443.

(3)

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

In the matter of CAROLINA POWER & LIGHT CO. Et al.) Docket 50-400 O.L.
Shearon Harris Nuclear Power Plant, Unit 1)

'84 JUN -4 P2:17

CERTIFICATEOF SERVICE

I hereby certify that copies of The attached prefiled testimony of Dr. Carl Johnson in the form of a letter to Wells Eddleman, with all attachments thereto

HAVE been served this 31 day of May 1984, by deposit in the US Mail, first-class postage prepaid, upon all parties whose names are listed below, except those whose names are marked with an asterisk, for whom service was accomplished by Express Mail

NOTE: There is also hand exchange with Applicants June 1 '84.

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DS03

May 30, 1984

Mr. Wells Eddleman
718 Iredell Street
Durham, NC 27705

RE: Shearon Harris Nuclear Power Station

Dear Mr. Eddleman:

The total mass of uranium in an equilibrium core for this reactor will amount to 159,412 pounds. The Hiroshima nuclear bomb contained about 28 pounds, and the core will contain uranium equivalent to about 5,700 Hiroshima bombs. This amount will be expended in about three or four years in the production of electricity. This comparison is made in order to consider the potential effects of the radioactive fission and activation products produced by the fissioning of uranium in the reactor core. This fissioning process is the same as that in a nuclear bomb, except that the rate of reaction has been controlled.

There have been about 1,000 nuclear bomb tests conducted around the world to date since 1945. A 1979 N.R.C. memo estimated the total number of deaths from cancer from worldwide fallout from these tests to range from 24,000 to 72,000; and for birth defects, all generations, as much as 168,000. The radioactive wastes produced in reactors such as this one must be stored securely for millions of years in order to protect the people of North Carolina. In fact, reactors such as this one develop pinhole openings and cracks in the fuel rods during operation, which permit radionuclides to be released throughout the period of operation. An article in Health Physics journal (Table 1) lists 240 different radionuclides of potential importance in the routine releases in the nuclear fuel cycle. These include the radioactive isotopes of all of the trace elements and other elements important in nutrition which will be taken up and concentrated in the food chain.

A list of about 500 radionuclides of importance in the assessment of contamination around nuclear facilities was published in Health Physics journal in

October of last year. Table 2 lists the heavier isotopes from that report. These include 11 isotopes of plutonium alone. The most important one, plutonium 239, has a half-life of about 24,000 years. Plutonium 242 has a half-life of 376,000 years; plutonium 244 has a half-life of 82 million years. It is apparent that nuclear plants such as Shearon Harris will present a threat to populations living within 50 to 100 miles of the plant for a period of time quite a bit longer than mankind can hope to exist.

The range of health effects that can be induced by exposure to ionizing radiation (including those among about 500 radionuclides of importance in the radiological assessment of contamination around nuclear installations) are partially listed in the 1980 report of the National Academy of Science Committee on the Biological Effects of Ionizing Radiation. As time goes by, we may add more types of cancers and health effects to this growing list.

The relative toxicity of some of these radionuclides of commercial importance are expressed in terms of maximum permissible body burden per cubic centimeter (quarter teaspoon) in Table 3. One cc, or one-quarter teaspoon of one of the important byproducts of the nuclear pile, will exceed the maximum permissible body burden for 11.5 billion nuclear workers or 1.2 trillion people. The amounts of some of the isotopes of plutonium, americium, and curium (the latter two are very similar to plutonium) produced yearly by a 1,000 megawatt nuclear power plant are listed in Table 4. These amounts must be multiplied by .9 times to represent the Shearon Harris plant (a 900 megawatt plant). About nine million curies of plutonium alone will be produced each year. The fallout from all nuclear weapons testing, from about 30,000 pounds of uranium and plutonium, contaminated the entire earth to 0.1 to 0.3 picocuries per square centimeter by 1970. In Table 5, we see from the study of plutonium workers that inhaled plutonium lodges in every organ and tissue in the body, including the brain, heart, aorta, testes, thyroid, etc.

Attached is a copy of two reports in Health Physics journal (a). In the first it is reported that alpha recoil aerosols (these are the alpha radiation emitting isotopes like plutonium, americium and curium) are able to penetrate 4 and 5 high efficiency particulate air filters in series. This is possible because of the highly energetic recoil resulting from the forceful ejection of the heavy alpha particles, which dislodges single atoms and groups of atoms from the surface of plutonium, uranium, americium or curium, so that continuously self-splitting self-scattering particles are formed. The result is that these transuranics around such plants as the Rocky Flats Plant or nuclear power plants are mostly in the form of single atoms or particles too small to measure. Such particles are absorbed extremely well in the lungs when inhaled and travel throughout the body to every organ and tissue by the blood and lymphatic circulations. An experiment in which dogs were allowed to inhale microcurie amounts of plutonium and americium (a microcurie is one millionth of a curie) resulted in the following organ doses to dogs: 863 rem to lung, 43,700 rem to pulmonary lymph nodes, 3250 rem to bone, 1,320 rem to liver, 170 rem to kidney and 46 rem to gonads (Barr NF, AEC, 1974) (b).

How many filters are in use in series at the proposed Shearon Harris reactor plant? The second article, a book review of "The Nuclear Air Cleaning Handbook" points out that the usual method of measuring efficiency of such industrial filters, a light scattering photometer, does not yield a meaningful efficiency value since it is purely an "empirical leak test, since the photometers see aerosol downstream with a different particle size distribution from that which it sees upstream. Quantitatively it is not a direct measure of efficiency in terms of mass or activity or even number of particles. The authors recognize this and point it out in several places, but upon using the handbook as a reference for specific topics this explanation might be missed." Another problem with filtration is that the exhaust moving through such filtration systems in a nuclear plant is ionized, and an ionized airstream is not subject to the same static forces attributed to filters in other industries.

Studies conducted of plutonium indicate that plutonium in the air and similar compounds like americium and curium are often attached to particles such as dust particles, pollen, etc. The very finely divided plutonium dust (as with americium, curium, etc.) and plutonium attached to the other fine particles is carried hundreds of miles downwind. In fact, plutonium is monitored in the air in Antarctica by the Department of Energy. At one point in time, due to nuclear testing, plutonium levels in the stratosphere (at standard temperature and pressure) exceeded the permissible limits for the general public around the earth.

