BEFORE THE
UNITED STATES NUCLEAR REGULATORY COMMISSION
ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
UNITED STATES DEPARTMENT OF ENERGY PROJECT MANAGEMENT CORPORATION TENNESSEE VALLEY AUTHORITY	)	Docket No. 50-537
(Clinch River Breeder Reactor Plant)	)	

TESTIMONY OF CARL J. JOHNSON, M.D., M.P.H.

DATED: October 28, 1982

Q.1: Please identify yourself and state your qualifications.

A.1: My name is Carl J. Johnson. I reside at 42 Hillside Drive, Wheatridge, Colorado 80215. I am an Associate Clinical Professor of Social and Environmental Health at the University of Colorado School of Medicine. Previous to my present employment, I was Director of the Jefferson County Health Department. Additional background and qualifications are presented in my resume, attached as Exhibit 1 to my testimony.

Q.2: What is the subject matter of your testimony?

A.2: My testimony primarily relates to the NRC Staff's analysis of the environmental (health) impacts of the CRBR and its fuel cycle as presented in the NRC Staff's "Draft Supplement to Final Environmental Statement Related to the Construction and Operation of Clinch River Breeder Reactor," NUREG-0139, July 1982 (henceforth "DSFES").

Q.3: Are Staff's (and Applicants') estimates of environmental releases and environmental contamination from the proposed CRBR fuel cycle as reported in the DSFES realistic?

A.3: No.

Q.4: What is the basis for your disagreement?

A.4: First, Staff's (and Applicants') estimates of the

potential releases of transuranics from the proposed DOE fuel fabrication and processing plants are based on confinement factors (defined as release/throughput) proposed by DOE (DSFES, pp. D-9, D-14, D-15). These confinement factors are unrealistic, as evidenced by the releases experienced at DOE's Rocky Flats facility.

Second, the DOE cannot be trusted to reliably estimate and report radioactive releases from its facilities and environmental contamination as a result of these releases.

Q.5: Why do you believe the confinement factors assumed for plutonium and other transuranics at proposed CRBR fuel cycle facilities are unrealistic?

A.5: The assumed confinement factors at the proposed fabrication plant appear to be based on arbitrarily reducing by a factor of 100 a theoretical efficiency of a bank of three HEPA filters (DSFES, p. D-9). The basis for the confinement factors at the fuel processing facility is not stated -- only that they were proposed by DOE (DSFES, p. D-14).

As is evidenced by experience at Rocky Flats, accidents and leaks are the dominant release modes. The theoretical HEPA filter efficiencies and laboratory test results for these filters are largely irrelevant.

Furthermore, the methods of measuring the efficiency of HEPA filters are questionable and the results of such measurements are not a reliable indicator of the actual efficiencies.

With regard to the dominant release mode, during a major fire and explosion at Rocky Flats, all 620 filters in the main stack were blown out of the stack, releasing four years' accumulation of plutonium and uranium on the filters. (See Exhibit 2 attached to this testimony, particularly references 12-14.) Similarly, releases from chemical processing plants at the Savannah River Plant have been as large as two curies in a short period of time.

Further evidence that DOE proposed confinement factors are unreasonably small is found in the measured contamination at Rocky Flats, as compared to that projected or claimed by DOE. This is discussed below.

Q.6: What is the basis for your view that DOE cannot be trusted to reliably estimate and report radioactive releases from its facilities?

A.6: I enclose a reprint of a 1976 Science article reporting a survey that I conducted in collaboration with the U.S. Geological Survey of plutonium in surface dust around Rocky Flats, which is similar in many respects to the

proposed CRBR fuel cycle facilities, that is, the reprocessing and fabrication plants (Carl J. Johnson, et al., Science 193 488-490 (6 Aug. 1976), attached as Exhibit 3). Despite the results of the survey, the DOE persists in using a soil sampling technique that includes subsurface soil and fine gravel, a sample that yields misleadingly low concentrations of plutonium. Moreover, despite recent claims by the DOE plant personnel at Rocky Flats that air concentrations of plutonium around the plant were near that of "background," a separate monitoring system maintained by the Environmental Measurements Laboratory disclosed that plutonium in air levels at the plant has been the highest in the western hemisphere for every month measured. (See Exhibit 4, attached to my testimony.)

The large release of tritium to a stream that supplied water for the city of Broomfield in 1973 was not acknowledged by AEC personnel for three months. During that three month period, the people in Broomfield were not informed about the radioactive contamination of their water supply.

Q.7: Can the public rely on DOE monitoring efforts to ensure that future emissions of radionuclides from proposed CRBR fuel cycle facilities will not exceed projected levels,

and to ensure that frank and reliable information will be promptly released if evacuation of the public must be considered in case of accident, or to permit precautions to be taken in case of unexpected releases due to accidents?

A.7: Judging from the prior record of the AEC (whose functions in this area are now performed by DOE, NRC, and the ORP of the EPA), the public cannot rely on the monitoring at such installations. As noted above, during a major fire and explosion in 1957, large quantities of plutonium and uranium, accumulated on filters, were released to the environment. The public was told that "tests after the fire indicated no release of radiation of consequence," despite a survey around the plant by plant personnel indicating high levels of contamination of soil at two elementary schools, one six miles away and one 12 miles away, and on private land. The plant resumed operation several days later without the benefit of monitoring of stack emissions. It was operated in this manner until the 8th day after the fire. Internal plant correspondence indicated that plant personnel were aware that monitors maintained in the surrounding area were reporting plutonium in air concentrations at least an order of magnitude less than actually present.

Q.8: Did the Staff realistically estimate the radiation absorbed dose to the public due to gaseous effluents of plutonium and transuranic elements from the CRBR fuel cycle?

A.8: As far as I can tell, the Staff did not report the dose to the public from transuranics. The Staff only reports whole body person-rem dose commitment, which is inappropriate for plutonium and other transuranic exposures.

As noted above, DOE plants working with plutonium (e.g., Rocky Flats and the Savannah River Plant) have had large releases of radioactivity in stack effluents. Excessive releases of radioactivity have not been limited to plutonium but include other transuranics and, at least at SRP, tritium and radioiodine, as well. Transuranics in exhaust plumes from such plants can travel for many miles and, around the Rocky Flats plant, account for nearly as much plutonium at 60 km from the plant as from worldwide fallout, according to a report in Health Physics by Poet and Martell, who also reported several times as much plutonium from Rocky Flats as from worldwide fallout in the eastern suburbs of Denver, over 35 km from the plant.

Extremely small doses of plutonium have produced measurable effects. A study of plutonium workers at Rocky Flats found that doses as small as 400 to 4,000 picocuries

internally have caused a 33% increase in the rate of chromosomal abnormalities in circulating lymphocytes. This effect, compared to similar effects induced in uranium miners and in survivors of Hiroshima and Nagasaki who received large doses of radiation, indicate high doses of radiation at the cellular and tissue levels.

A recent report by Dreyer, et al. (attached to my testimony as Exhibit 5), supported jointly by the NRC and EPA, which served as the basis for one or more NUREG publications, has now been shown to be wrong. (See Exhibit 6 attached to my testimony.) The Dreyer report claims that doses for the public from DOE's Rocky Flats plant in Denver are at least five orders of magnitude smaller than is actually the case. (See Exhibit 4.)

The current DOE position on population effects downwind from DOE's Rocky Flats plant is that there would be less than one case of cancer expected in the next 70 years in the Denver area. However, my study, funded by the National Cancer Institute and published by the Royal Swedish Academy of Sciences last year (Exhibit 2), and using federal data from the Third National NCI Survey of Cancer Incidence, found an excess of 491 cases of cancer in the Denver area attributable to discharges from the plant for the three-year period 1969-1971. The net impact of the plant on the Denver area population could result in

an excess of 3,000 to 6,000 cases or more of cancer in the next 70 years.

Q.9: Just how toxic is plutonium?

A.9: The excretion rate of plutonium from bone is about one-half in 200 years (see ICRP 2). So, if inhaled or ingested, it stays in the body for very long periods of time. As little as 400 to 4,000 picocuries, total body burden, in adults has been shown to cause an increase of 33% in the rate of chromosome aberrations. Extrapolating to the fetus and considering differences in radiosensitivity and body weight (150 lbs./1.5 lbs. x 20/1), a body burden of 0.2 to two picocuries could induce a similar effect in the fetus and, of course, a smaller dose would induce a similar effect on a smaller fetus. Because of the small number of cells in a fetus, the rapid rate of growth and the length of life span remaining, and the multiplicative effect of injuries generated in chromosomes and to cell metabolism, this dosage level would not be acceptable. In actual fact, considering public health principles, and providing a safety factor in a dose for a fetus, a maximum permissible body burden could be placed as low as two femtocuries (0.002 pCi) of plutonium, and similar limits for other transuranics.

A large number of isotopes and transuranics are

routinely released at the Rocky Flats plant and would be released by the proposed CRBR fuel cycle. Additive and potentiating effects must be considered for all radionuclides in toto. A list of 240 different longer-lived radionuclides routinely released by nuclear plants are listed in the April 1980 issue of Health Physics.

Doctors Morgan and Meyers independently suggested that the current estimate of toxicity of plutonium is understated by over 200 times. A study in rats found that five nanocuries caused an increase of 10% in lung cancer in rats. J. L. Park has found that doses of 80 to 90 nanocuries of plutonium in dogs can cause death. Work by Cross, et al. (attached as Exhibit 7 to my testimony), indicates that dogs are about 100 times more resistant to cancer per unit dosage of uranium ore dust and radon than man. This may be extrapolated to exposures to plutonium, in which case less than one nanocurie could induce death in man.

Barr reports an investigation in which dogs were allowed to inhale one microcurie of various isotopes of plutonium, curium, or americium. There were large differences in the dosage to each organ, i.e., 3250 rem to bone, 1320 to liver, 170 to kidney, 46 to gonads, 863 to lung, and 43,700 to pulmonary lymph nodes. Other organs would receive appreciable doses as well. Such dose

distributions to organs must be considered in making comprehensive dose estimates. Every pharmaceutical house in the world relies on studies with dogs and other experimental animals in order to extrapolate toxicity to man. Do the dose models used by the ICRP have an adequate base in empirical science? A permissible body burden in man of 40 nCi (0.040 microcuries) could result in doses of 130 rem to bone, 53 to liver, 7 to kidneys, 2 to gonads, 34 to lung, and 1748 to lymph nodes, based on the dog studies. But man may be 100 times more radiosensitive to plutonium than the dog.

Q.10: Are the estimates of fatal cancers in the work force population reasonable?

A.10: No. First, NRC Staff in the DSFES apparently has failed to consider the occupational exposure in the CRBR fuel cycle. Second, although the DOE study of Rocky Flats plutonium workers (Voelz, et al.) appeared to claim that there were no measurable effects on plutonium workers, another study of cancer incidence found the ratio of brain tumors to all cancer among 3900+ Rocky Flats workers at the plant to be eight times higher than expected, compared to all Colorado white males. The rate of malignant melanoma was three times higher than expected, and respiratory cancer was 25% higher than expected, compared

to all Colorado white males. The actual effects may be higher than these figures indicate, because of the well-known healthy worker effect, described for persons who are healthy enough to have a good work record, who are able to pass security clearance and a higher educational level.

Q.11: Do current NRC/DOE guidance limits for radionuclides provide adequate protection to the public?

A.11: No. The NRC/DOE would permit 10,000 picocuries of uranium per liter of drinking water. Current EPA guidance limits concentrations of uranium in water to no more than 10 picocuries per liter based on estimates of risk to health. The AEC (now NRC/DOE) formerly would permit three million picocuries of tritium per liter of water. This was later reduced to one million pCi/liter. The EPA, which obtained authority in 1976 for regulation of drinking water, has reduced this limit to 20,000 pCi/liter.

Q.12: The EPA developed maximum permissible soil concentration limits for plutonium in 1977 (EPA 520/4-77-016). How do you assess this proposed guidance?

A.12: This guidance is inadequate. Although still urged by the Office of Criteria and Standards of the Office of Radiation Protection of the EPA (OCS, ORP, EPA), it was

not signed into law by President Carter and to date has not been signed by President Reagan. The OCS, ORP, EPA is administered by a former AEC officer. The EPA report suggests that below 20 picocuries/cm^2 is sufficient that no remedial action is required of transuranic contaminated soils around any nuclear facilty in the country (including the proposed CRBR fuel cycle facilities). However, this standard is ten times less protective than an Interstate Commerce Commission guideline limiting contamination of trucks hauling radioactive materials to less than 4.4 dpm (2 picocuries) of alpha radiation per square centimeter. In other words, a child may play near Rocky Flats on private land in soil containing 10 times more plutonium per square centimeter than is permitted for truck drivers hauling radioactive materials. In contrast, the usual protection, or safety factor for the public, is to reduce an occupational concentration limit by up to 100 times, for very obvious reasons. In other words, the child would not be permitted to play on the surface of his backyard if there were more than 0.02 picocuries of plutonium per square centimeter. Yet the EPA, presumably supportive of the NRC/DOE, urges a limit of 20 picocuries per square centimeter. The DSFES is inadequate in its failure to address the adequacy of the current and proposed transuranic standards.

Exhibit 2 (Carl J Johnson)

ROYAL SWEDISH ACADEMY OF SCIENCES

Cancer Incidence in an Area Contaminated with Radionuclides Near a Nuclear Installation

Report

By Carl J Johnson, 42 Hillside Drive, Denver, Colorado 80215, USA

Anglo cancer incidence for the period 1969–1971 was evaluated in census tracts with and without contamination by plutonium and other radionuclides from the Rocky Flats (nuclear weapons) plant near Denver, Colorado (1970 population 1 019 130). Exposures of a large population in the Denver area to plutonium and other radionuclides in the exhaust plumes from the plant date back to 1953. Cancer incidence in males was 24 percent higher, and in females, 10 percent higher in the most contaminated suburban area (population 154 170) (nearest the plant), compared to the unexposed area (population 423 870), also predominantly suburban, which had virtually the same age-adjusted rate for all cancer as the state. The adjacent study area more distant from the plant had an excess cancer incidence of 15 percent in males. The excess cases of cancer were mostly leukemia, lymphoma and myeloma and cancer of the lung, thyroid, breast, esophagus, stomach and colon, a pattern similar to that observed in the survivors of Hiroshima and Nagasaki. The ratio of cancer of the more radiosensitive organs to other classes of cancer was 12.2 percent higher in the area near the plant (17.6 percent in males, 11.9 percent in females). These ratios were not significantly changed with the deletion of lung cancer. Cancer of the gonads (especially of the testes), liver, and, in females, pancreas and brain contributed to the higher incidence of all cancer in areas near the plant. The increase in incidence of all cancer and for certain classes of cancer in the exposed population supports the hypothesis that exposure of general populations to small concentrations of plutonium and other radionuclides may have an effect on cancer incidence.

A nuclear weapons plant (weapons components and research) in Jefferson County, Colorado has routinely released plutonium (Pu) and other actinides and radionuclides in the exhaust from plant smokestacks since 1953 (1). Plutonium is a very potent carcinogen and considered the most important risk to health, and so is monitored on a regular basis. Release of other actinides and radionuclides is checked less frequently (1).

While exhaust ducting filters—five high efficiency particulate air (HEPA) filters in series—effectively remove Pu particulates larger than 0.3 micrometers (μm) in diameter from the exhaust stream (13 000 000 m^3 daily from the main stack), leaks do occur (2) and one report (1972) estimates "the number of individual particles emitted from 776 Building to be on the order of millions per day" (3). About half the particles are below 0.1 μm in diameter and behave like gas molecules (3). In addition, small particles of Pu (Pu oxide) and other alpha radiation-emitting nuclides can diffuse through the filter arrangement due to the constant fragmentation and self-scattering effect of the alpha recoil phenomenon (Table 1) (4).

There is a "dissemination of the finest radionuclide particles throughout the area over a radius of several miles from the plant site" and "these smallest particles are not noticeably reduced in number by gravitational settling to three miles from the apparent point of origin and presumably reached much further afield" (5, 6).

Sampling stations draw air from the filtered exhaust stream through a collecting filter. An evaluation of filter efficiency in which two millipore filters were arranged in tandem disclosed a "large and variable percent of the particles on the backup filter" (32–69 percent), indicating an underestimation of Pu releases (5, 6).

Routine releases of Pu in exhaust from the plant ranged from an annual average concentration of 0.03 picocuries or 0.06 disintegrations per minute per cubic meter (pCi/m^3 or dpm/m^3) in 1953 to 1.05 pCi or 2.33 dpm/m^3 in 1962 (Table 1) compared to a guideline limiting Pu in plant exhaust to less than 0.12 dpm/m^3 (7). Plutonium concentrations in the air at the Rocky Flats plant are consistently the highest (1970–1977) in the U.S. Department of Energy (DOE) monitoring network, which has 51 stations positioned throughout the western hemisphere (8). The DOE station at the eastern (downwind) boundary of the plant has recorded an average concentration of 2072 attocuries/m^3 (aCi/m^3) of plutonium over the eight year period, compared to 32 aCi/m^3 for New York City and 5 aCi/m^3 for the station with the lowest concentration (8).

