					
Lutetium (Lu)	0.09 (0.02-0.44)	0.22 (0.04-0.40)	0.07 (<0.01-0.43)					
Samarium (Sm)	1.2 (0.4-3.8)	2.6 (0.87-4.3)	0.61 (0.56-2.2)					
Silver (Ag)	0.03 (0.02-0.08)	0.02 (0.01-0.06)	0.03 (0.01-0.07)					
Tellurium (Te)						0.025	0.03	<0.02
Terbium (Tb)	0.02 (0.04-0.65)	0.34 (0.06-0.63)	0.21 (0.06-0.58)					
Thallium (Tl)	0.66 (0.12-1.3)							
Tungsten (W)	0.82 (0.04-4.2)	0.69 (0.22-1.2)	0.75 (0.13-3.3)					
Ytterbium (Yb)	0.56 (0.27-1.5)	0.83 (0.18-1.4)	0.38 (0.13-0.78)					
Reference		7		5		6		

TABLE II-3. SUMMARY OF TRACE ELEMENTS IN COAL*

Element	Number of surveys included	Arithmetic mean	Geometric mean	Unbiased standard deviation	Range
Aluminum	4	13000 ppm	12,761 ppm	2900 ppm	10,000-17,000 ppm
Antimony	8	2.1	1.6	1.5	0.45-5
Arsenic	22	9.4	6.5	8.1	0.8-34.9
Barium	19	188	131	158	31-500
Beryllium	24	1.3	1.1	0.6	0.2-2.5
Boron	24	49	37	34.	7-116
Bromine	8	16	14	10	4.7-36.1
Cadmium	14	2.6	1.1	4.1	0.1-16.2
Calcium	7	7500	6200	4900	2000-17000
Cerium	3	17	16	7.4	11-25
Cesium	5	1.1	0.75	0.84	0.11-2.0
Chlorine	6	1100	990.	490.	300-1700
Chromium	29	16	14	8.4	1.5-39.4
Cobalt	28	10	8.0	6.6	1.02-25
Copper	27	12	11	5.2	3.2-25.
Dysprosium	3	1.3	1.2	0.86	0.63-2.3
Europium	5	0.32	0.31	0.12	0.2-0.52
Fluorine	16	81	74	37	30.-160
Gallium	9	4.2	3.9	1.7	2.0-7
Germanium	9	5.3	4.0	3.7	0.91-13
Gold	2	0.45	0.042	0.21	0.03-0.06
Hafnium	5	0.81	0.79	0.24.	0.54-1.2
Indium	3	0.16	0.15	0.065	0.10-0.23
Iodine	3	1.3	1.1	0.68	0.52-1.7
Iron	9	13000	11000	7400	2890-24300
Lanthanum	12	9.5	9.0	3.3	5.1-15
Lead	20	3.3	2.6	11	0.02-35
Lithium	13	38	33	22	16-78
Lutetium	3	0.13	0.11	0.081	0.07-0.22

(continued)

TABLE II-3. (continued)

Element	Number of surveys included	Arithmetic mean	Geometric mean	Unbiased standard deviation	Range
Magnesium	8	2600	1400	3300	500-10,000
Manganese	23	31	21	28	1.42-125
Mercury	15	0.15	0.10	0.17	0.012-0.73
Molybdenum	27	5.2	3.9	3.2	0.08-12
Nickel	29	170	17	830	3.3-4480
Phosphorous	4	104	97	43	64-150
Potassium	9	2400	2000	1400	500-5000
Rubidium	8	28	19	30	4.6-100
Samarium	3	1.5	1.2	1.0	0.61-2.6
Scandium	8	3.7	3.4	1.6	1.43-5.89
Selenium	22	3.6	3.1	2.1	0.8-10.4
Silicon	4	23500	23000	4700	17000-28000
Silver	3	0.027	0.026	0.0058	0.02-0.03
Sodium	12	2100	1100	2900	150-10300
Strontium	5	140	120	80	35-260
Sulfur	3	22000	18000	14000	7600-36000
Tantalum	5	0.25	0.24	0.094	0.15-0.33
Tellurium	3	0.025	0.025	0.0050	0.02-0.03
Terbium	3	0.19	0.11	0.16	0.02-0.34
Thallium	4	0.375	0.34	0.21	0.02-0.66
Thorium	5	2.9	0.95	0.95	2.1-4.5
Tin	19	1.8	1.6	1.0	0.4-4.6
Titanium	12	600	510	310	75-1135
Tungsten	3	0.75	0.75	0.065	0.69-0.82
Uranium	6	1.4	1.3	0.38	1-2.03
Vanadium	26	27	24	11	4-50
Ytterbium	3	0.59	0.56	0.23	0.38-0.83
Yttrium	3	12	11	3.4	7.7-110
Zinc	23	57	27	73	0.05-270
Zirconium	20	59	52	24	7.6-110

*calculated from data contained in Tables II-1 and II-2

part of the ash which is entrained in the combustion gas leaving the boiler. While most of this fly ash is collected in either mechanical collectors and/or electrostatic precipitators, a small quantity of this material may pass through the collectors and be discharged into the atmosphere. The vapor is that part of the coal material which is volatilized during combustion. Some of these vapors are discharged into the atmosphere; others condense onto the surface of fly ash particles and may be collected in one of the fly ash collectors. For the majority of elements found in coal, most of their quantity (95 percent or more) will be found in the ash fractions, while the remainder (5 percent or less) will be discharged into the atmosphere. The quantity of vapors produced depends primarily on the temperature history of the combustion gases and the concentrations and properties of the various elements in the coal (11).

The distribution of the ash between the bottom ash and fly ash fractions is a function of the burner type, the type of coal (ash fusion temperature), and the type of boiler bottom (wet or dry). The first factor, burner type, is especially significant in determining the distribution. The second factor, ash fusion temperature, is important in that ashes with lower fusion temperatures tend to be melted within the boiler and collected as bottom ash. Finally, wet bottom boilers are designed to produce and process a much larger proportion of bottom ash than dry bottom boilers (11).

The ash particles vary from less than one micron to 4 cm in diameter. The fly ash fraction generally consists of fine spherical particulates usually ranging in diameter from 0.5 micron to 100 microns. The pH of fly ash contacted with water may vary from 3 to 12, with the pH for the majority of pulverized coal-burned fly ashes contacted with water ranging from 8 to 12 (11).

Table II-4 presents the average composition of fly ash from six domestic power plants (11). The concentration of trace elements in the fly ash depends on the particle size. Generally, increasing concentrations are correlated with decreasing particle size (see Table II-5). There is a definite enrichment of certain elements in the smallest particles emitted from a power plant. These elements include lead, thallium, antimony, cadmium, selenium, arsenic, nickel, chromium, zinc, and sulfur. The highest concentrations of the trace constituents occur in particulates in the 0.5 to 10.0 micron diameter range.

Table II-6 presents the concentrations of coal and fly ash at different locations in the United States. This table also presents enrichment factors which can be used to estimate the elemental composition of any fly ash, provided the elemental composition of the burned coal is known. The enrichment factor is defined as the concentration in the fly ash divided by the concentration in the coal. Later in this report, the enrichment factors are used to estimate the average and maximum elemental concentrations in all fly ash found in the United States. Table II-7 shows enrichment factors for averaged analysis of National Bureau of Standards coals and fly ashes (13) and for three power stations using unidentified coals (14).

Table II-8 summarizes the enrichment factors found in Tables II-6 and II-7. Examination of this table will show that fly ash will contain approximately 10 times the concentration of the trace elements (except for volatile trace elements; i.e., mercury, bromine, and chlorine) found in coal. This information can be used along with coal compositions found in Tables II-1, II-2, and II-3 to predict the concentrations found in fly ash for the different regions of the country assuming that each individual element in each

TABLE II-4. COMPOSITION OF FLY ASHES FROM
DIFFERENT (UNSPECIFIED) LOCATIONS ACROSS
THE UNITED STATES (10)

Compound or Element	Number of Determinations	Arithmetic Mean	Geometric Mean	Unbiased Standard Deviation	Range
SiO ₂ (%)	5	51.	50.	8.	42.-59.
Al ₂ O ₃ (%)	5	23.	22.	5.	17.-28.
Fe ₂ O ₃ (%)	6	9.	7.	7.	3.8-20.4
CaO (%)	6	6.	5.	5.	3.2-17.
SO ₃ (%)	4	0.8	0.7	0.6	0.4-1.7
MgO (%)	5	1.5	1.4	0.5	0.96-2.23
Na ₂ O (%)	5	1.3	1.2	0.6	0.38-1.88
K ₂ O (%)	5	1.3	1.1	0.8	0.4-2.4
P ₂ O ₅ (%)	4	0.5	0.2	0.5	0.04-1.00
TiO ₂ (%)	5	0.9	0.9	0.3	0.43-1.17
Arsenic (ppm)	6	27.	14.	41.	6.-110.
Beryllium (ppm)	5	6.	6.	2.	3.-8.
Boron (ppm)	4	366.	325.	226.	200.-700.
Cadmium (ppm)	6	3.	1.	3.	0.5-8.0
Chromium (ppm)	6	126.	81.	112.	20.-300.
Cobalt (ppm)	6	17.	14.	12.	6.-39.
Copper (ppm)	6	89.	84.	36.	54.-140.
Fluorine (ppm)	5	345.	266.	255.	100.-624
Lead (ppm)	6	52.	47.	24.	30.-80.
Manganese (ppm)	6	202.	188.	79.	100.-298.
Mercury (ppm)	6	3.	0.1	8.	0.01-20.
Nickel (ppm)	6	82.	52.	76.	10.-207.
Selenium (ppm)	6	16.	14.	8.	6.9-26.5
Vanadium (ppm)	6	212.	177.	144.	90.-440.
Zinc (ppm)	6	230.	135.	274.	50.-740.

