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

Report

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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 1019130). 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 154170) (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 (l). 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 particu- lates 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 selfscattering effect of the alpha recoil phenomenon (Table l) (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 fficiency 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 of 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 US 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 re- leases recorded on the eighth day (an esti- mated 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 filter s in the main plenum had not been changed since they had been installed four years earlier and may have contained many kilo- grams 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 contamina- tion 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 I). 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 I) has been contaminated with isotopes of Pu and other radionuclides (22-29). Uranium has been released by the open burning of over I000 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).

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/cm^2, 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/cm^2), but is 10 times more protective than a proposed Environmental Protection Agency (EPA) guideline to protect the general public (44 dpm/cm^2, a guideline that has been criticized.

Month	19S4(b l	1955	1956	1957	1958	1959	1960	1961	1962
Jan	0.03	0 11	006	0 36	046	2 84	0 13	2 84	068
Feb	003	011	0 05	008	0 96	(d)	0)6	1 21	7 79
Mar	004	0 11	006	0 64	5 59	0 25	008	072	092
Apr	002	0.12	0 07	008	0 35	018	0 09	1 24	1 24
May	0 05	008	0 21	0.04	4 97	015	0 40	1 20	0 89
Jun	0 03	005	009	0 20	566	0 56	0.94	113	0.34
Jul	007	004	0 23	0 40	3 19	1 87	0 53	0.77	0 54
Aug	006	0.02	0 20	0 09	080	1 05	1 42	1 21	132
Sep	0 ,:6	0 12	0 23	lcl	1 73	0 89	0 69	1 20	1 47
Oct	006	0 05	0 58	664	081	0 57	3 26	0.60	503
Nov	010	0 06	033	0 50	042	0.19	1 32	0.85	2.44
Dec	014	0 04	0 15	2 01	1 25	0 12	1 12	0 44	5 33
Annua l Average	**006**	**0 08**	**019**	110 ·	**218**	**0.96**	**085**	1.12	2 33

(a) **Federal guideline for maximum permissible air concentrations for such exhaust plumes 1s 0.12** dpmlm' Daily exhaust volume from main stack exceeds 13 000 000 m'
lb) Data incomplete for 1953 leverage O 03 dpmtm'l andfor 1963 (average 7 63 pC1tm'l.
(cl Ftre on September 11, 1957 Sept 1-10. O 68 dpm/m': Sept 11-18. no sample (elec trical power failure following a maier fire! Sept 19-30, 74 74 dpm/m' and on Sept. 19, 2086 10 dpmlm'
(di All filters changed in the main filter plenum Feb 1-13, 5 32 dpm/m'; Feb 14- 28, 0 21 dpmlm'
(el Estimated, not including Pu released during the fire or for six days aher

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

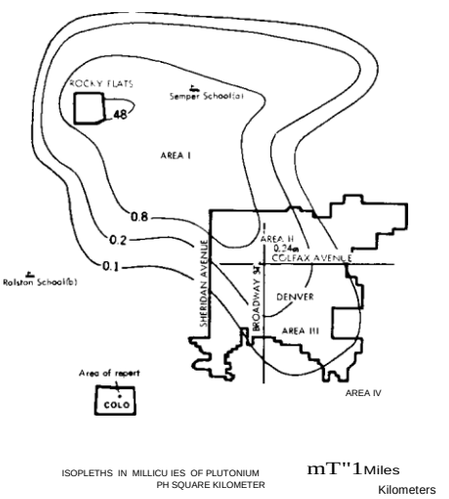

Figure 1. Denver **area** census tracts within **isopleths for soil contamination with plutomium downwind from the Rocky Flats plant. The offsite soil contamination was reported on March 13, 1958 to be as follows (19):**
a) At the Semper Elementary School; 12 000 disintegrations per minute per kilogram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

Resuspension of Pu-contaminated soil increases with wind speed to the 2.1 pow- er, and the ratio of Pu 238 to Pu 239 in- creases 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 sing- le Pu atoms and Pu particles with dia- meters 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/1), a stream leaving the plant site to 209 pCi/1(1), and a nearby water district to 2.29 pCi/1 has been reported (I, 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/1 to 0.16 pCi/1 (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 (I). The major route of exposure is the inhala- tion 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 faci- lity (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 exposure (from Reference 22).