The air concentrations of Pu obtained from ambient air monitors are of dubious validity, because, as Chapman states "Although we maintain air samplers in neighboring populated areas, these are not visited daily because of the cost involved and because we found them to give the same value as air samplers collected daily on site. The samplers are visited fortnightly principally to insure that they are operating and can be used as a defensive measure in case of an incident on the plant site. Consequently, dust loading restricts the air flow and gives an unrealistically low computed value for air activity. To transmit these values would raise questions of falsification of data in the minds of lay readers because they are about an order of magnitude lower than those reported from the air sampling stations of other observers" (9). In addition to problems with dust loading, incompatible wind speeds, and the diffusion through filters of alpha active aerosols, these filters are less efficient than the industrial HEPA filters through which the Pu particulates have already passed.

Unusual releases have occurred, especially in major fires in 1957 and 1969 (7, 8, 10, 11). Average measured concentrations of Pu in exhaust plumes from the main stack at the plant were as high as 948 pCi/m^3 for the eighth day after a fire and explosion in 1957, which blew out the filter system (12–14). There are no records of emissions for the seven-day period during the fire and after, but those unmeasured releases may have been 4 to 5 orders of magnitude greater than the releases recorded on the eighth day (an estimated 12 millicuries, or about 200 mg of Pu) (12–14). The releases of Pu and other transuranics in the 1957 fire may represent the most important exposure to the population near the plant during the period 1953–1971. "The 620 HEPA filters in the main plenum had not been changed since they had been installed four years earlier and may have contained many kilograms of Pu (estimates range as high as 250 kg or about 15 000 curies). Large plumes of Pu-contaminated smoke from the 150 foot high stack continued throughout the night. Eyewitnesses reported it to be very dark in color, 80 to 100 feet high, blowing south, east and southeast" (12–14).

Estimates of the amount of Pu released are based on a study which found that an average of 13 grams of Pu were deposited daily on the first-stage filters (15,16). The filters in that system had been in operation no more than four months, and each filter contained as much as 68 grams of Pu. The average amount ranged from 16.6 grams (26 days) to 42 grams (4 months). In one month the filters could collect 0.5 kilograms or more of plutonium, of which 86 percent was water-soluble. (Pu nitrate) due to nitrates present in the exhaust (17). When the stack monitors were placed back in operation eight days after the fire, the guidelines for stack emissions were exceeded by 16 000 times for that day, greater than a permitted release over a 50-year period.

An unknown quantity (14–20 kg) of Pu metal burned up in the fire. Burning Pu forms submicron-sized particles of plutonium oxide. According to a report made by the Atomic Energy Commission (AEC), these particles do not settle out from industrial exhaust plumes, and are so small as to move like metal fumes and do not account for the pattern of soil contamination around the plant (18).

There was concern about offsite contamination with plutonium by the fire. However, only three offsite soil samples were taken (19). All showed contamination by the plant. A soil sample taken at the Ralston Elementary School 12 miles south-southwest of the plant contained 12 000 dpm/kg of "possible enriched uranium" and a sample taken at the Semper Elementary School six miles east of the plant contained 16 000 dpm/kg of "possible enriched uranium" (Figure 1). A third sample from private property contained 18 000 dpm/kg of "possible plutonium". These concentrations are 150 to 225 times higher than Pu concentrations in soil from accumulated worldwide fallout from nuclear weapons' testing according to measurements of "background levels" in Colorado soil, or between 4200 and 6300 times higher than the "background level" (0.003 dpm/g) measured in South Carolina (20). These soil concentrations only indicate the passing of a very heavily contaminated smoke plume containing very large amounts of Pu and other actinides and radionuclides. An official at the plant afterward requested a "crash" survey as part of a nationwide AEC Project, repeating a request in earlier telegrams for reports "containing information relating to radioactivity in the atmosphere and the fallout therefrom, which is of direct interest to and must be known by the public in order to evaluate dangers to life" (21).

A large area downwind from the facility (Figure 1) has been contaminated with isotopes of Pu and other radionuclides (22–29). Uranium has been released by the open burning of over 1000 barrels of contaminated lathe oil (30). In addition, waste lathe oil from the milling of Pu metal stored in several thousand corroded barrels outdoors at the plant spilled out on the ground between 1958 and 1968, and contributed at least 5.8 curies to the offsite contamination (30).

Month	1954(b)	1955	1956	1957	1958	1959	1960	1961	1962
Jan	0.03	0.11	0.06	0.36	0.46	2.84	0.13	2.84	0.68
Feb	0.03	0.11	0.05	0.08	0.96	(d)	0.16	1.21	7.79
Mar	0.04	0.11	0.06	0.64	5.59	0.25	0.08	0.72	0.92
Apr	0.02	0.12	0.07	0.08	0.35	0.18	0.09	1.24	1.24
May	0.05	0.08	0.21	0.04	4.97	0.15	0.40	1.20	0.89
Jun	0.03	0.05	0.09	0.20	5.66	0.56	0.94	1.13	0.34
Jul	0.07	0.04	0.23	0.40	3.19	1.87	0.53	0.77	0.54
Aug	0.06	0.02	0.20	0.09	0.80	1.05	1.42	1.21	1.32
Sep	0.06	0.12	0.23	(c)	1.73	0.89	0.69	1.20	1.47
Oct	0.06	0.05	0.58	6.64	0.81	0.57	3.26	0.60	5.03
Nov	0.10	0.06	0.33	0.50	0.42	0.19	1.32	0.85	2.44
Dec	0.14	0.04	0.15	2.01	1.25	0.12	1.12	0.44	5.33
Annual Average	0.06	0.08	0.19	110 – (e)	2.18	0.98	0.85	1.12	2.33

(a) Federal guideline for maximum permissible air concentrations for such exhaust plumes is 0.12 dpm/m³. Daily exhaust volume from main stack exceeds 13 000 000 m³.
(b) Data incomplete for 1953 (average 0.03 dpm/m³) and for 1963 (average 7.63 pCi/m³).
(c) Fire on September 11, 1957. Sept. 1–10, 0.68 dpm/m³; Sept. 11–18, no sample (electrical power failure following a major fire); Sept. 19–30, 74.74 dpm/m³ and on Sept. 19, 2086.10 dpm/m³.
(d) All filters changed in the main filter plenum. Feb. 1–13, 5.32 dpm/m³; Feb. 14–28, 0.21 dpm/m³.
(e) Estimated, not including Pu released during the fire or for six days after.

Table 1. Monthly average plutonium 239 concentration, in disintegrations per minute per cubic meter (dpm/m³), in the air leaving the main exhaust duct of Building 771 (a) (from Reference 7).

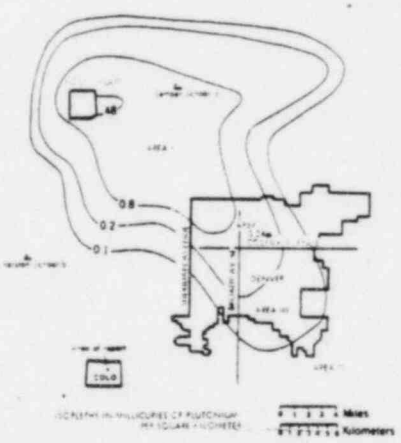

Figure 1. Denver area census tracts within isopleths for soil contamination with plutonium downwind from the Rocky Flats plant. The offsite soil contamination was reported on March 13, 1958 to be as follows (19):
a) At the Semper Elementary School; 16 000 disintegrations per minute per kilogram (dpm/kg) of "possible enriched uranium".
b) At the Ralston Elementary School; 12 000 dpm/kg of "possible enriched uranium".
c) "Possible plutonium", 18 000 dpm/kg on private property east of the Rocky Flats plant.

Concentrations of Pu in soil may be compared to current and proposed guidelines for areas with risk of human exposure. Only a Soviet standard of 0.44 dpm/cm², or 0.44 dpm/g of soil (by convention) is in the same order as the surface soil concentrations of Pu in the major part of the area studied (Table 2) (22). An Interstate Commerce Commission guideline for trucks hauling radioactive materials permits a concentration 10 times greater (4.4 dpm/cm²), but is 10 times more protective than a proposed Environmental Protection Agency (EPA) guideline to protect the general public (44 dpm/cm²), a guideline that has been criticized.

Resuspension of Pu-contaminated soil increases with wind speed to the 2.1 power, and the ratio of Pu 238 to Pu 239 increases from about 2 percent (surface soil) to 20–40 percent in airborne soil (31). As much as 50 pCi/g of Pu in airborne soil has been reported in the area. A study of Pu particle size in the soil suggested that single Pu atoms and Pu particles with diameters less than the minimum detectable equivalent diameter (0.09 μm) accounted for the majority of Pu 239 and Pu 240 activity in the soil (32).

Contamination of an aquifer under the facility to 2.5 picocuries of Pu per liter (pCi/l), a stream leaving the plant site to 209 pCi/l(1), and a nearby water district to 2.29 pCi/l has been reported (1, 33). Pu in chlorinated water is soluble to the extent that a recommendation has been made that the concentration limit be reduced from 1600 pCi/l to 0.16 pCi/l (26, 27), so these concentrations of Pu are of concern (34, 35).

Contaminated water is a significant source of exposure for only a small fraction of the Denver area population (1). The major route of exposure is the inhalation of airborne particles of Pu and other radionuclides by people living in the path of exhaust plumes from the plant, and (for those living near the plant), the inhalation of Pu in resuspended surface dust. No reports of measured population doses have been made, but work in progress confirms the presence of Pu from the facility (identified by isotope ratio) in autopsy specimens of persons in the area (36).

There has been no prior investigation of health effects for residents of areas contaminated by Pu. (Pu, an alpha radiation emitter, has a very slow rate of excretion and is thus retained in the body for many years.) Although Pu is present in exposed persons in higher concentration in bone (where the half-life is about 200 years) autopsy studies of nuclear plant workers have demonstrated Pu in all organs (37). Animal studies suggest that effects of Pu may include leukemia, neoplasms of bone, lung and liver, and genetic injury

Table 2. Guidelines concerning contamination concentrations of alpha radiation (plutonium) for areas that provide risk to human expusure (from Reference 22).

Country	Millicuries per km	Microcuries per m	Disintegrations per minute per g. dry soil or per cm	Purpose	Type
USSR	—	0.002	0.44	hands and work under clothing before cleaning	Occupational
	—	0.006	1.33	work surfaces after cleaning	Occupational
	—	0.015	3.33	work clothing and surfaces before cleaning	Occupational
US	10	0.01	2.20	Colorado. Surface soil	Occupational
	—	0.02	4.40	Interstate Commerce Commission (Dept. of Transportation) pertains to interior of vehicles previously used for transportation of radionuclides	Occupational
	40	0.04	8.80	urban, suburban, recreation areas (a)	Public
	200	0.2	44.00	soil surface in residential areas (U.S.E.P.A. proposed)	Public
	—	0.35	77.00	establishes an "extraordinary nucleas occurrence" (b)	Public

(a) Recommended by U.S. at an International Symposium on Radiological Protection of the Public in a Nuclear Mass Disaster (June, 1968) (Reference 22).
(b) U.S. Code of Federal Regulations, Chapter 10, Sections 140–84, 140–85. U.S. Nuclear Regulatory Commission, Washington, DC (1968).

(38, 39). Conservative reports suggest that maximum permissible doses of Pu for workers should be reduced to about 67 pCi (trachiobronchial lymph nodes), or about 170 pCi (bone) (40, 41). Inhalation and retention of a few particles of Pu of respirable size ($< 5\,\mu m$ in diameter) could exceed this amount (42). Lymphocyte chromosome aberrations in Pu workers in the lowest exposure group (1–10 percent maximum permissible body burden of Pu, or 400 to 4000 pCi) exceeded by 33 percent those of workers with no measurable body burden (43), further supporting a more conservative estimate of the body burdens of Pu having potential health effects.

A preliminary study of leukemia and lung cancer deaths compared eight census tracts around the facility with 19 census tracts with a similar population in the relatively uncontaminated part of the county (a census tract is a small area designated for statistical purposes in certain cities and in standard metropolitan statistical areas—SMSA's—in the United States). A higher age-corrected leukemia death rate was noted in the contaminated area ($p = 0.01$) and the age-specific (45–64 years) death rate from lung cancer was more than twice as great as for the control area ($p < 0.05$) (44, 45). A preliminary study of congenital malformations coded at birth found a rate of 14.5 per 1000 births for a large suburban city near the plant compared with a rate of 10.4 for the remainder of the county, and 10.1 for the state of Colorado, a difference of interest (47).

In order to determine if exposure of a large population to a small concentration of Pu and other radionuclides had produced a measurable effect on cancer incidence, the following investigation was conducted.

METHOD

Cancer incidence data was acquired by census tract from the National Cancer Institute's (NCI) Third National Cancer Survey (1969–1971) with the assistance of the Colorado Regional Cancer Center (48–50). The incidence of cancer for each cancer class was determined for census tracts pre-selected within Pu isopleth areas (Figure 1) with decreasing concentration of Rocky Flats Pu (identified by isotope ratio) in soil, based on an area-wide survey (core samples to a depth of 10 cm) made by the AEC in the Denver area in 1970 (18, 24). Census tracts divided by an isopleth were included in the area containing the major part of the census tract.

The isopleths in Figure 1 are approximate but useable in comparing the incidence of health effects between areas with decreasing environmental contamination around a point source of emission and with populations that are similar in size. Area I, within the Pu concentration range 40–0.8 millicuries/km^2 (mCi/km^2), lies between 3 and 21 km from the center of the Rocky Flats Plant along the principal wind vector. Area II (0.8 to 0.2 mCi/km^2) extends from 21 to 29 km and Area III (0.2 to 0.1 mCi/km^2) from 29 to 35 km.

The Pu content of soil reported in the AEC survey was used as a surrogate measure of exposure through pathways other than those that originate from the soil (ie an indication of the direction of exhaust plumes from the Rocky Flats Plant since 1953). That actual exposures to radionuclides have been much larger is suggested by a survey of Pu in surface respirable dust to a distance of 32 km around the plant. Concentrations of Pu as much as 3390 times greater than that in Colorado "background" concentrations were observed (169.5 dpm/g and 0.05 dpm/g respectively) compared to a maximum concentration of 26 times background for the AEC survey, which sampled subsurface soil and coarse particles 2 mm in diameter and smaller with the windblown material (18).

Data were retrieved from NCI automated data processing tapes using a program developed by Berg and Finch (50), with an approach similar to that reported by Monson (51), and most recently utilized by Blair, *et al* (52, 51). Age-specific cancer rates for whites (excluding persons with Spanish surname, because the population of the area near the plant is virtually all white, with few persons of Spanish surname) were calculated for the Denver Standard Metropolitan Statistical Area (SMSA), and expected case numbers calculated by applying the SMSA age-specific cancer incidence rates to the 11 corresponding age groups in each sub-area, and summing the products to obtain a standardized expected incidence (cases expected/area population) for each area. The number of cases of all cancer or the classes of cancer in each area divided by the standarized expected incidence provided a risk ratio (observed/expected).

Area IV, the unexposed population (comprising the remainder of the Denver SMSA) had an age-adjusted cancer incidence (males, 269 and females, 226 per 100 000) virtually identical to that for the state (males, 268 and females, 227 per 100 000) (48). The risk ratio for Area IV was assumed to be 1.0 and the exposed populations (Areas I–III) were compared to Area IV. The population in Area IV is predominantly suburban, as is the population for Area I nearest the plant, and these two areas have a mean age more similar (Table 3) than those of Areas II and III, and so those two areas provide the most important comparisons. Median income and education levels of the study and control populations were considered with the aid of 1970 census data (Table 3), in order to weigh the possible importance of such associated factors as smoking, diet and alcohol.

The population in the eight census tracts in Area I nearest the plant was small and had had rapid development and recent in-migration (an estimated population of 16 000 in 1960, and 44 000 in 1970, during which time the population of Denver did not appreciably change) (49). Area IV, like Area I, is mostly suburban, and part of this area also had a rapid growth in population between 1960 and 1970. The evidence indicates heaviest exposures in 1957. Since there is a latent period for neoplasms, many persons in the eight census tracts nearest the plant would not have had sufficient time in residence to exhibit an effect from exposure to Pu. An influence on cancer incidence would be first apparent in the large population areas with lower rates of in-migration. The ef-

	Distance from Rocky Flats on principal vector	Plutonium mCi/km² (soil < 2 mm)	Anglo Population		Population Characteristics				Incidence of cancer compared to unexposed population					
			Male	Female	Median Education years	Median Income	Median Age Years		Male		Female		Total	
							Male	Female	Cases obs/exp	o/e-1	Cases obs/exp	o/e-1	Cases obs/exp	o/e-1
Area I	3–21 km	48.0–0.8	75,250	78,920	12.04	>8,891	25.8	29.8	644/519**	+ 24%	636/581*	+ 10%	1280/1100**	+ 16%
Area II	21–29 km	0.8–0.2	90,300	103,900	11.95	6,367	34.6	36.8	1086/947**	+ 15%	1154/1100	+ 5%	2240/2047**	+ 10%
Area III	29–35 km	0.2–0.1	117,370	129,530	12.69	12,094	30.6	33.5	1078/1000	+ 8%	1149/1109	+ 4%	2227/2109	+ 6%
Areas I–III	3–35 km	48.0–0.1	282,920	312,350	12.22	8,668			2808/2466**	+ 11%	2939/2790**	+ 5%	5747/5256**	+ 9%
Area IV	> 35 km	0.1	210,670	213,190	12.97	8,055	24.2	25.9	1114	0	1260	0	2374	0

(a) Ref. 48, the National Cancer Institute's Third National Cancer Survey. Incidence Data (expected case numbers calculated by applying the SMSA age-specific cancer incidence rates to the corresponding age groups in each area, and summing the products to obtain a standardized expected incidence (cases expected/area population) for each area. The study areas are then compared to the control area. "Anglo" includes all white except those with Spanish surname.

