TRACE AND MINOR ELEMENT STACK EMISSIONS
(lb/yr-1000MW)

Element/Station	Station I	Station II	Station III
Coal Type	Sub-bituminous	Sub-bituminous	Lignite
Emission Control	Venturi Scrubber	Electrostatic Precipitator	Cyclone
Aluminum	390,000	350,000	6,900,000
Antimony	41	33	1,8QO
Arsenic	500	8.2	11,000
Barium	9,800	<3,000	<70, 000
Beryllium	29	<50	280
Boron	16,000	10,000	630,000
Cadmium	190	18	650
Calcium	1,300,000	610,000	17,000,000
Chlorine	430,000	330,000	410,000
Chromium	18,000	6.500	41,000
Cobalt	310	170	2,900
Copper	1,400	1,400	20,000
Fluorine	20,000	31,000	350,000
Iron	210,000	110,000	8,800,000
Lead	1,200	670	3,800
Magnesinm	210,000	90,000	4,200,000
Manganese	5,300	2,000	68,000
Mercury	530	190	960
Molybdenum	8,600	350	33 000
Nickel	2,400	3,300	30,000
Selenium	410	1,400	3,300
Silver	17	4.1	<40
Sulfur	28,000,000	27,000,000	83,000,000

Titanium	19,000	24,000	190,000
Uranium	140	35	1,400
Vanadium	9,800	2,900	28,000
Zinc	6,000	940	33,000
Fly Ash	3,900,000	2,900,000	97,000,000

From "Coa1 Fired Power Plant Trace Element Stuty. Volume 1. A Three Station Comparison", U.S. Dept. of Commerce report PB-257293, Sept. 1975, page 31.

Element	Mean conc. (ppm)	Ton/yr per plant	Ton/yr total US	Est. value $/lb	$/yr total US
Al	26,400	105,600	16,262,400	$1.15	$37,400M
Cd	0.4	1.6	246.4	2.50	1,227
Cr	29.54	118.2	18,202	2.00	72.8
Co	7.78	31.12	4,792.5	2.60	24.9
Cu	20.38	81.52	12,554	0.90	22.6
Eu	0.641	2.56	394.2	3,400.00	2,681
Fe	15,100	60,400	9,301,600	0.07	1,302
Ga	7.13	28.5	1,098	1,135.00	2,492
Hf	0.994	3.98	612.9	75.00	91.9
Hg	0.335	1.34	206.4	200.00	82.6
In	0.522	2.09	321.9	4.00	2.58
La	14.49	57.96	8,925.8	29.00	481.2
K	4,550	18,200	2,802,800	2.00	11,211
Mg	3,419	13,676	2,106,104	1.50	6,318
Mn	39.5	157.6	630.4	3.00	3.78
Mo	2.14	8.56	1,318.2	3.00	7.91

Ni	17.9	71.6	11,026.4	3.60	79.4
Pb	10.8	43.2	6,652.8	0.09	1.2
Rb	37.1	148.4	22,853.6	11,350.00	519
Sb	1 14	4 56	702.2	2.50	3.5
Sc	5.86	23.44	3,609.8	34,050.00	246
Se	4.55	18.2	2,802.8	30.00	168.2
Sm	2.86	11.44	1,761.8	2,270.00	7,999
Sr	115.6	460.8	70,963.2	80.00	11,354
Ta	0 333	1 33	204.8	800.00	327.7
Th	4.58	18.32	2,821.3	2,400.00	13,542
Ti	1,242	4,968	765,072	100.00	153.0
U	2.08	8.32	1281.3	2,400.00	6,150
V	45.49	181.16	27,898.6	5.00	279.0
Zn	26.42	105.68	16,274.7	0.70	22.8
				TOTAL:	$104,266 M

Frst 2 colums from Lyon, et al, Nuclear Activation Techniques in the Life Sciences, IAEA, 1978 CoalElem AG ORNL