In reviewing information on monitoring of levels of radionuclides at various points in the plant and in the effluents from the plant, I note that only relatively small numbers of radionuclides are considered. There is not a complete listing of the approximately 500 different radionuclides of importance in the radiological assessments of contamination around nuclear facilities. Further, there is only one actinide (neptunium 239) considered of 80 (listed in Health Physics Journal) of importance in the radiological assessment of contamination around nuclear facilities. These include three isotopes of actinium, nine of thorium, five of protactinium, 11 of uranium, 8 of neptunium, 11 of plutonium, 7 of americium, 9 of curium (500,000 curies per year produced in a 2.9 megawatt reactor), 3 of berkelium, 7 of californium, 4 of einsteinium and 3 of fermium. All of these compounds are extremely radiotoxic and many of them have very long half-lives. All have radioactive and hazardous progeny. For example, one millionth of a gram of californium 252, which could pass through a series of filters and be blown for many miles in an exhaust stream, is a radiation source emitting about 3 million neutrons per second (170 million per minute). Yet, of all of these 80 actinides, only one is listed, neptunium 239, with a half-life of 2.4 days. Neptunium 239 becomes plutonium 239, an alpha-emitter with a half-life of 24,000 + years. Other isotopes of neptunium have very long half-lives. Neptunium 237 has a half-life of 2.1 million years and Neptunium 236, a half-life of 1.1 million years.

The projected releases of radioactive gases appear to be unrealistically small in comparison with actual releases at other plants. The Oyster Creek power plant, for example, in Ocean County, New Jersey, releases 1.2 million curies of radioactive gases in the exhaust plume each year, and about 50 curies of radioactive particulates, including a large amount of radioiodine and neptunium. At times persons in residential areas downwind from this Oyster Creek plant are actually within the exhaust plume and can inhale the radioactive gases and particulates. Inversion conditions may aggravate the problem by trapping accumulations of radioactive gases and particulates. The EPA surveillance report describing these releases also lists the actual releases for a number of other plants as well, and all release large amounts of radioactive gases and particulates. I believe the projected releases for this plant are much smaller than what the actual releases will be.

The various routes by which persons may be exposed to radioactive emissions is indicated in Figure 1. I note that on page 5.2.4-4 there are no dose estimates for the fetus, yet the fetus is most susceptible to radiation, especially in the first two months of gestational age as indicated by fetal mortality data from Three Mile Island (c).

On Page D7 I note that the total releases of radioactive materials in liquid effluents are estimated to be 0.2 curies per year per reactor. How does this compare to actual experience at other reactors? On page D8 I note the nearest drinking water intake at Lillington, North Carolina is just 24 hours transit time away. What are the projections of contamination at the aquifer under the plant by radioactive discharges and the onsite storage of nuclear waste?

The population within 50 miles of this plant in about 40 years is estimated to exceed 2,300,000 people. Depending on weather conditions, exhaust plumes from the plant may travel along the ground for 50 miles in a discrete manner, meaning that persons will at times actually be within such plumes, inhaling the radioactive gases and particulates. Further, if a war should break out in the

next 40 years, two researchers at Oak Ridge have projected the effects of targeting nuclear reactor cores such as the two at Shearon Harris (Chester and Chester, Journal of Nuclear Technology, 1976). The dark areas in a figure in this report correspond to areas still radiating over a thousand millirads per hour from the ground alone after one year. If some of the 2.3 million people within 50 miles of Shearon Harris could escape to a nuclear fallout shelter before the reactors are targeted, and were able to stay below ground in their shelter for one year, they would still not be able to survive after leaving the shelter. In fact, the effect of disseminating the 159,412 pounds of highly radioactive nuclear fuel in an operating nuclear plant with its accumulated plutonium, americium, curium and other highly radiotoxic wastes would make the entire state of North Carolina uninhabitable for thousands of years.

Farm animals and poultry will also inhale radioactive gases and particulates and ingest contaminated feed, water and surface soil; and the eggs, milk, meat and produce within 50 miles of the plant should be carefully monitored for the 500 different radionuclides of potential importance in the radiological assessment of contamination around nuclear power plants.

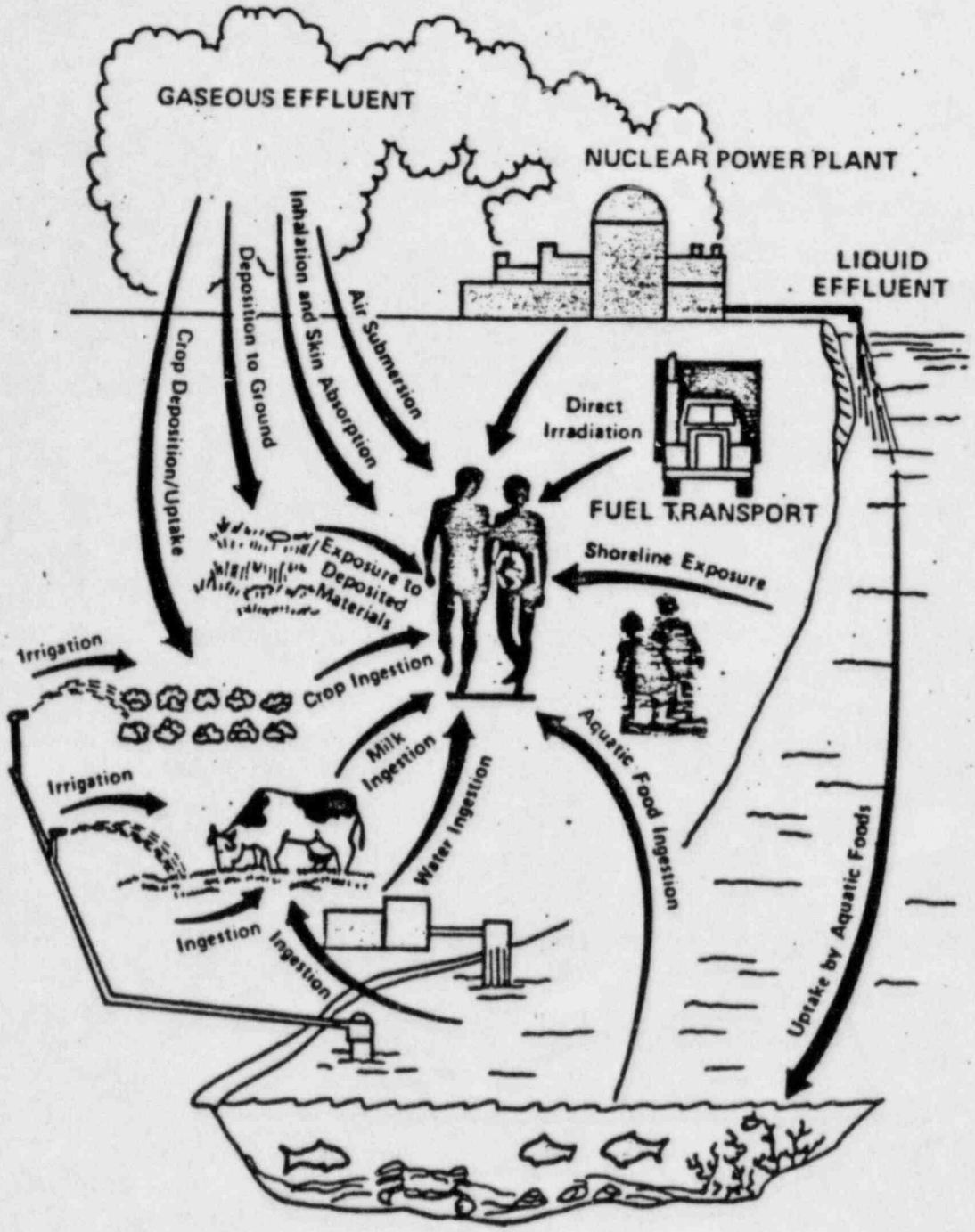
Sincerely yours,

Carl J. Johnson, M.D., M.P.H.