(b) Millicuries per square kilometer, calculated from Pu concentrations in soil to 10 cm in depth, including gravel < 2 mm in diameter.

(c) This data is for total population (49).

(d) $X^2 = \frac{(|obs - exp| - 0.5)}{npq}$ where n = population size, p = incidence of cancer, and q = 1 − p. The X^2 used with the variance = npq is a more conservative test than the Mantel-Haenszel X^2 (58). Use of a somewhat more conservative test devised by Professor Lars Ehrenberg of the University of Stockholm, $Z = \frac{n - n_1}{\sqrt{n_1 (n - n_1)/n}}$ did not change the level of significance noted here and in Table 4.

* Critical X^2 value at a 95% confidence level. ** Critical X^2 value at a 99% confidence level.

(e) (observed/expected − 1) × 100, compared to Area IV, the unexposed population.

Table 3. Census tract areas selected by decreasing soil concentrations of Rocky Flats plutonium, Anglo population size, median income and education, and total incidence of cancer for 46 cancer sites, by sex, for the period 1969–1971 (a)

	Area I 48–0.8 millicuries/kilometer					Area II 0.8–0.2 millicuries/kilometer					Area III 0.2–0.1 millicuries/kilometer					Area IV (unexposed)	
Population (1970)	75,250 Male Cases		78,920 Female Cases		Total	90,300 Male Cases		103,900 Female Cases		Total	117,370 Male Cases		129,530 Female Cases		Total	210,670 Male	213,190 Female
Site	obs/exp (b)	o/e-1 (c)	obs/exp	o/e-1	o/e-1	obs/exp	o/e-1	obs/exp	o/e-1	o/e-1	obs/exp	o/e-1	obs/exp	o/e-1	o/e-1	obs	obs
Lung and Bronchus	109/82*	33%	21/24	(12%)	23%	209/143**	46%	53/48	10%	37%	179/158	13%	54/48	12%	13%	174	51
Other Respiratory	20/13	54%	3/2	50%	53%	21/23	(9%)	7/5	40%	0	26/26	0	2/5	(60%)	(10%)	32	5
Leukemia	27/19	42%	14/17	(18%)	14%	28/31	(10%)	34/33	3%	(3%)	37/34	9%	52/33**	58%	33%	45	38
Lymphoma, Myeloma	35/25	40%	28/25	12%	26%	48/40	20%	38/49	(22%)	(3%)	51/45	13%	43/49	(12%)	0	59	56
Tongue, Pharynx, Esophagus	17/12	42%	6/3	100%	53%	43/18**	139%	25/7**	257%	172%	29/20	45%	10/7	43%	44%	24	7
Stomach	22/16	38%	11/14	(21%)	10%	27/30	(10%)	27/32	(16%)	(13%)	30/32	(6%)	21/23	(9%)	(7%)	34	27
Colon, Rectum	100/68*	47%	103/75**	37%	42%	144/130	11%	178/160	11%	11%	135/135	0	152/143	6%	3%	144	146
Liver and Biliary	10/5	100%	7/10	(30%)	13%	23/13*	77%	23/22	5%	31%	19/13	46%	19/21	(10%)	12%	5	3
Pancreas	20/22	(9%)	21/15	40%	11%	37/41	(10%)	35/32	9%	(3%)	39/43	(9%)	32/30	7%	(3%)	46	30
Testis	11/5	120%	–	–	–	14/6*	133%	–	–	–	15/7	114%	–	–	–	13	–
Ovary	–	–	34/27	26%	–	–	–	59/48	23%	–	–	–	66/52	27%	–	–	63
Thyroid	3/6	(50%)	24/16	50%	23%	8/10	(20%)	33/26	27%	14%	11/12	(8%)	23/29	(21%)	(17%)	18	42
Brain	13/11	18%	10/8	25%	21%	10/17	(41%)	10/12	(17%)	(31%)	12/20	(15%)	19/14	36%	6%	27	20
Other Sites	257/235	9%	354/345	3%	6%	474/445	8%	632/625	3%	5%	490/455	8%	656/655	0%	3%	493	772
All Cancer	644/519**	24%	636/581*	10%	16%	1086/947**	15%	1154/1100	6%	10%	1078/1000*	8%	1149/1109	4%	6%	1114	1260

(a) From the National Cancer Institute's Third National Cancer Survey. Incidence Data. Expected case numbers calculated by applying the SMSA age-specific cancer incidence rates to the corresponding age groups in each area, and summing the products to obtain a standardized expected incidence (cases expected/area population) for each area. The study areas are then compared to the control area. "Anglo" includes all white except those with Spanish surname. (48)

(b) $X^2 = \frac{(|obs - exp| - 0.5)}{npq}$ when n = population size, p = incidence of cancer, and q = 1 − p. The X^2 used with the variance = npq is a more conservative test than the Mantel-Haenszel X^2 (58).

* Critical X^2 value at a 95% confidence level. ** Critical X^2 value at a 99% confidence level.

(c) (observed/expected − 1) × 100 compared to Area IV, the unexposed population. Percentages in parentheses are negative (less than expected).

Table 4. Anglo cancer incidence by sex, and by cancer site, in the Denver metropolitan area over a period of three years (1969–1971) by areas of census tracts with and without plutonium soil contamination by the Rocky Flats plant (a)

fect of the inclusion of the eight census tracts nearest the plant with the remainder of Area I is to understate any environmentally-related difference in cancer incidence.

RESULTS

The total incidence of cancer for the period 1969–1971 is summarized in Table 3 for 46 cancer classes by isopleth area of Pu concentration. Compared to males in the unexposed area (Area IV), there was an incidence of cancer 24% higher in males in Area I, nearest the plant and 15% higher in Area II, further from the plant. (For confidence levels, see Table 3, column 10.) The corresponding values for females were 10% in Area I and 5% in Area II, and for both sexes 16% and 10%. The higher incidence of all cancer in the exposed areas represents more cases than expected (both sexes) of cancer of the lung, leukemia, lymphoma and myeloma (only males), and cancer of the tongue, pharynx and esophagus, colon and rectum, liver, (only males) pancreas, only females) gonads, thyroid (only females) and brain (only females).

The incidence of lung and bronchial cancer for males in Area I was about 33 percent higher than for males in the uncontaminated area (Table 4). This higher incidence persisted in Area II (46% higher). In all exposed areas, 497 cases were observed where 383 were expected, for males. For both sexes in all exposed areas, 625 cases were observed where 503 were expected.

There was a significant excess (58%) of cases of leukemia in females in Area III, with the largest study population. For both sexes in all exposed areas, 192 cases of leukemia were observed where 167 were expected. There was a higher incidence of lymphoma and myeloma in males in all exposed areas (134 cases observed/110 expected).

A most unexpected discovery was the unusually high incidence of cancer of the testis (40 cases observed/18 expected) throughout the exposed area (Areas I–III) (53–55). The incidence of cancer of the ovary was also higher (24%) throughout the exposed areas.

The incidence of cancer of the colon and rectum was much higher for both males and females in Area I (42% higher for both sexes) and for all exposed areas (812 cases observed/711 expected). The incidence of cancer of the liver, gall blad-

Male Age Category	0–14		15–44		45–54		55–64		65–74		75 +	
(Population: Area I, IV) Cancer Classes	24,825 o e (b)	66,530 E (c)	31,395 o e	98,521 E	8,351 o e	24,092 E	5,750 o/e	12,652 E	3,148 o/e	5,683 E	1,785 o/e	3,175 E
All classes	20/9.1*	25	52/40	126	71/64	185	147/127	278	194/149**	270	169/130**	230
Lung and bronchus	0/0	0	8/3.5	11	14/13	37	37/25	54	34/31	55	16/9.6	17
Leukemia	6/4.2	11	13/2.9**	9	1/1.0	3	6/1.8	4	2/1.7	3	2/1.1	2
Lymphoma, myeloma	1/1.9	5	19/7.3**	23	3/1.4	4	8/2.7	6	5/1.7	3	3/1.1	2
Stomach	0/0	0	1/0.3	1	6/2.1	6	3/3.2	7	8/6.1	11	4/5.1	9
Colon	0/0	0	3/2.5	8	6/5.2	15	15/12	26	15/9.4	17	29/13**	23
Liver	0/0	0	0/0.3	1	0/0.3	1	3/0	0	1/0.6	1	2/1.1	2
Pancreas	0/0	0	1/0.6	2	3/3.5	10	6/4.1	9	7/6.6	12	3/7.3	13
Testis	1/0	0	8/3.2	10	1/0.7	2	0/0.5	1	1/0	0	0/0	0
Breast	0/0	0	1/0.3	1	0/0	0	0/0	0	1/0	0	0/0.6	1
Thyroid	0/0	0	1/3.2	10	1/1.4	4	0/1.4	3	1/0.6	1	0/0	0
Brain	1/0.4	1	2/2.2	7	3/1.7	5	4/2.3	5	2/3.3	6	1/1.7	3
Unknown	0/0	0	0/0.6	2	3/1.4	4	4/5.5	12	11/3.9*	7	5/2.8	5
Female (Population: Area I, IV)	23,648	64,433	33,113	99,552	8,727	23,379	6,140	12,963	4,031	7,593	3,257	5,273
All classes	5/7.0	19	103/84	253	106/116	310	130/118	249	144/104**	195	148/144	234
Lung and bronchus	0/0	0	2/1.3	4	2/5.6	15	5/5.2	11	9/7.5	14	3/4.3	7
Leukemia	0/1.8	5	5/1.3	4	0/1.1	3	7/0.9*	2	2/1.1	2	1/2.5	4
Lymphoma, myeloma	1/0.7	2	19/7.0**	21	1/0.7	2	9/2.4*	5	5/2.1	4	11/3.1*	5
Stomach	0/0	0	1/0.3	1	0/1.1	3	2/3.3	7	2/1.6	3	6/8.0	13
Colon	0/0	0	3/4.0	12	8/0.9	23	14/8.5	18	16/8.5	16	39/25*	40
Liver	0/0	0	0/0.7	2	0/0.4	1	0/0	0	1/0	0	2/0	0
Pancreas	0/0	0	2/0.3	1	2/2.2	6	9/4.3	9	5/3.2	6	3/4.9	8
Ovary	0/0	0	8/5.3	16	7/7.5	20	9/6.2	13	7/4.2	8	3/3.7	6
Breast	0/0	0	34/34	101	40/44	119	37/30	64	46/27*	51	33/30	49
Thyroid	1/0	0	12/8.3	25	3/2.6	7	4/0.9	2	0/2.7	5	4/1.8	3
Brain	2/1.8	5	3/2.0	6	1/0.7	2	2/1.9	4	2/1.1	2	0/0.6	1
Unknown	0/0	0	1/0.7	2	2/2.6	7	3/0.9	2	7/5.9	11	8/6.2	10
Total (Population: Area I, IV)	48,473	130,963	64,508	198,073	17,078	47,471	11,890	25,615	7,179	13,276	5,042	8,448
All classes	25/16	44	155/123*	379	177/178	495	277/247*	527	338/251**	465	312/277	464
Lung and bronchus	0/0	0	10/4.9	15	16/19	52	42/30	65	43/37	69	19/14	24
Leukemia	6/5.9	16	18/4.2**	13	1/2.2	6	13/2.8**	6	4/2.7	5	3/3.6	6
Lymphoma, myeloma	2/2.6	7	38/14**	44	4/2.2	6	17/5.1**	11	10/3.8*	7	14/4.2**	7
Stomach	0/0	0	2/0.6	2	6/3.2	9	5/6.5	14	10/7.8	14	10/12	20
Colon	0/0	0	6/6.5	20	14/17	48	29/20	44	31/18*	33	68/38**	63
Liver	0/0	0	0/1.0	3	0/0.7	2	3/0	0	2/0.5	1	4/1.2	2
Pancreas	0/0	0	3/1.0	3	5/5.8	16	15/8.4	18	12/9.7	18	6/13	21
Gonads	1/0	0	16/8.5*	26	8/7.9	22	9/6.5	14	8/4.3	8	3/3.6	6
Breast	1/0	0	35/33	102	40/42.8	119	37/30	64	47/28**	51	33/30	50
Thyroid	1/0	0	13/11	35	4/4.7	13	4/2.3	5	1/3.2	6	4/3.6	3
Brain	3/2.2	6	5/3.6	13	4/2.5	7	6/4.2	9	4/4.3	8	1/2.4	4
Unknown	0/0	0	1/1.3	4	5/4.0	11	7/6.5	14	18/9.7*	18	13/9.0	15

(a) Ref. 48 The National Cancer Institute's Third National Cancer Survey: Incidence Data
(b) o = observed cases in Area I, e = expected number of cases (actual number of cases in Area IV × population in Area I/population in Area IV)
(c) E is the number of cases in Area IV
* $p < 0.05$
** $p < 0.01$ (standardized Z test for normal approximation to the binomial proportion, ref. 58)

Table 5. Anglo cancer incidence by sex, age and by cancer class, in the Denver metropolitan area over a period of three years (1969–1971) by areas of census tracts with and without plutonium soil contamination by the Rocky Flats Plant: Area I compared to Area IV (Control) (a).

der and "other biliary" was higher in males throughout the three exposed areas (77% higher in Area II; for all exposed areas, 52 cases observed/31 expected). Cancer of the tongue, pharynx, and esophagus was high for both sexes in all three study areas (89 cases observed/50 expected for males, and 41 cases observed/17 expected for females). According to the statistical test used, the remaining variances may be random.

The strongest comparisons can be made between Area I, a predominantly suburban area near the plant with heaviest exposure, and Area IV, also predominantly suburban with little or no exposure and having virtually the same age-adjusted incidence rate for all cancer as that for the state of Colorado. The number of cancer cases observed for these two areas in the three-year study period are compared by age and sex in Table 5.

For both sexes, the general pattern is that of excess incidence of all cancer in all age categories in Area I, with no significant exception. There was an excess of all cancer in the age group 0–14 years (25 observed/16 expected), 15–44 years (155/123), 55–64 years (277/247), 65–74 years (338/251) and over 75 years (312/277). This difference was due principally to an excess of cancer in males in the age groups 0–14 years, 15–44 years, 65–74 years, and over 75 years. An excess incidence of all cancer was also noted in females with no significant exception, especially in the age group of 15–44 years and 65–74 years.

The higher incidence of all cancer was chiefly due to cancer of lung and bronchus, especially in the males, and to cancer of the colon in both sexes. The incidence was higher above the age of 55. Exceptions were an excess of cancer of the lung and bronchus in males in the age range 15–44 years and cancer of the colon in females in the age group 45–64 years.

There was a higher incidence of leukemias, lymphomas and myelomas in both sexes in Area I. In males there was a higher incidence of leukemia in the age group 15–44 years of age (13/2.9) and of lymphomas and myelomas in the age group 15–44 years (19/7.3). In females, there was a higher incidence of leukemia in the age group 55–64 (7/0.9) and of lymphomas and myelomas in the age groups 15–44 years (19/7.0), 55–64 years (9/2.4), and 75 + years (11/3.1).

A higher incidence of breast cancer was found for females in the age group 65–74 years (46/27). This age-specific excess incidence was obscured when the data was age-adjusted.

The incidence of cancer of the testis is again noted, with one case occurring in the small population (24,825) in the age category 0–14 near the plant and none occurring in the larger control population (66,530). In the next older age category, 15–44, eight cases were observed where 3.2 were expected.

With one exception (ages 65–74), there were more cases of cancer of the thyroid in females than expected, and an excess of cancers of unknown origin, especially in the age range 65–74 years.

Investigation of the ratios of cancers of radiosensitive organs to other cancers (Table 6) found higher ratios in the population near the plant, compared to the unexposed population in Area IV (+12.2%, +9.7% and +3.4%, respectively, for both sexes in Areas I, II and III). Males had a higher ratio near the plant, 17.6% higher, than did the females (11.9% higher). Deleting lung cancer changed only slightly the ratio of cancers

of radiosensitive organs to other cancers (11.7% higher for both sexes; 17.9% for males and 13.6% for females).