TABLE II-5. CONCENTRATIONS AND CONCENTRATION TRENDS
WITH DECREASING FLY ASH PARTICLE SIZE FOR SELECTED ELEMENTS (11)

Particle diam. (microns)	Pb (ppm)	Tl (ppm)	Sb (ppm)	Cd (ppm)	Se (ppm)	As (ppm)	Ni (ppm)	Cr (ppm)	Zr (ppm)	S (wt %)	Percent of Particles in This Size Category
Fly Ash Retained in Plant											
A. Sieved Fractions											
74	140	7	1.5	10	12	180	100	100	500	...	66.30
44-74	160	9	7	10	20	500	140	90	411	1.3	22.89
B. Aerodynamically Sized Fractions											
40	90	5	8	10	15	120	300	70	730	0.01	2.50
30-40	300	5	9	10	15	160	130	140	570	0.01	3.54
20-30	430	9	8	10	15	200	160	150	480	...	3.25
15-20	520	12	19	10	30	300	200	170	720	...	0.80
10-15	430	15	12	10	30	400	210	170	770	4.4	0.31
5-10	820	20	25	10	50	800	230	160	1100	7.8	0.33
5	980	45	31	10	50	370	260	130	1400	...	0.08

Particle diam. (microns)	Fe (wt %)	Mn (ppm)	V (ppm)	Si (wt %)	Mg (wt %)	C (wt %)	Be (ppm)	Al (wt %)
Fly Ash Retained in Plant								
A. Sieved Fractions								
74	...	700	150	...	...	...	12	...
44-74	18	600	260	18	0.39	11	12	9.4
B. Aerodynamically Sized Fractions								
40	50	150	250	3.0	0.02	0.12	7.5	1.3
30-40	18	630	190	14	0.31	0.21	18	6.9
20-30	...	270	340	...	...	0.63	21	...
15-20	...	210	320	...	...	2.5	22	...
10-15	6.6	160	320	19	0.16	6.6	22	9.8
5-10	8.6	210	330	26	0.39	5.5	24	13
5	...	180	320	...	...	...	24	...

TABLE II-6. CONCENTRATION OF TRACE ELEMENTS IN COAL AND FLY ASH
IN DIFFERENT GEOGRAPHICAL LOCATIONS (10)

Name	Eastern Interior (IL, IN, Western KY)			Southwestern (AZ, NM, CO, UT)			KY, Southern IL [mean (range)]		
	Coal	Fly Ash	Enrichment Factor ^a	Coal	Fly Ash	Enrichment Factor ^a	Coal	Fly Ash	Enrichment Factor ^a
Aluminum							11000 (10500-13000)	67000 (57000-74000)	5.9(5.4-6.5)
Antimony	0.5	12	24		14		<1	≤10	
Arsenic	14	120	8.6		130		8.8(3.8-1.8)	141(27-349)	12.4(5.7-19.4)
Barium	59	450	7.6				120(100-150)	1700(300-3000)	16(2-30)
Beryllium	<5	3-17					0.3 (<5)	3 (15-17)	10
Bismuth							<10	2	
Boron	100-200	250-3000	2.5-15				166(100-200)	1750(250-300)	9.2(2.5-15.)
Bromine							2.3(2.0-2.6)	<2-5	<2
Cadmium	6 (0.46)	160 (8.0)	26.7(17.4)						
Calcium							4200(3600- 5100)	17200(14000- 22000)	4.2(3.7-4.4)
Cesium							1.5(1.5-1.5)	18(15-21)	12(10-14)
Chlorine	355-407	<5-50	<0.01-0.14				407	50	0.12
Chromium	20 (20)	310(500)	15.5-25				82(30-150)	160(70-250)	2.4(1.1-3.8)
Cobalt	0 (3.0)	60 (41)	13.7				3.9(3.3-5)	37(25-51)	9.3(7.6-10.2)
Copper	20(50-100)	100(300-400)	5(3-8)	9.6	280	29.2	67(50-100)	367(300-400)	6(4-8)
Europium							0.24(0.17- 0.31)	1.7(1.6-1.8)	7.9(5.2-10.6)
Fluorine	<2-60	<10-100	ca. 1.7						
Gallium							13	70	5.4
Germanium							10(5-15)	135(70-200)	14(13-14)
Iron							15800 (13000-20000)	100000 (93000-139000)	6.9(6.5-7.2)
Lanthanum							5.3(4.8-6.)	33(30-36)	6.2(6.-6.4)
Lead	<30(4.9)	200(80)	(16.3)		110		ca. 20	210(80-250)	ca. 10
Lithium							50(25-100)	280(200-350)	8.6(2-12)
Magnesium							1600(1500- 1700)	8600(5500- 11600)	5.3(3.2-6.8)
Manganese	90(34)	500(290)	5.6(8.5)				53(51-54)	321(316-325)	6.1(6.0-6.2)
Mercury	<2(0.122)	<0.2(0.03)	ca 0.1(0.4)				0.10(0.063- 0.170)	0.06(0.04- 0.10)	0.63(0.58-0.68)
Molybdenum	3.6	118	32.8	0.99	54	54.5	17(10-20)	350(150-700)	8.2(7-10)

(continued)

TABLE II-6. (continued)

Name	Eastern Interior (IL, IN, Western KY)			Southwestern (AZ, NM, CO, UT)			KY, Southern IL [mean (range)]		
	Coal	Fly Ash	Enrichment Factor ^a	Coal	Fly Ash	Enrichment Factor ^a	Coal	Fly Ash	Enrichment Factor ^a
Nickel	90 (<100-150)	500 (500-1000)	5.6 (>3.3)				ca. 100	666 (500-1000)	ca. 5-7
Niobium							< 15	10 (6-15)	
Phosphorous							50	500	10
Potassium							2200 (2000-2500)	16000 (11700-19700)	7.1 (5.8-7.9)
Rubidium							86 (17-200)	380 (200-650)	9.8 (1.5-16.25)
Selenium	2.2	25	11.4	1.9	73	38.4	3.0 (2.6-3.2)	24 (23-24)	8.2 (7.5-8.4)
Silicon							50000	300000	6
Silver							<2-5	<3-5	
Sodium							700 (690-720)	6400 (5800-7000)	9.2 (8.0-10.3)
Strontium							200	300	1.5
Tantalum							0.1	1.2	12
Tellurium	1-3	<1-10	<10				2 (1-3)	<1-ca. 10	
Thallium	2	40-100	20-50				<2	70 (40-100)	
Thorium							2.7 (2.4-3)	20 (18-23)	7.8 (6.-9.6)
Tin							20	20	1
Titanium	510	6080	11.9				640 (500-710)	3480 (1500-5000)	5.6 (3.5-7.3)
Tungsten							1	5	5
Uranium							2.7 (1.67-3.3)	18 (15-21)	7.2 (5.0-10.2)
Vanadium	28.5	440	15.4				34 (12-69)	307 (100-780)	9.1 (4.0-11.7)
Zinc	1100 (46)	5900 (740)	5.4 (16.1)	7.3	360	49.3	170 (85-250)	2200 (500-3000)	23.6 (12.0-35.3)
Zirconium							40	100	2.5

^a Conc. in fly ash/conc. in corresponding coal.

TABLE II-7. ENRICHMENT FACTORS FOR FLY ASH/COAL
FROM UNSPECIFIED GEOGRAPHICAL LOCATIONS

NBS* Coal and Fly Ash						
Name	Enrichment Factors	Number of Coal Samples Analyzed	Number of Fly Ash Samples Analyzed	Station 1	Station 2	Station 3
Antimony	1.97	10	10	2.32	4.4	3.04
Arsenic	7.0	5	4	12.3	8.5	16.17
Barium	8.0	9	10	12.	7.	7.5
Beryllium				11.8	5.76	6.23
Boron				6.41	7.5	6.31
Cadmium				13.9	28.	17.66
Chromium	5.94	11	10	3.73	3.	8.23
Cobalt	7.14	11	10			
Copper				5.65	5.09	2.1
Germanium					4.17	5.7
Hafnium	7.92	11	10			
Iron	7.3	11	10	6.98	0.43	1.45
Lanthanum	6.86	5	4			
Lead				7.11	12.14	6.28
Magnesium	7.47	4	5			
Manganese				9.81	4.	6.57
Mercury				0.9	0.68	
Molybdenum					4.92	15.12
Nickel	6.57	3	3	14.86	5.82	5.77
Protactinium	5.16	5	4			
Rubidium	5.39	11	10			
Scandium	6.79	11	10			
Selenium				0.4	1.45	4.66
Strontium	9.87	11	10			
Tantalum	7.5	11	10			
Thorium	7.87	11	10			
Titanium	6.65	4	4			
Ytterbium	5.65	5	5			
Zinc				2.3	1.48	12.5
Reference	13	13	13	14	14	14

*National Bureau of Standards

TABLE II-8. SUMMARY OF ENRICHMENT FACTORS

Name	Number of Determinations	Arithmetic Mean	Geometric Mean	Standard Deviation	Range
Aluminum	1	5.9	5.9		
Antimony	5	7.	4.	9.	1.97-24.
Arsenic	6	11.	10.	3.	7.-16.17
Barium	6	10.	9.	4.	7.-16.
Beryllium	4	8.	8.	3.	5.76-11.8
Boron	4	7.	7.	1.	6.31-9.2
Bromine	1	<2.	<2.		
Cadmium	5	21.	20.	6.	13.9-28.
Calcium	1	4.2	4.2		
Cesium	1	12.	12.		
Chlorine	2	0.13	0.13	0.01	0.12-0.14
Chromium	7	9.	7.	8.	2.4-25.
Cobalt	3	10.	10.	3.	7.14-13.7
Copper	7	8.	6.	9.	2.1-29.2
Europium	1	7.9	7.9		
Fluorine	1	ca. 1.7	ca. 1.7		
Gallium	1	5.4	5.4		
Germanium	3	8.	7.	5.	4.17-14.
Hafnium	1	7.9	7.9		
Iron	5	5.	3.	3	0.43-7.3
Lanthanum	2	6.5	6.5	0.5	6.2-6.86
Lead	5	10.	10.	4	6.28-16.3
Lithium	1	8.6	8.6		
Magnesium	2	6.	6.	2	5.3-7.47
Manganese	6	7.	6.	2	4.-9.81
Mercury	5	0.5	0.4	0.3	0.1-0.9
Molybdenum	5	23.	16.	21	4.92-54.5
Nickel	7	7.	6.	4	3.3-14.86
Phosphorous	1	10.	10.		
Potassium	1	7.1	7.1		
Rubidium	2	8.	7.	3	5.39-9.8
Scandium	1	6.8	6.8		
Selenium	6	11.	5.	14.	0.4-38.4
Silicon	1	6.	6.		
Sodium	1	9.2	9.2		
Strontium	2	6.	4.	6.	1.5-9.87
Tantalum	2	10.	9.	3.	7.5-12.
Tellurium	1	<10.	<10.		
Thallium	2	35.	32.	21.	20-50
Thorium	2	7.84	7.83	0.05	7.8-7.87
Tin	1	1.	1.		
Titanium	3	8.	8.	3.	5.6-11.9
Tungsten	1	5.	5.		
Uranium	1	7.2	7.2		
Vanadium	2	12.	12.	4.	9.1-15.4
Ytterbium	1	5.65	5.65		
Zinc	7	16.	9.	17.	1.48-49.3
Zirconium	1	2.5	2.5		
Using Arithmetic Means Above*	44	9.	8.	6.	1.-35.

