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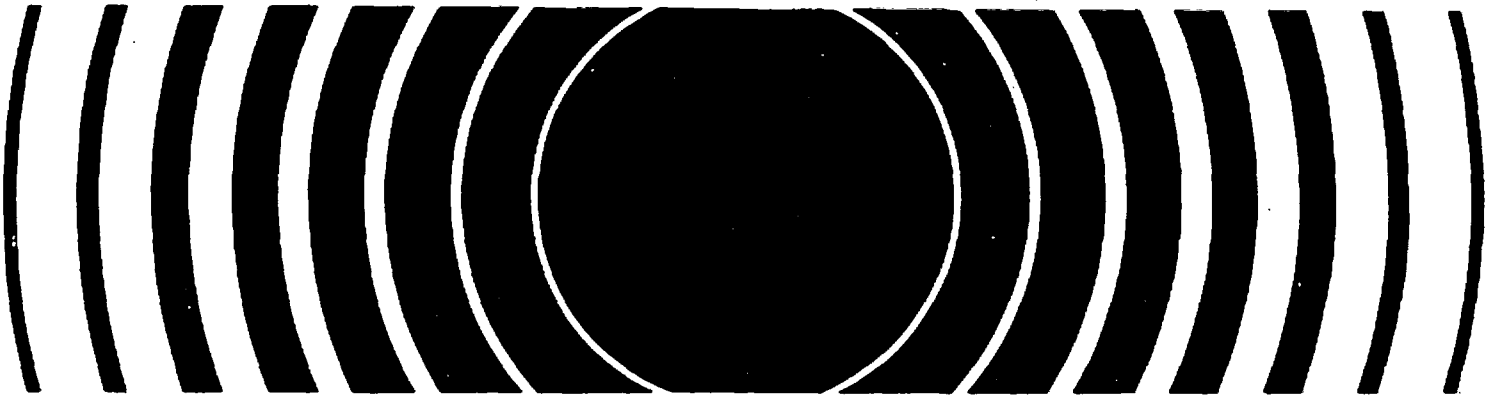
EPA/520/6-90/008
April 1990

EPA

Radiation

Idaho Radionuclide Study



RADIONUCLIDE EXPOSURE STUDY

POCATELLO AND SODA SPRINGS, IDAHO

April 1990

US ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS
LAS VEGAS FACILITY

FOREWORD

In December 1989 the National Research Council published its Biological Effects of Ionizing Radiation or BEIR 5 Report which offers new risk estimates from radiation exposure. These new risk factors are about twice the risk factors used within this report. The Environmental Protection Agency has not incorporated the BEIR 5 risk estimates into its risk calculation procedures. The risk factor associated with the conclusions in this report is 400 cancer deaths attributable to radiation exposure per one million person-rem of dose.

The risks expressed in this report are based on calculations that assume a lifetime (about 70 years) of exposure to the conditions that were measured.

As the elemental phosphorus industry in southeast Idaho is about 35 years old, the actual risks to the population as a whole are less than the estimated risks reported here. However, if the population and the use of phosphorus slag in building materials remain or increase in the same proportions as they exist today, these risk levels will be reached within forty years. At that time, we estimate the probability of contracting cancer due to exposure from elemental phosphorus slag to be about one chance in 2,500 in Pocatello and one chance in 700 in Soda Springs.

Wayne A. Bliss, Director
Las Vegas Facility
Office of Radiation Programs

STATEMENT OF FINDINGS

As committed by EPA in 1985 when it promulgated emission standards for radionuclides as hazardous air pollutants, a radionuclide exposure study has been conducted in southeastern Idaho to estimate the radiation dose resulting from the elemental phosphorus industry.

From April 1986 through September 1988, the Office of Radiation Programs' Las Vegas Facility, investigated the dispersion of radionuclides through the environs of Pocatello and Soda Springs, Idaho, the relative importance of their sources and pathways affecting the populations of both towns, and the magnitude of the attendant risks. One of the most significant components of risk to the inhabitants was the exposure to gamma rays originating from elemental phosphorus waste.

The Las Vegas Facility conducted the investigation in cooperation with EPA's Region 10 office, the State of Idaho, the Idaho Mining Association, the governments of Bannock and Caribou counties, and the towns of Pocatello, Chubbuck and Soda Springs, and with the contracted assistance of EG&G and Battelle's Pacific Northwest Laboratory.

Gamma ray exposures to the populations of Soda Springs and Pocatello, with the attendant risks, and the corresponding values for average and maximally exposed individuals in both communities, are listed in Tables A through E. Exposure to outdoor sources is the greatest contributor to the population dose in Pocatello, due to slag used in street paving, while that to the residents of Soda Springs is mostly due to indoor (home) exposure, caused by slag in home foundations. Inclusion of the airborne components, principally due to airborne polonium-210 and lead-210, increase both dose and risk estimates, as shown in Table F and Figure A.

TABLE A. SUMMARY OF ANNUAL NET POPULATION DOSES, BY AGE AND ACTIVITY GROUP, FOR SODA SPRINGS, FROM ELEMENTAL PHOSPHORUS WASTES (Person-rem)

Location	Employed Adults	Teenage and non-employed Adults	Children	Infants	Total by Exposure Elements
Main Floor	35.98	27.36	11.85	13.32	88.51
Basement	13.22	10.06	4.35	3.14	30.77
Driveway	3.58	5.42	2.35	0	11.35
Sector*	4.80	9.21	6.46	1.39	21.86
Community	5.09	15.65	3.97	1.47	26.18
Workplace	18.70	0	0	0	18.70
Total by age group	81.37	67.69	28.99	19.32	197.4

TABLE B. SUMMARY OF ANNUAL NET POPULATION DOSES BY AGE AND ACTIVITY GROUP, FOR POCATELLO, FROM ELEMENTAL PHOSPHORUS WASTES (Person-rem)

Location	Employed Adults	Teenage and non-employed Adults	Children	Infants	Total by Exposure Elements
Main Floor	83.94	50.05	25.29	26.47	185.75
Basement	13.91	8.29	4.19	3.00	29.39
Driveway	40.34	48.21	24.37	0	112.92
Sector*	41.17	61.96	49.77	11.49	164.39
Community	49.58	119.74	37.59	14.10	221.01
Workplace	89.50	0	0	0	89.50
Total by age group	318.44	288.25	141.21	55.06	803.0

* General vicinity of residence.

TABLE C. YEARLY RISK FOR THE POPULATIONS OF POCATELLO AND SODA SPRINGS

Community	Annual Population Dose	Risk
Pocatello	803 person-rem	0.3 deaths/year among 57,000 people
Soda Springs	197.4 person-rem	0.1 deaths/year among 3,800 people

TABLE D. CALCULATED NET GAMMA-RAY DOSES (mrem/yr) TO AVERAGE INDIVIDUALS IN POCATELLO AND SODA SPRINGS

Community	Average Annual Individual Dose	Lifetime Risk
Pocatello	14 mrem	0.0004
Soda Springs	52 mrem	0.0014

TABLE E. CALCULATED NET GAMMA-RAY DOSES (mrem/yr) TO MAXIMALLY EXPOSED INDIVIDUALS IN POCATELLO AND SODA SPRINGS

Community	Maximum Annual Individual Dose	Lifetime Risk
Pocatello	145 mrem	0.004
Soda Springs	205 mrem	0.006

Lifetime risk values represent the probabilities of contracting a fatal cancer, i.e. "4 in 1000" for the maximally exposed individual in Pocatello (Table D) and "6 in 1000" for the maximally exposed individual in Soda Springs, (Table E) assuming they remain in their respective communities throughout their lifetime.

TABLE F. GAMMA DOSE AND RISK ESTIMATES, INCLUDING AIRBORNE COMPONENT, TO MAXIMALLY EXPOSED INDIVIDUALS IN POCATELLO AND SODA SPRINGS

	Pocatello	Soda Springs
Airborne Dose Contribution	23 mrem	4 mrem
Slag Dose*	145 mrem	205 mrem
Total Effective Whole Body Dose	168 mrem	209 mrem
Lifetime Risk**	0.005	0.006

* From exposure to gamma rays from slag material. There is no radon dose component; radon levels, where measured, were indistinguishable from background.

** "Lifetime Risk" represents the probability of contracting a fatal cancer caused by radiation exposure above background for individuals residing in the subject communities during 70 years (a "lifetime.") The maximally exposed individual in Pocatello has "5 in 1000" chances of dying of cancer, while the corresponding individual in Soda Springs incurs a risk of "6 in 1000" of dying due to the same cause.

ANNUAL DOSES COMPARED TO MAXIMUM ANNUAL DOSES
(mrem/year)

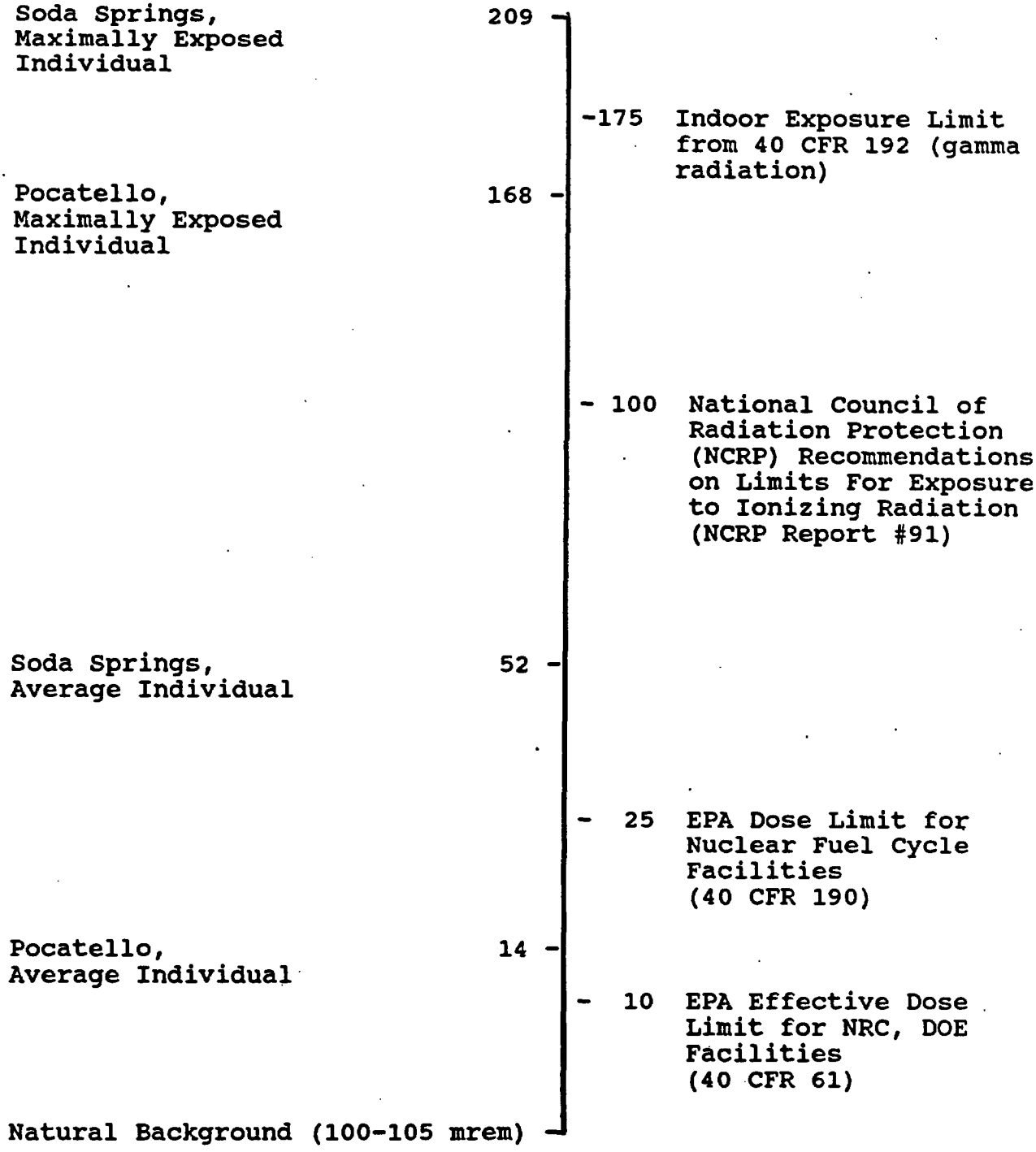


Figure A. Slag and Airborne Doses, as Compared to Recommended Maximum Annual Doses in Excess