DISCUSSION

The incidence of all cancer in the suburban area near the plant (Area I) was significantly higher than that in the unexposed population (Area IV) which had virtually the same age-adjusted cancer incidence as the state. Exposed Area II, more distant from the plant, had a correspondingly smaller excess incidence of all cancer compared to Area IV. Area III, most distant from the plant, had an incidence of all cancer slightly greater than expected.

The data were corrected for age, sex, race and ethnicity. Other possible confounding factors include urban-suburban differences, income, education, air pollution, occupation, smoking habits, and diet. Data were not available by census tract for smoking, drinking and dietary habits, but these were assumed to be associated with income and education. Area II includes the Denver urban core (Figure 1), much of the low-income housing, and a lower educational and income level (usually associated with a higher incidence of cancer) but has a lower incidence of cancer than Area I, a suburban population near the Rocky Flats plant demographically similar to Area IV (Table 3). Area III has an educational level slightly higher than Areas I and II, and slightly lower than Area IV. This area has the highest income level, and has a higher cancer incidence than Area IV. Differing levels of income and education do not appear to be important as a cause for the higher incidence of cancer in areas near the plant.

Area II has more air pollution than Area I, but has lower cancer incidence than Area I, which is nearer to the Rocky Flats plant. In considering occupation, the distribution of Rocky Flats Pu workers approximates the distribution of population between exposed and unexposed populations (1). Old radium mill tailing sites are located in Area II, under streets and parking lots and in commercial and industrial areas, and may cause an accumulation of radon in rooms in a small number of non-residential buildings. This would appear to have no noticeable effect on the results of this investigation (56).

The higher incidence of cancer in males accentuates a sex difference noted for the unexposed population and for the state. This is partly due to the smoking habits of men. Pulmonary irritants (ie cigarette smoke) can result in a greater respiratory deposition rate of small inhaled particles, such as Pu particles (57). Smoking habits alone can not account for the profile of classes of cancer found in excess, except for respiratory cancer.

Area I had a population with a younger mean age than Areas II and III (though not quite as young as Area IV), but had a higher cancer incidence than those two older urban areas. The method of age adjustment (see footnote for Tables 3 and 4) across the 11 age groups (NCI) should correct for these age differences, which are minor between the principal comparison populations in Area I and Area IV. The higher age-adjusted cancer incidence found in Area I was confirmed by age-specific comparison with Area IV.

The age-adjusted incidence of all cancer was significantly higher near the plant, due to more cases than expected of a number of individual classes of cancer, including those noted to be in excess in the survivors of Hiroshima and Nagasaki: leukemia, lymphomas and myelomas and cancer of the lung, thyroid, breast, esophagus, stomach and colon. Cancer of gonads (especially the testis) liver, pancreas and brain also contributed to the higher incidence of all cancer in the areas near the plant. The classes of cancer found to be in excess are for the most part those developing in the more radiosensitive tissues of the body. There was not an excessive incidence of bone cancer, perhaps because of its longer latent period.

The remarkably higher incidence of cancer of the testis in the three exposed areas merits special attention. One possible explanation is the demonstrated propensity of plutonium to concentrate in gonads (53–55). The higher incidence of cancer of the ovary is also consistent with this hypothesis.

That the age-adjusted rates of all cancer near the plant are higher is confirmed by an inspection of age-specific cancer incidence for Areas I and IV (Table 5). This was due in part to higher age-specific incidence of leukemia, lymphoma and myeloma, and cancer of breast, colon, and cancer, site unknown for certain age-specific groups. Cancer of the lung, stomach, liver, gonads, thyroid and brain also contributed to the higher incidence of all cancer near the plant. The general trend of all cancer of radiosensitive organs was clearly upward near the plant, but in some classes of cancer the numbers of cancer cases in each age category were too small in the three-year period of the investigation to be statistically significant.

Further indication that the populations in the path of exhaust plumes of the Rocky Flats plant have been affected is provided by an examination of the ratios of cancers of radiosensitive organs to other cancers, compared to that ratio for the unexposed population in Area IV (Table 6). These are the cancers found in excess in the survivors of Hiroshima and Nagasaki: leukemia, lymphomas and myelomas, and cancer of the lung, thyroid, breast, esophagus, stomach and colon. These cancers occurred in greater proportion than expected in the exposed population (12.2% higher in Area I for both sexes; 17.6% higher for males, and 11.9% higher for females). This ratio decreased in Areas II and III for males, but persisted for females. The exclusion of lung cancer (because smoking habits are an important factor in lung cancer) makes little change (11.7% higher for both sexes in Area I; 17.9% higher for males, and 13.6% higher for females).

Table 6. Anglo cancer incidence in the Denver metropolitan area over a period of three years (1969–1971), by areas of census tracts with and without plutonium soil contamination by the Rocky Flats Plant. A comparison of the ratios of cancers of radiosensitive organs (a) to other cancers by sex and by exposure to plutonium from the plant (b).

	Area	Population	Total cancer cases	(c) cancers of radiosensitive organs	(d) Other cancer cases	(e) ratio c:d	relative risk (e:e − 1) · 100
Total	IV	422 866	2374	1251	1123	1.114	0(e)
	I	154 170	1280	711	569	1.250	+12.2%
	II	194 190	2240	1232	1008	1.222	+ 9.7%
	III	246 905	2227	1192	1035	1.152	+ 3.4%
Male	IV	210 670	1114	500	614	0.814	0(e)
	I	75 250	644	315	329	0.957	+17.6%
	II	90 300	1086	507	579	0.876	+ 7.6%
	III	117 370	1078	474	604	0.784	− 3.7%
Female	IV	213 670	1260	751	509	1.475	0(e)
	I	78 920	636	396	240	1.650	+11.9%
	II	103 900	1154	725	429	1.690	+14.6%
	III	129 530	1149	718	431	1.666	+12.9%

(a) Cancers of radiosensitive organs: defined as those found in excess in survivors of Hiroshima and Nagasaki: leukemia, lymphoma and myeloma, and cancer of the lung, thyroid, breast, esophagus, stomach and colon (from Reference 59).

(b) Cancer incidence data from the National Cancer Institute's Third National Cancer Incidence Survey: Incidence Data. The population in Area IV is considered a control population with no exposure to plutonium and other actinides and radionuclides from the Rocky Flats plant. The population in Area I has the greatest exposure to these radionuclides, those in Area II have less exposure, and those in Area III have the least exposure (from Reference 48).

CONCLUSION

A conservative analysis of cancer incidence in the Denver SMSA over a three-year period (1969–1971) found a higher incidence of all cancer in areas contaminated with Pu, compared to the unexposed area. The consistency of the increase in incidence of all cancer and for certain categories of cancer with increas-

ing concentration of Pu in soil supports the hypothesis that exposure of the general public to low concentrations of Pu in the environment may have an effect on cancer incidence. The higher incidence of cancer in the areas near the plant were due to more cases than expected of leukemia, lymphoma and myeloma and cancer of the lung, thyroid, breast, esophagus, stomach and colon, a pattern similar to that observed in the survivors of Hiroshima and Nagasaki. Cancer of gonads (especially the testis) liver, pancreas and brain contributed to the higher incidence of all cancer near the plant. Further study is warranted to pursue the investigation of poorly-understood, complex dose-effect relationships between the concentrations of many radionuclides in cells and organs and the incidence of cancer and other somatic and genetic effects in general populations residing near nuclear installations.

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SCIENCE

Exhibit 3 (Carl J. Johnson)

Plutonium Hazard in Respirable Dust on the Surface of Soil

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Plutonium Hazard in Respirable Dust on the Surface of Soil

Abstract. *Plutonium-239 in the fine particulate soil fraction of surface dust is subject to suspension by air currents and is a potential health hazard to humans who may inhale it. This respirable particulate fraction is defined as particles ≤ 5 micrometers. The respirable fraction of surface dust was separated by ultrasonic dispersion and a standard water-sedimentation procedure. Plutonium concentrations in this fraction of off-site soils located downwind from the Rocky Flats Nuclear Weapons Plant (Jefferson County, Colorado) were as much as 380 times the background concentration. It is proposed that this method of evaluation defines more precisely the potential health hazard from the respirable fraction of plutonium-contaminated soils.*

Methods of evaluating Pu inventories in soils are important because of the possibility of soil contamination near Pu processing plants and nuclear generating stations and areas where Pu has been accidentally released—for example, at Palomares, Spain, and Thule, Greenland, where Pu was released in airplane accidents in January 1966 and January 1968, respectively. Evaluation of Pu (*1*) in the soil is of special importance in contaminated areas that are now considered for residential development. One such area is in the vicinity of the Rocky Flats Nuclear Weapons Plant (Jefferson County, Colorado), which is currently operated by Rockwell International for the Energy Research and Development Administration (ERDA). Activities at the plant include processing radioactive chemicals and making weapons from radioactive metals (*2*).

The Colorado State Health Department in 1973 proposed an interim standard for soil contaminated with Pu, setting the maximum allowable concentration at 2 disintegrations per minute per gram (dpm/g) (*3*). Land with Pu concentrations in excess of the standard would require ameliorative treatment before residential development could be approved. However, the standard fails to define "soil." Either single or composite samples of the soil at a depth of 0 to 0.5 cm from numerous locations in a development area are required. Because such samples include soil particles much too large to be resuspended or inhaled, the possible risk to health cannot be properly evaluated (*4*). Further, no provision is made to prevent the treated soil from being recontaminated by redeposition of Pu from more highly contaminated soils upwind. This redeposition mechanism potentially exists because winds in the area exceed 30 km/hour for 500 to 600 hours yearly. Wind speeds commonly reach 130 km/hour or more, with winds blowing predominantly to the east and southeast toward the Denver metropolitan area (Figs. 1 and 2).

The plant is located about 16 km northwest of Denver and about 8 km from the cities of Boulder, Westminster, and Arvada. Approximately 200,000 people live within 16 km and 600,000 people within 32 km of the plant. Residential development is now proposed within about 5 km of the plant (Fig. 1), involving as many as 3000 homes or a potential population of about 10,000 persons (*5*).

Since the plant began operation in 1953, there have been two major fires (1957 and 1969), a large release of Pu to off-site soils from a spill of metal-laden cutting oil, and an accidental release of Pu to the air in 1974. The major sources of off-site contamination are considered to be emissions from the 1957 fire and the oil leakage from corroded barrels of contaminated cutting oil that were stored

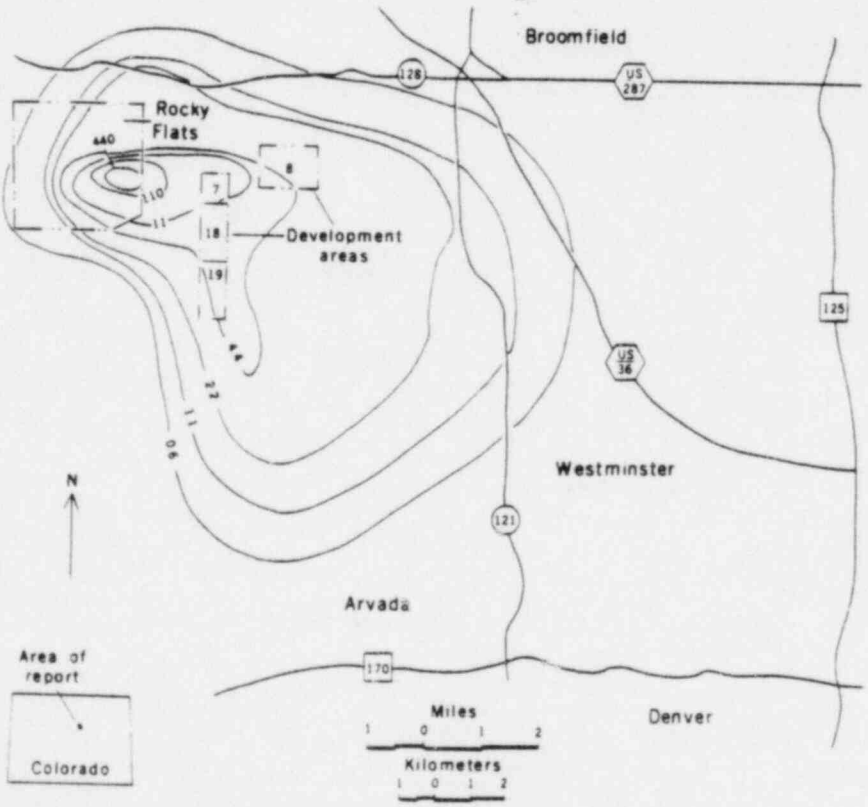

Fig. 1. Rocky Flats Nuclear Weapons Plant and proposed housing development area. Isopleths are labeled in disintegrations per minute per gram of whole soil, calculated from values in (*2*).

outside beginning in 1958 (*2*, *6*). Although leakage of the barrels was first detected in 1964, storage in this manner continued until 1968. The oil-spill area has since been partially covered with asphalt.

A survey of Pu inventories in off-site soils was conducted by the Health and Safety Laboratory of the Atomic Energy Commission in 1970 (*2*). The results are used in Fig. 1. An off-site area of more than 50 km² had concentrations of Pu in excess of 10 mc/km². Soil samples were collected to a depth of 20 cm, which was considered sufficiently deep to account for the total deposition of Pu. The Pu inventory was based on the weight of the whole soil sample, including plant parts but excluding larger rocks.

Contaminated soils must be measured against a background of Pu released during atmospheric weapons testing. Of the 300 to 500 kc of Pu released worldwide, about 10 to 15 kc is estimated to be present in the soils of the United States and less than 10 percent is still suspended in the atmosphere. In Colorado the background level has been estimated to be 0.04 pc/cm² or 0.08 dpm per gram of whole soil (*7*).

Sampling localities, each about 4 ha in area, were selected within proposed residential development areas downwind from the plant (Fig. 1). Several sampling sites were randomly selected within each locality. In addition, one stream-sediment sample in section 18 and one sample of eolian sediment in section 19 were collected. Within a 4-m² area at each site, when the ground surface was dry, a representative quantity of loose, surficial (about 0 to 0.5 cm deep) soil material was collected with a clean brush and a clean plastic container. This area provided a sufficiently large composite sample. All samples were compared against a background level estimated from a control sample collected about 23 km south-southeast of the Rocky Flats plant.

The samples were analyzed in random order so that any systematic laboratory error would be converted to a random error. The objective in sample preparation was to disperse the soil microaggregates to expose the Pu as much as possible. Each sample was sieved through a 2-mm stainless steel screen; only the material that passed through the screen was retained for analysis. Approximately 50 g of material in the size fraction ≤ 2 mm was placed on a steam bath and treated with hydrogen peroxide to oxidize the organic material, particularly that present as grain coatings or cementing agents.

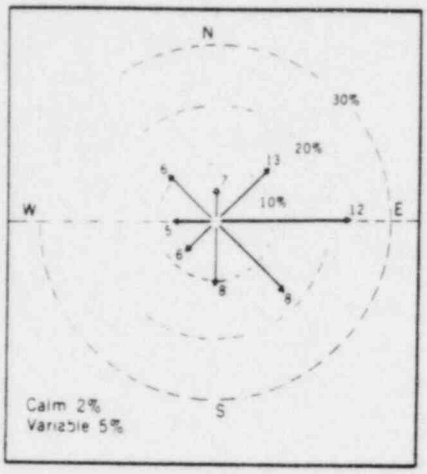

Fig. 2. Rose diagram showing average direction and velocity of wind at Rocky Flats for 1953 to 1970. Arrows point in the direction of wind movement; velocity (miles per hour) is given at the end of each arrow; concentric circles show frequency of wind direction (*2*).

Table 1. Analyses of Pu in respirable dust (size fraction ≤ 5 μm in soil material ≤ 2 mm) and in whole soil. In column 2 respirable dust is shown as the percentage of whole soil (≤ 2 mm). Localities are shown in Fig. 1. Values are given as disintegrations per minute per gram of material ≤ 5 μm; for Health Department samples these are averages of two analyses. Relative enrichment (RE) is the ratio of measured value to background value.

Locality	Health Department samples			Contractor's samples (*13*)	
	Respirable dust (%)	Pu in respirable dust			
		dpm/g	RE	dpm/g	RE
		Section 7			
7-1	36.1	83	180	13.5	169
7-2	41.4	59	130		
7-3	17.9	120	270	14.1	176
7-4	18.8	170	380		
		Section 18			
18-1	19.8	36	80	0.2	2.5
18-2	29.6	24	53	0.14	1.8
18-3	27.0	26	58	2.96	37
18-4	25.1	40	89	0.14	1.8
		Section 19			
19-1	62.2	1.4*	3.1		
19-2	46.3	2.1†	4.7	0.23	2.9
19-3	36.5	1.3†	2.9		
		Section 8			
8-1	47.7	1.1†	2.4	0.05	0.6
8-2	51.2	1.0†	2.2		
8-3	42.1	3.8†	8.4		
8-4	31.5	2.8†	6.2		
8-5	47.0	9.6	21	0.72	9.0
8-6	48.8	8.1	18		
8-7	37.6	11	24		
8-8	33.3	7.7	17		
8-9	24.8	14	31	0.72	9.0
8-10	25.7	19	42		
8-11	34.5	9.4	21		
8-12	37.9	6.9	15		
		Background			
Control	48.9	0.45	1	0.08	1

*Eolian sediment from ground surface. †Sample from recently disturbed soil.