Country	Milli-curies per km	Micro-curies perm	Disintegrations per minute per g dry soil or per cm	Purpose	Type
USSR		0 002	0 4	hands and work unde-r clothong before clean - ong	Occupational
		0006	1 33	work surfaces after cleaning	Occupattonal
		0015	3 33	work clothing and surfaces before cleanong	Occupational
us	10	001	2 20	Colorado Surface s011	Occupational
		0 02	4 40	Interstate Commerce Commission (Dept of Transportation) per- tains to interior of vehicles previously used for transportation of rad1onucltdes	Occupational
	40	0.04	8 80	urban. suburban, re - creation areas (a)	Publtc
	200	02	44 00	soil surface ,n res ,- dent1al areas lU S E P A proposed)	Publtc
		0 35	7700	establishes an "extra ordinary nuclear occur- rence·· (61	Publtc

(al Recommended by U S at an Internattonal Symposium on Radiological Protection of the Publtc 1n a Nuclear Mass Disaster (June. 19681 (Reference 221
(bl U .S Code of Federal Regulattons , Chapter 10, Secttons 140- 84, 141>-85 US uclear Regulatory Comm 1ss1on . Washong ton, DC (1968 1.

(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 µm 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 conyerative 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 com- pared 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 iso- pleth were included in the area containing the major part of the census tract.

The isopleths in Figure I are approx- imate but useable in comparing the inci- dence 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 millic uries/km^2 (mCi/km ^{2}), lies be- tween 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} ex- tends 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 (5 I), 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-Ill) were compared to Area IV. The population in Area **IV** is predominantly suburban, as is the popula- tion 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 inmigration (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 neaoplasms, 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 inmigration. The ef-

Area	Distance from Rocky Flats on principal vector, km	Plutonium (soil 2 mm)	Anglo Population Male	Anglo Population Female	Median Education years	Median Income	Median Age Years Male	Median Age Years Female	Male Cases obs exp	Male o e-1	Female Cases obs exp	Female o e-1	Total Cases obs exp	Total o/e-1
Area I	3-21 km	48 0-0 8	75 250	78920	12 04	8891	25 8	29 8	644'519..	· 24°0	636 581"	• 10°.	12001110· ·	+ 1s•.
Area II	21-29 km	O.!Hl 2	90 300	103 900	11 85	6367	34 6	36 8	1086/947.. ..,.	15°0	115411100	5°'o	2240/2047" •	+ 10°0
Area III	2 35km	0 2-01	117 370	129 530	12 69	12 094	306	33 5	107811000	a•.	1149/1109	+ 4•.	2227/2109 +	s•.
Areas 1-111	3-35 km	48 0-0 1	282 920	312 350	12 22	8668			2808/2466 •	of- 11 •.	2939127/90" • +	5•1o	5747/5256' • +	g•.
Area IV	.>35 km	<01	210 670	213190	12 97	8055	24 2	25.9	1114	0	1260	0	2374	0

(al Ref 48, the at,onal Cancer Instttute's Third attonal 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 stadard,zed expected incidence (cases expected/area** populat10nl for each area The study areas are then compared to the control area " Anglo " includes all white except those with Spanish surname

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

(cl This data 1s for total population (49)

(d) X· (obs exp 0 5 / npq wt",ere n population s,ze. p incidence of cancer, and q 1 p The X· used with the variance npq Is a more conservative test than the Mantel-Haenszel X ' (581 Use of a somewhat more conservative test devised by Professor Lars Ehrenberg of the University of Stockholm, Z n n n. + l!!..J n • did not change the level of s1gnof1cance noted here and in Table 4

Critical X value at a 95% confidence level • • Cnt1cal X value at a 99°0 confidence leve:

(el lobse rved ¹expected 1l X 100, compared to Area IV, the unexposed populatton

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

Site	Area I 48-0 8 millicur ies.kilometer, Population (19701 75,250 **Male Cases** obs·exp	(b)oie l	78,920 **Female Cases** (c)obs'exp	010 1	Total ole-1	Area II 0 8-0 2 millicuries kilometer, 90,300 **Male Cases** obsiexp	ole 1	103,900 **Female Cases** **obs,exp**	o/e 1	Total oie-1	Area III 0 2-0 1 millicuries kilometer, 117,370 **Male Cases** **obs/exp**	o,e 1	129,530 **Female Cases** obsiexp	oie-1	**Total** ole-1	Area IV (unexposedl 210,670 **Male** obs	213, 190 **Female** obs
Lung and **Bronchus**	109182"	33°0	21124	112°.1	23°0	2091143° °	46°0	53148	10°.	37°0	1791158	13°0	54148	12°.	13°0	174	51
Other Respir- **atory**	20113	54•.	312	50•.	53°0	21/23	19°0)	715	40•.	0	26126	0	2/5	(60°ol	110•.1	32	5
Leukemia	27119	42°0	14/17	(18•.,	14•.	28131	(10•.1	34/33	3•.	(3°0)	37/34	9•.	52/33..	59•.	33°0	45	38
Lymphoma , **Myefoma**	35125	40•.	28125	12°.	2s0 •	48140	20°0	38,49	122· ,	13°0)	51/45	13°0	43/49	112•.1	0	59	**56**
Tongue , Ph• · **rynx, Esopha - gus**	17/12	42°.	613	100•.	53°0	43118..	139°.	2517••	257°.	172°0	29120	45°0	10/7	43°0	44•.	24	7
Stomach	22/16	39•.	11/14	(21•• ,	100..	27/30	110°.1	27/32	(16%1	(13°0)	30132	15•.1	21/23	19°0)	I7"o)	34	27
Colon, **Rectum**	100168"	47 .	103175 ' •	37°0	42,,,	1441130	11 ••	1781160	11 ••	11 ••	135/135	0	152/143	5•.	3•.	144	146
Liver and Biliary	1015	100°.	7/10	130°0)	13°0	23113"	77°0	23122	5•.	31 °o	19113	46°0	19/21	(10°0)	12°0	5	3
Pancreas	20/22	19%1	21/15	40 °.	11,.	37141	110•.1	35/32	9•.	(3•o)	39143	(9°0)	32/30	1•.	13°0)	46	30
Testis	1115	120°,.				1416	133°0				1517	114°0				13	
Ovary			34127	2s0 •				59148	23°0				66152	27°0			63
Thyroid	316	150%)	24/16	50•.	23°0	8/10	120•.1	33/26	27°0	14°0	11112	(8•.)	23129	(21°0)	(17"o)	18	42
Brain	13/11	1s•.	10/8	25°1o	21 .,.	10117	(41•• ,	10/12	(17°0)	131°0)	17120	(15°ol	19114	36°0	6"•	27	20
Other Sites	2571235	9•.	354 345	3•.	6'to	4741445	a•.	632,625	3•.	5•.	4901455	a•.	6561655	O•.	3•,.	493	772
All Cancer	6441519" •	24 o	6361581 •	10°.	1s 0•	1086/947" •	15•.	115411100	5•.	10•.	107811000"	a•.	1149 1 11 09	4•.	6·	1114	1260

la) From the **ational Cancer Inst1tute's Third** attonal 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 ,nc1dence (cases expected/area** populattonl for each area The study areas are then compared to the control area " Anglo " includes all white except those with Spanish surname. (48)

lb) **X (obs exg: 0 5 / npq when n population s,ze. p incidence of cancer. and q 1** p The X **used with the variance npq Is a more conservative test than** the Mantel-Haenszel X · 1581

Critocal X' value at a 95,.confidence level • • Critocal X' value at **a** 99°. confidence level

(cl lobservedl expected) 100 compared to **Area** IV, the unexposed population Percentages in parentheses are negatove (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 Fiats plant (al**

feet of the inclusion of the eight census tracts nearest the plant with the remainder of Area I is to understate any environmen· tally-related difference **in** cancer inci- dence.