*Except for mercury, tellurium, bromine and chlorine.

piece of coal in the United States is chemically and physically identical to that element in every other piece of coal in the United States. These calculations were performed on the information contained in Table II-3, and the results can be found in Table II-9. For the reader's convenience, actual fly ash concentrations (arithmetic means from Tables II-4 and Table II-6) are included.

TABLE II-9. ESTIMATED ELEMENTAL COMPOSITION OF FLY ASH, (PPM)

Name	From Table II-3 ^a		Table II-4	Table II-6		
	Arithmetic Mean	Maximum	Arithmetic Mean	IL, IN, Western KY	AZ, CO, UT, NM	KY, Southern IL
Aluminum	76700	100300	60900			67000
Antimony	15	35		12	14	<10
Arsenic	103	384	27	120	130	141
Barium	1880	5000		450		1700
Beryllium	10	20	6	3-17	<5	3-17
Bismuth						2*
Boron	343	812	366	250-3000*		1750
Bromine	<32	<72				<2-5
Cadmium	55	340	3	8.0-160		
Calcium	31500	71400	43000			17200
Cesium	13	24				18
Chlorine	143	221		<5-50	50	
Chromium	144	355	126	310-500*		160
Cobalt	100	250	17	41-60		37
Copper	96	200	89	100-400*	280	367
Europium	3	4				1.7
Fluorine	ca. 140	ca. 270	345*	<10-100		
Gallium	23	38				70
Germanium	42	104				135*
Hafnium	6	9				
Iron	65000	121500	63000			100000
Lanthanum	62	98				33
Lead	83	350	52	80-200	10	210
Lithium	327	671				280
Magnesium	15600	60000	9000			8600
Manganese	217	875	202	290-500		321
Mercury	0.075	0.365	3	0.2	54	0.06
Molybdenum	120	276		118	54	350*
Nickel	1190	31360	82	500		666
Niobium						10
Phosphorous	1040	1500	2200*			500
Potassium	17000	35500	10800			16000
Rubidium	224	800				380
Scandium	25	40				
Selenium	58	166	16	25	73	24
Silicon	141000	168000	238000			300000*
Silver						<3-5*
Sodium	19320	94760	9600			6400
Strontium	840	1560				300
Tantalum	2.5	3.3				1.2
Tellurium				<1-10*		<1 - ca. 10
Thallium	13	23		40-100		70
Thorium	24	35				20
Tin	1.6	4.6				
Titanium	4800	9080	5400	6080		3480
Tungsten	4	4				5*
Uranium	10	15				18*
Vanadium	324	600	212	440		307
Ytterbium	3	5				
Zinc	912	4320	230	740-5900*	360	2200
Zirconium	148	275				100

^a Calculated using enrichment factors (Table II-8)

* This number, rather than the maximum calculated from Table II-3 (Column 3) is used in subsequent calculations.

III. COST OF TESTING FLY ASH-FILLED CONCRETE FOR ENVIRONMENTAL HAZARD

In this section, the approximate costs of analyses which would indicate the possible environmental hazard associated with fly ash are estimated in 1978 dollars. The range in estimates is due to the variation between laboratories, the uncertainties involved in making any estimate, and the possibility that an increased volume will result in a lower cost per sample. Thus, performing 500 analyses may cost much less per sample than the cost of performing one analysis.

A. Measurement of Total Radioactivity of Fly Ash

Total radioactivity of fly ash is measured by gamma-ray spectrometry. The apparatus measuring gamma radiation consists of a detector assembly containing either sodium iodide crystal or lithium drifted germanium detectors, a shield, a power supply, an amplifier, and a pulse height analyzer.

The instrument is first calibrated with a known nuclide standard for energy response. The fly-ash sample is placed in a container, and the container is placed in the counting chamber of the detector. The pulse spectrum of the fly-ash sample is measured. From the positions of the photo peaks and from the history of the fly ash, identification and quantitation of the nuclides present are obtained.

To convert the calculated gamma count rate of each nuclide identified, to a photon emission rate, the quantitation is performed by using the equation:

$$\text{dpm} = \frac{C}{A \times E}$$

where: dpm = disintegrations per minute
 C = observed counts per minute
 A = fractional abundance of the gamma ray
 E = photon detection efficiency

Cost/Analysis = \$500-\$1000 per sample

B. Testing Fly Ash for Radium-226

Radium-226 is an alpha (α) emitting nuclide. Because of its α -particles emission, it can be measured at about 1 pCi/g concentration for quantitation. Radium is separated from fly ash treated with strong nitric acid, reprecipitated by co-precipitation with mixed barium and lead sulfates. The resulting precipitate is dried on a counting plate, weighed to determine chemical yield, and alpha counted to determine the total disintegration rate of Ra^{226} .

Radium-226 alpha radiation is measured by an alpha particle counter, consisting of either a proportional detector or a scintillation detector and a scalar. The detector can discriminate Ra^{226} α -emissions from other radionuclide α -emissions since each α -emission has a discrete energy associated with it. After measuring the alpha activity of the nuclide, the level of radium-226 is calculated as follows:

$$\text{Alpha activity due to } \text{Ra}^{226} \text{ cpm/g} = \frac{1}{m} \left(\frac{A}{txE} \right) \times B$$

where: A = total counts accumulated
 B = background in counts per minute
 E = counting efficiency in percent x 0.001
 t = time of counting in minutes
 m = g of fly ash.

Cost/Analysis

Sample preparation	= \$180 - 200
Sample counting	= \$ 90 - 100
Calculation & reporting	= \$ 90 - 100
Total	\$360 - 400/sample

C. Elemental Composition of Fly Ash

Fly ash generated from various coal-fired power plants have almost identical composition as far as the gross elemental composition is concerned. The major components of fly ash, shown in Table II-4, are determined by x-ray spectrometry.

Cost/Analysis \$1,000 - 1,500/sample

For the trace metals, fly-ash samples are usually analyzed by three well-developed, highly sensitive methods:

- (1) X-ray fluorescence
- (2) Atomic absorption
- (3) Instrumental neutron activation

Cost/Analysis = \$1,500 - 2,500/sample

D. Organics in Fly Ash

Fly ash going through such a high heating process normally will not have the common organic compounds. Rather more stable organic compounds like polyaromatic hydrocarbons (PAH) and some other hetrocyclic compounds have been found in coal-produced fly ashes.

The common laboratory experiment for the analysis of PAHs and other related organics in fly ash is extracting these organics with suitable organic solvents and analyzing the extractants for organics. A known amount of fly ash is placed in a Soxhlet Extractor and extracted with pentane or hexane for 24 hours. The extract is then concentrated and the concentrate is analyzed by GC/MS for general qualitative analysis. The identification is confirmed by GC/MS.

Cost/Analysis = \$900 - 1,500/sample

E. Environmental Risks

Several laboratory measurement experiments could be designed to study the environmental risks associated with the fly ash. The following are a few exploratory ideas:

- Check room air in situ for low-level radiation using appropriate portable radiation detection equipment, e.g., G.M. counter, and proportional counter.

- Collect room air and dust particles through impingers; analyze the material from the impingers by sophisticated low-level radiation, trace element, and organic compound analyses in the laboratory.
- Wash the floors and walls with commonly used cleansing agents; analyze the wash water for low-level radiation, trace elements, and organic compounds.
- More comprehensive studies can be performed by crushing fly ash-filled concrete, filling glass columns with ash particles, leaching the columns with water having a pH between 4.5 to 5.5 (rain-water simulation under environmental conditions over a time period), and analyzing the leachate for radiation as well as trace metals and organic compounds.

A typical testing and evaluating program to obtain preliminary information will involve:

- Sampling and analyses in situ - 100 man hours
\$4,000 - 4,500
- Leachability and analyses in laboratory under simulated conditions - 300 man hours (\$12,000 - 14,000).

IV. ESTIMATION OF ENVIRONMENTAL IMPACTS

A. Multimedia Environmental Goals and Source Analysis Models

Multimedia Environmental Goals (MEGs) and Source Analysis Models (SAMs) refer to two interrelated mathematical techniques which attempt to predict the environmental impacts of new and developing technologies. The two techniques were developed by the U.S. Environmental Protection Agency (EPA) and constitute the most painstaking and thorough literature search and the most rational method for estimating environmental impacts developed to date (15).

MEGs are concentrations in the waste streams or in the environment, which should cause no environmental damage. The MEG which is applicable to a waste stream is called the Minimum Acute Toxicity Effluent (MATE), and that which is applicable to the receiving medium after dilution of the waste stream is called the Estimated Permissible Concentration (EPC) or Ambient Level Goal (15).

The MEGs result from standardized mathematical manipulations of laboratory values, existing federal standards, or suggested maximum safe concentrations of individual pollutants. The laboratory values include the lethal concentration in food or water for 50 percent of the organisms (LC_{50}); the amount (dose) which is lethal to 50 percent of the organisms when given by injection, forced feeding, inhalation, etc. (LD_{50}); and the "threshold" concentration or dose which shows a specific response (such as carcinogenesis) in the mean number (50 percent of the organisms (TL_m)). The suggested maximum safe concentrations include

the Threshold Limit Values, as recommended by both the American Conference of Governmental Industrial Hygienists and the National Institute for Occupational Safety and Health (15).