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INTRODUCTION

In 1979, the U.S. Environmental Protection Agency (EPA) listed radionuclides as hazardous air pollutants and was required by the Clean Air Act to issue emission standards for radionuclides. In October 1984, EPA was ordered by the U.S. District Court, Northern District of California, to issue standards for elemental phosphorus plants and other source categories under Section 112 of the Clean Air Act.

Phosphorus ores contain approximately 60 times the levels of natural radioactivity normally found in the Earth's crust. Some of the radioactivity is released to air and water during processing of the ores, and some is distributed in the environment through the use of solid byproduct wastes. The EPA has established a radionuclide standard limiting polonium-210 (Po-210) air emissions per elemental phosphorus plant to 2 curies per year (Ci/y).

At the issuance of the standard in 1985, EPA stated:

> "The areas surrounding two plants, the FMC plant in Pocatello, Idaho and the Monsanto plant in Soda Springs, Idaho are characterized by high total levels of radiation from a variety of sources. The storage and widespread use of slag, and possibly other waste products from these plants, have significantly increased the natural background radiation levels in parts of the communities. In particular, phosphate slag from these plants has been widely used in aggregate in road and house construction in these areas. EPA and the State of Idaho will initiate a total assessment of the various sources and will investigate ways to reduce or prevent risks from growing."

In 1987, the U.S. Environmental Protection Agency's (EPA) Office of Radiation Programs' Las Vegas Facility (ORP/LVF) contracted with Battelle's Pacific Northwest Laboratory (PNL) to conduct a study to determine the radiation exposure to Pocatello and Soda Springs residents from the local phosphorus industry that had been operating for several decades.

The objective of the study was to determine the magnitude and relative importance of the various industrial sources of radiation and to estimate the dose to the affected populations. Following a review of pertinent literature, two components were considered to be most significant: gamma dose and risk estimates from using elemental phosphorus wastes, and the dose and risk estimates due to air emissions from the phosphorus plants. Conspicuously absent were the elevated radon concentrations expected to originate from phosphogypsum; radon levels were found to be indistinguishable from background.

I. GAMMA DOSE AND RISK ESTIMATES OF ELEMENTAL PHOSPHORUS WASTES

This section of the report is devoted to: (A) the purpose and scope of the gamma radiation study; (B) a summary and analysis of the survey data; (C) a description of exposure scenarios; (D) the computation and compilation of gamma radiation exposure estimates; and (E) summary and discussion of results.

A. Purpose and Scope

The purpose was to estimate annual radiation doses from local sources of gamma radiation to maximally exposed individuals and to the collective population of the cities of Pocatello and Soda Springs, Idaho. The estimation of radiation doses was based on ambient radiation measurements made in the respective communities.

B. Summary and Analysis of Survey Data

A brief summary of the data collection methods used for both aerial and ground surveys, as well as figures, follow.

1. Aerial Survey

Aerial surveys of the Pocatello and Soda Springs communities were performed in June and July 1986 by the Remote Sensing Laboratory of EG&G, Inc., Las Vegas, Nevada. Selection of the area to be surveyed was based on the presence of elemental phosphorus plants, the long-term, widespread use of phosphorus slag material from the plants throughout the area, and the local population distribution. Fort Hall was also surveyed to measure background radiation levels in the same geographic area.

The aerial survey of Pocatello included the FMC elemental phosphorus plant, the Simplot phosphate fertilizer plant, and the municipal airport. The survey covered an area of over 200 square kilometers.

The Soda Springs site aerial survey covered over 40 square kilometers, and included the Monsanto elemental phosphorous plant and the Kerr-McGee vanadium plant.

The aerial measurement system consisted of twenty sodium iodide scintillation detectors and data acquisition equipment mounted on a helicopter. Each area was surveyed along predetermined parallel lines spaced 76 meters apart at a mean altitude of 46 meters above ground. More detailed discussions of the systems and procedures used can be found in the EPA report documenting these surveys (Berry 1987), as well as in separate publications (Jobst 1979, Clary 1981, and Boyns 1976).

The aerial survey exposure rate contours were projected and enlarged so that the areas contained within the contours could be planimetered by sector prior to use in calculating population exposures. For ease of data processing, the "sectors" used in calculation were the result of partitioning both communities into radial grids along 16 compass directions, with circular subdivisions every 1.6 kilometers (1 mile) from the grid centers. The grid centers were elemental phosphorus plants in each community. The average aerial exposure rates by sector, resulting from this survey, are provided in Figure 1 for Pocatello and Figure 2 for Soda Springs.

2. Ground Survey

Ground surveys of specific residential properties in Soda Springs and Pocatello were performed in the summer and fall of 1987. Properties surveyed were obtained through a request for volunteers within the communities.

At each residence, indoor measurements were made on the main floor and in the basement using a Reuter-Stokes pressurized ion chamber (PIC). The corresponding outdoor measurements were obtained with a Ludlum Scintillometer Model 19, in the front yard, back yard, garden, driveway, sidewalk, and street in front of the residences surveyed. The average outdoor exposure rates from the ground surveys are provided by sector in Figure 3 for Pocatello and Figure 4 for Soda Springs. The ground survey covered 100 homes in Pocatello and 19 homes in Soda Springs.

3. Comparison of Ground and Aerial Survey Data

The comparative data shown in Table 1 suggest the validity of using the aerial survey data for areas not included in the ground survey. Although the table compares aerial and ground data obtained in Pocatello, similar considerations apply to Soda Springs. For some sectors of both communities, the ground survey data indicated higher exposure rate ranges than indicated for the same districts by the aerial data (adjusted to 1 meter above the ground surface). This is because the aerial data measurements average the exposure rate over much larger areas than the ground survey data, thereby showing a lower average exposure rate range for what could be rather small, isolated areas contaminated with phosphorus slag (Berry 1987). On the other hand, those areas within the city known to include larger pockets of phosphorus slag showed the highest exposure rate ranges in the aerial survey.

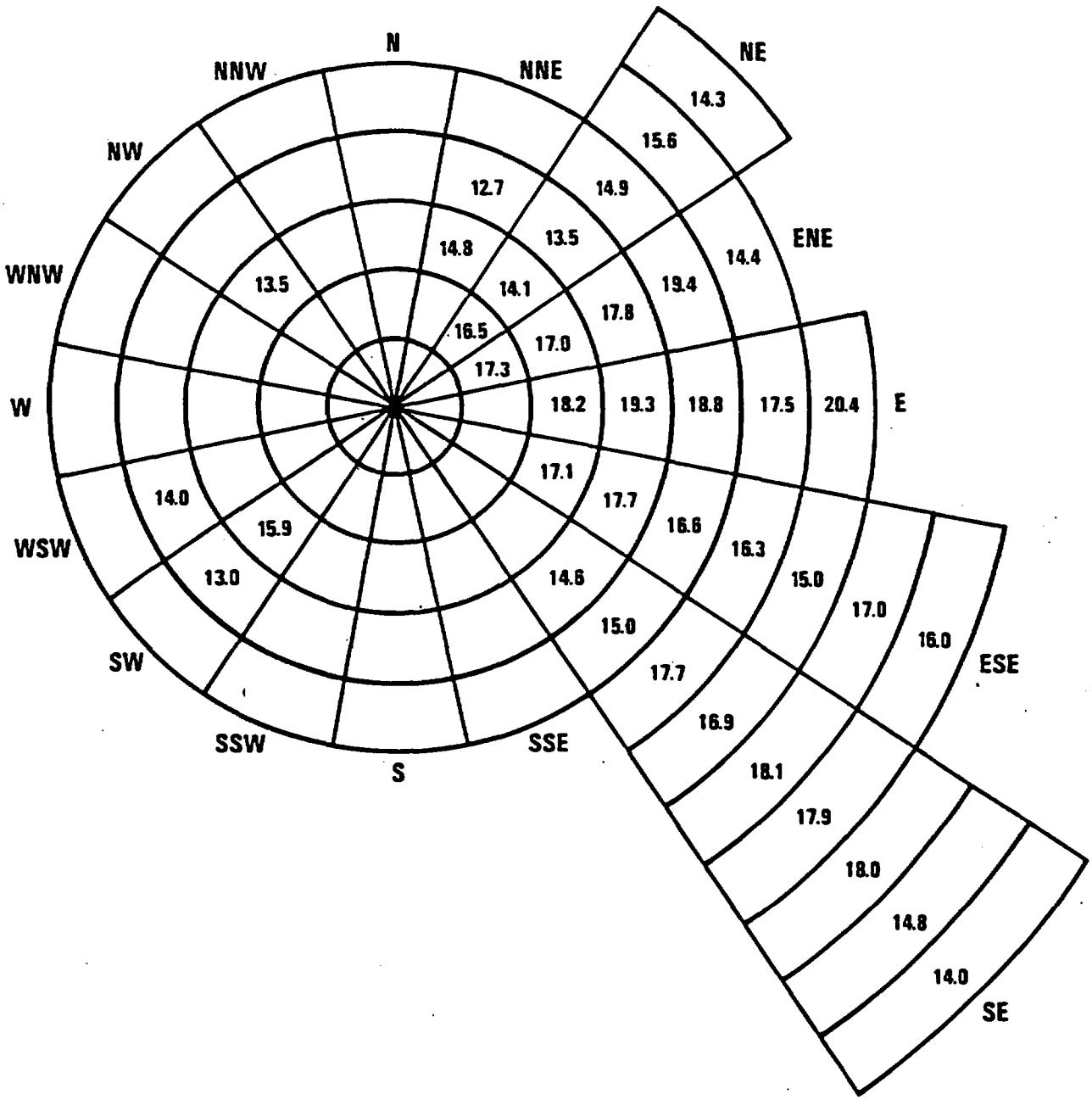

Figure 1. Pocatello Sector Average Aerial Exposure Rates (Adjusted To 1 Meter Above Ground Level) in μR/h.