The samples were washed and filtered to remove soluble salts and dispersed with a 300-watt ultrasonic probe for 15 minutes (*8*).

Particles were separated according to size by a standard water-sedimentation technique (*9*). Sodium metaphosphate was added when necessary to avoid flocculation. The suspension containing the desired size fraction was collected and freeze-dried (*10*). The sedimentation technique is an arbitrary measure of the "effective" diameter of particles with irregular shapes that have settling rates equivalent to those of spheres of the same diameter and density. The threshold parameters used were based on particles of plutonium oxide having an effective maximum diameter of 5 μm and a density of 11.46 g/cm³. The soil particles separated include other mineral grains that have an equivalent maximum settling velocity, but that also have some combination of smaller density and larger diameter. The size fraction thus defined is hereafter called the soil material ≤ 5 μm or "respirable dust" because we assume this size fraction to be an adequate measure of the respirable material.

Plutonium concentrations are given in Table 1. The results shown are the averages of the determinations for duplicate split samples by two laboratories (*1*). Averaging the two determinations is justified because a *t*-test indicates no significant difference between determinations at $P = .05$. Analytical procedures used for Pu were those described by Talvitie (*11*, *12*).

Our estimate of background is 0.45 dpm per gram of soil material ≤ 5 μm. Samples from areas immediately downwind from the plant show evidence of Pu contamination considerably above background in the respirable dust. The sampling area in section 7, which is about 2.4 km immediately downwind from the plant area, has the largest amounts of Pu: 59 to 170 dpm/g. Sites 7-3 and 7-4 are on the flat crest of a low ridge that trends east from the plant, and sites 7-1 and 7-2 are on the north-facing slope of the same ridge but about 12 m lower in elevation. Section 8, which is on the principal wind vector but about 5 km downwind, has 1 to 19 dpm/g. Although sample sites in section 18 are nearly the same distance from the plant as those in section 7, we measured less Pu there, perhaps because section 18 lies away from the principal wind vector. Section 19, which is farther from the plant and from the principal wind vector, has the lowest values. Eolian sediment (sample 19-1) that was derived from a freshly plowed field upwind

had only 1.4 dpm/g. The field is located in a zone of expected contamination about 3.3 km southeast of the plant area. Plowing tends to distribute the Pu throughout the plowed layer and reduce its probability of entrainment for the present, but it also creates a more erosive surface until plant cover is reestablished. Stream sediment collected in section 18 contained 9.4 dpm/g. This sediment could be susceptible to wind erosion during periods when the stream was at low flow or dried up.

The distribution of Pu in respirable dust may be compared with previous determinations by other methods in the same areas (*13*). However, the different denominators used to express concentrations make it inappropriate to draw direct comparisons between Pu in respirable dust and in whole soil. The present maximum allowable level in Colorado, 2 dpm per gram of whole soil, represents an enrichment of 25 times the background level for whole soil (0.08 dpm/g). Corresponding enrichment factors based on respirable dust are given in Table 1: for example, sample 7-1 contains 180 times more Pu in the respirable dust fraction than is contained in our background sample.

The surficial soil materials at different locations contain different percentages of material ≤ 5 μm (Table 1). The Pu concentration per gram represents a potential dose rate. This concentration is to be distinguished from a total inventory of respirable Pu. The greatest long-term hazard, expressed as the largest total inventory, occurs at sites where both the concentration per gram and the percentage of material ≤ 5 μm are high.

Several sampling sites appear to have been disturbed recently by land-development activity. In particular, sites 8-1 through 8-4 lie in a zone where elevated levels of Pu could be expected. These samples have Pu enrichment factors of no more than about eight times background, compared with 15 to 40 times background only 0.6 km closer to the source (samples 8-5 through 8-12). Disturbance of the ground surface may account for this diminished concentration, or the local topography may have produced a fallout "shadow."

Estimates of health hazards from Pu have been made on the basis of air-monitoring data (*14*), measurements of total soil inventories of Pu (*2*, *6*), and measurements of Pu concentration on the surface of the soil (*13*). Air-monitoring data are of importance in estimating human exposure through inhalation, and have been used with soil-contamination data to estimate resuspension factors (*15*). These factors are influenced by the moisture content of soil, wind speed, elevation above ground, type of ground cover, and presence of paved surfaces. Mechanical disturbances such as those produced by plowing, vehicular traffic, construction work, or street sweeping can resuspend surface dust. However, air-monitoring data and resuspension factors do not account for the total Pu hazard in residential areas (*16*). Some examples of other types of potential exposure to Pu in the respirable dust on the surface of the soil are listed below.

1) Children playing on the ground or adults working outdoors can pick up mud and dirt on their shoes and clothing and thus introduce dust into their homes. Washing and drying of contaminated clothes can release significant amounts of dust through the exhaust of the dryer. Such a mechanism of exposure has been demonstrated by the finding of characteristic neoplasms in the wives of asbestos workers (*17*, *18*). Dust can also enter a house through windows and ventilating systems and be resuspended by household vacuuming and other cleaning operations (*19*). Pets track in fine particulates, which may eventually become airborne. These conditions can occur even if a developed area has grass cover.

2) Children playing outdoors may eat food with soiled hands and in other ways ingest or inhale unusual amounts of dust. Heavy-metal intake by this method was found to be important in children with lead poisoning who lived near a smelter at El Paso, Texas (*20*).

3) Heavily used playgrounds tend to be dusty, and strenuous playground activity can result in suspension and inhalation of dust by children.

4) Local resuspension of dust may occur in the preparation and maintenance of domestic gardens. Plutonium that has been plowed under before residential development may again be exposed by digging for gardens.

The present regulatory code in Colorado requires that soils with radiation contamination that surpass the interim standard of 2 dpm per gram of whole soil must receive special treatment to reduce the hazard to acceptable levels (*7*). Mixing the soil by plowing is presently accepted as one technique for treatment of contaminated land. We believe that this is an insufficient treatment because (i) plowing tends to displace the Pu particles from the ground surface to some position at depth, but the Pu is still in the soil; (ii) a treated area can be recontaminated either from untreated land upwind or from subsequent accidental releases of radioactive material; and (iii) subsequent disturbance of the soil by construction activity or cultivation by home gardeners may expose Pu particles at the surface again.

Useful data for evaluating the health hazards of Pu contamination of soil may be obtained by determining the amount of Pu in the respirable-dust fraction (material ≤ 5 μm) on the surface of the soil. It would be more realistic to base interim standards on the respirable-dust fraction because the very small particles in this fraction have the greatest potential for suspension and inhalation.

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17 February 1976; revised 27 April 1976

Exhibit 4 (CDR J Johnson)

C. RADIONUCLIDES AND TRACE METALS IN SURFACE AIR

by Herbert W. Feely, EML
Lawrence E. Toonkel, EML
Richard J. Larsen, EML

Since January 1963, the Environmental Measurements Laboratory (EML), formerly the Health and Safety Laboratory (HASL), has been conducting the Surface Air Sampling Program. This study is a direct outgrowth of a program initiated by the U. S. Naval Research Laboratory (NRL) in 1957 and continued through 1962. The primary objective of this program is to study the spatial and temporal distribution of specific natural and man-made radioisotopes, and of trace metals in the surface air. Other special studies of surface air contamination have been performed during the course of the program.

Sampling Sites and Collection

Many of the original NRL sites, which are grouped roughly along the 80th Meridian (West), have been continued in the current program. Since 1963 a number of other sites have been added to investigate the possible effects of longitude, elevation, proximity to coastlines, over-ocean effects and localized contamination. As specific studies are completed, or as data appear to become redundant, stations are terminated. It is expected, however, that the continuity of sampling will be maintained at most of the sites. The present network extends from about 71°North to 90°South. Table 3a lists the sampling stations

along with their coordinates and elevations, and indicates whether or not each is currently active in the program.

For the routine program, approximately 1400 cubic meters of ambient air per day are drawn through a 20 centimeter diameter Microsorban or glass fiber filter at each land station. At the ocean stations, about 2200 cubic meters of air per day were filtered by 20x20 cm Microsorban filters. Most filters are changed on the 1st, 8th, 15th and 22nd of the month, or more frequently if the filter becomes clogged. At stations where filter loading is minimal because of the low concentrations of particulates in the air, filters are changed only once a month. Such monthly changes were begun in September 1974 at Thule, Kap Tobin and Mauna Loa Observatory. The filters are returned to EML at the end of each month. Currently each filter is cut in half, and one half is included in a monthly composite sample which may be sent to a contractor laboratory for radiochemical analysis. A two-inch diameter circle is cut from the second half of each filter and monthly composite samples prepared from these circles are set aside, eventually to be analyzed for trace metals using x-ray fluorescence. The remainder of the second half is incorporated into a monthly composite sample for gamma counting and spectrometric analysis and subsequent retention for possible future work.

PLUTONIUM - 239 CONCENTRATIONS IN SURFACE AIR DURING 1977

(ATTOCURIES / CUBIC METER)

SITE	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	
MOOSONEE, ONTARIO	1.31	1.31	1.31	23.60	23.60	23.4C	11.30	11.30	11.30	8.82	8.84	8.84	
NEW YORK, NEW YORK	7.13	7.13	7.13	33.00	32.90	33.CC	27.70A	27.80A	27.70A	16.00	16.00	16.CO	21.0
ROCKY FLATS, COLORADO #1	492.00	676.00	279.00	2000.00	1750.00	1750.00	88C.00	886.00	1480.00	1483.00	879.00	549.00	1092
ROCKY FLATS, COLORADO #4	81.80	33.10	65.10	198.00	436.00	435.00	253.00	--	121.00	121.00	184.00	116.00	186
LIVERMORE, CALIFORNIA	--	--	--	--	30.40	37.30	66.10	58.00	32.60	37.30	58.90	14.90	
MIAMI, FLORIDA	7.66	7.67	7.65	31.60	31.60	31.60	14.80	14.90	14.90	39.80	34.00	34.00	
MAUNA LOA, HAWAII	13.30	13.20	34.20	34.20	--	--	--	--	131.00	35.10	29.00	28.90	40.0
LIMA, PERU	2.36	2.37	2.38	1.35	1.35	1.35	2.46	2.47	2.46	2.99	3.00	3.01	
CHACALTAYA, BOLIVIA	1.36A	1.36A	1.36A	2.73A	2.73A	2.73A	6.28	6.29	6.28	2.03	2.03	2.03	
SANTIAGO, CHILE	4.44	4.42	4.42	2.35	2.35	2.35	1.82	1.83	1.82	8	8	8	
PUNTA ARENAS, CHILE	1.49	1.49	1.49	0.42A	0.43A	0.42A	0.45A	0.49A	0.49A	--	--	--	0.8

-- NO DATA

ERRORS ARE LESS THAN 20% EXCEPT:
A -ERROR BETWEEN 20% AND 100%
B -ERROR GREATER THAN 100%

PLUTONIUM - 239 CONCENTRATIONS IN SURFACE AIR DURING 1971

(ATTOCURIES / CUBIC METER)

SITE	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	
NORD, GREENLAND	18.50	22.60	31.10	44.10	34.20	35.30	28.30	16.70	14.50	12.40	17.00A	11.90	
THULE, GREENLAND	34.10	40.70	83.50	93.10	62.30	50.80	67.10	39.70	14.00	--	18.90	20.80	
MOOSONEE, ONTARIO	23.60	14.70	46.20	71.20	100.00	126.00	98.40	53.70	33.80	21.60	--	--	
SALT LAKE CITY, UTAH	31.80	47.40	83.90	203.00	238.00	315.00	154.00	88.90	60.70	37.00	32.90	33.50	110.5
NEW YORK, NEW YORK	26.60	22.30	44.40	59.30	111.00	133.00	135.00	92.60	38.30	25.60	14.20	17.50	59.98
ROCKY FLATS, COLORADO #1	1960.00	--	7140.00	9730.00	4920.00	8730.00	3800.00	2980.00	3540.00	4040.00	5770.00	3160.00	5070
STERLING, VIRGINIA	22.60	30.90	52.00	81.40	118.00	84.20	100.00	57.00	27.70	19.00	18.60	17.70	
MIAMI, FLORIDA	53.60	67.20	106.00	142.00	125.00	76.40	67.70	25.20	17.40	7.94	22.70	--	
BIMINI, BAHAMAS	50.80	81.30	136.00	137.00	168.00	87.50	79.90	33.10	20.30	20.80	59.90	--	
MAUNA LOA, HAWAII	48.00A	52.30	76.40	42.50	122.00	180.00	89.20	44.00	24.50	23.00	22.30	20.70	
SAN JUAN, PUERTO RICO	26.70	32.00	57.90	--	--	--	--	--	--	--	9.52	15.80	
BALBOA, PANAMA	--	--	--	--	22.40	33.30	30.80	13.00	1.82A	0.81A	3.63A	13.00	
MERIDA, VENEZUELA	--	--	--	--	--	--	--	14.80	--	--	--	--	
PICO ESPEJO, VENEZUELA	--	--	--	--	--	--	--	7.04	--	--	--	--	
LA AGUADA, VENEZUELA	--	--	--	--	--	--	--	10.10A	--	--	--	--	
GUAYAQUIL, ECUADOR	29.20	8.10	3.27A	5.66	6.36A	15.30	58.10	5.11	6.67	14.00	18.90	7.75	
LIMA, PERU	35.20	36.50	36.80	--	52.60	68.90	143.00	56.30	29.80	40.80	36.70	48.50	
CHACALTAYA, BOLIVIA	13.50	1.64A	4.25A	8	5.88A	190.00	78.90	25.50	50.70	36.70	--	7.11A	
ANTOFAGASTA, CHILE	37.00	42.60	28.20	22.70	23.20	55.40	213.00	70.40	16.10	32.60	26.70	23.60	
ISLA DE PASCUA-EASTER IS	22.50	--	19.30	8.39	7.13	19.90	45.60	8.03	15.80	13.30	14.10	12.90	
SANTIAGO, CHILE	55.40	--	36.60	50.90	18.20	80.80	55.80	61.50	27.40	32.70	23.60	24.30	
PUERTO MONTT, CHILE	71.50A	24.10	26.70	17.20	19.30	25.30	23.80	12.20	11.60	18.60A	11.00	12.90	
PUNTA ARENAS, CHILE	11.30	12.50	16.80A	--	10.30	11.40	11.30	--	--	--	--	--	
ANTARCTICA	16.20	11.30	8.89	8.91	7.97	3.56	13.00	6.79	4.30	4.48	4.18	8.69	8.2
SOUTH POLE STATION	30.40	39.30	29.30	26.40	22.30	--	16.90	14.90	16.30	15.50	16.10	36.80	

-- NO DATA

ERRORS ARE LESS THAN 20% EXCEPT:
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B -ERROR GREATER THAN 100%

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(10)

NOTES

The Feasibility of Epidemiologic Studies of Cancer in Residents Near the Rocky Flats Plant

(*Received* 12 *January* 1981; *accepted* 21 *April* 1981)

Introduction

THE ROCKY FLATS PLANT is a government-owned, contractor-operated Department of Energy facility. Its primary function in support of the U.S. Nuclear Weapons Program is the construction of weapons components from plutonium, uranium, stainless steel, beryllium and other materials. In the spring of 1969, a serious fire occurred at the plant. Concern that the fire had resulted in the release of significant amounts of plutonium prompted a series of environmental measurements. These data indicated measurable levels of ^{239,240}Pu in the soil immediately east of the plant (Ma70). If there were substantial population exposure to plutonium, the most likely health effects would be bone and lung cancer (Ha79).

Residents of Jefferson County, east of the plant are concerned about potential health effects from releases of radioactive substances from the Rocky Flats Plant. Historically, the area surrounding the plant has been sparsely settled. In 1940, only 31,000 people lived in Jefferson County. Within a decade the population size has nearly doubled, and by 1970, the county had approx. 235,000 residents. This rapid growth has led to increasingly vocal demands for assessment of the potential health risks from exposure to plutonium and other radioactive substances.

An evaluation of cancer incidence could be obtained through an epidemiologic study. However, before such an investigation is initiated, it is important to evaluate the feasibility of obtaining an unambiguous answer of high statistical certainty, i.e. an answer that would precisely define the health risk from radiation exposure. 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.

Population Exposure to Radiation

The Environmental Measurements Laboratory (EML, formerly HASL) of the Department of Energy conducted two series of environmental soil measurements involving sites as much as 40 miles from the plant (Kr70, Kr76A). The results of these studies yielded the isopleth maps (contours of equal ^{239,240}Pu concentration in soil) shown in Fig. 1. Leaking cutting oil drums were determined to be the actual source of contamination which began in about 1967. Krey later utilized mass spectrometric analyses to separate plutonium due to global fallout from that originating from Rocky Flats and reported two further contours at 0.3 and 0.2 mCi km^{-2} (Kr76B). Over the last 10 yr, EML has also maintained four ambient air samplers in the vicinity of the plant at various times. Two of these sites were maintained as late as 1979 and are indicated on Fig. 1.