In their derivation of the MEGs, the developers assumed that synergistic and antagonistic actions could be ignored. In spite of these apparent limitations, the MEG approach is based on an extensive literature search, and the mathematical manipulations provide an inherently rational approach to the establishment of order-of-magnitude safe limits for individual pollutants (15).

The SAM uses the MATE part of the MEGs to address the problem of source identification and goal comparison. The SAMs assume no environmental interaction, even though this assumption is not often realized in the environment. The SAMs are designed to predict when an environmental hazard will occur, especially when accurate and detailed information on the waste streams is available (15).

Unfortunately, since applicable data does not as yet exist, the MEGs cannot take into account various factors which can affect the environmental impact of individual pollutants. These factors include:

- (1) Toxicity differences related to the oxidation state or form of the element
- (2) Water hardness
- (3) Organic complexes
- (4) Bioconcentration

- (5) Reduction of the toxic effects of one substance by another substance also present in the media
- (6) Increase in the toxic effects of one substance by another substance also present in the media
- (7) Acidity
- (8) Acid rain.

These various factors and their influence on the applicability and validity of the MEGs are discussed at length in Reference 15. In spite of the apparent possible deficiencies which may be introduced by these factors, the MEGs are the best methodology developed to date to estimate the possible environmental hazards of new and developing technologies.

B. Estimation of the Relative Hazard Offered by Individual Inorganic Pollutants

The pathological effect of several elements is shown in Tables IV-1 and IV-2. In these tables, a plus sign (+) indicates that the effect is observed, a minus sign (-) indicates that the effect is not observed, and a blank space indicates that no information is available. It is hoped that the blank spaces can be filled as more information becomes available. In general, inclusions in these tables indicate that a particular element and/or their compounds or complexes should be of environmental concern. The ranking of many of the elements with respect to their absolute toxicity can be found in Tables IV-3 and IV-4. Table IV-3 is a ranking system which simply counts the number of plus

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TABLE IV-4. COMPARISON OF THE ABSOLUTE TOXICITY POTENTIAL OF TRACE ELEMENTS AS ESTIMATED BY THE HITTMAN SYSTEM AND THE MEG SYSTEM AND ESTIMATION OF THE RELATIVE TOXICITY OF THESE MATERIALS IN FLY ASH

Element	Hittman ranking system	MEG hazard potential	Hittman ranking x avg. conc. fly ash	Hittman ranking x max. conc. fly ash	MEG ranking potential x avg. conc. fly ash	MEG hazard potential x max. conc. fly ash	Composite ranking x avg. conc. fly ash	Composite ranking x max. conc. fly ash
*Cadmium	46	30	2530	15640	1650	10200	1650	10200
*Mercury	31	30	2	11	2	11	2	9
*Lead	31	22	2573	10850	1826	7700	1752	7388
*Arsenic	29	25	2987	11136	2575	9600	2262	8431
*Selenium	29	26	1682	4814	1508	4316	1302	3728
*Thallium	28	20	364	644	760	460	749	440
*Nickel	26	26	30940	815360	30940	815360	25559	673558
*Beryllium	25	30	250	500	300	600	232	463
*Copper	23	20	2208	4600	1920	4000	1680	3500
*Zinc	20	12 ^d	18240	86400	10944	51840	11420	54094
*Antimony	19	26 ^a	285	665	390	910	288	672
*Chromium	15	30	2160	5325	4320	10650	2864	7061
Manganese	7	15	1519	6125	3255	13125	2123	8560
Fluorine	7	Not ranked	980	2415				
Sulfur (Hydrogen Sulfide)	6	12 ^d						
Nitrogen (Nitrate/Nitrite)	6	Not ranked						
Iron	6	Not ranked	3.9x10 ⁵	7.3x10 ⁵				
Cobalt	5	24	500	1250	2400	6000	1363	3408
Vanadium	2	16	648	1200	5184	9600	2803	5191
Bismuth	Not ranked ^b	20			40	40		
Uranium ^e	Not ranked ^b	20			200	300		
Iridium	Not ranked ^b	16			5232	10736		
Barium	Not ranked ^b	16			30080	80000		
Tellurium	Not ranked ^b	16			4	160		
Germanium	Not ranked ^b	16			672	2160		
Gallium	Not ranked ^b	15			345	570		
*Silver	Not ranked ^b	14			70	70		
Potassium	Not ranked ^c	12 ^d			2.0x10 ⁵	4.3x10 ⁵		
Magnesium	Not ranked ^c	12 ^d			1.9x10 ⁵	7.2x10 ⁵		
Strontium	Not ranked ^c	12 ^d			10080	18720		
Roron	Not ranked ^c	12 ^d			4116	36000		
Aluminum	Not ranked ^c	12 ^d			9.2x10 ⁵	12.0x10 ⁵		
Titanium	Not ranked ^c	12 ^d			57600	1.1x10 ⁵		
Molybdenum	Not ranked ^c	12 ^d			1440	4200		
Tungsten	Not ranked ^c	12 ^d			48	60		
Nitrogen (Ammonia)	Not ranked ^c	8 ^d						
Scandium	Not ranked ^c	8 ^d			200	320		

* On EPA's list of 65 toxic substances.

^a Antimony trioxide. Elemental antimony ranked at 20.

^b Too little information was available to rank these elements.

^c Not considered a sufficient environmental risk.

^d MEG hazard potentials less than 13 are not considered to be associated with hazardous material.

^e Based on chemical rather than radiological effects.

signs in Tables IV-1 and IV-2. This number is then called the Hittman Ranking System Number. The MEG Hazard Potentials (Table IV-4), derived by use of the MEG methodology, are obtained by a system which performs mathematical manipulations on the MEGs. The former system is partially inadequate since, for example, the syndrome "carcinogenesis" is ranked equally with "nausea" while the latter system is partially inadequate since it neglects all chronic toxic effects (except carcinogenesis) such as (chronic) brain and nervous system pathology, behavioral modification, reproductive effects, and shortened life span. In spite of the fact that these two types of inadequacies seem contradictory, the ranking of the absolute toxicities of elements using these two systems is remarkably consistent (see Table IV-4) (15).

A "composite ranking number" was calculated according to the following formula:

$$\text{Composite Ranking Number} = \frac{\frac{\text{Hittman Ranking} \times 30}{46} + \text{MEG Hazard Potential}}{2}$$

This formula normalizes Hittman Ranking Numbers (maximum 46) to MEG Hazard Potentials (maximum 30). These numbers, found in Table IV-4, have been calculated for all elements on which information is available. Since the inherent deficiencies of the two ranking systems seem to partially cancel each other, the composite ranking number may be the best indicator of possible environmental toxicity in absolute terms (15). However, many of the elements which have been ranked high using either ranking system, are present in fly ash in minute amounts. For example, although cadmium is ranked highest in absolute toxic potential, using both the Hittman System (Table IV-3) and the MEGs Hazard Potential

(Table IV-4), the average concentration of cadmium in fly ash is approximately 55 mg/kg (Table II-9). As another example, mercury is ranked second highest in absolute toxic potential, using both the Hittman System and the MEGs Hazard Potential; however, the average concentration of mercury in fly ash is approximately 0.075 mg/kg. On the other hand, aluminum is relatively abundant in fly ash (average: 76,700 mg/kg). Since aluminum is known to damage living systems when present at higher concentrations, the environmental impact of aluminum may be greater than the environmental impact of cadmium or mercury since there is approximately 1400 times more aluminum than cadmium, and approximately 1.0×10^6 times more aluminum than mercury in fly ash.

In order to provide a more realistic ranking of the relative environmental hazard potential of using fly ash in cement, the values provided as indices to rank trace elements according to absolute toxicity by the Hittman System, the MEG System, or the Composite Ranking Number were multiplied by the concentration of the individual pollutants in fly ash. The results of these calculations are given in Table IV-4. Since the deficiencies of the Hittman and MEG Systems tend to cancel each other, the "Relative Environmental Hazard Potential," calculated using the Composite Ranking Number, may be the most significant indicator of possible environmental hazard. The elements and compounds have been ranked according to the Relative Hazard Potential, using the Composite Ranking Number when both the MEG Hazard Potential and the Hittman Ranking Number were available (thus making calculation of the Composite Ranking Number possible). When either the Hittman Ranking Number or the MEG Hazard Potential were unavailable, the Relative Hazard Potential was calculated using the available ranking number. The elements were then ordered according to their Relative

Hazard Potential. This order is: aluminum, iron, potassium, magnesium, titanium, barium, nickel, zinc, strontium, lithium, boron, chromium, vanadium, arsenic, manganese, lead, copper, cadmium, molybdenum, cobalt, selenium, fluorine, germanium, gallium, antimony, thallium, beryllium, scandium, uranium, silver, tungsten, bismuth, tellurium, and mercury. This ranking system thus rates the relatively innocuous elements such as aluminum and iron quite high on the list.