CJJ:mc

Pathways of Radiation to Man

FIGURE 1



*This schematic figure is from NRC and EPA documents. However, the children and the fetus have been added, since the NRC and the EPA consider only non-smoking adults. The children are about ten times more sensitive to radiation than the adults and the fetus about 20 times more sensitive. The children were taken from a photograph by W. Eugene Smith. (CJJ)

TABLE 1

RADIATION OCCURRING IN ROUTINE RELEASES FROM NUCLEAR FUEL CYCLE FACILITIES*
DOSE-RATE CONVERSION FACTORS FOR IMMERSION IN CONTAMINATED AIR
DOSE RATE AT BODY SURFACE FOR AIR CONCENTRATION OF 1 MICROCURIE PER CUBIC CM

LIGHT NUCLIDES

Nuclide			Half-life	Total Dose Rate (Millirem/yr)
HYDROGEN	H	3	12.35Y	5.19E 07
SELENIUM	SE	10	1.4E 06Y	1.82E 09
CARBON	C	14	5730Y	4.46E 08
NITROGEN	N	13	9.97M	1.33E 10
FLUORINE	F	18	109.74M	1.08E 10
SODIUM	NA	22	2.602Y	2.09E 10
SODIUM	NA	24	15.00H	4.08E 10
PHOSPHORUS	P	32	14.29D	6.17E 09
ARGON	AR	41	1.827H	1.34E 10
CALCIUM	CA	41	1.4E 05Y	2.45E 07
SCANDIUM	SC	46	83.80D	1.85E 10
CHROMIUM	CR	51	27.704D	3.15E 08
MANGANESE	MN	54	312.5D	7.27E 09
MANGANESE	MN	56	2.5785H	2.20E 10
IRON	FE	55	2.7Y	3.08E 07
IRON	FE	59	46.6D	1.14E 10
COBALT	CO	57	270.9D	1.25E 09
"		58	70.8D	8.74E 09
"		60	5.271Y	2.28E 10
NICKEL	NI	59	7.5E 04Y	3.98E 07
"		63	96Y	1.56E 08
"		65	2.520H	1.04E 10
COPPER	CU	64	12.701H	2.76E 09
ZINC	ZN	65	244.1D	8.15E 09
"		69M	13.76H	3.81E 09
"		69	57M	2.87E 09
SELENIUM	SE	79	6.5E 04Y	4.91E 08
BROMINE	BR	82	35.30H	2.42E 10
"		83	2.39H	2.94E 09
"		84	31.80M	2.65E 10
"		85	172S	9.20E 09
KRYPTON	KR	83M	1.83H	3.68E 08
"		85M	4.48H	3.65E 09
"		85	10.72Y	2.26E 09
"		87	76.3M	1.86E 10
"		88	2.84H	2.03E 10
"		89	3.17M	2.78E 10
"		90	32.32S	3.27E 10
RUBIDIUM	RB	86	18.66D	6.76E 09
"		87	4.7E 10Y	7.08E 08
"		88	17.8M	2.39E 10
"		89	15.2M	2.74E 10
"		90M	258S	3.90E 10
"		90	153S	3.49E 10
STRONTIUM	SR	89	50.55D	5.19E 09
"		90	28.5Y	1.76E 09
"		91	9.5M	1.19E 10
STRONTIUM	SR	92	2.71M	1.35E 10
YTTRIUM	Y	90M	3.19H	5.91E 09
"		90	64.0H	8.25E 09
"		91M	49.71M	4.85E 09
"		91	58.51D	5.39E 09
"		92	3.54H	1.50E 10
"		93	10.1H	1.11E 10
ZIRCONIUM	ZR	93	1.5E 06Y	1.78E 08
"		95	63.98D	7.42E 09
"		97	16.90H	7.77E 09
NIOBIUM	NB	93M	13.6Y	2.69E 08
"		95M	86.6H	2.07E 09
"		95	35.15D	7.01E 09
"		97M	60S	6.42E 09
"		97	72.1M	9.81E 09
MOLYBDENUM	MO	93	3.5E 03Y	1.34E 08
"			66.02H	4.86E 09
TECHNETIUM	TC	99M	6.02H	1.23E 09
"		99	2.13E 05Y	7.60E 08
"		101	14.2M	7.14E 09
RUTHENIUM	RU	103	39.35D	4.75E 09
"		105	4.44H	1.04E 10
"		106	368.2D	9.17E 07
RHODIUM	RH	103M	56.12M	3.50E 08
"		105M	45S	1.14E 09
"		105	35.36H	2.05E 09
"		106	29.9S	1.43E 10
PALLADIUM	PD	107	6.5E 06Y	8.50E 07
"		109	13.46M	3.23E 09
SILVER	AG	109M	39.6S	7.77E 08
"		110M	252.2D	2.45E 10
"		110	24.6S	1.07E 10
"		111	7.45D	3.34E 09
CADMIUM	CD	113M	13.6Y	1.66E 09
"		113	9.3E 15Y	8.38E 08
"		115M	44.6D	5.59E 09
"		115	53.46H	4.73E 09
INDIUM	IN	115M	4.3H	2.94E 09
"		115	5.1E 15Y	1.37E 09
TIN	SN	123	129.2D	4.69E 09
"		125	9.64D	9.86E 09
"		126	1E 05Y	1.87E 09
ANTIMONY	SB	124	60.20D	1.96E 10
"		125	2.77Y	4.60E 09
"		126M	19.0M	1.87E 10
"		126	12.4D	2.70E 10
"		127	3.85D	8.75E 09