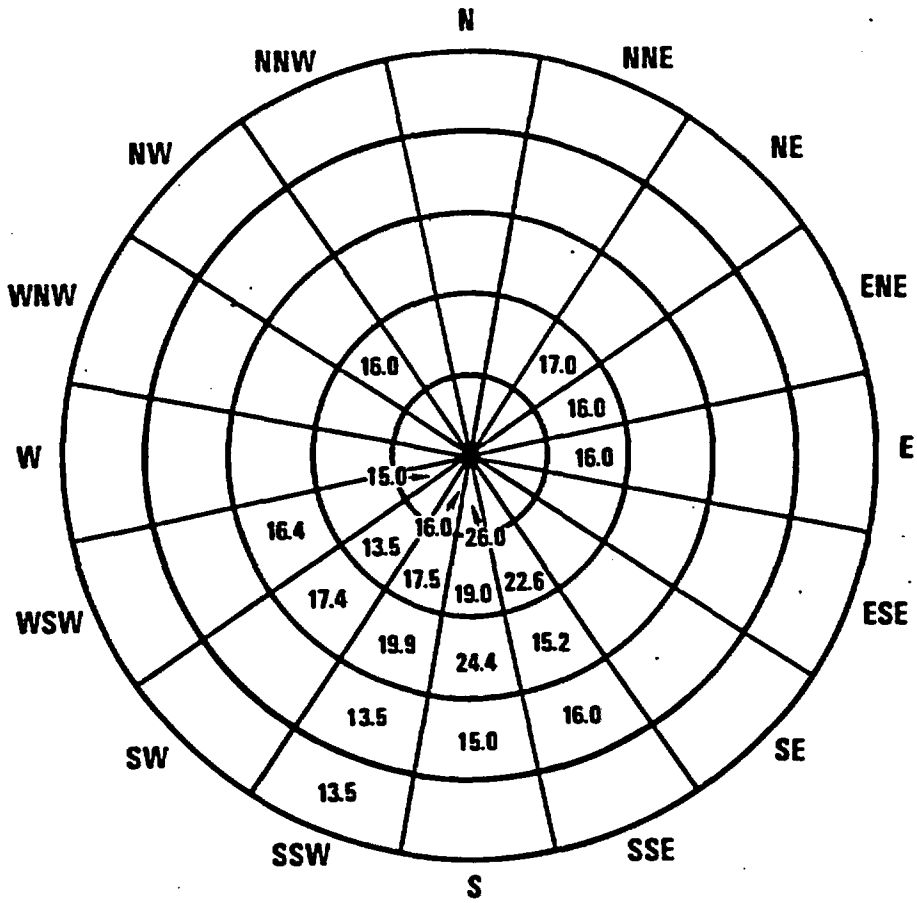

Figure 2. Soda Springs Sector Average Aerial Exposure Rates (Adjusted to 1 meter Above Ground Level) in μR/h.

TABLE 1. An Example Comparison of Ground (1 Meter) and Aerial (corrected to 1 Meter) Gamma-Ray Exposure Rate Ranges[1]

Exposure Rate Category	Exposure Rate Range (μR/h)	Percent of Measurements at Given Exposure Rates	
		Aerial	Ground
A	<9	0	0
B	9-11	0	5
C	11.1-14.5	36	41
D	14.6-17	36	29
E	18-22	23	12
F	23-30	5	4
G	31-50	0	3
H	51-100	0	6

Due to the greater field of vision of airborne detectors, aerial exposure rate measurements may average readings from large areas, thus misrepresenting small zones of high exposure rates detectable by ground surveys. Accordingly, the results of the aerial surveys of both communities were adjusted to represent ground level exposure rates by the use of aerial/ground ratios, intended to account for possible bias in aerial survey data.

For the community as a whole, aerial/ground ratios, shown in Table 2, were based on average aerial survey data and the average of ground survey measurements. These aerial/ground ratios were applied to aerial survey averages obtained for individual sectors, except for those for which enough ground survey data were present to justify an independently calculated aerial/ground ratio.

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[1]As noted in Figure 5 of Berry 1987.

TABLE 2. Comparison of Average Outdoor Gamma Ray Exposure Rates in Pocatello and Soda Springs, Based on Aerial Surveys and Modified by Aerial/Ground Ratios

	Pocatello	Soda Springs
Community Average Aerial Exposure Rates, (corrected to 1 meter above ground) in μR/h	18.6	20.7
Average Aerial/Ground Ratios (based on empirical data, with ground survey values obtained with a Ludlum Scintillometer Model 19, at 1 meter above ground)	0.93	0.81
Community Average Exposure Rates, in μR/h (corrected by aerial/ground ratios to correspond to Ludlum Model 19 Scintillometer values at 1 meter)	20.0	25.6
Community Average Exposure Rates, in μR/h Adjusted to Pressurized Ion Chamber (PIC) Values (a standard for human exposure determination)	16.6	19.8
Net Community Average Exposure Rates, Adjusted to PIC Values in μR/h (minus background of 12 μR/h)	4.6	7.8

The general procedure for estimating outdoor exposure rates follows:

1. Exposure rates observed for each sector during the aerial survey were divided by the appropriate aerial/ground ratios. The resultant gross community average exposure rates correspond to scintillometer ground level measurements, since these were the instruments predominantly used during the ground survey, and thus for obtaining aerial/ground ratios.

2. The results were then adjusted to PIC exposure rates by the following regression equation:

$$E(PIC) = 0.582\ E(L\text{-}19) + 4.9\ \mu R/h$$

where E(PIC) = exposure rate, μR/h, as measured by a Pressurized Ion Chamber (PIC)

E(L-19) = exposure rate, μR/h, as measured by a Ludlum Scintillometer Model 19 (L-19)

The regression equation was generated by a comparison of PIC and corresponding scintillometer values on the main floors and basements of Pocatello and Soda Springs residences.

The adjustment was needed since exposure rates obtained by PIC are standard for establishing human exposure.

3. The environmental background, as determined by previous PIC measurements was then subtracted.

When fewer than 20 outdoor measurements were available in a sector, as shown in Figures 3 and 4, the aerial/ground ratio was based on community averages rather than on sector data. If more than 20 outdoor measurements were available in a sector, as was the case in Pocatello, individually determined sector aerial/ground ratios were used to correct sector exposures, as shown in Figure 5.

Sector averages were then multiplied by the number of individuals, in Figures 6 and 7, and exposure scenario hours to obtain the average population exposure in that sector. The exposures were then summed to provide a total population exposure, for future risk estimates.

C. Exposure Scenarios

1. Selected Exposure Scenarios

One single, basic set of exposure scenarios was developed for Pocatello and Soda Springs, to estimate time spent by individuals of different age groups in different exposure environments, such as the main floors and basements of their homes, adjacent driveways, sidewalks and streets, the general vicinity (sector), and the community as a whole. In addition, employed adults were divided into those subjected to indoor and outdoor exposures at their places of work.

Population exposures utilized these scenarios by distributing the residents in various zones in each community among the age groups mentioned above, applying the findings of the aerial and ground surveys to determine exposure rates applicable to each group in each zone and finally summing the results.

Maximum exposure rates observed at locations included in the scenario were multiplied by the corresponding time intervals and the results were combined to generate total exposures for maximally exposed individuals, in each of the groups addressed in the scenario. Such combinations of maximum exposures, though hypothetical, were considered to be possible. When conditions

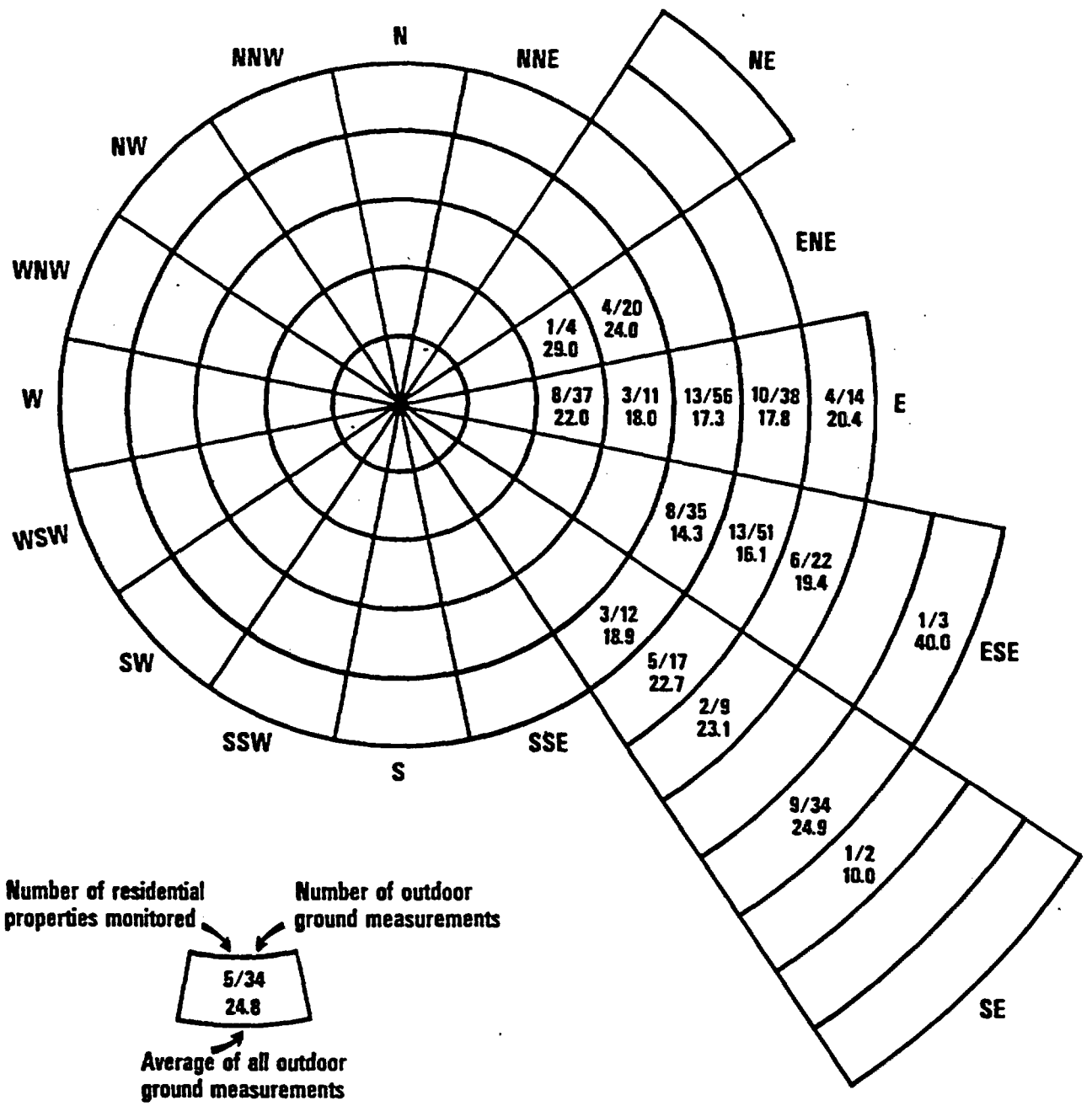

Figure 3. Average Outdoor Ground Survey Exposure Rates in μR/h, by Sector, in Pocatello, Including the Number of Properties Surveyed and the Number of Measurements.

