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Environmental Consequences of Postulated Radionuclide Releases from the Battelle Memorial Institute Columbus Laboratories JN-1b Building at the West Jefferson Site as a Result of Severe Natural Phenomena

J. D. Jamison
E. C. Watson

February 1982

Prepared for
Division of Environmental Impact Studies
Argonne National Laboratory
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with the U.S. Department of Energy
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Pacific Northwest Laboratory
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SUMMARY

Potential environmental consequences in terms of radiation dose to people are presented for postulated radionuclide releases caused by severe natural phenomena at the Battelle Memorial Institute Columbus Laboratories JN-1b Building at the West Jefferson site. The severe natural phenomena considered are earthquakes, tornadoes, and high straight-line winds. Maximum radioactive material deposition values are given for significant locations around the site. All important potential exposure pathways are examined. The most likely 50-year committed dose equivalents are given in Table 1 for the maximum-exposed individual and the population within a 50-mile radius of the plant. The maximum radioactive material deposition values likely to occur offsite are also given in Table 1.

The most likely calculated 50-year collective committed dose equivalents are all much lower than the collective dose equivalent expected from 50 years of exposure to natural background radiation and medical x-rays. The most likely maximum residual plutonium contamination estimated to be deposited offsite following the events are well below the Environmental Protection Agency's (EPA) proposed guideline for plutonium in the general environment of 0.2 $\mu Ci/m^2$. The likely maximum residual contamination from beta and gamma emitters are far below the background produced by fallout from nuclear weapons tests in the atmosphere.

TABLE 1. Most Likely 50-Year Committed Dose Equivalents and Maximum Radionuclide Deposition Values

Event	Organs of Reference	50-Year Committed Dose Equivalent[a] Population (person-rem) Most Likely Release	Population (person-rem) Conservative Release	Nearest Residence (rem) Most Likely Release	Nearest Residence (rem) Conservative Release	Maximum Radionuclide Deposition Offsite ($\mu Ci/m^2$) Alpha Emitters	Beta-Gamma Emitters
Earthquake	Lungs	1.2×10^{-2}	4.6×10^{-1}	4.6×10^{-6}	1.8×10^{-4}	8.2×10^{-7}	8.2×10^{-5}
	Bone	2.1×10^{-2}	8.0×10^{-1}	7.3×10^{-6}	3.1×10^{-4}		
75-mph Wind	Lungs	4.6×10^{-6}	4.6×10^{-5}	1.1×10^{-9}	9.7×10^{-9}	1.2×10^{-10}	1.2×10^{-8}
	Bone	7.9×10^{-6}	8.0×10^{-5}	1.8×10^{-9}	1.7×10^{-8}		
95-mph Wind	Lungs	5.1×10^{-6}	2.2×10^{-3}	1.3×10^{-9}	6.3×10^{-7}	4.6×10^{-9}	4.6×10^{-7}
	Bone	8.9×10^{-6}	3.9×10^{-3}	2.2×10^{-9}	1.1×10^{-6}		
115-mph Wind	Lungs	3.0×10^{-4}	7.6×10^{-3}	6.7×10^{-8}	2.3×10^{-6}	1.2×10^{-8}	7.1×10^{-7}
	Bone	4.8×10^{-4}	1.2×10^{-2}	1.1×10^{-7}	3.7×10^{-6}		
300-mph Tornado	Lungs	9.3×10^{-2}	3.7	1.2×10^{-6}	4.9×10^{-5}	2.4×10^{-7}	2.4×10^{-5}
	Bone	1.6×10^{-1}	6.5	2.1×10^{-6}	8.5×10^{-5}		

(a) Translocation Class Y has been assumed.

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INTRODUCTION

This study estimates the potential environmental consequences in terms of radiation dose to people resulting from postulated releases of plutonium and other radionuclides caused by severe weather or other natural phenomena. The accident scenarios considered include earthquakes, tornadoes, and high winds. This is one in a series of reports on commercial plutonium fabrication facilities sponsored by the U.S. Nuclear Regulatory Commission and coordinated by Argonne National Laboratory.

Figure 1 illustrates the information requirements for such a study and how the data are utilized to estimate dose. The amount and form of radioactive material released into the atmosphere was estimated by Mishima et al. (1981). The atmospheric transport and dispersal of released plutonium was estimated by Pepper (1980) for tornadoes, and by the NRC for earthquakes.[(a)] The site characteristics and demography around West Jefferson, Ohio were provided by the NRC.[(b)] The population distribution given in Table 2 was used to calculate the population doses.

(a) Annual average atmospheric dispersion values for the Site transmitted by a letter from L. G. Hulman of NRC/DSE to R. B. McPherson of PNL, April 5, 1978.

(b) "Description of the Site Environment," transmitted by letter from Leland C. Rouse of NRC to Battelle Columbus Laboratories, Attn: Mr. Harley L. Toy, April 23, 1981.