TABLE 1.1: AMOUNTS OF ELEMENTS MOBILIZED INTO THE ATMOSPHERE AS A RESULT OF WEATHERING PROCESSES AND THE COMBUSTI0N OF FOSSIL FUELS

	Fossil Fuel Concentration		.....Fossil Fuel Mobilization			Weathering Mobilization	
	Coal	Oil	Coal	Oil	Total	River Flow	Sediments
Element	....	ppm	....	x 10^9 g/yr	.....	x 10^9 g/yr	.....
Beryllium	3	0.0004	0.41	0.00006	0.41	—	5.6
Boron	75	0.002	10.5	0.0003	10.5	360	
Sodium	2,000	2	280	0.33	280	230,000	57,000
Alumin	10,000	0.5	1,400	0.08	1,400	14,000	140,000

um							
Chlorine	1,000	-	140	-	-	-	280,000
Calcium	10,000	5	1,400	0.82	1,400	540,000	70,000
Titanium	500	0.1	70	0.02	70	180	9,000
Vanadium	25	50	3.5	8.2	12	32	280
Chromium	10	0.3	1.4	0.05	1.5	36	200
Manganese	50	0.1	7	0 02	7	250	2,000
Iron	10,000	2.5	1,400	0.41	1,400	24,000	100,000
Cobalt	5	0.2	0.7	0.03	0.7	7.2	8
Nickel	15	10	2.1	1.6	3.7	11	160
Copper	t 5	0.14	2.1	0.023	2.1	250	80
Zinc	50	Q25	7	0.04	7	720	80
Arsenic	5	0.01	0.7	0.002	0.7	72	
Selenium	3	0.17	0.42	0.03	0.45	7.2	
Molybdenum	5	10	0.7	1.6	2.3	36	28
Cadmium	-	0.01	-	0.002	-	-	0.5
Tin	2	0.01	0.28	0.002	0.28	-	11
Barium	500	0.1	70	0.02	70	360	500
Mercury	0.012	-	0.0017	1.6	1.6	2.5	1.0
Lead	25	0.3	3.5	0.05	3.6	110	21

From: Bertine, K. K. and Goldberg, E. D., Fossil Fuel Combustlon and the Major Sedimentary Cycle, Science, Vol. 173: 233-235, 1971.

Coal as a source of fissile material

World coal production in 1991 amounted to 5,100 MT.

Thus, 6,630 tons of uranium and 16,320 tons of thorium were
introduced to the biosphere. (Potassium - 40 is an additional source of long-lived radioactivity released with coal combustion)

This quantity of uranium includes approximately 94,146 pounds of
^{235}U, amounting to about 1,700 WW2 type weapons, or about 34
megaton explosive yield equivalent, that year alone.

If fly ash and other combustion solids are captured, a single coal
fired utility of 1000 MWe yields sufficient fissile rnaterial (^{235}U) to
fuel more than one 20 kT gun-type weapon each year.

Coal cornbustion is a source of large quantities of fissile and fertile
materials. Activation of fertile isotopes can produce enormous
quantites of fissile material that exceed the thermal energy value of
the coal originally combusted.

Radon, a decay product of both uranium and thorium, has half-lifes of no more than 3.8 days. Thus, the diffusion of radon into the atmosphere from soil involves only that portion of radon released that lives long enough to become airborne. Mining and combustion of coal releases large quantities radon parents, uranium and thorium, that contribute to the radon burden of the biosphere by reducing the media inhibiting radon diffusion.

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Cosmic source neutrons

The oonstant flux of neutrons from cosmc ray cascades in the atmosphere, in addition to other naturally produced neutrons, is a souroe of neutrons to:

1 activate 238U to 239Pu (increases fissile and toxic material, fission products and neutrons)

2. activate 232Th to 233U (increases fissile matenal, fission products and neutrons)

3. fission of 233U, 235U, 239pu (yields neutrons and fission products)

4. intermediate reactions (increases activation and decay products)

Ref: CRC Hardbook of lonizing Radiation: Protection and Dosimetry

1. Sea level cosmic source radiation dose ~ 300 microSv/yr (30 mrem/yr)

2. Sea level neutron fluence ~ 8 x 10^3 /cm^2-sec yields:

3.15 x 10^{18} °n/km-yr = 2.1 mrem/yr

Cosmic source neutrons range in energy from thermal to 10+ Mev. Cross-section for absorption and fission by high energy neutrons is not well known. Thermal neutron absorption in oxygen, nitrogen (air) is ~10^{-3} of uranium, thoriurn and plutonium isotopes, and ~10^{-6} of 233Th.