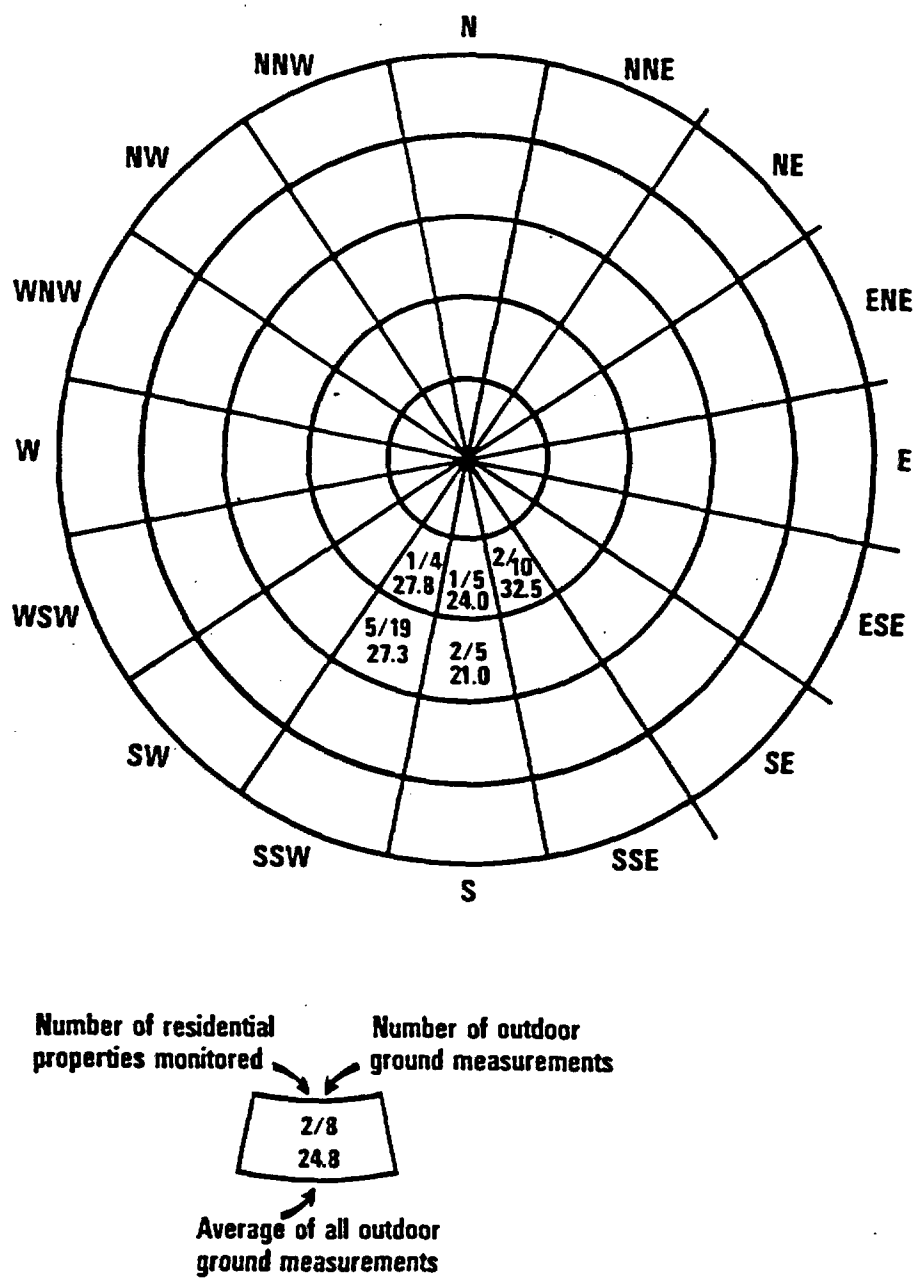

Figure 4. Average Outdoor Ground Survey Exposure Rates in μR/h by Sector, in Soda Springs, Including the Number of Properties Surveyed and the Number of Measurements.

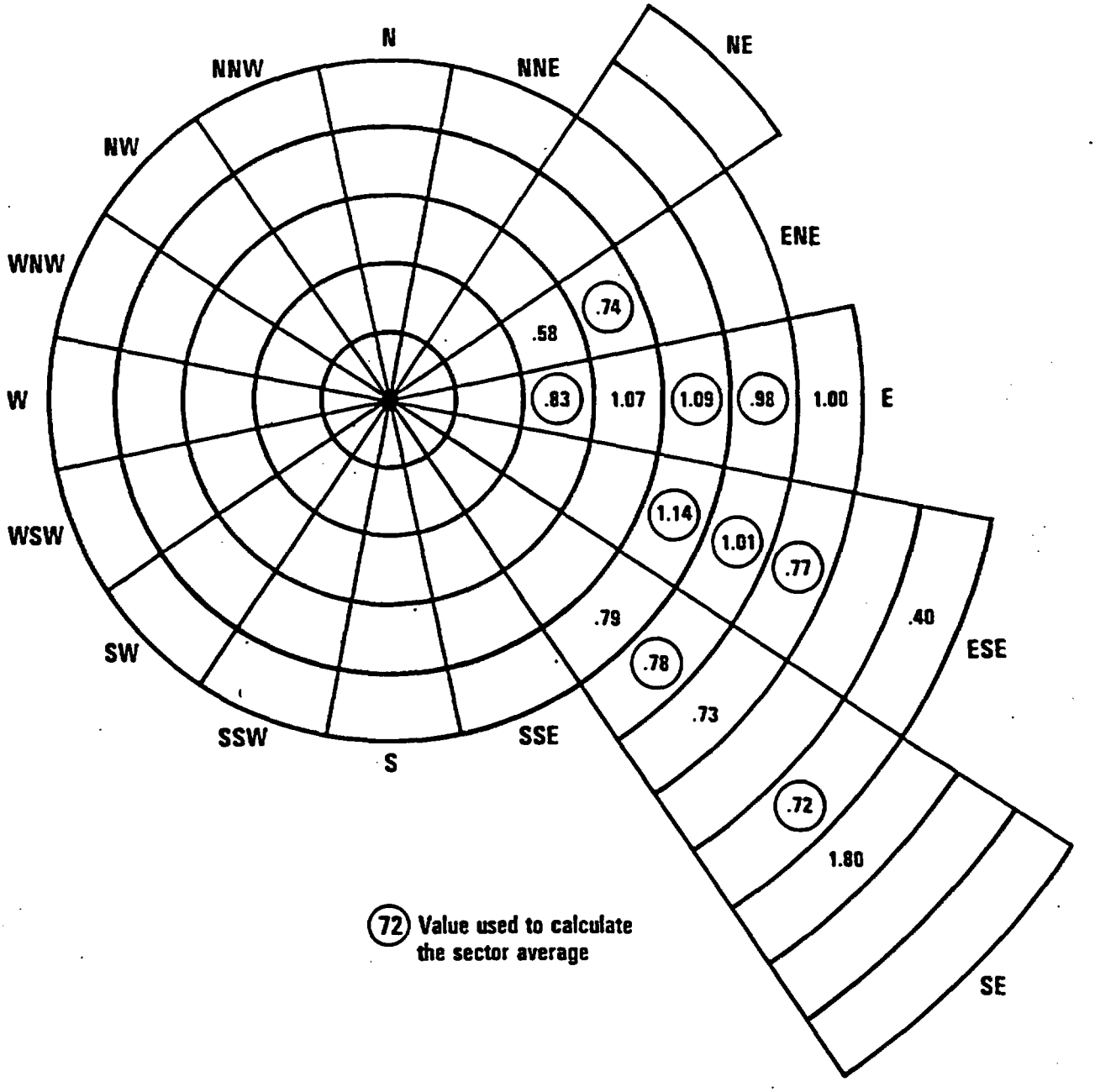

Figure 5. Ratio of Average Aerial to Ground-Based Exposure Rates in Selected Sectors of Pocatello