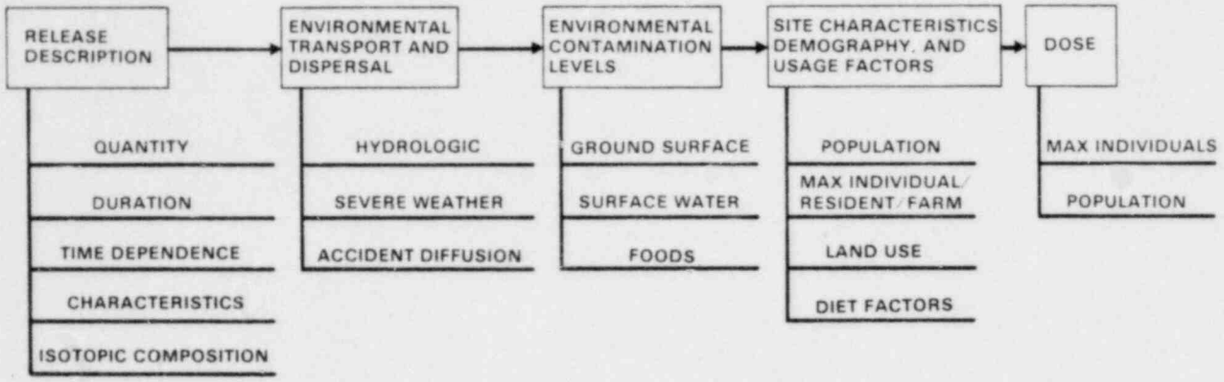

FIGURE 1. Accidental Environmental Consequences Evaluation

TABLE 2. 1980 Population Distribution Around Battelle Columbus Laboratories, West Jefferson Site[a]

	0-1	1-2	2-3	3-4	4-5	5-10	10-20	20-30	30-40	40-50
N	8	6	30	80	105	3,241	2,538	3,692	19,232	38,558
NNE	4	6	30	80	105	1,304	5,358	20,947	7,461	11,290
NE	2	6	30	80	105	3,310	4,405	7,734	6,631	16,466
ENE	2	6	30	80	105	18,499	109,046	11,809	8,419	11,956
E	2	6	30	80	105	18,040	342,003	42,808	10,255	53.990
ESE	2	6	30	80	105	34,158	170,123	23,960	39,354	15,115
SE	0	495	30	80	105	7,240	45,405	9,298	7,591	6,259
SSE	0	105	30	80	105	16,028	9,860	3,496	6,115	8,886
S	0	6	30	80	105	610	4,574	3,107	4,707	11,739
SSW	2	6	200	300	105	635	4,807	3,543	4,667	7,343
SW	4	6	2,000	1,800	105	1,846	5,798	2,390	6,345	16,152
WSW	2	6	150	300	105	402	7,318	7,095	29,774	184,704
W	2	6	30	80	105	728	2,074	71,132	28,610	65,312
WNW	2	6	30	80	105	561	2,547	14,966	5,636	9,794
NW	4	6	30	80	105	423	1,754	3,344	17,568	9,754
NNW	4	6	30	80	105	711	2,282	3,318	3,429	6,086
Total	40	684	2,740	3,440	1,680	107,739	719,892	232,639	205,794	473.404

Total within 50 miles = 1,748,052.

(a) The population distribution around the BCL West Jefferson, Ohio site, provided by the NRC was based on 1970 census data. Using county growth rate information from the Statistical Abstracts of the United States and other sources, estimates of the 1980 sector populations were made to give a truer picture of dose consequences.

ENVIRONMENTAL EXPOSURE PATHWAYS FOR RADIONUCLIDES

The potential environmental exposure pathways for radionuclides released to the atmosphere and water are shown in Figure 2. Our experience has shown that the more important pathways for exposure to atmospheric releases of plutonium and daughter products are inhalation, cloud submersion, ingestion, and direct ground irradiation. For chronic atmospheric releases of plutonium, the most important of these pathways is inhalation (Selby 1975, Friedman 1976, Anspaugh et al. 1975, EPA 1977). It can also be shown that inhalation is the only important pathway for acute atmospheric releases of plutonium (see Appendix A). Therefore, the exposure parameters for the other radionuclides are chosen to maximize the inhalation dose, and only the radiation doses from inhalation during initial cloud passage and from inhalation of resuspended environmental residual contamination are calculated.