Inhalation is the only significant pathway for human exposure to plutonium or other actinides. Therefore, airborne plutonium must be estimated from 1967, the estimated time of initial environmental contamination. Prior to the initiation of air sampling, air concentration levels can be estimated from a sediment core taken from Standley Lake. Hardy *et al.* derived two independent methods of dating the sections in this sediment core using the deposition rate of ^{137}Cs from global fallout and ^{238}Pu from the SNAP-9A satellite (Ha78). From their date profile and their measurements of the ^{239,240}Pu in strata from the core, it is possible to estimate the air concentrations from 1967 to 1974 (Table 1).

These data may then be used to estimate the upper limit of the α-dose to the tracheobronchial tree and bone surfaces (Ha79). The estimates assume that persons living in areas with contaminated soil inhale the calculated concentrations of plutonium on a continuous basis. For the purpose of estimating a 50-yr α-dose it is assumed that the air concentrations as measured at site number 4 in 1975 (see Fig. 1) will persist without reduction for 50 yr and that air concentrations may be scaled from sampling site number 4 to other sites according to the ratio of the measured ^{239,240}Pu in soil. Fifty-year α-dose estimates for basal cells in the tracheobronchial tree and bone surface cells are shown in Table 2. These assumptions probably overestimate exposure by an order

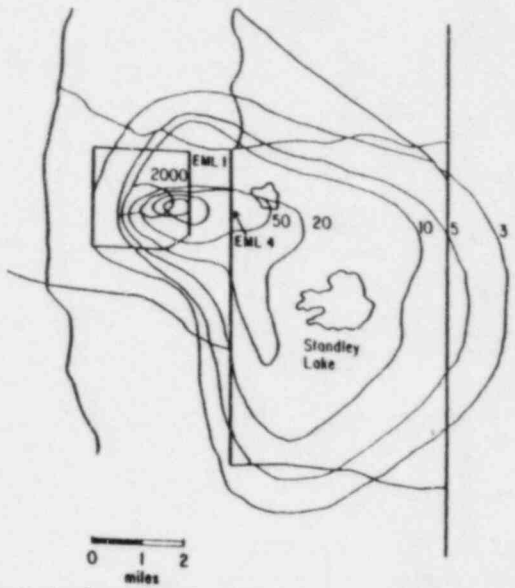

FIG. 1. Plutonium levels range from 3 to 2000 mCi km^{-2} estimated levels due to global fallout 1.7 ± 0.5 mCi km^{-2}. Source: Krey and Hardy, HASL-235, 1970.

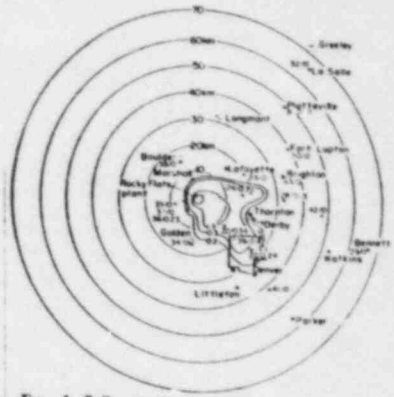

FIG. 1. Soil sampling sites in north central Colorado are designated by X. The first of the adjacent pair of numbers to the site represents the site number. The second (following the slash) represents the Rocky Flats plutonium in mCi/km^2 measured at the site. The heavy irregular lines reflect the isoconcentration contours of Rocky Flats plutonium in the soil expressed as mCi/km^2. The concentric arcs reflect the radial distances from the center of the Rocky Flats plant.

(46)
Source: Krey, in Health Physics 30:209 (1976)

*Table 1. Measured ^{239,240}Pu deposition rate at Standley Lake and calculated ^{239,240}Pu air concentration at EML site 4**

Year	Standley Lake ^{239,240}Pu sediment deposition rate (mCi m^{-2} yr^{-1})*	Air Concentration (fCi m^{-3} at EML site 4 (2000 mCi m^{-2} yr contour)**
1967	0.66 measured	0.27 calculated
1968	4.33 measured	1.80 calculated
1969	5.05 measured	2.10 calculated
1970	3.41 measured	1.42 calculated
1971	2.90 measured	1.21 calculated
1972	1.61 measured	0.67 calculated
1973	1.17 measured	0.49 calculated
1974	1.14 measured	0.47 calculated
1975	0.89 measured	0.37 measured

MEAN 0.70

* E.P. Hardy and others, "Time Pattern of Off-Site Plutonium Contamination from Rocky Flats Plant by Lake Sediment Analysis," USDOE Report EML-342, 1978.

** The air concentrations are calculated by multiplying the value in 1975 by the ratio of the deposition rates.

Exhibit S (Carl J. Johnson)

Table 2. 40-Yr α-dose beginning in 1967 to critical cells in the tracheobronchial tree and on bone surface from continuous inhalation of the ^{239,240}Pu concentrations

Location by contour	Absorbed alpha dose in 50 years: Basal cells in tracheobronchial tree[1]	Cells on bone surfaces[2]
2000 (nCi m^{-2})	0.3 mrad	1.8 mrad
500	0.08	0.5
250	0.04	0.2
75	0.01	0.07
30	0.005	0.03
20	0.003	0.02
10	0.002	0.01
5	0.0008	0.005
3	0.0005	0.003

(1) Absorbed alpha dose to shallow basal cells 22 μm below the surface of the tracheobronchial epithelium at Weibel generation 4 (segmental bronchi). The whole lung (pulmonary parenchyma) alpha dose is approximately 10 times the bronchial dose calculated here. However, whole lung has been shown not to be a critical site for lung cancer induction.

(2) Absorbed alpha dose to osteoprogenitor cells 10 μm from trabecular bone surface.

of magnitude. This exaggeration is offset somewhat by potential α-dose from ^{238}Pu and ^{241}Am which are not included in the calculations but would increase the dose by about 10%.

As evident in Table 2, even at the location of highest plutonium concentration in the soil (2000 nCi m^{-2}), estimates of the 50-yr doses received by the basal cells in the tracheobronchial tree and cells on bone surfaces are only 0.3 and 1.8 mrad, respectively.

In addition to exposure from Rocky Flats, area residents are also exposed to plutonium from global fallout. Krey estimated the mean plutonium levels from fallout in the Denver area to be 1.7 ± 0.5 mCi km^{-2} (Kr76B). Considering the variation in fallout plutonium levels, an equal or greater exposure from the Rocky Flats Plant would be necessary before one could distinguish the cause of any increased disease occurrence in the population. A level of 5 mCi km^{-2} may be a more reasonable limit of the minimum exposure level for study. This would define the area with measurable exposure from Rocky Flats as within 5 miles of the plant boundaries.

Furthermore, Colorado has one of the highest levels of natural background radiation in the United States due to the high altitude and geological composition of its terrain. Over 50 yr, the segmental bronchi of the lung receive an α-dose of about 7 rad (140 rem) from inhaled naturally-occurring radon daughters. The 50-yr background dose to cells on bone surfaces would be about 3 rem (Na75). The corresponding absorbed α-dose from the Rocky Flats Plant (0.006 rem and 0.036 rem, respectively) is very low in comparison to that of natural background over a 50-yr period.

Feasibility Evaluation

The number of excess lung and bone cancers can be estimated using BEIR models for cancer mortality from high LET radiations (Be80) and cancer incidence data from the National Cancer Institute's Surveillance, Epidemiology and End Results Reporting Program (Am80). Using the generous assumption that half of the 248,000 residents in Jefferson County and its neighbor to the east, Adams County, received the maximum organ doses of plutonium described previously and were followed from ages 10–75 yr, 4400 lung cancers and 70 bone cancers would be expected to occur spontaneously in the exposed. According to BEIR absolute risk projection models, a dose of 0.3 mrad to the lung over 50 yr would result in less than one additional case of lung cancer; similarly a dose of 1.8 mrad to the bone surface would result in less than one additonal bone cancer case. The expected excess number of cancers using BEIR relative risk models would be no different. The statistical power for detecting 1 extra cancer against a background of either 4400 or 70 would be

no greater than 6% (Ro79). Generally, an epidemiologic study would not be indicated unless the statistical power was at least 75%.

In conclusion, epidemiologic studies of cancer in residents near Rocky Flats are not warranted due to the extremely low population exposure levels. The increment in population radiation exposure from Rocky Flats is far below that from natural background and from global fallout in that area. Even if the BEIR risk estimates were too low by an order of magnitude, the statistical power of an epidemiologic study of lung or bone cancer would be insufficient.

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Long-term Clearance of Inhaled Magnetite and Polystyrene Latex from the Lung: A Comparison

(*Received* 23 *February* 1981; *accepted* 21 *April* 1981)

Introduction

THE POTENTIAL toxicologic hazard from particles depositing within the alveolar region of the lung is dependent to some extent upon the pathways and rates of clearance from this area. Specific characteristics of the particles themselves may be determinants of the mechanisms and efficacy with which they are cleared. For example, highly soluble particles may be rapidly removed, while relatively insoluble ones may be retained in the lung for long periods of time. Unfortunately, the relationship between clearance and most particle characteristics, e.g., size, shape, density, chemical composition, is not clear.

Recently, Halpern *et al.* (Ha81) described a pilot study of the long-term clearance of neutron-activated magnetite (Fe_2O_3·FeO) from the lungs of donkeys as measured both with a new magnetic detection and with an established radiologic detection technique. As another aspect of that study, the donkeys were simultaneously exposed to an aerosol consisting of ^{85}Sr tagged polystyrene

Exhibit L (Carl J. Johnson)

M.S. #82/384
17 August, 1982

COMMENTARY

Investigations of Health Effects in Populations Living Near Nuclear Installations

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

Recent American Journal of Public Health reports address health risks from "low-dose ionizing radiation", and refer to the controversy about the relationship between population exposures to radiation and subsequent health effects. (1,2) Similar reports were prepared for the Nuclear Regulatory Commission (NRC) and the Government Accounting Office. (3-5) Nine "candidate populations" for investigations of radiation effects are listed (1) but the authors judge that "no single population can be recommended for study on purely scientific grounds since the largest group offers only a small chance to obtain a definitive result", but "if social pressures and regulatory agencies mandate that such studies be attempted we would recommend prospective cohort studies of occupational populations". Such recommendations may have the effect of doctrine when supported by several federal agencies, and the field of radiation protection is too young to be burdened with doctrine. Epidemiological investigations must continue to be initiated in populations around nuclear plants, even if on an empirical basis.

One such "candidate population" lives in the Denver area and actually comprises the Denver Standard Metropolitan Statistical Area. (6) Most of the people in this area live downwind of the Rocky Flats nuclear weapons plant (RFP), which reprocesses plutonium and uranium and manufactures weapons components. This "candidate population" is inaccurately depicted and the exposures sustained are underestimated by at least five orders of magnitude by Dreyer, et al, who calculate an alpha radiation dose of 0.3 millirem (mrem) over 50 years to the trachiobronchial tree on which to base their feasibility estimates. (1) They later explain the chain of assumptions behind this calculated population dose in some detail (7), basing their estimates of population exposures downwind of RFP on an average air concentration of 0.37 femtocuries per cubic meter (fCi/m^3) of plutonium 239 measured in 1975 at the Department of Energy (DOE) Environmental Measurements Laboratory (EML) sampling site #4, east of RFP. (8) The authors overlook a number of important references which add information essential to such estimates. (9-29) The Energy Research and Development Administration (now DOE) Environmental Impact Statement (EIS) states (2-175) "as of 1975 the total site releases from RFP have been reduced nearly 1,000 times from 1965 levels". (9) Thus, the concentration of plutonium 239 in air at site #4

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was about 1000 times higher in 1965 and would be a more realistic data base for estimating exposures to people in the Denver area than would the air concentration of plutonium in 1975 selected by Dreyer, et al.

An internal official report indicates that alpha radiation releases from the main exhaust stack alone may have been five times greater than indicated in the EIS report, suggesting that air concentrations may actually have been 5000, not 1000 times greater. (6) EML site #4, selected by Dreyer, et al for their data base, is more distant from the usual direction of the exhaust plume from the plant than site #1, which was monitored for a longer period (1970-77) by EML and consistently had much higher concentrations of plutonium in air, over six times higher than the average concentration at site #4 selected by Dreyer, et al. Further, the air sampling filters are less efficient than any of the four to five individual industrial filters through which plutonium has already passed, and because of dust loading and other problems may actually understate plutonium concentrations in the air by an order of magnitude. (6) The exhaust plumes routinely emitted from the Rocky Flats plant in 1965 passing through the Denver area (the most common direction for such plumes) may have contained concentrations of plutonium 300,000 times greater than the air concentrations selected by Dreyer, et al as a base for their extrapolations of population radiation doses downwind. One investigation (1977) reported concentrations of 50,000 fCi of plutonium per gram in air-borne soil. (10) With a conservative assumption for this dusty, windy area of 1 gram of soil/m^3, this is about 135,000 times greater than the concentration used by Dreyer, et al for their population dose estimate. (1,7) A three hour exposure to this concentration of plutonium 239 in air would equal the 50 year exposure estimated by Dreyer, et al.

The accidental releases of plutonium are more important than the routine releases. (6,11) Dreyer, et al refer to "plutonium-contaminated cutting oil that leaked from a storage area within the plant" after 1968. (1) In a subsequent report, Dreyer, et al state "Leaking cutting oil drums were determined to be the actual source of contamination, which began in about 1967". (7) Actually, this source of contamination began in 1959 and was a problem until 1968. (12) Much more serious was a fire and explosion in 1957 which blew out all 620 industrial high-efficiency particulate air (hepa) filters in the main exhaust system at RFP. (13-16) The filters had not been changed in the four years of the plant's operation. The rate of accumulation of plutonium on the filters was described in several RFP reports and a single filter could accumulate more plutonium than the EIS acknowledges RFP releasing throughout a 24 year period of the plant's operation. (15,16) Most of the plutonium on the filters was water-soluble plutonium nitrate (17), which would not be represented by a core sample of sludge on the bottom of a nearby lake, upon which Dreyer, et al depend for air concentration estimates. (7) The plutonium monitors in the main stack were reported to be not operating during the fire or for one

week after, but for the eighth day following, recorded an average of 948,000 fCi/m^3 (the usual daily volume from the main stack is about 13,000,000 m^3). (15)

A clandestine survey by RFP personnel after the explosion and fire found over 5400 fCi of "possible enriched uranium" per gram of surface soil in the schoolyard at the Ralston Elementary School, 12 miles southwest of the plant, about 7300 fCi per gram of surface soil in the schoolyard at the Semper Elementary School, 6 miles east, and about 8200 fCi per gram of surface soil of "possible plutonium" on private land (plutonium concentrations were not reported for the schools). (18) This 1957 survey was unknown outside the D.O.E., N.R.C. and the Office of Radiation Programs of the Environmental Protection Agency until a report was published last August by the Royal Swedish Academy of Sciences (6), and is not cited in the reports by Dreyer, et al. An additional 12-20 kg of plutonium in glove boxes were burned in the fire. An RFP report notes that burning plutonium forms sub-micron sized particulates in air, that these particulates do not settle out readily from industrial exhaust plumes, and do not account for the pattern of soil contamination around the plant. (19) The same comment would apply to the accumulation of filtered uranium, plutonium and americium on the exhaust filter system which blew out in the explosion, and to the routine releases of plutonium, uranium, americium and other radionuclides in the plant exhaust. These actinides and other alpha radiation emitters are subject to the alpha recoil phenomenon, described in 1977. (20) The highly energetic projection of alpha particles from alpha emitters produces an energetic recoil which drives off single atoms and groups of atoms from the surface, with the effect that small particles of plutonium, uranium and other alpha emitters are continously sub-dividing and self-scattering, can migrate through banks of hepa filters and do not settle out to any great extent from industrial plumes, but can provide a risk of inhalation to persons in the path of those plumes.

Dreyer, et al take inhalation as the only significant pathway for human exposure to plutonium and state "therefore, air-borne plutonium must be estimated from 1967, the estimated time of the initial environmental contamination" (7), in contrast to their earlier reference (1) to complications by "other sources of radiation including radium and uranium in drinking water, radium waste deposits in Denver, global fallout, high levels of natural background radiation and tailings from radium mills and uranium mines". These possible sources of radiation have been shown to be not significant, except for two census tracts with about 7,000 people who have had drinking water contaminated with high levels of uranium from a uranium mine for nearly 20 years. (6,21)

Dreyer, et al report "considering the variation in fallout plutonium levels, an equal or greater exposure from RFP would be necessary before one could distinguish the cause of any increased disease occurrence in the population". (7) The EML report on concentration of plutonium in air utilized by Dreyer, et al also gives data for New York

City (NYC). The NYC data probably approximate levels for plutonium in 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. (8) The average concentration for the 8 year period reported by EML for NYC (1970-1977) was 0.03 fCi/m^3. The air concentration of plutonium relied on by Dreyer, et al for their dose estimate is over 12 times higher than from world-wide fallout and would appear to satisfy their criterion for exposure. The average concentration for plutonium 239 at EML site #1 near the usual direction of RFP exhaust plumes was 2.37 fCi/m^3 for the years reported (1971-1976), about 80 times the fallout level.