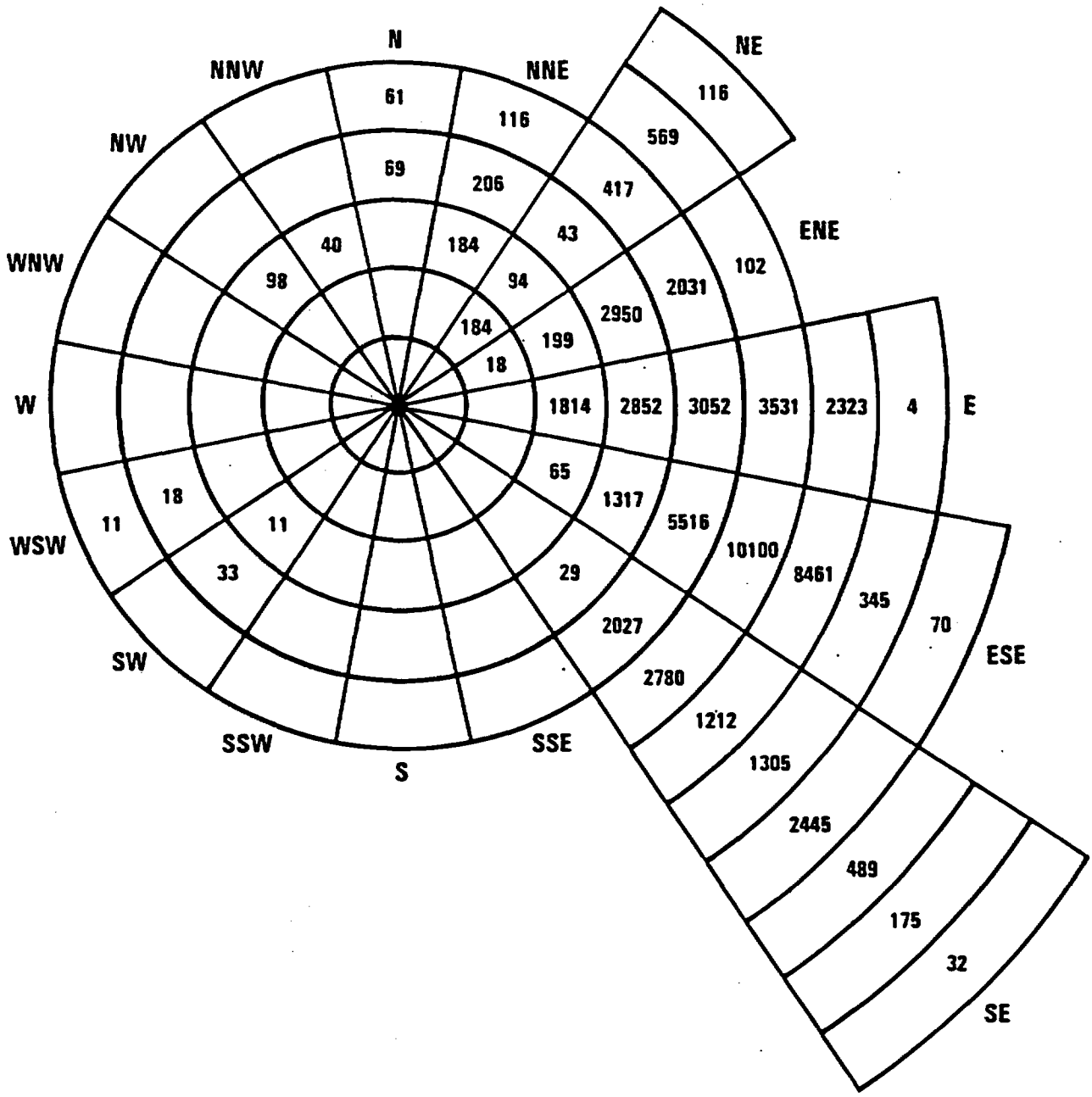

Figure 6. Estimated Pocatello Population Distribution

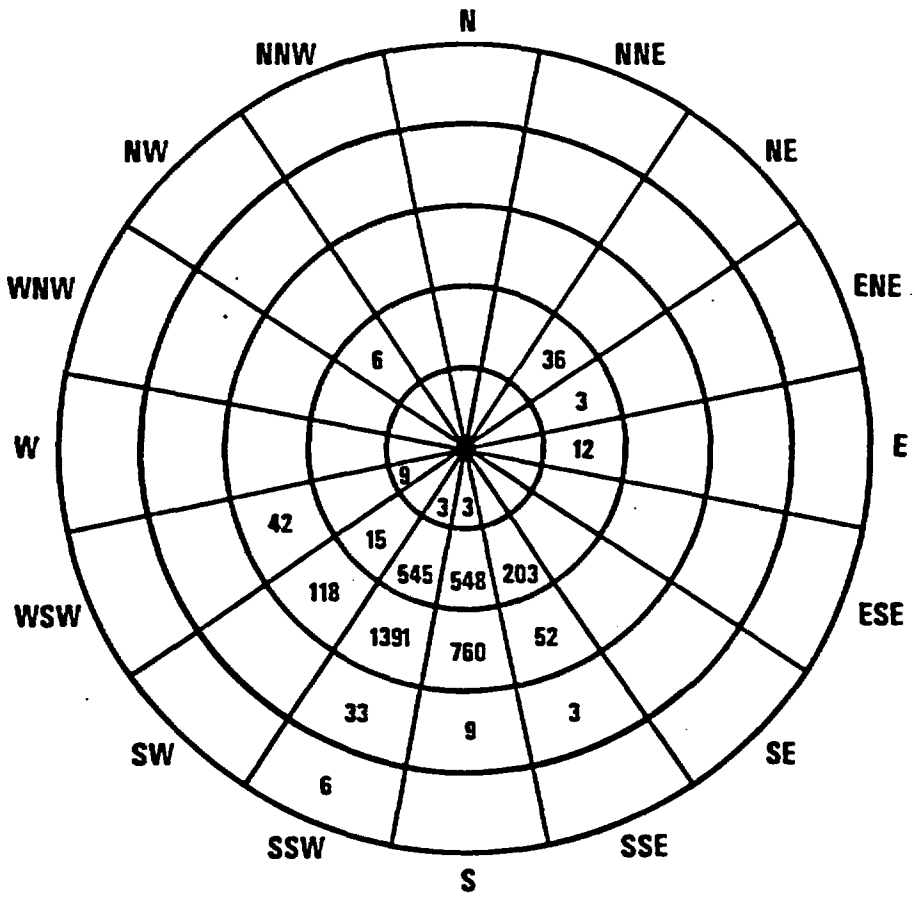

Figure 7. Estimated Soda Springs Population Distribution

observed during the survey diverged from those postulated by the scenario, and produced higher maximum individual exposures, the scenario was modified to accommodate these conditions. For example, the maximally exposed individual in Soda Springs was a teenager residing in the basement of his parent's home, which necessitated a change of scenario.

A summary of the scenarios used to determine potential radiation doses to individuals and the general population is provided in Table 3.

All residents (including those subjected to maximum exposures) were exposed 8000 h/yr in their respective communities. During the remaining 760 h/yr, the residents were assumed to be away from the communities and exposed only to background radiation.

2. Exposed Population

In general, the residents of Pocatello and Soda Springs were found to be exposed to gamma radiation, to varying degrees, during their daily activities; at their places of business; in and around their homes and property; and in the streets and sidewalks making up their neighborhood and the community.

The communities were divided into radial grids centered on the main stacks at the elemental phosphorus plants within each of the communities. The grids were composed of radial sectors in the 16 primary compass directions further subdivided at 1.6 kilometer (one mile) intervals.

To include all of the urban residential population in the Pocatello area, the one-mile sectors extended to 12 miles in the SE direction and to 9 miles in other directions. However, in Soda Springs none of the sectors had to be extended beyond five miles from the central point to include essentially all of the population.

The populations of individual sectors were calculated on the basis of the number of dwellings in each sector, as determined from 1986 aerial photographs, the 1980 census, and the County and City Data Book, 1988, U.S. Department of Commerce, Bureau of the Census. The total number of residents, according to these sources, was approximately 57,000 for Pocatello (including Chubbuck) and 3800 for Soda Springs.

In calculating maximum individual exposures the scenario included personnel employed by the phosphorus industry, as well as other non-phosphorus industry occupations.

TABLE 3. Assumed Exposure Conditions for Individuals in Pocatello and Soda Springs

Exposure Location	Exposure Period (h/yr)				Exposure Conditions (net exposure rate based on)
Exposure Location	Adult[1]	Teen[2]	Child[3]	Infant	
Home					
main floor	4300	4300	4300	6300	ground survey
basement	700	700	700	700	ground survey
Driveway*	200	400	400	0	ground survey average**
Sector	400	1000	1600	500	sector aerial survey avg+
Community	400	1600	1000	500	community aerial survey avg++
Work Place	2000	0	0	0	aerial survey average++

1 Adult: Employed adults, for purposes of scenario.
2 Teen: Individuals aged 13-19 years. For scenario purposes this group also includes adults in home occupations.
3 Child: Individuals of 5-12 years of age.

* Includes observed measurements for driveway, sidewalk, and street for each individual property surveyed at ground level.

** Average of driveway, sidewalk, and street readings for each individual property.

\+ Modified by ratio of average ground survey data within the sector (if greater than 20 outdoor measurements were available in that sector) to average aerial survey data within the sector. If fewer than 20 outdoor measurements were available in a sector, the modifier was the ratio of the average ground data for the community to the average aerial data for the community. The results were corrected further to correspond to PIC exposure rates, a standard for human exposure calculations.

++ Modified by ratio of average ground survey data (outdoor measurements only) for community to average aerial survey data within community. Adjustments to PIC exposure rates were made.

D. Gamma Radiation Exposure Estimates

This section provides a summary of the methods used and a listing of the steps taken to estimate the gamma radiation doses that could potentially be received by individual residents and the general population of Pocatello and Soda Springs.

External radiation doses have been estimated from the results of aerial and ground-based gamma radiation surveys. The measured exposure rates were reported in units of μR/h (0.001 mR/h), and the resulting exposure estimates were expressed in mR (milliroentgen). Although the exposure estimates were in mR, the calculated doses reported here are in dose equivalent units (mrem) to allow comparison with dose equivalents reported elsewhere in this document. Although the radiation exposure conditions in the environment (multi-energy radiation field) may differ considerably from the calibration conditions (gamma ray photons from a single or perhaps a few radioisotopes in air), the conversion factor relating mrem to mR is assumed to be "1.0" throughout this report. In this way it is possible to compare doses from other sources and from internal exposure (such as from inhalation or ingestion of radionuclides).

1. Selection of Exposure Rate Data

Aerial measurements generally were used to estimate outdoor gamma radiation exposures. That is, the aerial survey data, averaged for each sector, were multiplied by the ratio of ground-to-aerial survey data averaged within each sector, if greater than 20 outdoor measurements were available in a sector. Otherwise, aerial survey data for each sector was multiplied by the ratio of ground-to-aerial survey data averaged for the community as a whole. In either case, the resultant outdoor exposure rates for each sector were adjusted to correspond to PIC measurements, as previously explained.

Ground survey measurements were used to characterize exposure rates in the home environs (main floors, basements, and driveways) throughout the communities at large. No adjustment to PIC values were required for main floors and basements, since the values obtained during the survey were PIC readings. For driveways, sidewalks and streets surveyed with scintillometers, appropriate adjustments were made using the regression equation following Table 2.

Workplace exposures in Pocatello and Soda Springs were estimated by using both methods described above. Aerial survey data and aerial/ground ratios were employed for adult employees

in outdoor occupations*, distributed by sectors throughout both communities proportionately to the general population. For indoor occupations, employed adults were assumed to be exposed to the same distribution of exposure rates that were encountered in homes (main floors) during the ground survey.

2. Outline of Estimation Methods

The following assumptions were made in calculating indoor exposures to the residents of the various sectors:

- The ground surveys of main floor and basement exposure rates in both Pocatello and Soda Springs were representative of the conditions in these communities. The numbers of main floors and basements within specific exposure rate ranges, in the survey samples, correspond to similar distributions in the communities at large.

- Workers employed in indoor occupations were subjected to exposure rates following the same distribution as estimated for the communities at large, based on the ground survey, as above.

- For maximally exposed individuals, the "worst case" combinations of maximum exposure rates in the basement, main floor, and work place were projected, based on the ground survey. Conditions uncovered during the survey that would lead to higher individual exposures were also included in the estimate, even if only single instances of such somewhat unusual conditions were recorded, such as the case of a college student living in the basement of his parents' home, with exposure rates substantially in excess of background levels. Accordingly, an alternate scenario to that of Table 3 was developed, for a teenager spending 4300 hours in the basement and 700 hours on the main floor.

- Background exposure rates for Soda Springs residences were 12 μR/h; for Pocatello basements, 11 μR/h; and for Pocatello main floors, 10.5 μR/h, based on ground survey data.

- Each residence surveyed included an adult employed outside the home, an adult or teen not employed outside the home, a child of elementary school age, and a pre-school infant, for purposes of maximum individual exposure estimates.

* Farming and outdoor manufacturing, with number of workers estimated on the basis of the 1988 County and City Data Book, U.S. Department of Commerce.

Similar assumptions were made in calculating outdoor exposures:

- The ground survey "driveways" (the average of driveways, sidewalks, and streets) in both communities were representative of the conditions in the communities at large. The numbers of "driveways" within specific exposure rate ranges correspond to similar distributions in Pocatello and Soda Springs.

- Workers employed in outdoor occupations were apportioned among the various sectors proportionately to the population distribution in both communities, and assumed to be subject to the same exposure rates as previously calculated for those sectors.

- Maximum individual exposures from the driveway, the sector, the community and an outdoor occupation were estimated on the basis of a "worst case" combination of the corresponding exposure rates, and projected to occur to individuals subject to maximum rates in the basements and main floors of their homes. Conditions that would lead to higher individual exposures were also included in the estimate, even if the number of individuals subjected to such exposure rates could not be determined. Exposure rates up to 65 μR/h were expected (based on survey data) for phosphorus industry workers, railroad yard workers, and airline service/ maintenance crews.

- Background outdoor exposure rates for Pocatello and Soda Springs were 12 μR/h.