HEAVIER NUCLIDES

Nuclide		Half-life	Total Dose Rate (Millirem/yr)
TELLURIUM	TE	125M	58 D	1.25E 09
"		127M	109 D	8.08E 08
"		127	9.35 H	2.04E 09
"		129M	33.6 D	2.72E 09
"		129	69.6 M	5.37E 09
"		131M	30 M	1.42E 10
"		131	25.0 M	1.00E 10
"		132	78.2 M	2.91E 09
"		133M	55.4 M	2.60E 10
"		133	12.45 M	1.53E 10
"		134	41.8 M	1.03E 10
IODINE	I-	129	1.57E07 Y	6.86E 08
"		130	12.36 M	2.10E 10
"		131	8.04 D	5.02E 09
"		132	2.30 H	2.42E 10
"		133	20.8 H	8.96E 09
"		134	52.6 M	2.82E 10
"		135	6.61 M	1.70E 10
XENON	XE	131M	11.9 D	1.45E 09
"		133M	2.188 D	2.06E 09
"		133	5.245 D	1.60E 09
"		135M	15.65 M	4.61E 09
"		135	9.083 H	4.98E 09
"		137	3.83 M	1.73E 10
"		138	14.17 M	1.54E 10
CESIUM	CS	134M	2.90 M	1.20E 09
"		134	2.062 Y	1.49E 10
"		135	2.3E 06 Y	5.08E 08
"		136	13.1 D	2.00E 10
"		137	30.17 Y	1.53E 09
"		138	32.2 M	3.12E 10
"		139	9.40 M	1.76E 10
BARIUM	BA	137M	2.552 M	5.73E 09
"		139	82.7 M	8.25E 09
"		140	12.789 D	4.16E 09
"		141	18.27 M	1.52E 10
"		142	10.7 M	1.29E 10
LANTHANUM	LA	140	40.22M	2.47E 10
"		141	3.93M	8.76E 09
"		142	92.7 M	3.12E 10
CERIUM	CE	141	32.50 D	2.18E 09
"		143	33.0 M	6.25E 09
"		144	284.3 D	9.97E 08
PRASEODYMIUM	PR	143	13.56 D	2.82E 09
"		144M	7.2 M	5.04E 08
"		144	17.28 M	1.09E 10
NEODYMIUM	ND	147	11.06 D	3.59E 09
PROMETHIUM	PM	147	2.6234 Y	5.39E 08
"		148M	41.3 D	1.87E 10
"		148	5.370 D	1.14E 10
PROMETHIUM	PM	149	53.08 H	3.37E 09
"		151	28.40 HI	5.45E 09
SAMARIUM	SM	147	1.07E11 Y	0.0
"		151	90 Y	1.80E 08
"		153	46.7 HI	2.90E 09
EUROPIUM	EU	152M	9.32 H	7.07E 09
"		152	13.6 Y	1.11E 10
"		154	8.6 Y	1.32E 10
"		155	4.96 Y	1.07E 09
"		156	15.19 D	1.54E 10
GADOLINIUM	GD	152	1.1E14 Y	0.0
TERBIUM	TB	160	72.3 D	1.20E 10
HOLMIUM	HO	166M	1.20E 03 Y	1.62E 10
"		166	26.80 H	6.42E 09
WOLFRAM	W	181	121.2 D	4.03E 08
"		185	75.1 D	1.14E 09
"		187	23.9 M	6.71E 09
RHENIUM	RE	187	5E 10 Y	6.04E 06
THALLIUM	TL	207	4.77 M	4.41E 09
"		208	3.07 M	3.46E 10
"		209	2.20 M	2.45E 10
LEAD	PB	209	3.31 H	1.77E 09
"		210	22.3 Y	3.51E 08
"		211	36.1 M	4.49E 09
"		212	10.64 H	2.82E 09
"		214	26.8 M	4.75E 09
BISMUTH	BI	210	5.012 D	3.48E 09
"		211	2.13 M	4.71E 08
"		212	60.55 M	3.77E 09
"		213	45.65 M	5.14E 09
"		214	19.9 M	1.89E 10
POLONIUM	PO	210	138.378 D	7.36E 04
"		211	0.56 S	6.85E 07
"		212	3.05E-07 S	0.0
"		213	4.2E-06 S	2.63E 05
"		214	1.637E-04 S	9.48E 05
"		215	1.78OE-03 S	0.0
"		216	0.15 S	0.0
"		218	3.05 M	0.0
ASTATINE	AT	217	3.23E-02 S	2.58E 06
RADON	RN	219	3.96 S	5.35E 06
"		220	55.6 S	4.78E 06
"		222	3.8235 D	3.39E 06
FRANCIUM	FR	221	4.8 M	3.48E 08
"		223	21.8 M	3.83E 09
RADIUM	RA	223	11.434 D	1.80E 09
"		224	3.66 D	1.04E 08
"		225	14.8 D	1.03E 09
"		226	1600 Y	8.93E 07
"		228	5.75 Y	1.14E 08

ACTINIDES

Nuclide			Half-life	Total Dose Rate (Millirem/yr)
ACTINIUM	AC	225	10.0 D	3.05E 08
"		227	21.773 Y	1.19E 08
"		228	6.13 H	1.19E 10
THORIUM	TH	227	18.718 D	1.28E 09
"		228	1.9131 Y	1.98E 08
"		229	7.34E 03 Y	1.79E 09
"		230	7.7E 04 Y	1.30E 08
"		231	25.52 H	1.72E 09
"		232	1.405E 10 Y	1.08E 08
"		234	24.10 D	6.12E 08
PROTACTINIUM	PA	231	3.248E 04 Y	6.59E 08
"		233	27.0 D	3.38E 09
"		234M	1.17 M	7.40E 09
"		234	6.70 H	2.14E 10
URANIUM	U	232	71.7 Y	1.52E 08
"		233	1.585E 05 Y	5.16E 07
"		234	2.445E 05 Y	1.14E 08
"		235	7.1E 08 Y	1.59E 09
"		236	2.3415E 07 Y	9.67E 07
"		237	6.75 D	2.81E 09
"		238	4.468E 09 Y	8.57E 07
"		240	14.1 M	1.24E 09
NEPTUNIUM	NP	237	2.14E 06 Y	8.40E 08
"		238	2.117 D	7.09E 09
"		239	2.355 D	3.62E 09
"		240	7.4 M	8.62E 09
"		240	65 M	1.57E 10
PLUTONIUM	PU	236	2.851 Y	9.78E 07
"		238	87.75 Y	8.87E 07
"		239	2.439E 04 Y	5.17E 07
"		240	6.537E 03 Y	8.86E 07
"		241	14.4 Y	4.78E 07
"		242	3.87E 05 Y	6.93E 07
"		243	4.956 H	1.76E 09
"		244	8.26E 07 Y	5.91E 07
AMERICIUM	AM	241	433 Y	3.80E 08
"		242M	152 Y	3.70E 09
"		242	16.02 H	1.72E 09
"		243	7.38E 03 Y	6.09E 08
CURIUM	CM	242	160.2 D	8.28E 07
"		243	28.5 Y	2.26E 09
"		244	18.11 Y	7.23E 07
"		245	8.50E 03 Y	1.31E 09
"		246	4.73E 03 Y	6.76E 07
"		247	1.56E 07 Y	3.14E 09
"		248	3.39E 05 Y	5.09E 07
CALIFORNIUM	CF	252	2.638 Y	3.90E 07

* Abstract Dose rate conversion factors for external exposure to photon and electron radiation are calculated for 240 radionuclides of potential importance in routine releases from nuclear fuel cycle facilities.
D. C. KOCHER Health Physics Vol. 38 (April) pp. 543-621.