Environmental hazards which result from the use of fly ash-filled concrete may have their origin in materials leached from the concrete. Very little information was uncovered dealing with the leaching of material from fly ash. The results of the one study found are shown in Table IV-5. In this study, the term "partitioning factor" refers to the concentration in the aqueous phase divided by the concentration in the fly ash. (For example, the manganese concentration in the aqueous phase would be expected to be 70 ppm if the concentration of manganese in the fly ash is 200 ppm. Manganese partitioning factor equals $0.35 = 70 \div 200$.) Since only 20 of the 89 elements which might be in fly ash were studied and the form of one of the studied elements may be more soluble in a different fly ash sample, let us make the very conservative assumption that the partitioning factor for any element is 0.36 (the highest partitioning factor of any element for which data are available). Therefore, the concentration of a material in the leachate will be 0.36 times the concentration of the material in the concrete. From Table IV-5 we see that this represents more than the maximum amount one would expect in the leachate, even if we assume, also very conservatively, that leaching from fly ash is unaffected by the fly ash being incorporated in concrete. Let us also assume that only materials in the first two millimeters of the surface

TABLE IV-5. AMOUNT OF ELEMENTS EXTRACTED FROM MIDWESTERN
FLY ASH BY DISTILLED WATER AT 25°C FOR 48 HOURS (16)

Element	Partitioning Factor*	Element	Partitioning Factor*
Antimony	0.021	Manganese	0.35
Arsenic	0.041	Phosphorous	0.11
Barium	0.002	Potassium	0.06
Cadmium	0.19	Silicon	0.001
Calcium	0.013	Sodium	<0.052
Chlorine	0.057	Thallium	0.25
Cobalt	0.13	Titanium	0.015
Iron	0.007	Vanadium	0.039
Lead	0.034	Zinc	0.22
Lithium	0.17		
Magnesium	0.006		

Arithmetic Mean: 0.09
 Geometric Mean: 0.04
 Unbiased Standard Deviation: 0.10
 Range: 0.001-0.35
 Number of Determinations: 20

*Partitioning factor = $\frac{\text{concentration in aqueous phase}}{\text{concentration in fly ash}}$

of the block will be subjected to leaching at any one time. This assumption neglects percolation through the block but probably overestimates the surface leaching. An 8 x 16 x 8-inch concrete block contains more than 7,000 cubic centimeters of concrete, hence approximately 2 percent of the concrete is subjected to leaching, using the assumption that only the first 2 millimeters of the surface are subject to leaching (and that only one side of the concrete block is subject to weathering). For concrete pavement 10 cm thick (4 inches), the 2-mm assumption also gives 2 percent subject to leaching. Hence, let us assume that 2 percent of the concrete is subject to leaching. Using 200 pounds of fly ash per cubic yard of concrete gives 0.0617 pounds of fly ash per pound of concrete if one assumes a density of concrete of 120 pounds per cubic foot. This density is at the lower end of the density range and, hence, should represent the worst possible case. Using all these assumptions, the concentration in the leachate should be 0.000444 times the concentration in the fly ash. The assumptions made above are made such that the result, 0.000444, is the maximum number expected.

The SAM methodology calculates the Degree of Hazard. This number is simply the concentration expected in the waste stream divided by the appropriate MATE. Thus, a Degree of Hazard greater than one indicates that the concentration in the waste stream is greater than the MATE and that therefore, the MEG methodology indicates that adverse environmental impacts may be expected. These numbers, along with the actual maximum concentrations, are given in Table IV-6.

From the tabulated Degrees of Hazard, we see that, of the elements which may not normally be associated with concrete or with materials normally used with concrete, only

TABLE IV-6. DEGREE OF HAZARD WHICH MAY BE ASSOCIATED WITH LEACHATE FROM FLY ASH-FILLED CONCRETE

Element	Estimated Average Concentration in Fly Ash (ppm)	Estimated Maximum Concentration in Fly Ash (ppm)	MATE's				Estimated Maximum Average Concentration in Fly Ash x 0.000444 ^d	Degree of Hazard from Estimated Maximum Concentration in Leachate	
			Aqueous Effluents (mg/l)		Solid Wastes (ppm) ⁺			Health Based	Ecologically Based
			Health Based	Ecologically Based	Health Based	Ecologically Based			
Aluminum	76700	100300	80. ^a	1.0 ^a	160.	2.0	44.	0.56	44.**
Antimony	15	35	7.5	0.20	15.	0.40	0.0155	0.0021	0.077
Arsenic	103	384	0.250	0.050	0.5	0.1	0.17	0.68	3.4*
Barium	1884	3000	3.0	2.3 ^c	10.	5.0	2.2	0.44	0.89
Beryllium	10	20	0.030	0.055	0.060	0.011	0.0089	0.296	0.16
Bismuth	2	1	0.1		11.		0.00009	0.00015	
Boron	343	3000	47. ^a	25. ^a	93.	50.	1.33	0.028	0.053
Bromine	<32	<72	>6.75 ^b		>13.5 ^b		<0.032	<0.0047	
Cadmium	55	340	0.050	0.001 ^a	0.10	0.002	0.15	3.0*	151.*
Calcium	31500	71400	>6.75 ^b		>13.5 ^b		22.	<4.7*	
Cesium	13	24	>6.75 ^b		>13.5 ^b		0.01	<0.002	
Chlorine	143	221	>6.75 ^b		>13.5 ^b		0.098	<0.01	
Chromium	144	500	0.250	0.250	0.50	0.50	0.22	0.89	0.89
Cobalt	100	250	0.750 ^a	0.250 ^a	1.5	0.5	0.11	0.15	0.44
Copper	96	400	5.0	0.050	10.	0.1	0.18	0.036	3.6**
Europium	3	4					0.0018		
Fluorine	140	345					0.15		
Gallium	23	38	74.	0.044	150.		0.017	0.0002	0.38
Germanium	42	135	8.4	0.008	17.		0.060	0.007	7.5**
Hafnium	6	9	>0.675 ^a		>1.35 ^b		0.004	<0.006	
Iron	65000	121000	>0.675 ^a		>0.135 ^b		53.9	<80.**	
Lanthanum	62	98	>0.675 ^a		>1.35 ^b		0.044	0.06	
Lead	83	330	0.250	0.050	0.5	0.1	0.16	0.62	3.1*
Lithium	327	671	0.33	0.375	0.70	0.70	0.30	0.90	0.79
Magnesium	15600	60000	20. ^a	0.1 ^a	100.	174.	27.	0.30	0.31
Manganese	217	875	0.250	0.10	0.5	0.2	0.39	1.6**	3.9**
Mercury	0.075	0.365	0.010 ^a	0.250 ^a	0.02	0.5	1.6x10 ⁻⁴	0.016	6.5x10 ⁻⁴
Molybdenum	120	350	75. ^a	7. ^a	150.	14.	0.16	0.002	0.02
Nickel	1190	31360	0.230 ^a	0.010 ^a	0.45	0.02	13.9	60.**	1390.**
Phosphorus	1040	1500					0.67		
Potassium	17000	35500	30.	43.	60. ^b	86. ^b	15.8	0.53	0.37
Rubidium ^c	224	800	>0.675 ^b		>1.35 ^b		0.36	<0.53	
Scandium	25	40	800.		1600.		0.018	2.2x10 ⁻⁵	
Selenium	40	114	50.	25.	7.10		0.051	0.0010	0.0020
Silver	<3	5	0.250	0.005	0.5		0.0022	0.0089	0.44
Silicon	141000	108000	>0.675 ^b		>1.35 ^b		75.	<10.**	
Sodium	19320	94760	>6.75 ^b		13.5 ^b		42.	<6.2**	
Strontium	840	1560	46.		92.		0.69	0.015	
Tantalum	2.5	3.3	>0.675 ^b		>1.35 ^b		0.0015	0.0022	
Tellurium	<1	10	1.5		3.0		0.0044	0.0041	
Thallium	13	23	1.5 ^a		3.0		0.010	0.0069	
Thorium	23	35	>0.675 ^b		>1.35 ^b		0.016	<0.023	
Tin	1.8	4.6					0.0020		
Titanium	4800	9080	90. ^a	0.82	180.	1.6	4.0	0.045	4.9**
Vanadium	4	4	15.		30.		0.0018	0.0011	
Uranium	10	15	60. ^a	0.50	120.	1.0	0.0067	0.00011	0.013
Vanadium	324	600	2.5	0.15	5.	0.3	0.27	0.11	1.8**
Ytterbium	3	5	>0.675 ^b		>1.35 ^b		0.0022	<0.0033	
Zinc	912	4320	25. ^a		50.	0.2	1.9	0.077	
Zirconium	148	275	>0.675 ^b		>0.135 ^b		0.12	<1.8*	

a - This MATE may represent an environmentally hazardous level. See Reference 14.

b - Estimated from information contained in Reference 14.

c - Rubidium oxides are very toxic and should not be allowed into the environment.

d - From concentrations discussed in the text, this number should represent the maximum possible concentration expected in leachate fly ash - filled concrete.

* - A degree of hazard greater than 1.0 indicates that environmental harm may be expected.

+ - All solid waste numbers have been multiplied by 100 (Personal communication, William Rhodes, EPA).

** - These elements have degrees of hazard greater than 1.0, which indicates that environmental harm may be expected; however, these elements are normally present in concrete and products associated with concrete (such as steel) and the addition of fly ash to concrete should not represent a significant increase in this hazard.

arsenic, cadmium, germanium, lead, vanadium, and zirconium may be present in the leachate in environmentally unsafe levels. Aluminum, copper, iron, manganese, nickel, sodium, silicon, and titanium also have degrees of hazard greater than 1.0; however, these elements are major components of substances used in conjunction with concrete, and the level of these components added by the use of fly ash-filled concrete should not substantially change the environmental impacts. The information in Table IV-5 indicates that the percentage of arsenic, lead, and vanadium leached from the fly ash should be considerably less than the 36 percent assumed; using the actual percentage leached from these elements in the calculation reduces their Degrees of Hazard to less than one. The Degree of Hazard for zirconium is based on a maximum estimate for the MATE. When the actual MATE is determined, this Degree of Hazard will likely decrease to a number less than one. Both the maximum expected concentration and the average expected concentration of cadmium in fly ash is affected by the one high point of 16.2 ppm found in one sample of Utah coal (see Table II-1). If this point is excluded, the maximum expected cadmium concentration in coal is reduced to 2.9 ppm. This reduces the concentration expected in the leachate 5.6 times, which is much less than the applicable MATEs.

Germanium is the only trace element which this method predicts may leach out of the ash-filled concrete in environmentally hazardous levels. This method indicates that more information should be gathered on the effects of cadmium and germanium in the leachate from fly ash-filled concrete.

C. Organic Pollutants

PAH produced during combustion of coal is the major organic pollutant category present. These compounds will, upon cooling, condense out as discrete particles or condense onto the surface of existing particles. Atmospheric PAH is believed, therefore, to be almost exclusively associated with particulate matter (15,17).