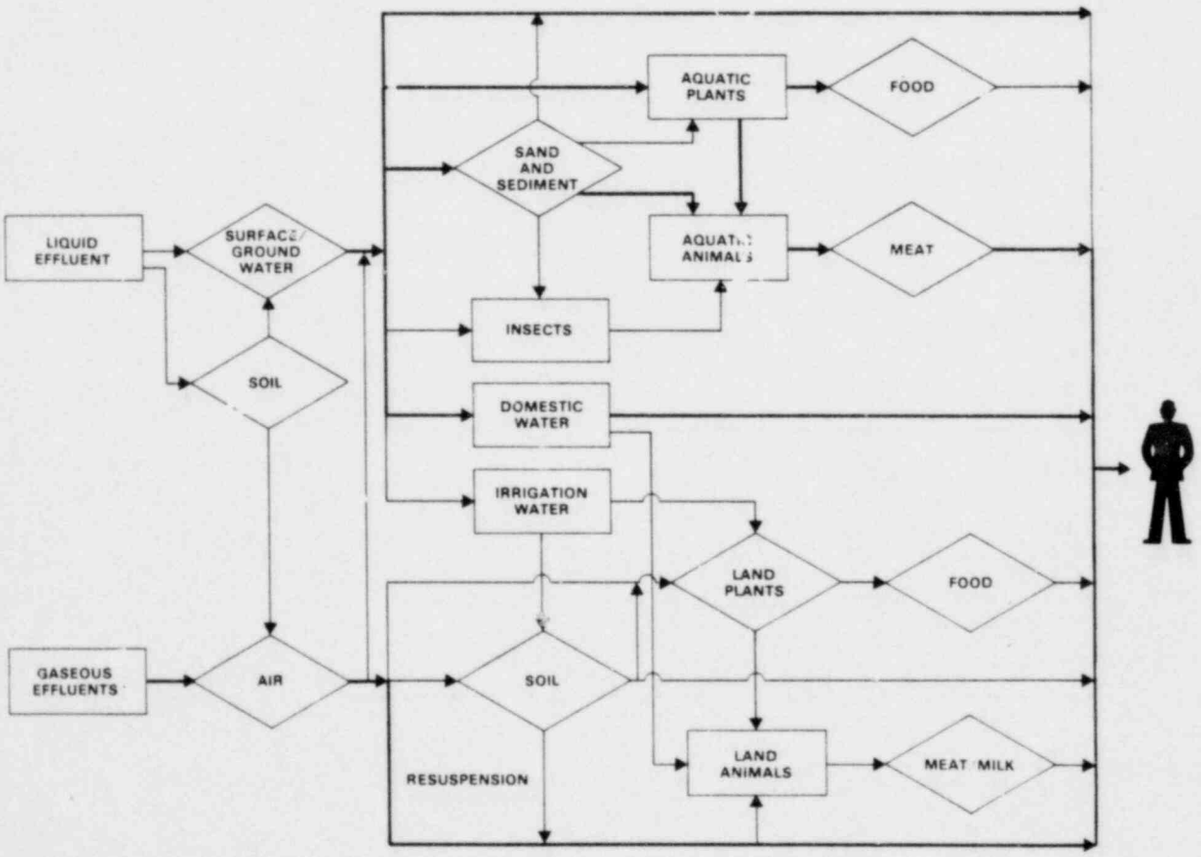

FIGURE 2. Potential Exposure Pathways for Radionuclides in the Biosphere

For liquid releases during a flood, the important exposure pathways are aquatic food ingestion, water consumption, irrigation with contaminated water and subsequent food ingestion, and shoreline exposure. The significant potential exposure pathways that have been discussed are shown in Figure 3.

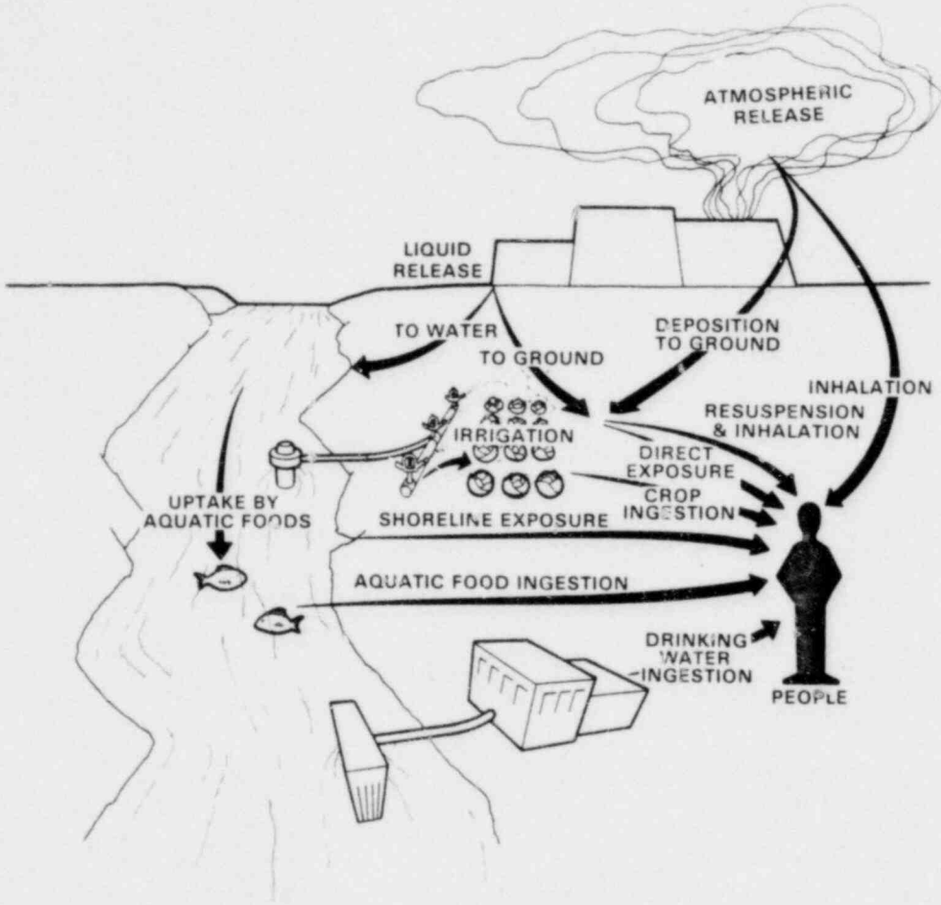

FIGURE 3. Significant Potential Exposure Pathways Through Which People May Be Exposed from an Accidental Release of Radionuclides

RADIATION DOSE MODELS FOR AN ATMOSPHERIC RELEASE

The equation for calculating committed radiation dose equivalents from acute inhalation is:

$$DC_{ir} = Q_i(E/Q)(BR)(DCF)_{ir} \quad (1)$$

where

- DC_{ir} • the committed dose equivalent to organ r from acute inhalation of radionuclide i, rem
- Q_i • the quantity of radionuclide i released to the atmosphere, µg
- E/Q • the accident atmospheric exposure coefficient, µg · sec/m^3 per µg released
- BR • the ventilation rate of the human receptor during the exposure period, m^3/sec
- $(DCF)_{ir}$ • the acute committed dose equivalent factor, rem per µg inhaled; a number specific to a given nuclide i and organ r which can be used to calculate radiation dose from a given radionuclide intake.

Human ventilation rates for three time periods were derived from ICRP recommendations (ICRP 1975): 3.3×10^{-4} m^3/sec for the period 0-8 hours; 2.3×10^{-4} m^3/sec for 8-24 hours; and 2.7×10^{-4} m^3/sec for greater than 24 hours.