TABLE 2

HEAVIER RADIONUCLIDES OF POTENTIAL IMPORTANCE IN ENVIRONMENTAL RADIOLOGICAL ASSESSMENTS (a)

		Mass No.	Half Life
Thallium	TL	200	26 hrs.
		201	73 hrs.
		202	12 days
		204	3.8 yrs
		207	4.8 min.
		208	3.0 min.
		209	2.2 min.
		210	1.3 min.
Lead	Pb	203	52 hrs.
		204M	1.1 hrs.
		205	15 billion yrs.
		209	3.2 hrs.
		210	22 yrs.
		211	36 min.
		212	10.6 hrs.
		214	27 min.
Bismuth	Bi	206	6 days
		207	33 yrs.
		208	3.7 yrs.
		210	5.0 days
		211	2.1 min.
		212	1.1 hrs.
		213	46 min.
		214	20 min.
Polonium	Po	209	102 yrs.
		210	138 days
		211	0.5 sec.
		212	0.3 u sec.
		213	4.2 u sec.
		214	0.2 m sec.
		215	18 m sec.
		216	146 m sec.
		218	3.0 min.
Astatine	At	211	7.2 hrs.
		217	32 m sec.
Radon	Rn	218	35 m sec.
		219	4.0 sec.
		220	56 sec.
		222	3.8 days
Francium	Fr	221	4.8 min.
		223	22 min.
Radium	Ra	222	38 sec.
		223	11 days
		224	3.6 days
		225	15 days
		226	1600 yrs.
		228	5.8 yrs.
Actinium	Ac	225	10 days
		227	22 yrs.
		228	6.1 hrs.
Thorium	Th	226	31 min.
		227	19 days
		228	1.9 yrs.
		229	7340 yrs.
		230	77000 yrs.
		231	26 hrs.
		232	14 billion yrs.
		233	22 min.
		234	24 days
Protactinium	Pa	230	17 days
		231	32760 yrs.
		233	27 days
		234	6.7 hrs.
		234M	1.2 min.

		Mass No.	Half Life
Uranium	U	230	21 days
		231	4.2 days
		232	72 yrs.
		233	159,200 yrs.
		234	244,500 yrs.
		235	704 million yrs.
		236	23.4 million yrs.
		237	6.8 days
		238	4.468 billion yrs.
		239	23 min.
		240	14 hrs.
Neptunium	Np	235	1.1 yrs.
		236	1.15 million yrs.
		236M	22 hrs.
		237	2.14 million yrs.
		238	2.1 days
		239	2.4 days
		240	1.1 hrs.
		240M	7.4 min.
Plutonium	Pu	236	2.9 yrs.
		237	45 days
		238	88 yrs.
		239	24131 yrs.
		240	6537 yrs.
		241	14 yrs.
		242	376,000 yrs.
		243	5.0 hrs.
		244	82 million yrs.
		245	10.6 hrs.
		246	10.9 hrs.
Americium	Am	241	432 yrs.
		242	16 hrs.
		242M	152 yrs.
		243	7380 yrs.
		244	10 hrs.
		245	2 hrs.
		246	25 min.
Curium	Cm	242	163 days
		243	28 yrs.
		244	18 yrs.
		245	8500 yrs.
		246	4750 yrs.
		247	15.6 million yrs.
		248	339,000 yrs.
		249	64 min.
		250	6900 yrs.
Berkelium	Bk	249	320 days
		250	3.2 hrs.
		251	57 min.
Californium	Cf	248	334 days
		249	351 yrs.
		250	13 yrs.
		251	900 yrs.
		252	2.6 yrs.
		253	17.8 days
		254	60 days
Einsteinium	Es	253	20 days
		254	276 days
		254M	39 hrs.
		255	40 days
Fermium	Fm	254	3.2 hrs.
		255	20 hrs.
		256	2.6 hrs.

(a)Kocher DC: Dose-rate comparison factors for external exposure to photons and electrons("calculated for approximately 500 radionuclides of potential importance in environmental radiological assessments" Health Physics 45:665-686 (1983)

TABLE 3

Relative toxicity of some radionuclides of commercial importance, expressed in terms of maximum permissible body burden per cubic centimeter

	Half-life	Curies/cc	Maximum permissible body burden: Nuclear workers	Maximum permissible body burden: General public	Commercial use
Plutonium 239	24,400 years	1.6	40 million	4.0 billion	Nuclear bombs and power plants
Plutonium 238	86 "	460	11.5 billion	1.2 trillion	Power source for pacemakers, satellites
Americium 241	475 "	82	2.05 billion	205 billion	Smoke-detectors for homes
Uranium* 235	710×10^6 "	6×10^{-5}	600	60,000	Nuclear bombs and power plants
Polonium* 210	140 days	89,470	895 billion	89.5 trillion	"Initiator" for nuclear bombs

* Assuming radiotoxicity of radium

Table 4

Curies of Plutonium, Americium, and Curium Radionuclides Reprocessed Yearly, for a 1000 Megawatt Nuclear Power Plant (Pigford, 1974)

Isotope	Uranium fueled water reactor (curies/Year)	Uranium-Plutonium fueled water reactor (curies/Year)	Fast breeder reactor (curies/Year
plutonium ^{236}	8,500	40,200	0.9
plutonium ^{238}	75,700	504,000	268,000
plutonium ^{239}	8,890	30,000	80,800
plutonium ^{240}	12,880	103,600	100,100
plutonium ^{241}	3,100,000	30,500,000	1,342,000
plutonium ^{242}	37	795	292
americium ^{241}	6,250	104,600	37,120
americium ^{242m}	110	2,650	1,869
americium ^{242}	110	2,650	1,869
americium ^{243}	474	7,980	1,074
curium ^{242}	313,000	2,920,000	1,096,000
curium ^{243}	109	860	83.1
curium ^{244}	67,800	736,000	26,500
Total plutonium alpha	106,000	678,000	449,000
Total americium alpha	6,830	113,000	38,200
Total curium alpha	380,000	3,650,000	1,120,000

TABLE 5

Plutonium concentrations in organs of nuclear plant workers in picocuries* per kilogram (pCi/kg)**