The primary ecotoxicological concern with PAH is the carcinogenic propensity of many of these compounds. Acute and chronic toxicity are of lesser concern; the systemic acute dose of LD₅₀ (the lethal dose for 50 percent of animals tested) is extremely high compared to the dose necessary to produce carcinogenic effects (15,17).

In a recent study, risk to workers exposed to coal tar pitch volatiles (topside of the ovens averaged 3.15 mg/m³) was a function of both exposure level and length of exposure. Lung cancer developed over a period of time varying from 10 to 40 years, with an average of 25 years. A threshold limit of 0.2 mg/m³ for a period of 30 years apparently did not increase the carcinogenic risk. Since it is highly unlikely that PAH will be desorbed from fly ash and diffuse through the concrete at rates fast enough to reach this concentration, it is unlikely that PAH will represent a hazard when fly ash is used as a concrete filler (15,17).

Aliphatic hydrocarbons generally are not toxic in low doses. They usually are simple asphyxiants before their toxic levels are reached. Evidence indicates that aliphatic hydrocarbons are rapidly eliminated from the lungs in the unchanged state. No effects were reported for aliphatic compounds at levels below 1700 mg/m³. Aliphatic hydrocarbons

also do not tend to accumulate in body tissues; thus cumulative toxicity from repeated exposure to low atmospheric concentrations is improbable, and these compounds should not pose a problem in fly ash-filled concrete (15,17).

The aromatic hydrocarbons are biochemically and biologically active. The vapors are much more irritating to the mucous membranes than equivalent concentrations of the aliphatic group. Systemic injury can result from the inhalation of vapors of the aromatic compounds, and hematological abnormalities, including leukemia, are associated with chronic benzene inhalation. No effects, however, have been reported at levels below 25 ppm, which is much above the level which would be expected from desorption from fly ash used as a concrete filler (15,17).

D. Radiation

Radioactivity refers to the tendency of certain elements to transform into other elements by changes in the structure of their nuclei. Generally, these changes involve the emission from the nucleus of either alpha or beta particles. The emission of these particles from the nucleus may or may not be accompanied by gamma radiation. In most cases there is no way to predict if a particular alpha or beta emission will be accompanied by a gamma emission, but the percentage of alpha or beta emissions which will be accompanied by gamma emissions is known for each radioactive decay reaction.

When a radioactive element decays, a new element is formed which itself is usually subject to decay. The decay series for the naturally occurring radionuclides is shown in

Figure IV-1. Each of these decay steps emits either an alpha or a beta particle so that the transformation of U^{238} to Pb^{206} releases a total of 14 alpha or beta particles. Since the first member of each decay series has a relatively long half-life when compared to the other members, a steady-state condition is established which is known as "secular" (or "radioactive") equilibrium. This steady-state condition allows one to calculate the concentration of each of the daughter radionuclides shown in Figure IV-1.

The reports of Coles and coworkers (18) and Kocster and Zieger (19) deal exclusively with radionuclides. Using this information in addition to the study of Swanson and coworkers (20) and other studies mentioned in Table II-1 gives the following estimation for average and maximum concentrations for uranium and thorium for any one survey of samples of U.S. coals:

TABLE IV-7. ESTIMATED CONCENTRATION OF URANIUM AND THORIUM IN U.S. COALS (ppm) (4,6,18,19,20)

<u>Element</u>	<u>Number of Surveys</u>	<u>Arithmetic Mean</u>	<u>Geometric Mean</u>	<u>Unbiased Standard Deviation</u>	<u>Range</u>
Uranium	11	2.4	2.0	2.1	1-8.1
Thorium	10	4.6	4.1	2.3	2.1-9.8

It should be mentioned that there exists one report (21) which indicates that "nucleotides" may range as high as 5,000 ppm in coal. However, the source and number of samples taken to support this concentration are not known, and it is not expected that coal which is this radioactive would be commonly found. The highest verified average uranium content in any U.S. coal is 8.1 ppm in Iowa coal. The highest verified average concentration of thorium is

THE URANIUM (-RADIUM) DECAY SERIES

THE URANIUM-ACTINIUM DECAY SERIES

THE THORIUM SERIES

Figure IV-1. Decay series for naturally occurring uranium and thorium isotopes

approximately 9.8 ppm in this same survey of Iowa coals.
(The maximum concentrations in Iowa were 42.9 ppm and 52.3 ppm respectively.)

Use of the reports mentioned in the previous paragraph and the reports summarized in Table IV-8 gives the following enrichment factors:

TABLE IV-8. URANIUM AND THORIUM COAL/FLY ASH ENRICHMENT FACTORS*

<u>Element</u>	<u>Number of Reports Used in Calculation</u>	<u>Arithmetic Mean</u>	<u>Geometric Mean</u>	<u>Unbiased Standard Deviation</u>	<u>Range</u>
Uranium	4	5.2	4.5	2.4	1.7-7.2
Thorium	3	6.5	6.2	2.2	3.9-7.87

*Using reports dealing only with radionuclides, as well as the previously mentioned reports dealing with radioactive and non-radioactive elements.

Using this information, we calculate the expected average and maximum concentrations of uranium and thorium. These are shown in Table IV-9.

TABLE IV-9. EXPECTED AVERAGE AND MAXIMUM CONCENTRATIONS OF URANIUM AND THORIUM IN ANY U.S. FLY ASH

<u>Nuclide</u>	<u>Average Expected U.S. Fly Ash</u>	<u>Maximum Expected U.S. Fly Ash Using Average Calculated Enrichment Factor</u>	<u>Maximum Expected U.S. Fly Ash Using Maximum Calculated Enrichment Factor</u>
Uranium	12.5 ppm	42 ppm	58 ppm
Thorium	29.9 ppm	64 ppm	77 ppm

The most conservative assumption possible is that all coals contain the average amount of thorium and uranium

found in the most radioactive coal found in the United States. The literature surveyed showed that this coal would be the Iowa coal with 8.1 ppm uranium and 9.8 ppm thorium. The most conservative calculation possible to estimate the concentration of nuclides in fly ash is 7.2 for uranium and 7.87 for thorium. These calculations give a maximum concentration in fly ash of 58 ppm for uranium and 77 ppm for thorium. This gives 0.0116 pounds (5.3 grams) uranium and 0.0154 pounds (7.0 grams) thorium per 200 pounds of fly ash.

If a "secular equilibrium" is assumed to exist, the decay series shown in Figure IV-1 can be used to determine the total number and type of radioactive decay products expected to result from the decay of 5.3 grams of uranium or 7.0 grams of thorium and associated daughter products. For example, 5.3 grams of uranium would be expected to contain 5.26 grams U^{238} . (The natural abundance of the U-238 isomer is 99.27 percent.) The half life of U^{238} is 4.51×10^9 years, which indicates that, of the 1.33×10^{22} atoms of U^{238} present in 5.26 g of U^{238} , 64,500 atoms will undergo nuclear transformation in one second. This is equivalent to 1.76 microcuries. (A curie is 3.7000×10^{10} nuclear transformations per second.) Since "secular equilibrium" has been assumed, for each U^{238} decaying to Th^{234} , one Th^{234} must decay to Pa^{234m} , etc., so that the steady-state condition is realized. Thus for the total 14-step decay series $U^{238} \longrightarrow Pb^{206}$, 24.6 microcuries of radiation would be expected. From the known decay characteristics of the decay reactions shown in Figure IV-1, the total alpha, beta, and gamma emissions expected can be calculated. These calculations have been performed for the most radioactive sample of (Iowa) coal and appear in Table IV-10. It should be noted that this fly ash would contain 19.4 pCi Ra^{226} per gram. This amount is four times the proposed EPA radiological

TABLE IV-10. RADIOACTIVITY EXPECTED DUE TO DECAY OF THE URANIUM AND THORIUM SERIES ASSOCIATED WITH ONE CUBIC YARD OF FLY ASH-FILLED CONCRETE USING THE MOST RADIOACTIVE U.S. FLY ASH (MADE FROM IOWA COAL)

Series	DPS ^a	μCi	Total in μCi for Decay Series ^b	Emissions	Total Produced/Sec. For 1 Cubic Yard Fly Ash-Filled Concrete	Average Energy (MeV)	Maximum Energy (MeV)
Th ²³² →Pb ²⁰⁸	28,700	0.78	7.8	alpha beta gamma	1.7 x 10 ⁵ 1.1 x 10 ⁵ 7.6 x 10 ⁴	5.99 0.91 0.879	8.785+ 2.38 2.6146
U ²³⁸ →Pb ²⁰⁶	65,000	1.76	24.6	alpha beta gamma	5.0 x 10 ⁵ 3.8 x 10 ⁵ 2.3 x 10 ⁵	5.35 1.04 0.55	7.687 3.26 1.850
U ²³⁵ →Pb ²⁰⁷	3,200	0.09	0.9	alpha beta gamma	2.2 x 10 ³ 1.2 x 10 ³ 2.2 x 10 ³	5.94 0.788 0.357	8.01 1.44 1.265
Total U, Th→Pb	96,900	2.63	33.3	alpha beta gamma	6.7 x 10 ⁵ 4.9 x 10 ⁵ 3.1 x 10 ⁵	5.52 1.01 0.614	8.785+ 3.26 2.6146

^aDisintegrations per second for each isotope of the decay series.

^bBased on a 10-step decay series for thorium-232, a 14-step series for uranium-238, and an 11-step series for uranium-235.

hazard level; therefore, it is highly unlikely that such fly ash would be used in concrete.

Gamma emissions will be the primary area of concern even though, in a biological sense, an alpha particle is approximately 10 times more damaging than a beta or gamma emission. This greater potential for damage results from the relatively greater mass of the alpha particle. Fortunately, the greater mass of the alpha particle also makes it relatively easy to stop (average path length of approximately 2 cm in the air for the most energetic alpha expected from radiological decay). Most alpha and even beta particles which result from the decay of the naturally occurring radionuclides are incapable of penetrating the epidermal layer of the skin and can result in radiological damage only if the isotope capable of alpha decay is inhaled or ingested and absorbed from the intestinal tract. Gamma particles are much harder to stop because they have little mass and no charge. Gamma particles can penetrate organisms through the skin. However, the relatively low mass of the gamma emissions means that an organism can be exposed to more gamma emissions than alpha emissions of equal energy before the same amount of biological damage can be expected.