3. Quality Assurance

The following steps were taken to assure quality and continuity in deriving the gamma radiation dose estimates as part of the overall study effort:

- Contractor and EPA personnel evaluated reasonableness of EG&G aerial survey results by comparing them to ground survey data.

- The PNL Project Manager, and EPA staff from the Office of Radiation Programs in Washington, DC, and the Las Vegas Facility developed exposure scenarios.

- Staff reviewed the field survey (ground-level) data to assure consistency between instruments.

- The ground and aerial survey data were converted to the same radial grids as the population data.

- The survey instruments used were calibrated with NIST (formerly National Bureau of Standards) traceable standards.

4. Gamma Radiation Dose Estimates

Table 4 divides the various age groups in Soda Springs into subgroups, based on the net gamma radiation levels to which they are exposed in their home environs. These exposure levels correspond to the distribution of gamma rates measured on main floors, basements and "driveways" during the Soda Springs home survey. It should be noted that "driveway" exposure rates average gamma measurements made on the driveway, the sidewalk and the street adjoining each residence included in the survey.

The durations of exposure for the various population groupings at the locations of interest were postulated in Table 3. The products of these time intervals and the net exposure rates in Table 4 result in Table 5, a tabulation of annual exposures, in excess of natural background, to which the groups under discussion were subjected. To facilitate future risk projections, the exposure borne by each group was expressed as a "population dose", i.e. by multiplying said exposure, in terms of "equivalent dose" (in rem) by the number of people in the group. The last column in Table 5 represents the sum of population doses for members of all age groups subjected to specific exposure levels, in a given location in or around the home. The sum of the entries in this column, 131 person-rem, represents the total population dose borne by the inhabitants of Soda Springs solely due to residing in their homes.

Similar considerations apply to the calculation of exposure and doses in the outdoor environment, here described in terms of "sector" and community average values. Given the exposure durations postulated by Table 3, varying for each age group, population exposures and doses in individual Soda Springs sectors would depend on the composition of the population of each sector, as summarized in Table 6. The corresponding sector exposure rates are based on the aerial survey values in Figure 2, modified by the aerial/ground ratios in Table 2, adjusted to PIC values by the subsequent regression equation, and reduced to net exposure rates by subtracting the environmental background (12 μR/h). Net community average exposure rates for Soda Springs are those calculated previously for Table 2, or 7.8 μR/h. Table 7 lists the net exposure rates, per sector, for the population of Soda Springs, and the corresponding net community exposure rates, to which all Soda Springs inhabitants are subjected equally, regardless of the sector in which they reside.

The durations of exposure to sector and community net gamma levels were given, by age group, in Table 3. The products of these time intervals, the population groups in Table 6, and net sector and community rates in Table 7 yield the annual exposures,

TABLE 4. POPULATION DISTRIBUTION BY NET EXPOSURE RATE[1] AND AGE GROUPS[2] IN HOME ENVIRONS (FIRST FLOOR, BASEMENT, DRIVEWAY) FOR SODA SPRINGS

Net Exposure Rate (μR/h)	Number of Employed Adults	Number of Teens	Number of Children	Number of Infants
FIRST FLOOR				
0	440	335	146	105
3.2	425	323	140	101
6.8	343	261	113	81
11.0	425	323	140	101
BASEMENT				
0	293	223	97	69
2.4	572	435	189	136
8.4	196	149	65	47
25.6	474	360	156	113
38.0	98	75	32	23
DRIVEWAY				
0	163	124	54	0
2.3	245	186	81	0
7.1	408	311	135	0
13.8	245	186	81	0
17.9	408	311	135	0
22.5	163	124	54	0

1 Tabulated exposure rates represent range averages.

2 The number of individuals in each age group is based on Bureau of Census data. Their further distribution among exposure rate ranges is based on the ground survey.

TABLE 5. ANNUAL POPULATION EXPOSURE, IN PERSON-REM, BY AGE GROUPS IN HOME ENVIRONS (FIRST FLOOR, BASEMENT, DRIVEWAY) FOR SODA SPRINGS

Net Exposure Rate μR/Hr	Exposure (Dose) Employed Adults	Teens	Children	Infants	Sum of Exposure
FIRST FLOOR					
0	0	0	0	0	0
3.2	5.86	4.46	1.93	2.04	14.29
6.8	10.02	7.62	3.30	4.27	25.21
11.0	20.10	15.28	6.62	7.00	49.00
BASEMENT					
0	0	0	0	0	0
2.4	0.97	0.74	0.32	0.23	2.26
8.4	1.16	0.88	0.38	0.28	2.70
25.6	8.48	6.44	2.79	2.03	19.74
38.0	2.61	2.00	0.85	0.60	6.06
DRIVEWAY					
0	0	0	0	0	0
2.3	0.12	0.17	0.07	0	0.36
7.1	0.57	0.87	0.38	0	1.82
13.8	0.69	1.02	0.44	0	2.15
17.9	1.47	2.24	0.97	0	4.68
22.5	0.73	1.12	0.49	0	2.34
Grand Total					130.61

TABLE 6. COMPOSITION OF POPULATION IN SECTORS BY AGE GROUPS FOR SODA SPRINGS

Sector	Population in Sector	Population of: Employed Adults In Sector	Teens in Sector	Children in Sector	Infants in Sector
NE2	36	15	12	5	4
ENE2	3	1	1	1	0
E2	12	5	4	2	1
SSE2	203	87	67	28	21
SSE3	52	22	17	7	6
SSE4	3	1	1	1	0
S1	3	1	1	1	0
S2	548	236	181	77	54
S3	760	327	251	106	76
S4	9	4	3	1	1
SSW1	3	1	1	1	0
SSW2	545	234	180	76	55
SSW3	1391	598	459	195	139
SSW4	33	14	11	5	3
SSW5	6	3	2	1	0
SW2	15	6	5	2	2
SW3	118	51	39	17	11
WSW1	9	4	3	1	1
WSW3	42	18	14	6	4
NW2	6	3	2	1	0

TABLE 7. NET EXPOSURE RATES IN EACH SECTOR AND IN COMMUNITY FOR SODA SPRINGS (μR/h)

Sector	Net Exposure Rate in Each Sector (μR/h)	Net Exposure Rate in Community (μR/h)
NE2	5.1	7.8
ENE2	4.4	7.8
E2	4.4	7.8
SSE2	9.1	7.8
SSE3	3.8	7.8
SSE4	4.4	7.8
S1	11.6	7.8
S2	6.5	7.8
S3	10.4	7.8
S4	3.7	7.8
SSW1	4.4	7.8
SSW2	5.5	7.8
SSW3	7.2	7.8
SSW4	2.6	7.8
SSW5	2.6	7.8
SW2	2.6	7.8
SW3	5.4	7.8
WSW1	3.7	7.8
WSW3	4.7	7.8
NW2	4.4	7.8

by age group and sector, for the residents of Soda Springs. Table 8 expresses the resultant values in terms of population dose, i.e. in "person-rem" for direct application in risk estimates. The Soda Springs population dose from outdoor activities beyond the home environs is calculated by summing the values in the last columns in Table 8, which total 48 person-rem.

Table 9 describes the workplace exposures for Soda Springs adults engaged in outdoor occupations. The basic assumption implicit in the tabulated values is that outdoor exposures incurred during work hours do not differ from exposures during other outdoor activities. Thus Table 9 follows the format of Table 7, in terms of net exposure rates, per sector, borne by 28% of the employed adults in the corresponding sector. The resulting exposures are expressed in terms of equivalent dose times the number of exposed adults, per sector, yielding a total of 6.6 person-rem.

Table 10 describes workplace exposures for Soda Springs adults in indoor occupations. Indoor workplace exposure rates are assumed not to differ from the main floor rates observed during the Soda Springs survey. Thus Table 10 employs the same exposure rate distributions as originally listed for Table 4 "First Floor" values, with the corresponding number of exposed employed adults reduced to 72%. The total population dose for indoor workers in Soda Springs amounts to 12.1 person-rem.

The sum of population doses for the various environments and age groups covered in Tables 5,8,9, and 10 results in a total population dose of 197 person-rem, incurred annually by the approximately 3800 residents of Soda Springs. This represents an average dose, per resident, of 52 mrem/yr above background.

Tables 11 through 17 provide the corresponding population and exposure (dose) data for Pocatello. The population dose due to exposures in the Pocatello area home environs is 328 person-rem, as shown in Table 12, and that from outdoor activities is 385 person-rem, in Table 15. Workplace exposures due to outdoor occupations add a total of 62 person-rem to the population dose, as seen in Table 16, and indoor occupations contribute an additional dose of 27 person-rem, in Table 17.

The sum of population doses for the various environments and age groups covered in tables 12,15,16 and 17 results in a total population dose of 803 person-rem, incurred annually by the approximately 57,000 residents of Pocatello. This represents an average dose, per resident, of 14 mrem/year above background.

TABLE 8. ANNUAL OUTDOOR EXPOSURE, IN PERSON-REM, BY AGE GROUP FOR SODA SPRINGS

Sector	Exposure (Dose) in Sector and Community: Employed Adults	Teens	Children	Infants	Sum of Outdoor Exposure
NE2	0.08	0.21	0.08	0.02	0.39
ENE2	0	0.02	0.02	0	0.04
E2	0.02	0.07	0.03	0.01	0.13
SSE2	0.59	1.45	0.63	0.17	2.84
SSE3	0.10	0.28	0.10	0.03	0.51
SSE4	0	0.02	0.02	0	0.04
S1	0.01	0.02	0.03	0	0.06
S2	1.35	3.44	1.40	0.38	6.57
S3	2.38	5.74	2.59	0.70	11.41
S4	0.02	0.05	0.01	0.01	0.09
SSW1	0	0.02	0.02	0	0.04
SSW2	1.24	3.24	1.26	0.37	6.11
SSW3	3.59	9.03	3.77	1.04	17.43
SSW4	0.06	0.17	0.06	0.01	0.30
SSW5	0.01	0.03	0.01	0	0.05
SW2	0.02	0.08	0.02	0.01	0.13
SW3	0.27	0.70	0.28	0.07	1.32
WSW1	0.02	0.05	0.01	0.01	0.09
WSW2	0.09	0.24	0.09	0.03	0.45
NW2	0.01	0.03	0.02	0	0.06
Grand Total					48.06

TABLE 9. WORKPLACE EXPOSURES FOR ADULTS EMPLOYED 2000* HOURS IN OUTDOOR OCCUPATIONS, IN SODA SPRINGS

Sector	Net Exposure Rate Workplace, Outdoors (μR/h)	No. of Employed Adults Exposed	Employed Adult Exposure (person-rem)
NE2	5.1	4	0.041
ENE2	4.4	1	0.009
E2	4.4	1	0.009
SSE2	9.1	24	0.437
SSE3	3.8	6	0.046
SSE4	4.4	1	0.009
S1	11.6	1	0.002
S2	6.5	65	0.845
S3	10.4	90	1.872
S4	3.7	1	0.007
SSW1	4.4	1	0.009
SSW2	5.5	65	0.715
SSW3	7.2	165	2.376
SSW4	2.6	4	0.021
SSW5	2.6	1	0.005
SW2	2.6	2	0.010
SW3	5.4	14	0.151
WSW1	3.7	1	0.007
WSW3	4.7	5	0.019
NW2	4.4	1	0.009
			6.599

* 40 hours per week, 50 weeks per year, totaling 2000 hours per year.