	Worker A	Worker B	Worker C	Other
Total plutonium in body, pCi	42,800	270	42,200	--
Estimated exposure period	15 years	16 years	17 years	--
Type of exposure	chronic inhalation	chronic inhalation	acute inhalation	--
	pCi/kg	pCi/kg	pCi/kg	% of total
Skin	n/a	n/a	42	0.2%
Trachea and larynx	34	n/a	n/a	--
Lung	21,888	1.4	23	--
Tracheo-bronchial lymph nodes	342,000	31	756	--
Liver	3,762	171	6,300	--
Bone	718	8.6	1,386	--
Brain	n/a	0.1	n/a	--
Brain stem	n/a	0.3	n/a	--
Heart	68	2.2	94	--
Aorta	410	n/a	n/a	--
Spleen	n/a	14	239	--
Testes	72	n/a	176	--
Prostate	51	n/a	n/a	--
Kidney	22	3.4	158	--
Bladder	233	n/a	n/a	--
Stomach	116	n/a	n/a	--
Small intestine	19	n/a	n/a	--
Large intestine	25	n/a	n/a	--
Pancreas	68	n/a	n/a	--
Abdominal lymph nodes	123	n/a	n/a	--
Thyroid	328	n/a	n/a	--
Adrenal	99	3.6	1,008	--
Muscle	41	n/a	13	2.6%
Fat	29	n/a	4.5	--
Omentum				7.5%
Soft tissues				3.0%

**one picocurie is a quantity of any radioisotope sufficient to release 2.2 disintegrations per minute. Each disintegration releases ionizing radiation.*

** Norwood WD, Newton Jr CE, Health Physics 28,669 (1975)

n/a (not analyzed)

Health Physics Pergamon Press 1977. Vol. 32 (May), pp. 445–447. Printed in Northern Ireland

Penetration of HEPA-Filters by Alpha Recoil Aerosols*

(*Received* 2 *November* 1976; *accepted* 9 *November* 1976)

THE SELF-SCATTERING of alpha-active substances has long been recognized and is attributed to expulsion of aggregates of atoms from the surface of alpha-active materials by alpha emission recoil energy, and to further propulsion of these aggregates by subsequent alpha recoils (Ma10, La18, Ru30; Ch27, Je29). Workers at Lowell Technological Institute recently suggested that this phenomenon might affect the retention of alpha-active material by HEPA filters, and found support in experiments with ^{212}Pb and its alpha-active daughters (Ry75). Work done at our laboratory over the last two years has confirmed that alpha-emitting particulate matter does indeed penetrate high-efficiency filter media much more effectively than do nonradioactive or beta-gamma-active aerosols. Filter retention efficiencies appreciably lower than the 99.97% expected for ordinary particulate matter have been observed with ^{212}Pb, ^{253}Es, ^{238}Pu and ^{239}Pu sources, indicating that the phenomenon is common to all of these. Similar amounts of a beta-gamma-active material placed in the test filter system showed no migration, but when homogeneously mixed with alpha-active material, the gamma activity migrated along with the alpha material.

Results of air-flow tests through filters in series, the first of which is loaded with an alpha-active nuclide, are consistent with a model in which small particules are dislodged from the "massive" surface of an alpha-active material and then repeatedly dislodged from positions on the filter fibers by the alpha recoils. The process shows some dependence on the physical form of the source material, but oxide dust, nitrate salt, and plated metal all seem to generate the recoil particles effectively. The amount penetrating a series of 4 or 5 filters depends on the total amount of activity in the source material, its specific activity, and the length of time of the test. Dependence on the air flow velocity is slight. It appears that this phenomenon has not been observed in previous experiments with alpha-active aerosols because the tests did not continue for sufficiently long periods of time (Et72; Et73a; Et73b, Et74; El74), although such tests adequately demonstrated that HEPA filters were as effective as expected in initially collecting aerosols of ^{238}Pu.

A mathematical model has been developed to describe the transport of the aggregate recoil particles through filter media, and our data have been fitted to these equations to obtain empirical transfer rate constants from the data obtained in our laboratory.

Using these rate constants, we can predict releases from filter systems under various conditions. Figure 1 shows a plot of the calculated air concentration of ^{238}Pu released by aggregate recoil from a series of four standard, 1000-cfm HEPA filters. Two loading situations are evaluated: (1) with 0.25 Ci placed on the first filter at time zero and (2) with the load accumulated over 1 yr at 0.042 Ci/month (a load of 0.25 Ci accumulated at 6 months). Real situations would probably be included between these extremes of one-time or continuous loading. Concentrations predicted to be released at the end of one year are the same for both cases, within the accuracy of the calculations, and amount to about 3.5×10^{-15} μCi/cm^3 at an airflow of 1000 cfm. Preliminary work with ^{239}Pu indicates that, with loadings of the same amount of activity, releases would be about 2 orders of magnitude smaller. These concentrations are sufficiently large to warrant attention by those responsible for containment of alpha-emitting radioactive material.

The conclusion should not be drawn from this work that more alpha-active material has been released through air filters than was known. Exit air streams have been monitored and releases are, in general, well documented. However, there have been reports of unexplained slow increases in alpha activity in exit air from alpha processing facilities. These instances were usually attributed to development of leaks in the filter system, and new filters were installed. This work suggests, instead, that the observed increases in exit-air alpha activity may have been due to the aggregate recoil particle penetration of the filter system. The installation of clean filters would, of course, also stop aggregate recoil penetration by removal of the source.

Although all the calculations presented above are based on laboratory experiments, recent analyses of HEPA filters that had been in service in a plutonium handling facility for 2–3 yr show the same patterns of plutonium distribution over a 4-filter system and indicate that the same phenomenon exists in "real life" situations. However, these data also suggest that penetration due to aggregate recoil may be lower in some cases, possibly due to admixed inert dusts.

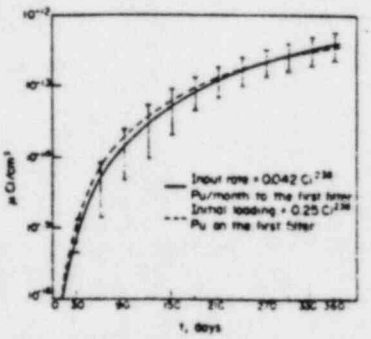


FIG. 1. Calculated concentration (μCi/cm^3) of ^{238}Pu in air released from four 1000-cfm HEPA filters in series.