Fifty-year committed dose equivalent factors were calculated using the computer code DACRIN (Houston, Strenge and Watson 1975). This code incorporates the ICRP Task Group Lung Model (TGLM) to calculate the dose commitment to the lung and other organs of interest (ICRP 1966). The organ masses used in the code have been modified to reflect the changes reported in ICRP-23 (1975). The translocation of americium from the blood to the organs of interest has been changed to the values suggested in ICRP-19 (1972).

Fifty-year committed dose equivalents per unit isotopic mass inhaled for particles with an AMAD[(a)] of one micrometer are listed in Appendix B for each plutonium isotope, ^{241}Am, and ^{90}Sr. The organs of interest in plutonium dosimetry are the total body, kidneys, liver, bone, and lungs; for ^{90}Sr the organs of interest are the total body, bone and lung.

The plutonium postulated to be released to the atmosphere is assumed to be in the form of plutonium oxides (Mishima et al. 1981). Lung retention, as described by the TGLM, depends upon the chemical nature of the compound inhaled. Compounds of plutonium largely fall into Class Y (retained for years) or Class W (retained for weeks). There is no evidence of plutonium existing in the environment as Class D (retained for days). Actinides in the oxide form are currently classified as Class Y (ICRP 1972), which is assumed in this study. Doses for plutonium as Class W material, however, are included in Appendix B.

The ^{90}Sr postulated to be released is assumed to be of Class D so that the dose to the total body and the bone by the inhalation pathway is maximized. However, to maximize the lung dose, the dose factor for Class Y material is used.

Plutonium particulates that deposit onto the ground surface from a plume can be resuspended to the atmosphere by natural processes, and subsequently inhaled by people. Therefore, ground contamination is an important factor when calculating doses via inhalation. Where deposition values were not provided (distances less than 5000 meters for the 0-2 hour period following an earthquake), the deposition velocity concept was used to estimate the plutonium deposition (Equation 2).

$$W_i = Q_i(E/Q)V_d \qquad (2)$$

(a) Activity median aerodynamic diameter.

where

- W_i • the concentration of radionuclide i on the ground surface, $\mu g/m^2$
- Q_i • the quantity of radionuclide i released to the atmosphere, μg
- E/Q • the accident atmospheric exposure coefficient, $\mu g \cdot sec/m^3$ per μg released
- V_d • particle deposition velocity, m/se

The deposition velocity of plutonium particles cannot be specified exactly because it will vary depending on the size distribution of the particles, the nature of the surface on which deposition occurs, the wind speed, and other meteorological variables. The deposition velocity for plutonium has been reported to range from 1×10^{-4} to 3×10^{-2} m/sec (Selby et al. 1975, Cohen 1977, Baker 1977, Gudiksen et al. 1976). A value of 1×10^{-3} m/sec is used in this report (Baker 1977). Deposition values for tornadoes were reported by Pepper (1979). The NRC estimated deposition values during earthquakes and annual average conditions.(a)

Resuspension rates for material deposited on the ground are time dependent and tend to decrease with time after initial deposition. Local conditions can be expected to strongly affect the rate, with rainfall, winds, and surface characteristics predominant. The exact relationships are not well-enough understood to account for these effects (Selby et al. 1975). However, the airborne concentration from resuspended material can be estimated using a resuspension factor, K. The resuspension factor is defined as the resuspended air concentration divided by the surface deposition. Values for K in the environment between 10^{-4} and 10^{-13} m^{-1} have been measured and reported (Selby et al. 1975, Friedman 1976, Anspaugh et al. 1975, EPA 1977, Cohen 1977, FES 1974, Bennett 1975, Hanson 1975, Martin and Bloom 1975, Sehmel 1977, Healy 1977, Anspaugh 1976). Until a more general model is available, which considers all the important variables affecting the resuspension process, Anspaugh (1975) recommends using a simple time-dependent model to predict the average airborne concentration of a resuspended contaminant:

(a) Transmitted by letter from L. G. Hulman of NRC/DSE to R. B. McPherson of PNL/ESD, April 5, 1978.

$$K(t) = 10^{-4} \exp(-0.15\ t^{1/2}) + 10^{-9} \quad (3)$$

where

- t • time since the material was deposited on the ground, days
- 10^{-4} • resuspension factor at time t = 0, m^{-1}
- 10^{-9} • resuspension factor after 20 years, m^{-1}

The second term in Equation 3, 10^{-9} m^{-1}, was added based on the assumption that there may be no further measurable decrease in the resuspension factor after 20 years. This assumption was deemed appropriate since the model was empirically derived to simulate experimental measurements out to 17 years, and contains no fundamental understanding of the resuspension process (Anspaugh et al. 1975). Figure 4 illustrates the time dependence of the resuspension factor.