The cement itself will provide some protection against radiation from nuclides contained within the concrete. For decay products which have the average energies given in Table IV-10, the penetration in cement for half of the entities are: alpha: virtually none, beta: less than 2 cm, and gamma: approximately 8 cm (22). Half of the most energetic gamma rays listed in Table IV-10 will be stopped by 10.7 cm of concrete.

A second factor to consider is the direction in which the decay product is emitted. Obviously decay products

traveling in directions parallel to the surface of the concrete in contact with the environment will likely become absorbed before they can interact with the environment. A radioactive decay product which begins its journey on the surface of a concrete product but travels into the block is much less likely to interact with the environment than one which begins its journey by traveling into the environment. Thus, only about one-fourth of the decay products will start their journey orientated in a direction which may cause environmental harm.

Let us consider an average (1200 ft^2) house which is constructed of concrete block on a concrete slab. Let us assume that the concrete used to make this house is filled with the most radioactive fly ash found in the U.S. (from our previous extrapolations). The radioactive decay emissions per cubic yard of this concrete will then be found in Table IV-10. Of these emissions, approximately one-fourth of more than half of the gamma rays emitted within 8 cm. of the interior of the house will reach the interior, while approximately one-fourth of less than half of the gamma rays emitted at a distance greater than 8 cm from the interior of the house will reach the interior of the house. As an approximation, let us consider only one-fourth of those gamma emissions which originate within 8 cm of the interior of the house. As a second approximation, let us assume that the concrete slab is solid concrete (neglecting the steel reinforcement) and that the concrete blocks are 50 percent concrete. If the walls of the house are 9 feet high, there is approximately 6 cubic yards of wall concrete within 8 cm of the interior of the house and approximately 12 cubic yards of a floor concrete within 8 cm of the interior of the house. Thus, a total of 1.4×10^6 gamma rays per second would be expected in the interior of the house (neglecting absorption by the air, rugs, paint, drapes, furniture,

etc.). The living area of the house is approximately 10,800 ft³ and a standard man occupies about 2.3 ft³ (22); hence, the standard man will be exposed to about 300 gamma rays per second while in the house. A 20-pound infant will be exposed to about 40 gamma rays per second. We may assume that the standard man absorbs all of the gamma rays to which he is exposed. Using the average energy for the gamma rays in Table IV-10, we find that the standard man is exposed to approximately 2.9×10^{-4} ergs per second of gamma irradiation, which is equivalent to 4.1×10^{-11} rads or rems per second, 3.6×10^{-6} rads or rems per day, or 0.0013 rads or rems per year. Since the relative biological effectiveness is one for both gamma and beta emissions, the rads and rems are equal (23).

How do these levels compare with the radiation levels to which a person is exposed from natural sources? At sea level the dose rate from cosmic radiation is about 0.030 rem per year in Florida and about 0.035 rem per year in Alaska. In mid-latitudes, it is about 0.033 rem per year at sea level, rising at an elevation of one mile to about 0.070 per year. On the average, the annual cosmic ray dose equivalent in the United States is probably about 0.040 rem (24).

The contribution from the ground outside of buildings varies from place to place. The terrestrial radiation (total gamma-ray dose rate less the cosmic-ray contribution) has been measured in more than 200 locations over a major portion of the United States. The terrestrial dose rates observed ranged from about 0.030 rem per year at Dallas, Texas, to about 0.13 per year at a location in Denver, Colorado. The structural materials of buildings contain widely varying amounts of natural radionuclides that contribute to the dose rate inside of buildings, but these materials attenuate the cosmic radiation and also the

terrestrial gamma radiation. Measurements within buildings indicate that the shielding effect of the structural materials outweighs the source effect, and that, on the average, the levels inside are about 90 percent of those outside of buildings. Thus, in the United States (bearing in mind the distribution of the population), the whole-body dose is about 0.1 rem per year, from cosmic and terrestrial radiation combined. Dietary intake contributes another 0.025 rem per year (24).

Thus, in total, natural radiation in the United States results in an estimated population-weighted average annual dose equivalent of about 0.125 rem. It is unlikely to be less than 0.10 rem for any individual and unlikely to be more than 0.40 rem for any significant number of people. This degree of exposure is not regarded currently as of sufficient magnitude to require separate consideration in the determination and control of an individual's medical or occupational exposure. There is no validated observed deleterious effect from natural background radiation in the portion of the population receiving the higher ranges of natural radiation, but it must be recognized that satisfactory epidemiological studies to determine such effects are probably impractical (24). Thus, the radiation added to the environment by using fly ash-filled concrete from the most radioactive coal found in the United States will not significantly increase the radiation exposure expected.

There is a gaseous alpha particle emitter in each one of the three natural radioactive series. Each of these gases is an isotope of the element having the atomic number 86. This element is usually called radon (sometimes emanation), and the gases are Rn^{219} (actinon), Rn^{220} (thoron), and Rn^{222} (radon). Radon is chemically inert; hence, no gas mask can separate it from the air chemically. When it gets

into the lungs, this gas is very destructive, since it is literally within a vital organ. The maximum permissible safe concentration of radon in the atmosphere is about 10^{-15} percent by volume (23). From the projections of the thorium and uranium found in coal, we predict that, if secular equilibrium is reestablished, the amount of radon isotopes associated with one cubic yard of concrete made with the most radioactive fly ash projected for the United States will be as shown in Table IV-11. Since sufficient time will not have elapsed for the formation of secular equilibrium, the figures in Table IV-11 are an overestimation of the amount of radon actually present.

TABLE IV-11. ESTIMATE OF THE MAXIMUM AMOUNT OF RADON ASSOCIATED WITH ONE CUBIC YARD OF FLY ASH-FILLED CONCRETE

<u>Isotope</u>	<u>Amount</u>	<u>Decay Product</u>	<u>Total Energy (ergs/sec)</u>	<u>Total Decomposing (sec.)</u>
Rn ²²²	1.1×10^{-11} g	alpha gamma	0.46 4.2×10^{-5}	65,000. 54.
Rn ²¹⁹	6.4×10^{-19} g	alpha gamma	0.034 2.8×10^{-4}	3,200. 570.
Rn ²²⁰	8.5×10^{-16} g	alpha gamma	0.40 7.4×10^{-5}	28,700. 85.

Total ergs/second produced: 0.89

The radon associated with the 18 cubic yards in the previously discussed concrete house will have 16.1 ergs per second of energy associated with it because of the radiological decomposition of radon. Let us consider the amount of radon in the house. It is known that the air in the average house undergoes a complete change every hour (25). This will upset the $U^{238} \rightarrow Pb^{206}$ secular equilibrium since the half-life of the gaseous member of this series, Rn²²², is 3.82 days. However, the secular equilibrium of the other

two series will not be upset since the half-life of Rn^{219} is 3.92 seconds and that of Rn^{220} is 54.5 seconds. If we assume that secular equilibrium $\text{U}^{238} \rightarrow \text{Ra}^{226}$ has been established and that the other two series are in equilibrium, we can calculate the amount of radon produced by 18 cubic yards of the most radioactive fly ash-filled concrete (3,600 pounds of the Iowa coal fly ash) in one hour. These calculations appear in Table IV-12.

The standard adult male in the house will have a total lung capacity of 0.20 cubic feet. If we assume that one-half the radon diffuses into the house (a very conservative assumption) we find that the man will be exposed to 1.9×10^{-4} ergs/hour due to alpha irradiation and 7.1×10^{-8} ergs/hour due to gamma irradiation of radon in the lungs. This is equivalent to 2.7×10^{-11} rads and 2.7×10^{-10} rems per hour or 2.4×10^{-7} rads and 2.4×10^{-6} rems per year.

Once again, using our very conservative assumption that one-half of the radon diffuses into the house, we find after one hour (assuming that the air change occurs just before the hour is up) the concentration of radon will be 1.6×10^{-10} micrograms per cubic meter or 1.8×10^{-18} volume percent. The maximum permissible concentration of Rn^{222} in air for occupational exposure for a 168-hour week is 10^{-8} microcuries per cubic meter. The concentration over any surface (such as the outside of a concrete building) which allows rapid mixing with the atmosphere should be even less; so the hazard should be less. Thus, using the very conservative assumptions of this report, for fly ash made from coal which contains the highest amount of uranium and thorium, there probably will not be a significant radiological hazard from radon. Further research in this area is needed.

TABLE IV-12. AMOUNT OF RADON PRODUCED AND EXPECTED TO BE PRESENT IN
ONE HOUR FROM 18 CUBIC FEET OF CONCRETE CONTAINING 200 POUNDS
OF IOWA COAL FLY ASH*

Isotope	Half-life	Grams Radon Produced Per Hour	Grams Radon Decaying Per Hour	Net Amount Radon Associated With 3,600 Pounds of Fly Ash in One Hour (g)	Decay Product	Total Energy (ergs/hour)
Rn ²²²	3.82 days	8.6×10^{-14}	6.4×10^{-16}	8.5×10^{-14}	alpha	12.8
					gamma	1.2×10^{-3}
Rn ²¹⁹	3.92 sec.	2.0×10^{-17}	$2.0 \times 10^{-17**}$	$1.2 \times 10^{-17**}$	alpha	0.6380
					gamma	5.2×10^{-3}
Rn ²²⁰	54.5 sec.	8.2×10^{-16}	$8.2 \times 10^{-16**}$	$1.5 \times 10^{-14**}$	alpha	7.06
					gamma	1.3×10^{-3}

* Assuming no radon at time zero.