A preliminary report of this work was presented at the 14th ERDA Air Cleaning Conference (Sun Valley, Idaho, 11–13 August, 1976), and a full paper is now being prepared for publication. This letter is written to draw the existence of this phenomenon to the attention of those persons responsible for air filtration in facilities handling alpha-emitting material, and to seek cooperation in obtaining data that will allow us to determine the degree to which aggregate recoil penetration affects the release of alpha active material from operating filter systems. In evaluating the usefulness of such data, the following should be kept in mind: (1) Systems where 3 or more filters are used in series are most likely to show the phenomenon since decontamination factors across the first filter (and sometimes across the second) may be as good as expected (3×10^3) when observation times are short compared to the half-life of the nuclide in question. In contrast, with aggregate recoil penetration, we have found decontamination factors of 2–10 across the third or fourth filter. (2) Analysis of samples of the actual filter material from all the filters in a 3-4-filter system that has been in service for several months would yield the most useful information for nuclides such as ^{238}Pu and ^{239}Pu. Data from air sample loops across the first and second filters will probably not be very definitive because essentially normal decontamination will be observed in cases where normal penetration predominates. Filter loops below the third filter should encounter very low air concentrations; for this reason, short sampling times may give quantities too small to analyze, while long sampling times would allow aggregate recoil to produce the same low retention by the sampling filter as by the regular filter. In neither case would a useful assay of the released activity be obtained.

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BOOK REVIEW

Nuclear Air Cleaning Handbook. C. A. BURCHSTED, A. B. FULLER and J. E. KAHN. ERDA 76-21. Oak Ridge National Laboratory, Oak Ridge, TN 37830, U.S.A. (1976).

THIS Handbook is a revision, updating and expansion of the highly respected publication ORNL-NSIC-65, *Design, Construction and Testing of High-Efficiency Air Filtration Systems for Nuclear Applications*. It is an extremely comprehensive Handbook and is practically indispensible to the designer or tester of air cleaning systems in nuclear facilities. While the book mainly deals with the application of high-efficiency (HEPA) filters it does contain valuable material on pre-filters, deep bed glass-fiber filters, sand filters and activated carbon absorbers. It also treats of the application of air cleaning systems to specific types of reactors and fuel processing plants. The Handbook illustrates the fact that successful air cleaning requires consideration of a whole system and not just the filter alone. Hence, the book deals with ducts, housing, layout, dampers and many other topics.

The novice in the field might be misled by the requirement of "99.97% efficiency" as measured with a light-scattering photometer. This is purely an empirical leak-test since the photometer "sees" an aerosol downstream with a different particle size distribution from that which it "sees" upstream. Quantitatively, it is not a direct measure of efficiency in terms of mass or activity or even number of particles. The authors recognize this and point it out in several places but if one uses the Handbook as a reference source for specific topics this explanation might be missed. The authors state several times that there is a great difference between the performance of the systems they describe and those found in other industries. This difference is beginning to diminish somewhat as air cleaning requirements in all industries are becoming more strict with tighter emission and ambient standards. This book shows that great improvements can still be made in industrial air cleaning and that the key to such progress is painstaking attention to detail. For this reason, this book should have applications beyond merely the nuclear industry.

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LETTERS TO THE EDITORS

Letters reflect the personal view of the author(s) and not necessarily that of the Editors. Letters are reviewed only to determine the appropriateness of the subject matter, to exclude obvious errors and to assure good taste. Anonymous letters are not published.

Epidemiologic Investigation of Cancer Incidence in People Living near Nuclear Installations

(*Received* 18 *August* 1982)

Dear Editors:

DREYER *et al.* calculated the feasibility of epidemiologic studies of cancer in people living near the Rocky Flats plant (RFP) (Dr82). Such feasibility evaluations and estimates of statistical power are based on a chain of assumptions which must be considered step-by-step. Dreyer *et al.* state "feasibility can be determined by reviewing the magnitude of population exposure and estimating (a) how many extra radiation-induced cancers may be expected to occur and (b) the statistical probability that the occurrence of these extra cancers could be detected."

Dreyer *et al.* focus on exposure to 0.37 fCi/m^3 of ^{239}Pu in air in 1975 as a basis for their dose estimates.* In fact, ^{234}U alone accounts for a greater proportion of the α-emitters released in the plant's exhaust than does ^{239}Pu (ERDA77). Americium-241 and ^{238}Pu from the plant may be more important than ^{239}Pu. Plutonium-241 accounts for more than 8 times more radioactivity in the main exhaust plume than does ^{239}Pu (ERDA77). In addition, a number of other radionuclides other than actinides are released (ERDA77; CDH80; JO81). Thus, Dreyer *et al.* by considering only ^{239}Pu, consider only one of a broad spectrum of radionuclides released by RFP.

Plutonium-239,240 in surface soil can serve as a surrogate to indicate the presence of a host of other radionuclides released by RFP, although higher relative activity may make other radionuclides of greater importance in air. Thus, ^{238}Pu which is released from the main stack in a ratio of 2:100 to ^{239,240}Pu, has been reported to account for 20–40% of plutonium found in air-borne soil (Se77).

*Although Dreyer *et al.*, refer to an estimate based on air concentrations of ^{239,240}Pu, their estimate is based on the air concentration of ^{239}Pu in 1975 (0.37 fCi/m^3) reported by the D.O.E. Environmental Measurements Laboratory (EML).

The radiotoxicity of plutonium is of considerable controversy. Dr. Morgan calculates that permissible exposures of plutonium in bone should be reduced about 240 times (Mo75). Dr. Myers suggests a reduction of the maximum permissible lung burden to 0.07 nCi (70 pCi, based on radiotoxicity to pulmonary lymph nodes, a reduction by about 228 times of the official guidelines for maximum lung doses for nuclear plant workers) (My72). A hundred-fold reduction in these recommended occupational maximum permissible doses for the public would permit a lung burden of only 70 fCi, and a body burden of only 166 fCi. A study of RFP workers found that workers who have only 1–10% of the body burden permitted by current DOE guidelines (400–4000 pCi) have about a 33% increase in the rate of chromosomal aberrations in blood lymphocytes (Br76). These findings suggest that the current official estimate of the radiotoxicity of plutonium is not protective by a factor of about 200.

Another area of controversy is the number of Denver area residents exposed to radionuclides from RFP. Figure 1 in the Dreyer *et al.* report is taken from "Krey and Hardy, HASL-255, 1970" (unpublished) indicating contamination from RFP extending for about 6 miles from the plant. Krey later published a report in *Health Physics* showing a different figure, indicating plutonium contamination of soil extending completely across Denver, to the southeast, well over 30 km from the plant (Kr76).