Another key link in the chain of assumptions required to develop risk estimates is the radiotoxicity of plutonium, which has aroused controversy. Two leading experts in the field independently suggested that permissible exposures to plutonium be reduced by over 200 times. (22,23) Their viewpoint is supported by the results of a chromosome study conducted of nuclear plant workers. (24) If permissible limits were to be so reduced, 156 fCi would be the maximum permissible body burden for the public and the maximum permissible lung burden would be only 70 fCi, (allowing a protective factor of 100 in relation to permissible limits for workers).

The clinical data at the bottom of the chain of assumptions on which dose estimates are made must be carefully reassessed from time to time. Animal studies are important. A study of radiotoxicity in which dogs were allowed to inhale one microcurie (1 uCi) of plutonium 239 produced the following doses: 863 rem to lung, 43,700 rem to pulmonary lymph nodes, 3250 rem to bone, 1320 rem to liver, 170 rem to kidney and 46 rem to gonads. (25) Similar doses were produced by the inhalation of one uCi of americium 241, plutonium 238 and 240. Assuming that a person absorbed the sub-micron plutonium in air inhaled at the concentration on which Dreyer, et al base their estimate (0.37 fCi/m^3), and assuming an annual ventilation volume of 7,000 cubic meters for 50 years, a person would inhale 130×10^3 fCi or 130 picocuries of plutonium. Applying the organ doses from dog to man (being conservative) from 1 uCi of plutonium 239 x $130/10^6$, a person would receive about 112 mrem to lung, 5.7 rem to pulmonary lymph nodes, 422 mrem to bone, 172 mrem to liver and 22mrem to kidney. However, the 0.37 fCi/m^3 data base grossly understates actual exposures.

Though Dreyer, et al focus on exposure to plutonium 239 in air as a basis for their dose estimates, in fact uranium 234 alone accounts for a greater proportion of alpha radiation released in the plant's exhaust. (9) Americium 241 and plutonium 238 from the plant may be more important than plutonium 239. Plutonium 241 accounts for more than 8 times more radioactivity in the main exhaust plume than does plutonium 239. In addition, a number of other radionuclides other than actinides are released routinely and

accidentally. Higher relative activity may make certain radionuclides of greater importance in air exposures than their concentration relative to plutonium in stack exhaust might indicate. Thus, plutonium 238 released from the main stack in a ratio of 2/100 to plutonium 239, 240 has been reported to account for 20 to 40% of plutonium in air-borne soil. (21)

A conventional approach to studies of health effects around a point source like a smelter or nuclear plant is the selection of study populations within concentric circles at arbitrary distance intervals from the plant site. A better approach selects one of the toxic substances released by the plant and utilizes isopleths drawn on the basis of the measured soil concentration of that contaminant in order to select aggregates of census tracts for study. (6) However, the concentration of the single contaminant measured in soil cannot somehow be taken as a measure of actual inhalation exposures of persons who at times are within the plant's exhaust plumes, and breathing contents of the exhaust plumes. The Atomic Energy Commission measured soil inventories of plutonium to a depth of 10 centimeters and published an isopleth figure indicating contamination of the Denver area with plutonium extending across the city of Denver beyond its southeastern limits. (26) Such core samples which include fine gravel do not get at levels of contamination of plutonium in surface dust or windblown material on the surface of soil, as described by reports in Science. (27,28) Studies of surface dust on private land found concentrations of plutonium to be as much as 3,390 times higher than background levels in an area where A.E.C. soil samples indicated plutonium 239 concentrations only about 30 times higher than fallout levels. (6)

Estimated exposures of Denver area residents to plutonium 239 from the plant were compared by Dreyer, et al to alpha doses to segmental bronchi of the lung alleged to be about 140 rem over 50 years from inhaled naturally-occurring radon daughters, and a dose to cells on bone surfaces of about 3 rem. (7) However, EPA estimates those doses to be only 300 mrem to the whole body for 50 years (6 mrem/year) and to endosteal cells, 1.2 rem for 50 years (24 mrem/year) for the average person in the U.S. (29) The ambient levels of uranium 238 and its progeny in air are really not much higher in Colorado than elsewhere, according to the EPA. For the year of July 1974-June 1975, the average concentration of uranium in air-borne particulates in the Denver area was 0.08 fCi/m^3. (29) The national EPA network summary for uranium was 0.05 fCi/m^3. (29) Some of the uranium may have come from world-wide nuclear weapons fallout and some from nuclear installations such as RFP (as described by the RFP EIS). This view is supported by the measureable levels of fissionable uranium 235 in air-borne particulates, which in Denver accounted for 0.005 fCi/m^3. (29) These levels of "naturally-occurring radionuclides" in air are not important in comparison with the much more radiotoxic plutonium and americium, but are part of the rationale for a local control population.

Discussion of feasibility and statistical power of proposed investigations of health effects in populations around nuclear plants and other point sources rest on a chain of assumptions, and the assumptions which provide the foundation for dose estimates are absolutely critical in any evaluation of the feasibility of such studies. The weight of evidence indicates exposures of the Denver area population to radionuclides from RFP are more than five orders of magnitude greater than those assumed by Dreyer, et al. I urge that an attitude of rigorous and critical scientific inquiry be applied to each link of the chain of assumptions upon which risk estimates of radiation exposure are developed, and upon which nuclear agencies place reliance in the promulgation of their doctrine concerning radiation hazards.

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CARCINOGENIC EFFECTS OF RADON DAUGHTERS, URANIUM ORE DUST AND CIGARETTE SMOKE IN BEAGLE DOGS

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Abstract—The development of pulmonary lesions in beagle dogs was studied following chronic inhalation exposures to radon (at 105 ± 20 nCi/l), radon daughters (at 605 ± 169 WL), uranium ore dust (at 12.9 ± 6.7 mg/m³) and cigarette smoke. Chronic exposures to mixtures of these agents caused significant lifespan shortening when compared with controls. Survival times of controls and smoke-exposed dogs were equivalent during the 4 to 5-yr mean survival time of the dogs exposed to radon-daughter and ore-dust mixtures (with or without added cigarette smoke).

Animals with tumors of the respiratory tract generally had cumulative radon-daughter exposures exceeding 13,000 WLM, and their survival time was longer than the survival time of nontumor-bearing animals. Under the conditions of the experiment, exposure to cigarette smoke was found to have a mitigating effect on radon daughter-induced tumors. It is uncertain whether this would be a general finding applicable to other levels of exposure to radon daughters, uranium ore dust and cigarette smoke.

Exposures to smoke from 10 cigarettes/d, 7 d/wk produced no significant respiratory tract lesions. However, exposure to 20 cigarettes/d, 7 d/wk resulted in pulmonary emphysema, fibrosis and chronic bronchitis and bronchiolitis.

Emphysema and fibrosis were much more prevalent and severe in the dogs exposed to mixtures which included radon daughters and uranium ore dust. These dogs also had adenomatous lesions which progressed to squamous metaplasia of alveolar epithelium, epidermoid carcinoma and bronchioloalveolar carcinoma. Pathologic changes in the airways of these dogs were most prominent in the nasal mucosa, and included a few squamous carcinomas in the nasal cavity.

We conclude that the beagle dog is a useful animal for modeling pulmonary lesions produced by uranium mine air contaminants. Tumors were produced at levels that did not greatly exceed some exposures reported for uranium miners. These tumors, found after approx. 50 mo of exposure, might partially account for the absence of tumors in experiments where exposures terminated before 50 mo.

INTRODUCTION

Animal studies have now been conducted for several decades in order to identify the nature and levels of uranium mine air contaminants that are responsible for producing the lung cancers observed among uranium miners. A more recent review of these and related experimental studies through 1970 appeared in the final report of subgroup I.B., Interagency Uranium Mining Radiation Review Group (IUMRRG71). The interagency report concluded, as did an earlier Federal Radiation Council report (FRC67), that experimental work prior to the 1970s had not shown that it was possible to produce pulmonary carcinomas in animals in a systematic way from controlled exposures to radon and ing controls (Group 4), were in apparently normal health following the deaths of Groups 1 and 2 animals. The follow-up on the Groups 3 and 4 dogs, including subsequent pulmonary function tests, will be published separately.

We have no explanation for the very high cumulative exposures that were necessary to induce tumors in the dogs. The exposures were nearly two orders of magnitude greater than those reported to cause lung cancer in man (Ar73b). A possible explanation is associated with exposure rate: Although 120–359 WLM may be sufficient to cause lung cancer in man (Ar73b), the longer human life span affords more time for carcinogenesis to proceed. Higher exposure rates may be necessary in experimental animals in order to increase the probability of lung cancer over their shorter life span. As a result, much of the radiation may be "wasted", i.e. not utilized in the formation of subsequent tumors. Nevertheless, this radiation is included in the animals' cumulative exposure. The importance of lifespan to carcinogenesis is supported by the data in Table 8 which indicate that the mean survival time for animals with tumors is greater than the mean survival time of non-tumor-bearing animals. This is to be expected, since tumors are scored when they reach a size sufficient for detection and animals that live longer are more apt to have tumors large enough to detect. Not considered in the explanation above, however, is the suspicion that other factors have not been adequately taken into account in the comparison of animals with man. Respiratory tract tumors among uranium miners are bronchogenic (specifically, in the larger bronchi), but in animal experiments they are bronchioloalveolar in origin and also occur in the nasal epithelium. There is some evidence that the individual radiation dose to the respective tissues may be lower in animals than in man, thereby necessitating a higher exposure (ignoring any differences in tissue sensitivities) to produce tumors in animals (De78). In addition, the dogs were simultaneously exposed to high concentrations of uranium ore dust (approx. 5–10 times the levels commonly encountered by miners (Co73)). This additional burden to stressed lungs resulted in a lower efficiency for tumor production by producing fibrosis and death from pulmonary insufficiency. (Animals that survived were sacrificed when they evidenced severe respiratory distress.) This idea receives support from three recent publications (Has79, Has80, Cr80). In the third work (Cr80), rats were exposed to varying concentrations of uranium ore dust and fixed cumulative levels of radon daughter exposure, or to varying rates of radon daughter exposure and fixed uranium ore dust concentrations and cumulative radon daughter exposures. The preliminary histopathologic data from these experiments suggest a trend toward increased lung tumor risk as radon daughter exposure rate and uranium ore dust concentration decreased. Finally, the actual exposure of uranium miners may have been underestimated. For these reasons a meaningful comparison of human and animal exposures required to produce tumors is not possible at this time.

A follow-up study is now in progress. Dogs are being exposed (4 h/day, 5 d/wk) to carnotite ore dust (at ~15 mg/m³) to determine the carcinogenic potential of uranium ore dust alone, and to clarify the role of ore dust in the production of the massive pulmonary fibrosis observed in the dogs of Groups 1 and 2. (These lesions were not observed in the studies by Morkin (Mo73), who did not utilize uranium ore dust as an associated carrier aerosol for the radon daughters).

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Exhibit 7 (Carl J. Johnson)

Suggested Reduction of Permissible Exposure to Plutonium and Other Transuranium Elements

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The historical development of the value of maximum permissible body burden of ^{239}Pu is presented and present considerations for the revision of this standard are given. Some evidence is presented that the linear hypothesis may not be sufficiently conservative at low dose rates and especially for the actinide elements. Until certain questions are answered about the particle problem, it will not be possible to set a satisfactory maximum permissible body burden for ^{239}Pu based on lung as the critical organ, but in the meantime some studies suggest that the present maximum permissible body burden based on bone should be reduced at least by a factor of 200.

roduction

PERHAPS THERE HAS NEVER BE- fore been an enterprise that was planned carefully for its safety and never be- a risk that has been so thoroughly alied and guarded against as has been the ce with the nuclear energy industry and concern to avoid unnecessary exposure to izing radiation. It is ironical that in part ecause of this concern and in spite of the ct that we now probably know far more out the effects of this radiation on man an about any of the other common haz- ds, exposure to the radiations associated ith nuclear energy seem to frighten and en- ender fear that is all out of proportion in omparison with the everyday risks from ch things as medical x-ray, food additives, nd environmental pollutants from the burn- g of fossil fuels. However, on second ought this public concern for radiation xposure probably should not be surprising ecause, except for unusual precautionary easures and constant vigilance, there likely ere day will be a major accident with very erious consequences. Even though most of he public may be convinced of a very low robability of such a serious accident, we re reminded frequently in our newspapers f what could happen from accidental re- ase into the public domain of large quanti- ties of radioactive material from nuclear power plants, from spent fuel operations, or from shipping accidents.

A considerable portion of the credit for the remarkable safety record of the nuclear energy industry as one of the safest of all modern industries must be given to the untiring efforts of members of the health physics profession with whom I have been associated for over 30 years, and which profession I have seen grow from a group of 5 health physicists at the University of Chicago in 1943 to a worldwide organization today of over 10,000 professionals. Our lot as a growing profession of health physicists has been a most interesting and challenging one but it has not always been easy, because there were times when some of my associates were demoted or lost their jobs because they refused to yield to pressures to lower our standards or compromise for unsafe conditions.

We were constantly resisting pressures of engineers and production supervisors to relax what they called our ridiculous conservatism. Sometimes we were forced to set exposure limits that were lower than our management wanted and perforce they were often little better than guesses because in some areas we had almost no experience or supporting experimental data. For example, one of the earliest papers[1] showing how to

adionuclides and giving values of permissi- le body burden and permissible concentra- ion of some 20 radionuclides was delayed r almost a year when I presented it for ublication in 1945 because some of the ermissible occupational exposure values calculated were much lower than those in e in weapons production operations. I ad at that time almost no metabolic data r some of these radionuclides. For the st part I had to rely on a series of publica- n by J. G. Hamilton et al.[2] on the metab- sm of fission products, plutonium, and er actinide elements in mice and rats l in a few cases data on only 3 or 4 s were available. The maximum permissi- internal dose rates for occupational ex- ure that I used in making these early ulations were 36 R/y for β and γ radia- and 3.6 rep/y (~ 3 rad/y) for α radia- On this basis and using available meta- data the value I obtained for ^{239}Pu for ... maximum allowable lung burden of the occupational worker was 0.035 μCi and for bone burden was 0.42 μCi. The standard man data I used were based on typical human values collected and summarized for me by M. J. Cook.[3]

The first semiofficial values for body burden of the radionuclides were developed at the Chalk River Canada Conference[4] in 1949. These values were later reviewed at the Harwell, England Conference in 1950. From about 1950 to 1973, I was chairman of the Internal Dose Committees of both the International Commission on Radiological Protection (ICRP) and of the National Council on Radiation Protection (NCRP) and so must assume some of the blame for shortcomings of our Handbooks on Internal Dose. During this period there were four principal publications of our Internal Dose Handbooks giving values of organ burden (q_f) and body burden (q) and maximum permissible concentrations in air (MPC_a)

TABLE I

Maximum Permissible Body Burdens for ^{239}Pu

Source of Value	Occupational		For Population at Large	
	qf_1 (μCi)	q_1 (μCi)	qf_1 (μCi)	q_1 (μCi)
Early Oak Ridge Nat. Lab. (KZM-1947)[5]	0.42 [b]	0.50 [b]	—	—
	0.035 [l]	0.12 [l]	—	—
Chalk River Conference 1949[4]	—	0.0068	—	0.00006 [b]
	—	—	—	—
Early Los Alamos Nat. Lab. (WHL-1948)[3]	—	0.063 [*b]	—	—
	—	—	—	—
ICRP—Handbook 52 (1953)[7]	0.03 [b]	0.04 [b]	(0.003) [b]	(0.0043 [*b]
	0.003 [l]	0.003 [l]	(0.0003) [*l]	(0.0003) [*l]
ICRP—Br. J. Radiol. Supp. 6 (1954)[8]	0.03 [b]	0.04 [b]	—	—
	0.02 [l]	0.02 [l]	—	—
ICRP—Handbook 69 (1959)[9]	—	0.04 [b]	—	(0.004) [*b]
	—	—	—	—
NCRP—Handbook 7 (1959)[10]	0.03 [b]	0.04 [b]	—	—
	—	—	—	—

[b]—value based on dose to bone. [l]—value based on dose to lung. [*]—values in parentheses are based on suggested safety factor of 10. q—μc in total body based on indicated organ. qf_1—μc in indicated organ (bone or lung). [**]—W. H. Langham gave 0.032 μCi as a proposed LNL value in 1950.

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A PLEA FOR CONSISTENT LUNG BURDEN CRITERIA FOR INSOLUBLE ALPHA EMITTING ISOTOPES*

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(*Presented by* DAVID S. MYERS)

Abstract—There appear to be certain inconsistencies in establishing appropriate lung burdens for certain insoluble alpha-emitting isotopes. These inconsistencies will be discussed and a plea will be made for guidance in establishing consistent lung burden criteria.