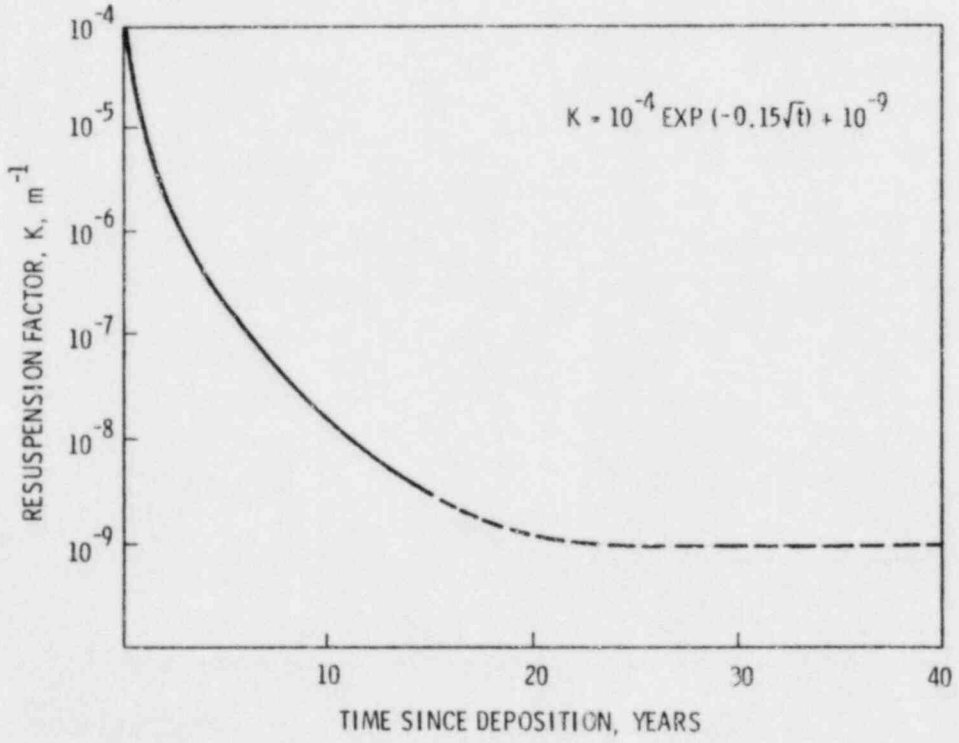

FIGURE 4. Time Dependence of the Environmental Surface Resuspension Factor

Equation 3 was integrated over each year post-deposition and divided by the integrated time period to determine the average resuspension factor for each year considered. Ninety-nine percent of the total 50-year exposure from resuspension occurs in the first 5 years. The chronic 50-year committed dose equivalent factor for inhalation remains relatively constant over this time period. Therefore, the 50-year committed dose equivalent from 50 years of exposure to resuspended plutonium can be estimated using chronic 50-year committed dose equivalent factors, and only the first 5 years of exposure to the resuspended material needs to be included. The committed dose equivalent from inhalation of resuspended material was calculated by:

$$DC_{ir} = W_i \, \overline{K}(BR)(DCF)_{ir} \, (3.16 \times 10^7) \qquad (4)$$

where

- DC_{ir} • the 50-year committed dose equivalent to organ r from one year of inhalation of radionuclide i, rem/yr of inhalation
- W_i • the concentration of radionuclide i on the ground surface for the year of consideration, $\mu g/m^2$
- $\overline{K}$ • the average resuspension factor for the year of consideration, m^{-1}
- BR • the ventilation rate of the human receptor (for a duration of greater than 24 hours), m^3/sec
- $(DCF)_{ir}$ • chronic committed dose equivalent factor, rem/μg inhaled
- 3.16×10^7 • conversion factor, sec/yr

Radiological decay of the deposited radionuclides and the buildup of ^{241}Am from the decay of ^{241}Pu were accounted for. Chronic 50-year committed dose equivalent factors for a one-year intake were calculated using DACRIN and are listed in Appendix B, Tables B.3 and B.4.

RESULTS

EARTHQUAKES

Committed radiation dose equivalents to several organs of the human body were calculated for a single earthquake event using the source terms given in Table 3.

TABLE 3. Estimated Quantity of Radioactive Material Released to the Atmosphere Following an Earthquake[a]

Time Period	Most Likely Release (μCi)		Conservative Release (μCi)	
	Alpha Emitters	Beta-Gamma Emitters	Alpha Emitters	Beta-Gamma Emitters
0-2 hr	0.1	10	4	2E+2
2-6 hr	2E-3	6E-2	3E-2	0.8
8-24 hr	4E-3	0.2	6E-2	2
1-4 da	3E-3	0.9	0.3	9
Total	0.11	11	4.4	2.1E+2

(a) Taken from Mishima et al. (1981). Only the quantity released in the respirable particle size range (less than 10 μm) was used to calculate doses.

A peak ground acceleration level in excess of 0.25 g was assumed for the earthquake event. Significant damage was not postulated for ground acceleration less than 0.25 g.

The radionuclide releases were given by Mishima et al. (1981) as microcuries of alpha emitters and beta-gamma emitters, because the material at risk in the damage scenarios was largely surface and water-borne contamination which has been characterized only in terms of its gross alpha or beta-gamma activity. It is known that the contamination originated in irradiated light-water reactor fuel, and contains plutonium isotopes and various long-lived fission product isotopes. For purposes of the dose calculations, the alpha activity is assumed to consist entirely of ^{239}Pu, the isotope with the largest inhalation dose conversion factors. Similarly, the beta-gamma activity is treated as though it is 100% ^{90}Sr. For both ^{239}Pu and ^{90}Sr, the bone and lungs are the organs which receive the highest dose.

For the 0- to 2-hour time period, accident atmospheric dispersion values for a 5% and 50% condition, calculated by the NRC for the West Jefferson site, were used to estimate potential committed dose equivalents to the population and a maximum individual. Annual average atmospheric dispersion and deposition values also calculated by the NRC were used for all other time periods. For the 5% condition (conservative) at greater than 2 hours, the annual average dispersion and deposition values were multiplied by a factor of 4, as recommended by Carson.[a] Four combinations of release and dispersion are considered: most likely release with most likely dispersion; most likely release with conservative dispersion; conservative release with most likely dispersion; and conservative release with conservative dispersion. These combinations are referred to as Case I, Case II, Case III, and Case IV respectively, and are used for all of the natural phenomena scenarios. The calculated committed dose equivalents are listed in Table 4. The corresponding estimated maximum radioactive material ground depositions at the site boundary, nearest residence, and farm are listed in Table 5. All the directions and distances given in the report are referenced to the JN-1b Building, which houses the High Energy Cell (HEC), a destructive examination facility with which most of the dispersible radioactive material is associated.