Dreyer *et al.* report that "leaking cutting oil drums were determined to be the actual source of contamination which began in about 1967." Actually, this source of contamination began in 1959 and was a problem until 1968 (Se71). However, a fire and explosion in 1957 blew out all 620 industrial high-efficiency particulate air (hepa) filters in the main exhaust system at the Rocky Flats plant and was a much more serious incident (DOE70; DOE58; Ow63; Wo71). The filters had not been changed in the 4 yr of the plant's operation. The plant requires this extensive filter system to prevent large releases of plutonium and uranium to the environment, but is only partially successful (Ow63). The rate of accumulation of plutonium on the filters was described in

ratio of the measured $^{239,240}Pu$ in soil." According to the ERDA EIS, the concentrations of ^{239}Pu in air at site # 4 were about 1000 times higher in 1965, or equivalent to about 370 fCi/m³. At site # 1, nearer the usual direction of exhaust plumes from the Rocky Flats plant, the concentration of ^{239}Pu was 1.18 fCi/m³ in 1975, and so could have been about 1180 fCi/m³ in 1965 and earlier.

The calculated air concentrations by Dreyer *et al.* ranging from 0.27 fCi/m³ in 1967 to a peak of 2.1 in 1969, can be compared to the measured releases between 1954 and 1962 from the main stack (Jo81; Ow63) and the reported "normal operational release" from all Rocky Flats plutonium facilities (ERDA77). The average concentration of plutonium in the exhaust plume reported for 1962 was 1059 fCi/m³, equivalent to 5025 μCi of plutonium released from the main stack alone that year (daily exhaust volume is about 13 million m³). This can be contrasted with the ERDA claim that there was "a normal operational release" of 2974 μCi from all facilities in 1962 (ERDA77).

Since only 28% of α radiation released in the main exhaust plume is $^{239,240}Pu$, the amount of α radiation released from the main exhaust stack alone in 1962 can be calculated to be about 18,000 μCi, not considering releases from many of the other stacks or from radioactive waste stored outside (ERDA77).

The D.O.E. EML fallout data for New York City may approximate levels for plutonium from world-wide fallout from nuclear weapons testing, although there is more precipitation there than in more arid parts of the U.S. such as Colorado (To79). The annual average concentrations of plutonium in air for New York City range from 0.006 fCi/m³ in 1976 to a high of 0.07 fCi/m³ in 1970, probably due to occasional weapons testing and perhaps also due to nuclear installations located around New York City. The average concentration for the eight-yr period reported (1970–77) was 0.03 fCi/m³. This "background from world-wide fallout from weapons-testing" can be compared to the estimates by Dreyer *et al.* for the period 1967–74 for site # 4 at RFP. The average of the estimates of Dreyer *et al.* is 1.05 fCi/m³, about 30 times higher than that for New York City. The average concentration for ^{239}Pu at RFP site # 1 reported by the Toonkel group for the period 1971–76 was 2.37 fCi/m³. This was over twice the average concentration for site # 4 estimated by Dreyer *et al.*, and about 80 times the fallout level.

It is clear that these levels of plutonium in the air are due to RFP and not to world-wide fallout, and should bring us to question the apparently trivial emissions of α radiation from RFP reported by ERDA (ERDA77). In any event, it is quite clear that in looking at earlier years, the routine releases were very much higher. This is confirmed both by the EIS report and by the AEC internal report indicating the measured releases of plutonium in the main exhaust from the plant (ERDA77; Ow63). The trend over time and the RFP reports suggest exposures ranging from about 80 fCi/m³ in 1959 to over 300 fCi/m³ in 1965, four orders of magnitude higher than fallout levels. Further, there is very good evidence that exposures in 1957 and 1958 were much larger than these (Jo81).

Dreyer *et al.* cite Krey's estimate that the mean plutonium levels from world-wide fallout in soil in the Denver area were 1.7 ± 0.5 mCi/km², and they say that an equal or greater exposure than that from world-wide fallout would be necessary from RFP before one could distinguish the cause of any increased disease in the population. However, the submicron sized plutonium particles in exhaust plumes simply do not settle out to any appreciable extent (Kr70). Isopleths of plutonium concentrations in soil can only serve to identify the usual direction of exhaust plumes from the plant over a period of years, and do not represent actual exposures to populations in the area.

A study of surface dust on private land found the concentration of plutonium to be as much as 3390 times higher than background levels in the area where Krey shows plutonium in whole soil samples to be only about 30 times higher than fallout levels (Jo81).

Further, the type of soil survey done by Krey *et al.* is designed to measure soil inventories of plutonium to a depth of 10 cm (including fine gravel) and does not get at levels of contamination of plutonium in surface dust or the windblown material on the surface of soil as described by reports in *Science* (Jo76; Jo77).

Another study reports 50,000 fCi of plutonium per g in air-borne soil (Se77) in the area (there may be 0.01–0.02 g dust/m³ of air*), which can be compared to the 0.37 fCi/m² of plutonium used by Dreyer *et al.* to calculate population doses (Dr82). In fact, they based their estimates on air concentrations of plutonium, not on soil concentrations, because "inhalation is the only significant pathway for human exposure to plutonium and other actinides (Dr82). It seems that even the air concentration of plutonium selected by Dreyer *et al.* a concentration about 30 times greater than background levels of plutonium in air, would meet their criterion for an exposure equal or greater than that from worldwide fallout necessary to produce detectable disease in a population.

Dreyer *et al.* continue with their assumptions: "Fifty-year α-dose estimates for basal cells in the

*The frequency of dust storms of ambient concentration 12 mg/m³ is approximately 14 days per yr over 10 Great Plains states (Sh74).

Re: Spontaneous Abortions following Three Mile Island Accident

The effects of exposure to radiation during the first several months after conception are of special interest, since the fetus is most susceptible to injury from mutagenic agents in this period, and such injuries may result in increased fetal losses.* In a recent report on fetal loss following the accident at the Three Mile Island (TMI) nuclear plant, there were 20 spontaneous abortions among 106 women** who were in their first two months of pregnancy[1] at the time of the TMI accident. The resulting rate of 187 fetal deaths per 1,000 pregnancies may be compared to 164 per 1,000 pregnancies** reported by Harlap, Shiono and Ramcharan in 1980, in the only recent study of this type.[2]

*Johnson CJ: Surveillance of radiation effects from nuclear installations: Fetal and infant death rates, childhood leukemia and cancer. Presented at the Annual Meeting of the American Association for the Advancement of Science in Detroit, May 26–31, 1983.

**Excluding those with induced abortions and spontaneous abortions under four completed weeks of gestation.

The application of the life table method to fetal mortality by gestational age in the study of fetal loss is useful.[1,2] However, the age of the fetus must be considered when a population of women in all stages of pregnancy are exposed to ionizing radiation at one point in time. The five-week-old fetus is much more sensitive to ionizing radiation than the fetus near term. This problem could be addressed by continuing the study for one year beyond the TMI accident, permitting age-specific comparisons between exposed and unexposed fetuses of the same gestational age. For surveillance, the life table method could be used to study effects on the fetus of women exposed in the first trimester, comparing fetal losses of exposed women by week of gestational age to a suitable comparison population. It may be possible to design an application of the life table method which could deal with this problem statistically.

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