**The half-lives of these isotopes are short enough to allow secular equilibrium to be established.

Total energy due to radon decay: alpha: 20.5 ergs/hour

gamma: 7.7×10^{-3} ergs/hour

Radiation damage to the human body depends on the dose, the dose rate, and the part of the body exposed. The permissible limits as found in the Radiological Health Handbook (22) are found below (Table IV-13):

TABLE IV-13. RADIATION PROTECTION GUIDES

<u>Type of Exposure</u>	<u>Condition</u>	<u>Dose (rem)</u>
Radiation worker: .		
(a) Whole body, head and trunk, active blood-forming organs, gonads, or lens of eye	Accumulated dose 13 weeks	5 times number of years beyond age 18 3
(b) Skin of whole body and thyroid	Year 13 weeks	30 10
(c) Hands and forearms, feet, and ankles	Year 13 weeks	75 25
(d) Bone	Body burden	0.1 μCi of Ra^{226} or its biological equivalent
(e) Other organs	Year 13 weeks	15 5
Population:		
(a) Individual (adult male)	Year	0.5 (whole body)
(b) Average	30 years	5 (gonads)

The whole-body gamma irradiation to a man who spends all of 30 years in the house will be approximately 0.039 rads or rems, while the exposure of the gonads will be approximately 3.3×10^{-5} . The radiation from beta emissions will be considerably less than the gamma irradiations, since the average path length of the beta emissions is approximately one-fourth of the path length of the gamma irradiation. Hence, the expected irradiation for a person spending 100 percent of his time in a concrete block house built on a

concrete slab filled with the most radioactive fly ash expected in the United States will be less than 0.078 times the dose recommended as an occupational limit by the International Committee on Radiation Protection (ICRP).

The ICRP also recommends that humans under the age of 18 and pregnant women not be exposed to radiation. This suggestion probably results from the rapidly reproducing cellular population in these classes of organisms. Rapidly reproducing cells are especially susceptible to damage due to broken chromosomes caused by radiation. Such damage can result in carcinogenesis, mutagenesis, or teratogenesis. However, these requirements are based on occupational exposures only. There is no place in this universe where the "no-radiation level" is realized. The recommendations do not attempt to deal with the maximum non-occupational exposure level which would not cause significant biological damage. As such, the ICRP recommendations concerning young and pregnant humans are inappropriate for comparison with the radiation levels discussed above.

As a second test, let us assume that the fly ash contains 10 pCi Ra²²⁶ per gram. This is twice the EPA-proposed level defining a substance as a radiation hazard. The gamma irradiation from Ra²²⁶ is very slight, with 4 percent of the decompositions giving gamma rays of energy 0.187 MeV and 0.001 percent of the decompositions giving gamma rays of 0.260 MeV. All other radioactive decays of Ra²²⁶ give no gamma irradiation. All decay of this radium isotope gives alpha particles. In 95 percent of these cases the alpha particle has an energy of 4.78 MeV, and in 4 percent of the cases the alpha particle has an energy of 4.59 MeV. Since the penetration of an alpha particle is virtually zero, only the gamma radiation will be environmentally significant. If the fly ash contains 10 pCi Ra²²⁶/g, one cubic yard of

concrete will contain approximately 34,000 atoms of Ra^{226} decaying per second or 1,400 gamma rays of energy 0.187 MeV and 0.34 gamma rays of energy 0.260 MeV produced per second. This is equivalent to 4.2×10^{-4} ergs and 1.4×10^{-7} ergs or 6.0×10^{-11} and 2.0×10^{-14} rem per second, respectively. There apparently is little danger of adverse health effects resulting from Ra^{226} .

In summary, in order to assess the possible radiological hazard of using fly ash-filled concrete, we have considered only one-fourth of the radiation which would be emitted from radionuclides within 8 cm of the interior of a concrete house with four concrete block walls on a concrete slab. We have only considered the most radioactive fly ash, which we extrapolated from our previous considerations in Section II of this report. We have neglected any leaching of materials such as leaching by seepage into the basement (which will probably be removed by pump or drain, radically reducing its potential impact). We have also neglected any effect of inhalation of concrete dust which might be formed when nails are driven into the walls. The likelihood of the presence of such dusts is reduced by rugs, paint, plaster, etc. The assumptions we have made should illustrate the worst practical case.

Since coal was formed millions of years before induced nuclear fission became a reality, the more hazardous radioisotopes which result from nuclear fission are not present. Indeed, in this respect, fly ash may be less a radiation hazard than other materials which have been subjected to nuclear fallout.

E. Legal Requirements

Table IV-14 lists the legal requirements and guidelines which may apply to the leachate from ash-filled concrete. Comparison of this table with Table IV-6 shows that some of the requirements and guidelines (as indicated by asterisks) may be exceeded in receiving media, if a 10x dilution of the leachate is assumed. One would expect at least this dilution level of the leachate in the environment. The elements which may cause a problem in this respect are: aluminum, arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, selenium, silver, thallium, thorium, titanium, vanadium, and zinc. If we assume a hundred-fold dilution, which is probably a more environmentally significant situation, the list is reduced to aluminum, chromium, copper, iron, nickel, selenium, thallium, vanadium, and zinc. Of the original list, aluminum, chromium, copper, iron, manganese, nickel, and zinc are common in materials used in conjunction with concrete, and the use of fly ash-filled concrete should not significantly aggregate the problems already present. Thus, present regulations and guidelines for selenium, thallium, and vanadium are the ones which are most likely to cause problems with regard to the use of fly ash-filled concrete.

TABLE IV-14. LEGAL REQUIREMENTS AND GUIDELINES WHICH MAY APPLY TO THE LEACHATE FROM ASH-FILLED CONCRETE (units are mg/l)

Name	Symbol	Drinking Water	Acceptable Level in Fresh Water "Critical Conc."	Effluent Standards (One Day Maximum)	Acceptable Level in Marine Water "Critical Conc."	Water Quality Criteria Federal Water Pollution Control Administration (FWPCA)		Derived Standards EPA Proposed Basis		Public Water Supply Intake EPA	Most Stringent State Standard	Standard as Critical Concentration in Potable Water	Maximum Acceptable Concentration for Livestock Drinking Water	Estimated Maximum Average Concentration in Leachate
						Surface Water	Irrigation	Freshwater	Marine					
Aluminum	Al	0.01*												44
Antimony	Sb	0.05	0.20		0.003			0.04				0.5		
Arsenic	As	0.05(0.01)*	0.02	1.0	0.002*	0.05	1.0	0.002*	0.1	0.01*	0.01*	0.2	0.016	
Barium	Ba	1.0				1.0					2.0			2.2
Beryllium	Be	1.0	0.100		0.02			0.01				1.0		0.0089
Bismuth	Bi	0.1			0.002							0.1		0.00089
Boron	B	1.0				1.0	0.75			1.0				1.3
Bromine	Br	3.0												0.032
Cadmium	Cd	0.01*		0.10 ^c		0.01*	0.005*			0.01*	0.01*	0.01*	0.05	0.15
Chloride	Cl	250												0.098
Chromium	Cr	0.05	0.005*		6x10 ⁻⁵ *	0.05	5.0	0.003*	2.05	0.05	0.30	0.02*	1.0	0.22
Cobalt	Co	0.05	0.100		0.003*							0.05	1.0	0.1
Copper	Cu	0.1(1.0)	0.02	0.1	0.001*	1.0	0.2	0.0005*	0.001*	1.0	0.05*	0.01*	0.5	0.18
Fluorine	F	1.4-2.4 ^d									15.0			0.15
Germanium	Ge	0.5											0.5	
Iron	Fe	(0.3)*		Dissolved: 0.6*							0.3*			54.0
Lead	Pb	0.05	0.01*	0.4	0.005*	0.05	5.0	0.01*	0.01*	0.05	0.05	0.01*	0.1	0.16
Magnesium	Mg	10												27.0
Manganese	Mn	0.05	0.01*	4.0 ^e	0.002*	0.05	2.0		0.1			0.01*		0.39
Mercury	Hg	0.002	0.001	0.002 ^f	5x10 ⁻⁵			2x10 ⁻⁴	2x10 ⁻⁴	0.002	0.0005	0.002	0.001	1.6x10 ⁻⁴
Molybdenum	Mo	0.5	0.01*		0.13		0.005*		0.005*			0.5		0.16
Nickel	Ni	0.05*	0.005*		0.001*		0.5*	0.008*	0.001*		1.0*	0.05*		13.9
Nitrate	N	10(45)												
Radium	Ra											0.001		
Rubidium	Rb	5												0.36
Selenium	Se	0.01	0.001*		0.002*	0.01	0.05	0.0001*	0.01	1.0	0.01	0.05	0.072	
Silver	Ag	0.05	0.001*		0.005				0.0005*	0.1	0.001*			0.0022
Sulfate	SO ₄ ²⁻	(250)												
Tellurium	Te		0.01		0.0001*					0.005		0.005		0.010
Thallium	Tl		0.01*									0.0005*		0.016
Tin	Sn	0.05										0.05		0.002
Titanium	Ti	0.1*												4.0
Tungsten	W	100										100		
Uranium	U	0.5		4 ^g										0.0018
Vanadium	V	0.1	0.05		0.01*		10.0	0.025*				0.1	0.1	0.27
Zinc	Zn	5				5.0	5.0			5.0	0.01*	0.05*	5	1.6
Zirconium	Zr	1												0.12
Coliform bacteria		1 bacteria per 100 ml		400 counts per 100 ml										
Fungi		0.001									0.30			
Reference		14,15	15	14	15	13	13	15	15	13	14	14	14	Table IV-6

*Value in parenthesis is for 1968 Public Health Service Drinking Water Standards; value is given only if different from Primary Drinking Water Regulation.

^bAs protected highest concentration found in leachate from fly ash filled concrete (Table IV-6).

^cFor Mining and Dressing, Base and Precious Metals: From Mills (Best Practical Technology (BPT)).

^dRelated to temperature.

^eLocal Mining, Mine Drainage (BPT).

^fFor Mining and Dressing, Base and Precious Metals: From Mine Drainage or Mills (BPT).

^gFor Mining and Dressing, Uranium, Radium, Vanadium Ores: Mine Drainage (BPT).

^hCanned and Preserved Fruits and Vegetables, Citrus Products (BAT, NSPS).

ⁱThis standard may be exceeded by the estimated maximum concentration in the leachate if the leachate is only diluted 10x before reaching the media.

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