TABLE 10. WORKPLACE EXPOSURES FOR ADULTS EMPLOYED 2000 HOURS IN INDOOR OCCUPATIONS, IN SODA SPRINGS

Net Exposure Rate Workplace, Indoors (μR/h)	No. of Employed Adults Exposed	Employed Adult Exposure (person-rem)
0	319	0
3.2	307	1.96
6.8	248	3.37
11.0	307	6.75
Grand Total		12.08

TABLE 11. POPULATION DISTRIBUTION BY NET EXPOSURE RATE AND AGE GROUPS IN HOME ENVIRONS (FIRST FLOOR, BASEMENT, DRIVEWAY) FOR POCATELLO

Net Exposure Rate (μR/h)	Number of Employed Adults	Number of Teens	Number of Children	Number of Infants
FIRST FLOOR				
0	9802	5841	2946	2113
0.5	10074	6003	3031	2170
1.5	5173	3082	1557	1115
2.6	1361	812	410	293
3.2	545	325	164	117
5.3	272	163	83	58
BASEMENT				
0	10890	6490	3277	2347
0.5	9802	5841	2949	2112
1.5	3811	2272	1147	822
2.4	2178	1298	655	470
7.4	545	325	164	117
DRIVEWAY				
0	2454	1458	734	0
0.6	4356	2596	1311	0
2.1	5989	3570	1802	0
4.0	2178	1298	655	0
7.7	1633	974	491	0
10.1	2178	1298	655	0
13.5	3811	2272	1147	0
16.4	1361	812	410	0
19.1	2450	1460	738	0
24.9	272	163	83	0
27.8	272	163	83	0
36.6	272	163	83	0

TABLE 12. ANNUAL POPULATION EXPOSURE, IN PERSON-REM, BY AGE GROUPS IN HOME ENVIRONS (FIRST FLOOR, BASEMENT, DRIVEWAY) POCATELLO

Net Exposure Rate μR/Hr	Exposure (Dose) Employed Adults	Teens	Children	Infants	Sum of Exposure
FIRST FLOOR					
0	0	0	0	0	0
0.5	21.66	12.91	6.52	6.83	47.92
1.5	33.36	19.88	10.04	10.54	73.82
2.6	15.22	9.08	4.58	4.80	33.68
3.2	7.50	4.43	2.26	2.36	16.55
5.3	6.20	3.71	1.89	1.94	13.74
BASEMENT					
0	0	0	0	0	0
0.5	3.43	2.04	1.03	0.74	7.24
1.5	4.00	2.39	1.20	0.86	8.45
2.4	3.66	2.18	1.10	0.79	7.73
7.4	2.82	1.68	0.85	0.61	5.96
DRIVEWAY					
0	0	0	0	0	0
0.6	0.44	0.52	0.26	0	1.22
2.1	2.39	2.86	1.44	0	6.69
4.0	1.74	2.08	1.05	0	4.87
7.7	2.45	3.02	1.52	0	6.99
10.1	4.36	5.19	2.62	0	12.17
13.5	10.29	12.27	6.19	0	28.75
16.4	4.49	5.36	2.71	0	12.56
19.1	9.31	11.10	5.60	0	26.01
24.9	1.36	1.63	0.83	0	3.82
27.8	1.52	1.81	0.92	0	4.25
36.6	1.99	2.38	1.21	0	5.58
Grand Total					328.00

TABLE 13. COMPOSITION OF POPULATION IN SECTORS BY AGE GROUPS FOR POCATELLO AREA

Sector	Population in Sector	Population: Employed Adults In Sector	Population: Teens in Sector	Population: Children in Sector	Population: Infants in Sector
N4	69	33	17	10	9
N5	61	29	17	9	6
NNE3	184	88	51	27	18
NNE4	206	98	57	29	22
NNE5	116	55	33	17	11
NE2	184	88	51	27	18
NE3	94	44	25	14	11
NE4	43	20	13	6	4
NE5	417	197	118	60	42
NE6	569	55	160	81	273
NE7	116	9	33	17	57
ENE2	18	9	5	3	1
ENE3	199	94	57	28	20
ENE4	2950	1396	834	419	301
ENE5	2031	960	575	288	208
ENE6	102	48	29	14	11
E3	1814	857	513	258	186
E4	2852	1349	808	405	290
E5	3052	1444	864	433	311
E6	3531	1670	998	502	361
E7	2323	1099	657	330	237
E8	4	3	1	0	0
ESE3	65	30	19	9	7
ESE4	1317	622	373	187	135
ESE5	5516	2609	1560	784	563
ESE6	10100	4778	2859	1434	1029
ESE7	8461	4002	2394	1201	864
ESE8	345	164	97	50	34
ESE9	70	33	19	10	8
SE4	29	14	9	4	2
SE5	2027	959	573	288	207
SE6	2780	1314	787	395	284
SE7	1212	573	344	171	124
SE8	1305	617	370	185	133
SE9	2445	1157	692	347	249
SE10	489	231	138	70	50
SE11	175	83	50	25	17
SE12	32	15	8	5	4
SW3	11	5	4	1	1
SW4	33	15	9	5	4
WSW4	18	9	5	3	1
WSW5	11	5	4	1	1

TABLE 14. NET EXPOSURE RATES IN EACH SECTOR AND IN COMMUNITY FOR POCATELLO AREA (μR/h)

Sector	Net Exposure Rate in Each Sector (μR/h)	Net Exposure Rate in Community (μR/h)
N4	1.5	4.6
N5	1.3	4.6
NNE3	2.1	4.6
NNE4	0.8	4.6
NNE5	1.5	4.6
NE2	3.2	4.6
NE3	1.7	4.6
NE4	1.3	4.6
NE5	2.2	4.6
NE6	2.6	4.6
NE7	1.8	4.6
ENE2	3.7	4.6
ENE3	3.5	4.6
ENE4	6.9	4.6
ENE5	5.0	4.6
ENE6	1.9	4.6
E3	5.7	4.6
E4	4.9	4.6
E5	2.9	4.6
E6	3.3	4.6
E7	5.6	4.6
E8	2.8	4.6
ESE3	3.6	4.6
ESE4	3.9	4.6
ESE5	1.4	4.6
ESE6	2.3	4.6
ESE7	4.2	4.6
ESE8	3.5	4.6
ESE9	2.9	4.6
SE4	2.0	4.6
SE5	2.3	4.6
SE6	6.1	4.6
SE7	3.4	4.6
SE8	4.2	4.6
SE9	7.4	4.6
SE10	4.1	4.6
SE11	2.1	4.6
SE12	1.6	4.6
SW3	2.8	4.6
SW4	1.0	4.6
WSW4	1.6	4.6
WSW5	1.3	4.6
NW3	1.3	4.6
NNW3	1.4	4.6

TABLE 15. ANNUAL OUTDOOR EXPOSURE, IN PERSON-REM, BY AGE GROUP FOR POCATELLO AREA

Sector	Exposure (Dose) in Sector and Community: Employed Adults	Teens	Children	Infants	Sum of Outdoor Exposure
N4	0.08	0.15	0.07	0.03	0.33
N5	0.07	0.15	0.06	0.02	0.30
NNE3	0.24	0.48	0.21	0.06	0.99
NNE4	0.21	0.47	0.17	0.06	0.91
NNE5	0.13	0.29	0.12	0.03	0.57
NE2	0.27	0.54	0.26	0.07	1.14
NE3	0.11	0.23	0.10	0.03	0.47
NE4	0.05	0.11	0.04	0.01	0.21
NE5	0.54	1.13	0.49	0.14	2.30
NE6	0.16	1.59	0.71	0.98	3.44
NE7	0.02	0.30	0.13	0.18	0.63
ENE2	0.03	0.06	0.03	0.00	0.12
ENE3	0.30	0.62	0.29	0.08	1.29
ENE4	6.42	11.89	6.55	1.73	26.59
ENE5	3.69	7.11	3.63	0.99	15.42
ENE6	0.12	0.27	0.11	0.04	0.54
E3	3.53	6.70	3.54	0.96	14.73
E4	5.13	9.91	5.04	1.38	21.46
E5	4.33	8.86	4.00	1.17	18.36
E6	5.28	10.64	4.96	1.42	22.30
E7	4.48	8.51	4.47	1.21	18.67
E8	0.01	0.01	0	0	0.02
ESE3	0.10	0.21	0.09	0.03	0.43
ESE4	2.11	4.20	2.03	0.57	8.91
ESE5	6.26	13.67	5.36	1.69	26.98
ESE6	13.19	27.62	11.87	3.55	56.23
ESE7	14.09	27.67	13.60	3.80	59.16

TABLE 15. ANNUAL OUTDOOR EXPOSURE, IN PERSON-REM, BY AGE GROUP FOR POCATELLO AREA (continued)

Sector	Exposure (Dose) in Sector and Community				Sum of Outdoor Exposure
	Employed Adults	Teens	Children	Infants	
SE4	0.04	0.08	0.03	0.01	0.16
SE5	2.65	5.54	2.38	0.71	11.28
SE6	5.62	10.59	5.67	1.52	23.40
SE7	1.83	3.70	1.72	0.50	7.75
SE8	2.17	4.28	2.09	0.59	9.13
SE9	5.55	10.21	5.70	1.49	22.95
SE10	0.80	1.58	0.78	0.22	3.38
SE11	0.22	0.47	0.20	0.06	0.95
SE12	0.04	0.07	0.04	0.01	0.16
SW3	0.01	0.04	0.01	0.00	0.06
SW4	0.03	0.08	0.03	0.01	0.15
WSW4	0.02	0.05	0.02	0.00	0.09
WSW5	0.01	0.03	0.01	0.00	0.05
NW3	0.11	0.24	0.09	0.03	0.47
NNW3	0.05	0.10	0.03	0.01	0.19
Grand Total					385.31

TABLE 16. WORKPLACE EXPOSURES FOR ADULTS EMPLOYED 2000 HOURS IN OUTDOOR OCCUPATIONS, IN POCATELLO

Sector	Net Exposure Rate Workplace, Outdoors (μR/h)	No. of Employed Adults Exposed	Employed Adult Exposure (person-rem)
N4	1.5	10	0.030
N5	1.3	9	0.023
NNE3	2.1	26	0.109
NNE4	0.8	29	0.046
NNE5	1.5	16	0.048
NE2	3.2	26	0.166
NE3	1.7	13	0.044
NE4	1.3	7	0.018
NE5	2.2	59	0.260
NE6	2.6	81	0.421
NE7	1.8	16	0.058
ENE2	3.7	2	0.015
ENE3	3.5	29	0.023
ENE4	6.9	419	5.782
ENE5	5.0	288	2.880
ENE6	1.9	15	0.057
E3	5.7	257	2.930
E4	4.9	405	3.969
E5	2.9	434	2.517
E6	3.3	502	3.313
E7	5.6	330	3.696
E8	2.8	1	0.006
ESE3	3.6	9	0.065
ESE4	3.9	187	1.459
ESE5	1.4	783	2.192
ESE6	2.3	1434	6.596
ESE7	4.2	1202	10.097
ESE8	3.5	49	0.343
ESE9	2.9	10	0.058
SE4	2.0	4	0.016
SE5	2.3	288	1.325
SE6	6.1	395	4.819
SE7	3.4	172	1.170
SE8	4.2	185	1.554
SE9	7.4	347	5.136
SE10	4.1	69	0.566
SE11	2.1	24	0.101
SE12	1.6	5	0.016
SW3	2.8	2	0.011
SW4	1.0	5	0.010
WSW4	1.6	2	0.006
WSW5	1.3	2	0.005
W3	1.3	14	0.036
NW3	1.4	6	0.014

TABLE 17. WORKPLACE EXPOSURES FOR ADULTS EMPLOYED 2000 HOURS IN INDOOR OCCUPATIONS, IN POCATELLO

Net Exposure Rate Workplace, Indoors (μR/h)	No. of Employed Adults Exposed	Employed Adult Exposure (person-rem)
0	6862	0
0.5	7052	7.05
1.5	3621	10.86
2.6	952	4.95
3.2	381	2.44
5.3	190	2.01
Grand Total		27.31

E. Summary and Results

Table 18 is a summary of net population doses in Soda Springs by age group and exposure scenario. The most significant dose is that received by employed adults and the dominant exposure environment is the home (main floor and basement).