RESULTS

The total incidence of cancer for the pe· riod 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, co- lumn 10.) The corresponding values for females were IO% 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 rec- tum, liver, (only males) pancreas, only fe- males) 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 un- contaminated area (Table 4). This higher incidence persisted in Area II (46% high- er). 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 inci- dence 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/IS 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		1!">-44		45--54		55--64		65--74		75 +	
(Population: **Area** I, IV) **Cancer Classes**	24 825 oleIbl	66.530 Elcl	31.395 a e	98.521 E	8.351 *ale*	24.092 E	5,750 *ote*	12,652 E	3.148 a e	5.683 E	1,785 *Ole*	3.175 E
All **classes**	20191•	25	52140	126	71164	185	1471127	278	194 149..	270	1691130..	230
Lung **and** bronchus	*010*	0	813 5	11	14113	37	37125	54	34 "31	55	1619 6	17
Leukemia	614 2	11	1312 9..	9	111 0	3	6'1 8	4	2/1 7	3	211 1	2
Lymphome , myeloma	1/1 9	5	19 '7,3..	23	311 4	4	812.7	6	5/1 7	3	311 1	2
Stomach	*010*	0	110 3	1	6/2 1	6	313 2	7	8, 6 1	11	415 1	9
Colon	*010*	0	312 5	**8**	615 2	15	15112	26	15194	17	29113..	23
Liver	010	0	0/03	**1**	010 3	1	3,0	0	110 6	1	211 1	2
Pancreas	010	0	1106	2	313 **5**	10	6141	**9**	7,6 6	12	317 3	13
Test is	110	0	8/3 2	10	110 7	2	0/0.5	1	110	0	010	0
Breast	010	0	110 3	1	010	0	*010*	0	110	0	0106	1
Thyroid	010	0	113 2	10	1114	4	0/1 4	3	1106	1	010	0
Brain	110 4	1	212 2	7	311 7	5	412 3	5	2/3 3	6	111 7	3
Unknown	010	0	*010* 6	2	311 4	4	4 5 5	12	1113 9•	7	512.8	5
Female (Popu11t.on **Area I**, IVI	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**	517 0	19	103164	253	1061116	310	1301118	249	144 104••	195	1481144	234
Lung end bronchus	*010*	0	211 3	4	2 5 6	15	&15 2	11	9 7 5	14	314 3	7
Leukemia	0/1 8	5	5113	**4**	0111	3	710 9·	2	2/1 1	2	1/2 5	4
Lymphoma, **myeloma**	110 7	2	1911O••	21	1/0 7	2	9'2 **4**•	5	5 2 1	4	11/3 1•	5
Stomach	*010*	0	1/0 3	1	011 1	3	2/3 3	7	2/1 6	3	618 0	13
Colon	*010*	0	314 0	12	8/0 9	23	14 8 5	18	1618 5	16	39125·	40
Liver	010	0	010 7	2	0104	1	*010*	0	110	0	210	0
Pancreas	010	0	2/0 3	1	212 2	6	914 3	9	5'3 2	6	314 9	**8**
Ovary	*010*	0	815 3	16	7/7 5	20	9,5 2	13	714 2	8	313 7	6
Breast	*010*	0	34134	101	40144	119	37/30	64	46/27·	51	33130	49
Thyroid	110	0	12183	25	3'2 6	7	4 '0 9	2	012 7	5	411 8	3
Brain	211 8	5	312 0	6	110 7	2	211 **9**	**4**	211 1	2	0/0 6	1
Unknown	010	0	1/0 7	2	212 6	7	310 **9**	**2**	7159	11	816 2	10
Total **(Population: Area I. IV)**	48.473	130.963	64.508	198.073	17,078	4, 7 471	11,890	**2&.1116**	7,179	13.276	5,042	8.448
All classes	25116	44	155 123•	379	177I17B	495	2771247"	527	338'251..	465	312/277	464
Lung and bronchus	*010*	0	10 49	15	16119	52	42/30	65	4,3 3 7	**69**	19114	24
Leukemia	6159	16	1814 2..	13	1/2 2	6	13/2 8..	6	4 '2 7	5	313 6	6
Lymphoma , myelom1	2/2 6	7	38114..	44	412 2	6	1715.1..	11	10/3 8·	7	1414 2..	7
Stomach	*010*	0	210 6	2	613 2	9	516 5	14	1017 8	14	10112	20
Colon	010	0	6/6 5	20	14 117	**48**	29 '2 0	44	31118·	33	68138..	63
Liver	*010*	0	011 0	3	*010.7*	2	3 '0	0	2/0 5	1	411 2	2
Pancreas	010	0	311 0	3	519 **8**	18	16184	18	12/9 7	18	6113	21
Gonads	1/0	0	1s18 5·	26	817 9	22	91e **e**	14	**8** '**4** 3	8	313 6	6
Breast	1/0	0	35133	102	40142 8	119	37/30	**64**	47 ' 28..	51	33130	50
Thyroid	1/0	0	13111	35	4,4 7	13	412 3	**5**	1/3 2	6	413 6	3
Brain	3'2 2	**8**	513 6	13	4 2 5	7	*614* 2	**9**	4 4 3	8	1/2 4	4
Unknown	010	0	111 3	4	5,4 0	11	716 5	,•	18 9 7 •	18	1319 0	15

(al Ref 48 The 1toonal Cone&, Insutute's Th,rd atoonal Cancer Survey Incidence Data
(bl o • observed c ,n Area I e • expected number of cases (actual number of cases on Area IV populat,on ,n Area 11papulat1on ,n Area IV)
(cl E 1s the number of cases ,n Area IV
• p≤OOS
·· P 0 01 lstandard,zed Z test for normal approx,ma1,on o the b,nom,al proportoon. 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 andwithout 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 /3 1 expected). Cancer of the tongue, pharynx, and esop- hagus was high for both sexes in all three study areas (89 cases observed/50 expec- ted for males, and 41 cases observed /17 expected for females). According to the statistical test used, the remaining varian- ces may be random.