The maximum permissible dose to the lungs as defined by existing radiation standards is 15 rem/year. The figure of 16 nCi is quoted widely in the literature as being the lung burden for insoluble ^{239}Pu. However, the new lung model specifies that 15% of the insoluble ^{239}Pu, which is cleared from the pulmonary region of the lung with a 500-day half-life, is deposited in the pulmonary lymph nodes. The new lung model further specifies that 90% of the insoluble plutonium deposited in the pulmonary lymph nodes remains there permanently.

If one considers the pulmonary lymph nodes as the critical organ, with a maximum permissible dose rate of 15 rem/yr, the amount of insoluble ^{239}Pu deposited in the pulmonary region of the lungs during a single inhalation event which lead to a maximum permissible respiratory lymph node burden is 1.1 nCi. For chronic inhalation situations, the permissible accumulated lung burden after 50 yr which will produce a maximum permissible respiratory lymph node burden is 0.07 nCi. Thus, unless it is decided that the lymph nodes should not be considered as the critical organ for exposure to insoluble ^{239}Pu, because of their apparent relative insensitivity to radiation dose, perhaps the maximum permissible amount of insoluble ^{239}Pu deposited in the lungs should be significantly reduced.

INTRODUCTION

THE MAXIMUM permissible annual dose to an individual's lungs as defined by existing radiation standards is 15 rem/yr.[1] In the case of lung doses resulting from alpha-emitting isotopes, the assumption is made that the alpha energy is deposited uniformly in the lung tissue and that the mass of the lungs is 1000 g.[2] The amount of alpha activity in the lungs which will produce a dose rate of 15 rem/yr is on the order of 10–20 nCi depending upon the effective energy of the alpha-emitting isotope.

For the purposes of this discussion and associated calculations, insoluble ^{239}Pu with a maximum permissible lung burden of 16 nCi will be used as representative of long-lived alpha-emitting isotopes. The MPC_a for insoluble ^{239}Pu for radiation workers is 4×10^{-11} μCi/cc.[1] This value is based on the "Original Lung Model"[12] which assumes that 12.5% of the inspired ^{239}Pu is retained in the lower respiratory tract and is cleared from that region with an effective half-life of 120 days.

In 1966 a revised lung model was promulgated by the ICRP's "Task Group on Lung Dynamics".[13] In addition to more clearly defining the deposition compartments in the respiratory system, the revised lung model considered (1) the effect of particle size on deposition, (2) the chemical form of the inhaled material, and (3) the specific clearance pathways from the various deposition compartments. It is of special interest in the case of insoluble isotopes that the revised lung model stipulates that 15% of the activity deposited in the pulmonary region is eliminated to the pulmonary lymph nodes and that 90% of this activity is retained in these lymph nodes permanently. Based on this revised lung model, the dose received by the pulmonary lymph nodes is considerably greater than the dose received by the pulmonary region of the lungs for either acute or chronic inhalation of insoluble ^{239}Pu.

ACCUMULATED ACTIVITY AND INTEGRATED DOSE COMPARISONS

The two types of inhalation exposures considered are acute and chronic. For each of these two exposure categories the following information is computed:

(1) Amount of activity remaining in the lungs after 50 yr,
(2) Integrated dose to the lungs at 50 yr,
(3) Amount of activity in the pulmonary lymph nodes after 50 yr, and
(4) Integrated dose to the pulmonary lymph nodes after 50 yr.

Acute inhalation

For purposes of this discussion, the acute exposure will be defined as an inhalation incident which deposits 26.7 nCi of insoluble ^{239}Pu oxide in the pulmonary region of the lungs. According to the revised lung model, 60% (or 16 nCi) of this deposited activity will be retained with a 500-day half-life; the remaining 10.7 nCi being cleared to the G.I. tract with a 24-hr half-life.[13]

Chronic inhalation

In this discussion the chronic exposure will be defined as an inhalation of 1 MPC_a of insoluble ^{239}Pu for the entire working lifetime (50 yr) of an individual.

The parameters for each of the exposure categories and the corresponding computations are shown in the Appendix and the results are shown in Table 1.

MAXIMUM PERMISSIBLE LUNG BURDEN

If the pulmonary lymph nodes are considered as the critical organ with a maximum permissible dose rate of 15 rem/yr, then the "maximum permissible lung burden" which would deposit sufficient activity into the pulmonary lymph nodes to deliver 15 rem/yr would depend on whether the inhalations were of an acute or chronic nature.

"Maximum permissible lung burden" for acute inhalation

As derived in the Appendix, the dose rate to the pulmonary lymph nodes is $6.59 \times 10^3 Q_L$ (nCi) rem/yr for insoluble ^{239}Pu. Thus, for a maximum permissible lymph node burden

$$Q_L = \frac{1.5 \times 10^3 \text{ rem/yr}}{6.59 \times 10^3 \text{ rem/yr/nCi}}.$$

$$Q_L = 0.23 \text{ nCi}.$$

Substituting the value of 0.23 nCi for Q_L in equation #5 (Appendix), setting $t = 50$ yr, the value of Q_{po} obtained is 1.70 nCi. Since 60% of the deposited activity is retained with a half-life of 500 days, then (60%) (1.7 nCi) or 1.02 nCi is the "maximum permissible lung burden" which will produce a maximum permissible pulmonary lymph node burden of 0.23 nCi for the acute inhalation exposure. This is less than $\frac{1}{15}$ of the currently accepted maximum permissible lung burden of 16 nCi.

"Maximum permissible lung burden" for chronic inhalation

The annual intake of insoluble ^{239}Pu required to produce a maximum permissible lymph node burden after 50 yr can be determined from equation #16 (Appendix). If $Q_L = 0.23$ nCi and $t = 50$ yr, then solving for I yields 0.034 nCi/yr. Then from equation #8, the lung burden after 50 yr of inhalation of 0.034 nCi/yr yields a value for Q_P of 0.067 nCi. Thus, the "maximum permissible lung burden" for chronic inhalation of ^{239}Pu which would produce a "maximum permissible pulmonary lymph node burden" of 0.23 nCi is 0.067 nCi. This value is less than 0.5% of the currently accepted maximum permissible lung burden.

MPC_a FOR CHRONIC INHALATION EXPOSURE

If we assume as shown in the previous section that the "maximum permissible lung burden"

Table 1. Activity accumulations and dose comparisons

Inhalation mode	Amount in lungs at 50 yr (nCi)	Accumulated dose to lungs at 50 yr (rem)	Amount in pulmonary lymph nodes at 50 yr (nCi)	Accumulated dose to pulmonary lymph nodes at 50 yr (rem)
Acute*	0	2.9×10^3	3.6	1.3×10^4
Chronic*	16	6.6×10^3	5.1×10^3	8.3×10^4

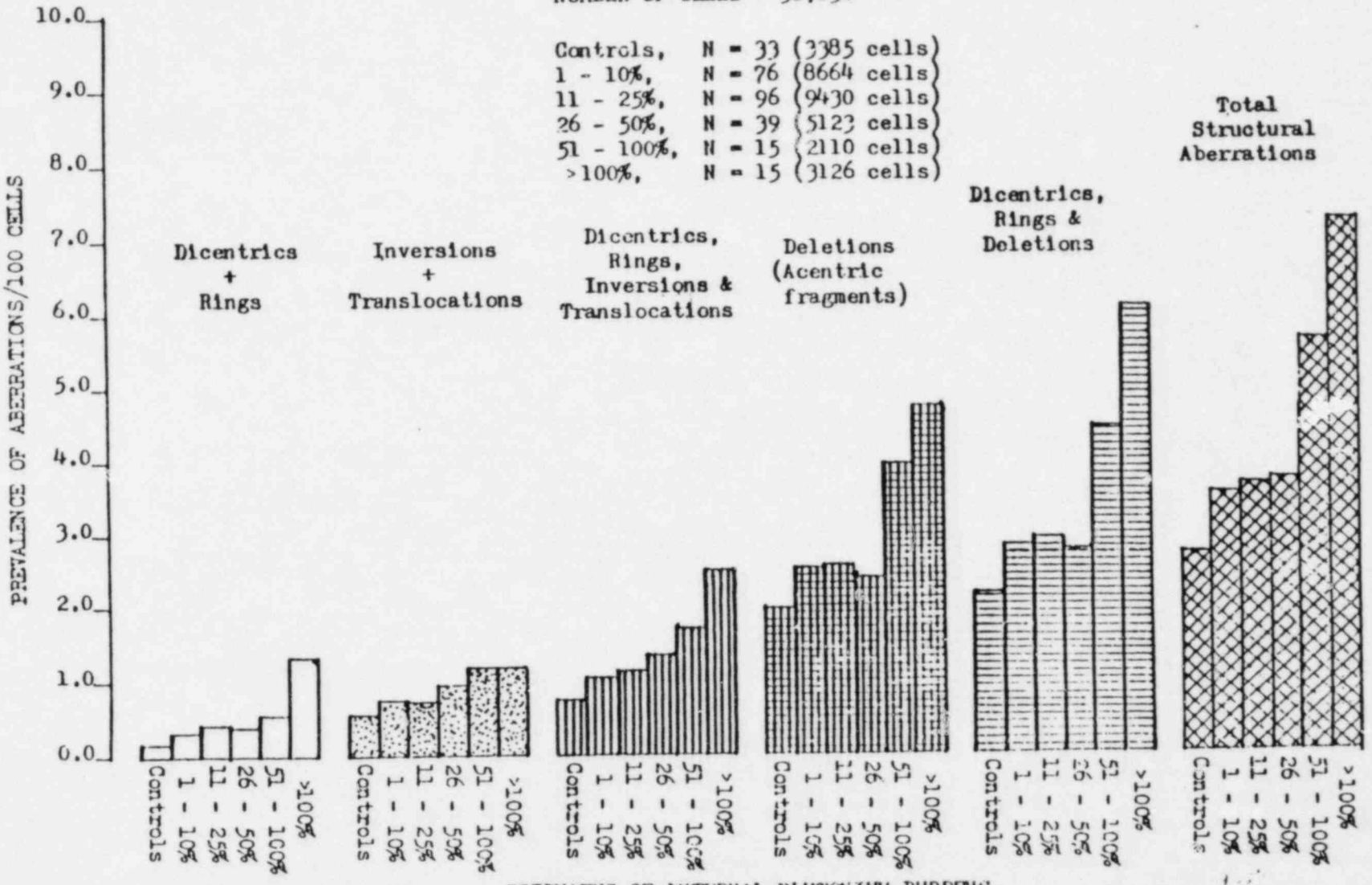
* [illegible]

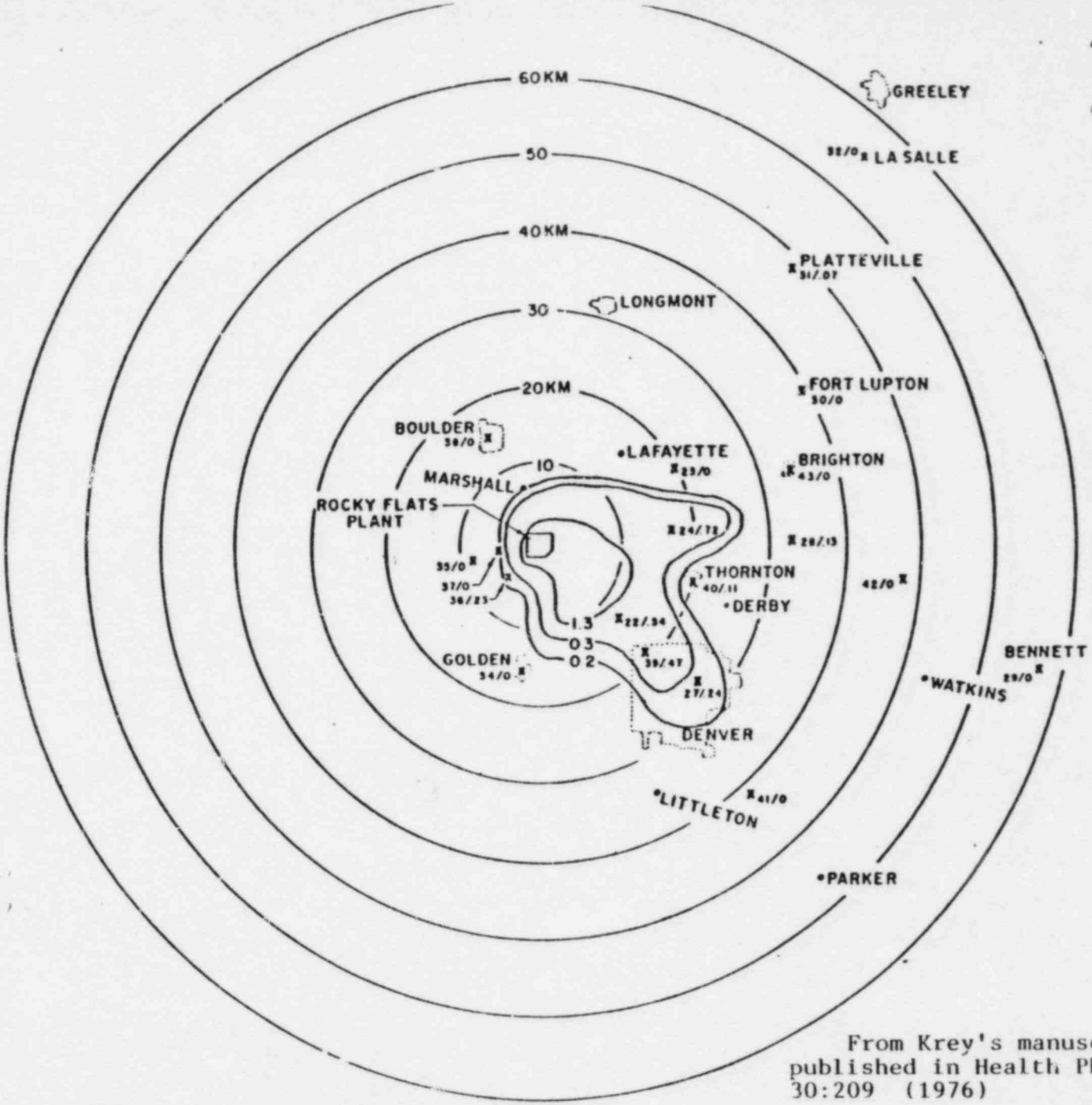
* Work performed under the auspices of the U.S. Atomic Energy Commission.

HISTOGRAMS OF THE PREVALENCE OF STRUCTURAL CHROMOSOME ABERRATIONS
IN ROCKY FLATS CONTROLS AND PLUTONIUM WORKERS
ARRANGED BY CHROMOSOME ABERRATION CATEGORIES

N = 274 MEN (PLUS 57 REPEATS)
NUMBER OF CELLS = 31,838

Controls,	N = 33	(3385 cells)
1 - 10%,	N = 76	(8664 cells)
11 - 25%,	N = 96	(9430 cells)
26 - 50%,	N = 39	(5123 cells)
51 - 100%,	N = 15	(2110 cells)
>100%,	N = 15	(3126 cells)





From Krey's manuscript, published in Health Physics 30:209 (1976)

BEFORE THE
UNITED STATES NUCLEAR REGULATORY COMMISSION
ATOMIC SAFETY AND LICENSING BOARD

In the Matter of

UNITED STATES DEPARTMENT OF ENERGY
PROJECT MANAGEMENT CORPORATION
TENNESSEE VALLEY AUTHORITY
(CLINCH RIVER BREEDER REACTOR PLANT)

DOCKET NO. 50-537

Affidavit of Dr. Carl J. Johnson

City of Wheatridge, Colorado) ss:

I, Dr. Carl J. Johnson, being duly sworn, depose and say that the foregoing testimony is true and correct to the best of my knowledge and belief.

Carl J. Johnson

Carl J. Johnson, M.D., M.P.H.
42 Hillside Drive
Wheatridge, CO 80215

Subscribed and sworn to
before me this 28th day
of October, 1982

Sofie B. Johnson - 701 E. Colfax Ave. Denver Co. 80203
Notary Public

My Commission expires April 18, 1984

BEFORE THE
UNITED STATES NUCLEAR REGULATORY COMMISSION
ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	
UNITED STATES DEPARTMENT OF ENERGY PROJECT MANAGEMENT CORPORATION TENNESSEE VALLEY AUTHORITY	Docket No. 50-537
(Clinch River Breeder Reactor Plant)	

CERTIFICATE OF SERVICE

I hereby certify that copies of TESTIMONY OF DR. THOMAS B. COCHRAN, PARTS III, IV, AND V, and TESTIMONY OF CARL J. JOHNSON, M.D., M.P.H., were served this 1st day of November 1982 by hand upon:

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Following classification review by the Division of Security, copies of the TESTIMONY OF DR. THOMAS B. COCHRAN, PART V, will be forwarded by the Division of Security to the following service list. Copies of TESTIMONY OF DR. THOMAS B. COCHRAN, PARTS III AND IV, and TESTIMONY OF CARL J. JOHNSON, M.D., M.P.H., have been served today by hand upon:

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