Table 19 is a similar summary of net population doses in the Pocatello area. The most significant dose is again that received by employed adults, with workplace exposure being the leading contributor. The dominant exposure environment is no longer the home, but the sector (immediate vicinity beyond the home environs) and the community at large.

The primary source of gamma radiation in both Pocatello and Soda Spring is radioactive slag, a residue from phosphate industry processes. The observations summarized in Tables 18 and 19 are compatible with the different uses found for this residual slag, in the two communities. In Soda Springs, radioactive slag was used in some home foundations, while in Pocatello it was repeatedly used in paving streets.

Table 20 relates the total population doses of Tables 18 and 19 and equates them to annual risk rates, in terms of cancer deaths per year in each community. These risk rates were based on the expectation that a population dose of 1,000,000 person-rem would result in roughly 400 cancer deaths per year, as derived from Hiroshima - Nagasaki data and other sources.

Tables 21 and 22 summarize the net gamma dose calculations for average and maximally exposed individuals in Pocatello and Soda Springs, respectively. The calculations for Pocatello are based on a hypothetical combination of maximum exposures in home environs, sector, community, and workplace. The resultant annual dose of 145 mrem corresponds to a fatal cancer risk of 0.00006 per year for the hypothetical maximally exposed individual, an employed adult. Based on the commonly accepted projection of 70 years under these conditions, this yearly risk represents a potential 0.004 lifetime risk to the individual in question.

This yearly dose to the maximally exposed individual in Soda Springs is based on a scenario noted during the home survey. A teenager having a basement bedroom who also spends time studying and watching television in the basement recreation room would occupy the basement 4300 hours annually, and spend only 700 hours on the first floor. His yearly dose is 205 mrem, corresponding to a fatal cancer risk of 0.00008 per year. If the subject individual were to maintain this lifestyle for 70 years, his lifetime risk would amount to 0.006 (Table 21).

A more likely scenario for potential lifetime exposure is that of the employed adult in Soda Springs, subjected to a hypothetical combination of maximum exposures in home environs, sector, community, and workplace. The resultant annual dose of 191 mrem corresponds to a lifetime risk of 0.005.

TABLE 18. SUMMARY NET POPULATION DOSES, IN PERSON-REM, BY AGE AND ACTIVITY GROUP, FOR SODA SPRINGS

Location	Employed Adults	Teenagers and non-employed Adults	Children	Infants	Total by Exposure Elements
Main Floor	35.98	27.36	11.85	13.32	88.51
Basement	13.22	10.06	4.35	3.14	30.77
Driveway	3.58	5.42	2.35	0	11.35
Sector	4.80	9.21	6.46	1.39	21.86
Community	5.09	15.65	3.97	1.47	26.18
Workplace	18.70	0	0	0	18.70
Total by age group	81.37	67.69	28.99	19.32	
Grand Total					197.4

Propagated sampling error estimates for exposure rates, population and time intervals allocated to each location included in the scenario yielded an equivalent standard deviation of ± 25 person-rem, a coefficient of variance of 13%.

TABLE 19. SUMMARY OF NET POPULATION DOSES, IN PERSON-REM, BY AGE AND ACTIVITY GROUP, FOR POCATELLO

Location	Employed Adults	Teenagers and non-employed Adults	Children	Infants	Total by Exposure Elements
Main Floor	83.94	50.05	25.29	26.47	185.75
Basement	13.91	8.29	4.19	3.00	29.39
Driveway	40.34	48.21	24.37	0	112.92
Sector	41.17	61.96	49.77	11.49	164.39
Community	49.58	119.74	37.59	14.10	221.01
Workplace	89.50	0	0	0	89.50
Total by age group	318.44	288.25	141.21	55.06	
Grand Total					803.0

Propagated sampling error estimates for exposure rates, population and time intervals allocated to each location included in the scenario yielded an equivalent standard deviation of ± 329 person-rem, a coefficient of variance of 41%.

TABLE 20. YEARLY RISK FOR THE POPULATIONS OF POCATELLO AND SODA SPRINGS

Community	Annual Population Dose (person-rem)	Annual Population Risk
Pocatello	803 ± 329	0.3 deaths/year among 57,000 people
Soda Springs	197 ± 25	0.1 deaths/year among 3,800 people

TABLE 21. CALCULATED NET GAMMA-RAY DOSES (mrem/yr) TO AVERAGE INDIVIDUALS IN POCATELLO AND SODA SPRINGS

Community	Average Individual Annual Dose (millirem/year)	Lifetime Risk
Pocatello	14 ± 6	0.0004
Soda Springs	52 ± 7	0.0014

TABLE 22. CALCULATED NET GAMMA-RAY DOSES (mrem/yr) TO MAXIMALLY EXPOSED INDIVIDUALS IN POCATELLO AND SODA SPRINGS

Community	Maximum Annual Individual Dose	Lifetime Risk
Pocatello	145	0.004
Soda Springs	205	0.0056

II. DOSE AND RISK ASSESSMENT FOR AIRBORNE EMISSIONS

This section of the report estimates dose and risk from radionuclides emitted from the elemental phosphorus plants in Pocatello and Soda Springs. The section discusses the assessment methodology used, the actual parameters used, and the dose and risk resulting from airborne exposure.

A. Assessment Methodology

The Clean Air Act Assessment Package - 1988 (CAP-88) computer model was used to estimate the dose and risk resulting from radionuclide emissions to air at Pocatello and Soda Springs. CAP-88 is a set of computer programs, databases and associated utility programs that models the transport of radionuclides from the emission point through the environment to exposed human populations, and estimates the resulting dose and health impact.

1. Environmental Transport

The computer program which models environmental transport in CAP-88 is AIRDOS-EPA. This program uses a modified Gaussian plume equation to estimate the average dispersion of radionuclides released from the stack. Plume rises were calculated assuming a heated, buoyancy-driven plume. Assessments were done for a circular grid with a radius of 80 kilometers (50 miles) around each facility.

AIRDOS-EPA was used to compute radionuclide concentrations in air, rates of deposition on ground surfaces, concentrations in food and intake rates to people from inhalation of air and ingestion of food produced in the assessment area. Estimates of the radionuclide concentrations in produce, leafy vegetables, milk and meat consumed by humans were made by coupling the output of the atmospheric transport models with the U.S. Nuclear Regulatory Commission Regulatory Guide 1.109 terrestrial food chain models.

2. Estimation of Dose and Risk

The computer program RADRISK was used to estimate dose and risk conversion factors. Factors were computed for the pathways of ingestion and inhalation intake, ground level air immersion and ground surface irradiation.

Estimation of dose and risk were made by the program DARTAB, which combines the inhalation and ingestion intake rates, air and ground surface concentrations output from AIRDOS-EPA with the dose and risk conversion factors from the RADRISK database.

DARTAB computed the dose and risk to the maximum exposed individual and to the collective population. DARTAB also tabulated the number of people and number of health effects at selected levels of risk.

B. Parameters Used in the Assessment

1. Population Data

Population distributions for Pocatello and Soda Springs, Idaho, were generated with the utility program SECPOP, which uses a database of 1980 Census data. Since census enumeration districts vary widely in their size, the census database is not very precise at estimating population groups close in to the facility. The distributions were modified with supplemental data obtained from surveys of the population within 5 km. of each facility.

Facility	Number of People Within 80 km.	Distance to Maximum Exposed Individual
FMC	170,000	1.8 km
Monsanto	100,000	2.4 km

2. Agricultural Data

Distributions of beef cattle, milk cattle and the land area under cultivation for food crop production in the assessment area were generated with the utility program FOODJOB, which uses state-wide average agricultural productivity data reported for Idaho. Site-specific data was prohibitively expensive to obtain.

3. Meteorological Data

Meteorological data reported from the Pocatello airport was used for the airborne dose assessment.

4. Plume Rise

The stack effluent from the calciner plants has a significant heat content that results in a substantial buoyant plume rise. The stack parameters used were:

Facility	Stack Height	Heat Emission (calories/sec)
FMC	31 m	9.5×10^5
Monsanto	27 m	5.0×10^5

5. Source Term

The total annual emissions were estimated from monitoring performed by EPA at the calciner plants in Soda Springs and Pocatello, Idaho during 1988. The radionuclides which are major contributors to dose and risk are lead-210 (Pb-210) and polonium-210 (Po-210). The source terms used were:

Facility	Source Term, Ci/year	
	Pb-210	Po-210
FMC Pocatello	0.14	10.
Monsanto Soda Springs	0.35	1.4

C. RESULTS OF THE DOSE AND RISK ASSESSMENT FOR AIR PATHWAY

FMC POCATELLO, IDAHO

Frequency Distribution of Individual Risks

RISK	Number of People	Deaths/Year at this Risk
1 to 10^{-1}	0	0
10^{-1} to 10^{-2}	0	0
10^{-2} to 10^{-3}	0	0
10^{-3} to 10^{-4}	5029	0.01
10^{-4} to 10^{-5}	94823	0.04
10^{-5} to 10^{-6}	73778	0.009
less than 10^{-6}	0	0
Total Number of Deaths/Year:		0.06

Maximum Exposed Individual

Effective Dose Equivalent (mrem/year): 23

Lifetime Risk: 0.0006, or 6 in 10,000

MONSANTO SODA SPRINGS, IDAHO

Frequency Distribution of Individual Risks

RISK	Number of People	Deaths/Year at this Risk
1 to 10^{-1}	0	0
10^{-1} to 10^{-2}	0	0
10^{-2} to 10^{-3}	0	0
10^{-3} to 10^{-4}	0	0
10^{-4} to 10^{-5}	5247	0.002
10^{-5} to 10^{-6}	32829	0.0008
less than 10^{-6}	62550	0.0006
Total Number of Deaths/Year:		0.003

Maximum Exposed Individual

Effective Dose Equivalent (mrem/year): 4

Lifetime Risk: 0.00008, or 8 in 100,000

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