Thus, prbability of neutron absorption by U, Th and Pu increases with decreasing neutron energy and quantity of fertile rnaterial, 232Th becoming 233U and 238U becoming 239Pu. Each product is fissionable and a source of additional neutrons if fissioned. Radiotoxcity level increases rapidly as a result of inbreeding of Pu.

CoalRad3 AG ORNL

U.S. Coal Samples: High Uranium Concentration

Location	Uranium (ppm)
Illinois Perry	103.30
Illinois Montgomery	94.10
Wyoming Sweetwater	75.38
Illinois Perry	43 39
Iowa Wapello	42.93
Iowa Wapello	34.57
Iowa Wapello	29.59
Pennsylvania Northumberland	25.24
Illinois Montgomery	20.51
Wyoming Sweetwater	19.47
Missouri Adacon	19.28
Iowa Wapello	18.70
Iowa Appanoose	17.93

Nebraska Otoe	17.06
Nebraska Pawnee	16.74
Mississippi Scott	16.70

From: Facer, J. F., Uranium in Coal, Rep. GJBX-56(79) USDOE, Grand Junction Office, Colorado, May, 1979

Plutonium in earth's oceans

I) surface area of oceans = 3.61 x 10exp6 km exp2

average depth of ooeans = 3 km
volume of ooean = 10.8 X 10exp7 km exp3 = 1.08 X 10exp21 liters

II) reported plutonium content
in tth Padfic Ocean is 1.3 - 9.4 x 10exp-4 pCi/l
lowvalue:(1.3) 2.1x10exp-15 gm/l high value:(9.4) 15.2x10exp-15 gm/l
III) quantity of plutonium:
low value: (1.3) 2.27 x 10exp3 kg high valve: (9.4) 16.4 x 10exp3 kg

IV) conclusion:

1. Nuclear weapon testing is said to have deposited plutonium in the biosphere. Quantity of material estirnated to be in a typical weapon is about 4 kg. Thus, reported quantity of plutonium in ocean water is sufficient for low value: 567.5 weapons high value: 4,100 weapons

2. Insufficient number of weapons have been tested (a few hundred) to account for this quantity of putonium in the biosphere.

(Land area has not been considered here.)

3. Natural origins may account for this discrepancy. Neutrons from cosmic ray collisions, along with neutrons from natural radioactiviy, provide a constant source of neutrons in the range of 10exp-2 1˚n/cm2-sec. Neutrons combined with available 238U make 239Pu. Increasing quantities of 238U released in coal combustion provide an increasing source of breedable material.

Coal-Plu AG ORNL

Radioactive Sources from Coal

Radioactive sources in coal result from:

Uranium-235 decay series
Thorium-232 decay series
Potassium-40 decay
Uranium-238 to Radium-226 decay
Radon-222 decay
Lead-210 to Polonium-210 decay

Primary concentration of constituents are:

Uranium (> 1.3 ppm)
Thorium (>3.2 ppm)
Potassium-40 (~0.054 ppm)

A 1000 MWe coal fired utility burns >4 x 10 exp 6 tons of coal/year.

Consequently, released primary radioactive material is:

Uranium = > 5.2 tons/yr
Thorium = > 12.8 tons/yr
Potassium-40 = >0.22tons/yr

Potassium participates directly in the food chain while uptake of U and Th is slower. Thus, released K-40 may present greater health effect hazards than larger quantities of U and Th.

CoalRad6 AG ORNL