TABLE 4. Fifty-Year Committed Dose Equivalents from Inhalation Following an Earthquake (Class Y)

Organ of Reference	Committed Dose Equivalents for: Population (person-rem)[a]				Nearest Residence (rem)[b]			
	Case I[c]	Case II	Case III	Case IV	Case I	Case II	Case III	Case IV
Total Body	3.8E-3	1.1E-2	1.5E-1	4.2E-1	1.4E-6	8.8E-6	5.7E-5	3.5E-4
Kidneys	1.3E-3	3.8E-3	5.1E-2	1.5E-1	5.1E-7	3.1E-6	2.0E-5	1.2E-4
Liver	4.2E-3	1.2E-2	1.6E-1	4.6E-1	1.6E-6	9.7E-6	6.4E-5	3.9E-4
Bone	2.1E-2	6.0E-2	8.0E-1	2.3E+0	7.9E-6	4.8E-5	3.1E-4	1.9E-3
Lungs	1.2E-2	3.4E-2	4.6E-1	1.3E+0	4.6E-6	2.8E-5	1.8E-4	1.1E-3

(a) Population within a 50-mile radius of the West Jefferson site.
(b) Located 760 meters SW of the JN-1b Building.
(c) Case I - most likely release with most likely dispersion; Case II - most likely release with conservative dispersion; Case III - conservative release with most likely dispersion; Case IV - conservative release with conservative dispersion.

(a) Letter transmitted from J. E. Carson of ANL/EIS to R. B. McPherson of PNL/ESD, October 24, 1978.

TABLE 5. Estimated Maximum Radioactive Material Deposition at Significant Locations Following an Earthquake (all particle sizes)

Location	Deposition ($\mu Ci/m^2$)							
	Case I		Case II		Case III		Case IV	
	Alpha	Beta-Gamma	Alpha	Beta-Gamma	Alpha	Beta-Gamma	Alpha	Beta-Gamma
Site Boundary[a]	1.4E-8	1.4E-6	4.6E-8	4.6E-6	5.0E-7	5.0E-5	1.7E-6	1.7E-4
Residence[b]	8.8E-9	8.8E-7	5.1E-8	5.1E-6	3.5E-7	3.5E-5	2.0E-6	2.0E-4
Farm[c]	2.1E-8	2.1E-6	4.4E-8	4.4E-6	8.2E-7	8.2E-5	1.7E-6	1.7E-4

(a) Located 430 meters E of the JN-1b Building.
(b) Located 760 meters SW of the JN-1b Building.
(c) Located 480 meters NNW of the JN-1b Building.

HIGH WINDS

Fujita (1977) reported that the probability of a 130-mph straight wind occurring at the West Jefferson site was approximately the same as for a 130-mph tornadic wind. Below 130 mph, the probability of a straight-line wind gust is higher than for a tornado of the same speed. Above 130 mph, the probability of tornadic winds was judged to exceed that of a comparable straight wind.

Mishima (1981) estimated the radionuclide releases for maximum wind speeds of 75, 95 and 115 mph. The quantities released to the atmosphere from these events are reported in Table 6.

TABLE 6. Estimated Radioactive Material Releases to the Atmosphere Following Straight-Line Winds[a]

Time Period	Quantity Released (μCi)											
	75 mph Wind				95 mph Wind				115 mph Wind			
	Most Likely		Conservative		Most Likely		Conservative		Most Likely		Conservative	
	Alpha	Beta-Gamma	Alpha	Beta-Gamma	Alpha	Beta-Gamma	Alpha	Beta-Gamma	Alpha	Beta-Gamma	Alpha	Beta-Gamma
0-2 hr	4E-3	4E-1	4E-2	4E+0	4E-3	4E-1	3E-1	1E+1	4.4E-3	5E-1	3E+0	1E+2
2-8 hr	2E-5	2E-3	2E-4	2E-2	2E-5	2E-3	6E-3	2E-1	1E-3	1E-2	2E-2	3E-1
8-24 hr	5E-5	5E-3	5E-4	5E-2	6E-5	5E-3	2E-2	6E-1	3E-3	4E-2	5E-2	9E-1
1-4 da	2E-4	2E-2	2E-3	2E-1	2E-4	2E-2	8E-2	3E+0	2E-2	2E-1	2E-1	4E+0
Total	4.3E-3	4.3E-1	4.3E-2	4.3E+0	4.3E-3	4.3E-1	4.1E-1	1.4E+1	2.8E-2	7.5E-1	3.3E+0	1E+2

(a) Only the quantity released in the respirable particle size range was used to calculate dose.

For the 0- to 2-hour time period, the most likely atmospheric dispersion values were provided by the NRC.[a] The wind was assumed to blow from the westerly directions (into the NNE, NE, ENE, E, ESE, and SE sectors), towards the sectors having the largest populations. The 0- to 2-hour dispersion values were multiplied by a factor of 10 to represent the conservative case. Significant deposition downwind is presumed to not occur during the 0- to 2-hour period. Committed radiation dose equivalents calculated for several organs of the human body are given in Tables 7, 8 and 9. Estimated maximum deposition of radioactive material at significant locations downwind are given in Tables 10, 11 and 12.