The strongest comparisons can be made between Area I, a predomina ntl y subur- ban area near the plant with heaviest ex- posure, and Area IV. also predominantly suburban with little or no exposure and having virtually the same age-adjusted **in•** cidence 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 signifi- cant exception . The was a n excess of all cancer in the age group 14 years **(25** observed/16 expected), 15-44 years **{15,/** 123), 55-64 years (277/247), **65-74** years (338/251) and over 75 years (312/277). This difference was due principally to an ex- cess of cancer in males in the age groups 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 exceptiort, especially in the age group of 15-44 years and 65-74 year!L

The higher incidence of all cancer was chiefly due to cancer of lung and bron- chus, especially in the males, and to can- cer of the colon in both **sexes,** The inci- dence was higher above the age of *55.* Exceptions were an excess of cancer of the lung and bronchus in males in the age range I5-44 years and cancer of the colon irl females in the age group 45-64 years.

There was a higher incidence of leuke- mias, lymphomas and myelomas in both sexes in Area I. In males there was a higher iflcidente of leukemia in the age group 15-44 years of age (13/2.9) and of lymphomas and mye lom as in the age group 15-44 years (19/7.3). In fema les , there was a higher incidence of leukemia in the age group 55-64 (7/0.9) and of lym- phmtlii!'i :ind 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 brea st cancer was found for females in the age group 65-74 years (46/27). This age-specific excess in- cidence 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 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 expec ted .

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 ne a r the plant, compared to the unexpo sed population in Area IV (+ 12.2 %, + 9.7 % and + 3.4 %, respec- tively , 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 1) 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

Table 6. Anglo cancer incidence in **the Denver metropolitan area over a period of three years (1961971**), **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 ,"opu la tio n		Tota l cancer cases	(cl cancers of rad iosensitive organs	(d i Other cancer cases	(el rat io c,d	relat ive risk (e e 1) " 100
Total	IV	423 866	2374	1251	1123	1 114	O(e')
	I	154170	1280	711	569	1250	+122°0
	II	194190	2240	1232	1008	1 222	+ 9 .7 °0
	Ill	246905	2227	1192	1035	1 152	+ 3 4°0
M ale	IV	210 670	1114	500	614	0 814	Ol e')
	I	75 250	644	315	329	0.957	+ 11 $°.
	II	90 300	1086	507	579	0 876	+ / $° .
	III	117 370	1078	474	604	0.784	3 7°0
Female	IV	213 670	1260	751	503	1 475	Ohl)
	I	78 920	636	396	240	1650	...11.9°.
	II	103900	1154	725	429	1 690	.....14 $°.
	III	129 530	1149	718	431	1 666	12 9•.

(a) "' **Cancers of rad1osens1t1ve or gans" defined as those found 1n excess 1n survivors of Hiroshima** and agasak1, l eukemi a, lymphoma and myeloma. and cancer of the lung, thyroid, breast, esophagus , stomach. and colon (from Reference 59)

lb) Cancer 1nc1dence data from the Na1,onal Cancer Ins11tu e's Third Nal1onal Cancer Incidence Survey. Incidence Data **The population in Area IV is considered a control populat ion with no exposure to** plutonium and other ac11nides and rad1onucloides from the Rocky Flats plan! The populaJ1on ,n Area I **has the greatest exposure to these ra,d onu clIdes, those in Area II have less exposure , and those in** Area III have the least exposure (from Reference 481

(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 slight- ly 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 distrib11tion of population between exposed and unexposed populations (I). 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 compari- son 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 num- ber of individual classes of cancer, includ- ing 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, pan- creas 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 radiosensi- tive 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, thyr- oid, breast, esophagus, stomach and co- lon. 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 de- creased 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).

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 gener- al 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 leuke- mia, lymphoma and myeloma and cancer of the lung, thyroid, breast , esophagus, stomach and colon, a pattern similar to that observed **in** the survivors of Hiroshi- ma and Naga saki. Cancer of gonads (espe- cially 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-under stood, 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 populatio ns residing near nuclear installa- tions.

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