TABLE 7. Fifty-Year Committed Dose Equivalents from Inhalation Following a 75-mph Straight-Line Wind (Class Y)

Organ of Reference	Committed Dose Equivalents for: Population (person-rem)				Nearest Residence (rem)[a]			
	Case I	Case II	Case III	Case IV	Case I	Case II	Case III	Case IV
Total Body	1.4E-6	6.7E-6	1.5E-5	6.7E-5	3.3E-10	1.5E-9	3.1E-9	1.5E-8
Kidneys	5.1E-7	2.4E-6	5.1E-6	2.4E-5	1.2E-10	5.3E-10	1.1E-9	5.3E-9
Liver	1.6E-6	7.6E-6	1.7E-5	7.6E-5	3.8E-10	1.7E-9	3.5E-9	1.7E-8
Bone	7.9E-6	3.7E-5	8.0E-5	3.7E-4	1.8E-9	8.2E-9	1.7E-8	8.2E-8
Lungs	4.6E-6	2.1E-5	4.6E-5	2.1E-4	1.1E-9	4.7E-9	9.7E-9	4.7E-8

(a) Located 760 meters SW of the JN-1b Building.

TABLE 8. Fifty-Year Committed Dose Equivalents from Inhalation Following a 95-mph Straight-Line Wind (Class Y)

Organ of Reference	Committed Dose Equivalents for: Population (person-rem)				Nearest Residence (rem)[a]			
	Case I	Case II	Case III	Case IV	Case I	Case II	Case III	Case IV
Total Body	1.6E-6	8.1E-6	7.1E-4	4.2E-3	4.0E-10	2.1E-9	2.0E-7	1.3E-6
Kidneys	5.7E-7	2.9E-6	2.5E-4	1.5E-3	1.4E-10	7.6E-10	7.1E-8	4.7E-7
Liver	1.8E-6	9.3E-6	8.0E-4	4.8E-3	4.5E-10	2.4E-9	2.3E-7	1.5E-6
Bone	8.9E-6	4.5E-5	3.9E-3	2.3E-2	2.2E-9	1.2E-8	1.1E-6	7.2E-6
Lungs	5.1E-6	2.6E-5	2.2E-3	1.3E-2	1.2E-9	6.7E-9	6.3E-7	4.2E-6

(a) Located 760 meters SW of the JN-1b Building.

(a) "Battelle Memorial Institute, West Jefferson Facility, Description of Site Environment," transmitted by letter from Leland C. Rouse of NRC to Battelle Columbus Laboratories, Attn: Mr. Harley L. Toy, April 23, 1981.

TABLE 9. Fifty-Year Committed Dose Equivalents from Inhalation Following a 115-mph Straight-Line Wind (Class Y)

Organ of Reference	Committed Dose Equivalents for: Population (person-rem) Case I	Case II	Case III	Case IV	Nearest Residence (rem)[a] Case I	Case II	Case III	Case IV
Total Body	7.6E-5	3.3E-4	1.9E-3	1.4E-2	1.7E-8	6.8E-8	5.7E-7	4.6E-6
Kidneys	4.3E-5	1.9E-4	1.1E-3	8.0E-3	9.5E-9	3.8E-8	3.2E-7	2.6E-6
Liver	1.4E-4	6.0E-4	3.4E-3	2.6E-2	3.0E-8	1.2E-7	1.0E-6	8.3E-6
Bone	4.8E-4	2.1E-3	1.2E-2	9.1E-2	1.1E-7	4.4E-7	3.7E-6	2.9E-5
Lungs	3.0E-4	1.3E-3	7.6E-3	5.7E-2	6.7E-8	2.7E-7	2.3E-6	1.8E-5

(a) Located 760 meters SW of the JN-1b Building.

TABLE 10. Estimated Maximum Radioactive Material Deposition at Significant Locations Following a 75-mph Straight-Line Wind (all particle sizes)

Location	Deposition ($\mu Ci/m^2$) Case I Alpha	Case I Beta-Gamma	Case II Alpha	Case II Beta-Gamma	Case III Alpha	Case III Beta-Gamma	Case IV Alpha	Case IV Beta-Gamma
Site Boundary[a]	1.2E-11	1.2E-9	4.9E-11	4.9E-9	1.2E-10	1.2E-8	4.8E-10	4.8E-8
Residence[b]	2.7E-12	2.7E-10	1.1E-11	1.1E-9	2.7E-11	2.7E-9	1.1E-10	1.1E-8
Farm[c]	6.8E-12	6.8E-10	2.7E-11	2.7E-9	6.8E-11	6.8E-9	2.7E-10	2.7E-8

(a) Located 430 meters E of the JN-1b Building.
(b) Located 760 meters SW of the JN-1b Building.
(c) Located 480 meters NNW of the JN-1b Building.

TABLE 11. Estimated Maximum Radioactive Material Deposition at Significant Locations Following a 95-mph Straight-Line Wind (all particle sizes)

Location	Deposition ($\mu Ci/m^2$) Case I Alpha	Case I Beta-Gamma	Case II Alpha	Case II Beta-Gamma	Case III Alpha	Case III Beta-Gamma	Case IV Alpha	Case IV Beta-Gamma
Site Boundary[a]	1.3E-11	1.3E-9	5.1E-11	5.1E-9	4.6E-9	4.6E-7	1.8E-8	1.8E-6
Residence[b]	2.8E-12	2.8E-10	1.1E-11	1.1E-9	1.0E-9	1.0E-7	4.0E-9	4.0E-7
Farm[c]	7.0E-12	7.0E-10	2.8E-11	2.8E-9	2.5E-9	2.5E-7	1.0E-8	1.0E-6

(a) Located 430 meters E of the JN-1b Building.
(b) Located 760 meters SW of the JN-1b Building.
(c) Located 480 meters NNW of the JN-1b Building.

TABLE 12. Estimated Maximum Radioactive Material Deposition at Significant Locations Following a 115-mph Straight-Line Wind (all particle sizes)

Location	Deposition ($\mu Ci/m^2$)							
	Case I		Case II		Case III		Case IV	
	Alpha	Beta-Gamma	Alpha	Beta-Gamma	Alpha	Beta-Gamma	Alpha	Beta-Gamma
Site Boundary[(a)]	1.1E-9	6.3E-8	4.4E-9	2.6E-7	1.2E-8	7.1E-7	4.9E-8	2.8E-6
Residence[(b)]	2.4E-10	1.4E-8	9.7E-10	5.6E-8	2.7E-9	1.6E-7	1.1E-8	6.3E-7
Farm[(c)]	6.1E-10	3.5E-8	2.4E-9	1.4E-7	6.8E-9	3.9E-7	2.7E-8	1.6E-6

(a) Located 430 meters E of the JN-1b Building.
(b) Located 760 meters SW of the JN-1b Building.
(c) Located 480 meters NNW of the JN-1b Building.

TORNADOES

Releases of radioactive materials following a 300-mph tornado were estimated by Mishima et al. (1981). The releases are presented in Table 13. Only the quantity released in the respirable particle size range was used to calculate doses.

TABLE 13. Estimated Quantity of Radioactive Materials Released to the Atmosphere Following a 300-mph Tornado

Time Period	Airborne Release of Radioactive Materials (μCi)			
	Most Likely Release		Conservative Release	
	Alpha	Beta-Gamma	Alpha	Beta-Gamma
0-2 hr	1E-1	1E+1	4E+0	2E+2
2-8 hr	2E-3	6E-2	3E-2	8E-1
8-24 hr	4E-3	2E-1	6E-2	2E+0
1-4 da	3E-2	9E-1	3E-1	9E+0
Total	1.4E-1	1.1E+1	4.4E+0	2.1E+2

Atmospheric dispersion and deposition values most likely to occur during a tornado were calculated by Pepper (1980). These values were assumed to apply during the first two hours after the event. During this time period, the tornadoes were assumed to move in north and easterly directions. Annual average atmospheric dispersion and depositon values were used for all other

time periods. As recommended by Pepper[a] and Carson, the tornado dispersion values were multiplied by a factor of 10 to represent the conservative case, and the annual average atmospheric dispersion and deposition values were again multiplied by a factor of 4. Committed radiation dose equivalents are given in Table 14. The estimated maximum ground contamination levels at the significant locations are listed in Table 15.

TABLE 14. Fifty-Year Committed Dose Equivalents from Inhalation Following a 300-mph Tornado (Class Y)

Organ of Reference	Committed Dose Equivalents for: Population (person-rem) Case I	Case II	Case III	Case IV	Nearest Residence (rem)[a] Case I	Case II	Case III	Case IV
Total Body	2.9E-2	2.9E-1	1.2E+0	1.2E+1	3.9E-7	3.9E-6	1.6E-5	1.6E-4
Kidneys	1.0E-2	1.0E-1	4.1E-1	4.1E+0	1.3E-7	1.3E-6	5.4E-6	5.4E-5
Liver	3.3E-2	3.3E-1	1.3E+0	1.3E+1	4.3E-7	4.3E-6	1.7E-5	1.7E-4
Bone	1.6E-1	1.6E+0	6.5E+0	6.5E+1	2.1E-6	2.1E-5	8.5E-5	8.5E-4
Lungs	9.3E-2	9.3E-1	3.7E+0	3.7E+1	1.2E-6	1.2E-5	4.9E-5	4.9E-4

(a) Located 48,000 to 64,000 meteres from the plant in the direction the tornado travels.

TABLE 15. Estimated Maximum Radioactive Material Desposition at Significant locations Following a 300-mph Tornado (all particle sizes)

Location	Deposition ($\mu Ci/m^2$) Case I Alpha	Case I Beta-Gamma	Case II Alpha	Case II Beta-Gamma	Case III Alpha	Case III Beta-Gamma	Case IV Alpha	Case IV Beta-Gamma
Site Boundary[a]	1.6E-9	1.6E-7	6.4E-9	6.4E-7	1.7E-8	1.7E-6	6.9E-8	6.9E-6
Residence[b]	6.0E-9	6.0E-7	6.0E-8	6.0E-6	2.4E-7	2.4E-5	2.4E-6	2.4E-4
Farm[b]	6.0E-9	6.0E-7	6.0E-8	6.0E-6	2.4E-7	2.4E-5	2.4E-6	2.4E-4

(a) Located 430 meters E of the JN-1b Building.
(b) Located 48,000 to 64,000 meters from the site in the direction the tornado travels.

(a) Letter transmitted from D. W. Pepper of SRL/ETD to R. B. McPherson of PNL/ESD, February 21, 1979.

DISCUSSION

The calculated committed dose equivalents are based on the ICRP Publication 2 Metabolic Model, the ICRP Task Group Lung Model and standard man parameter values. To the best of our knowledge, there are no reported assessments of the accuracy of dose calculations using these models and parameter values. Dose results are usually presented with no indication of the error associated with their use. Present insights into the degree of uncertainty involved are very limited and qualitative (Hoffman 1978). Dose results presented in this paper are probably within a factor of ±10. However, studies should be conducted to determine the uncertainties associated with these kinds of calculations.

The estimated average annual whole-body radiation dose from natural background radiation in Ohio is reported to be 140 mrem/yr (Klement 1972). Therefore, an individual receives a total-body dose of about 7.0 rem from exposure to natural background radiation during a 50-year period. The collective dose equivalent from 50 years of exposure to natural background radiation to the total body of the population within a 50-mile radius of the West Jefferson site is 1.2×10^7 person-rem. The average annual dose to the total body of an individual from medical x-ray examination is about 20 mrem (United Nations 1977). This average dose corresponds to a 50-year collective dose equivalent of 1.8×10^6 person-rem. The dose contribution from fallout is negligible when compared to natural background radiation and medical x-ray exposure. If a radiation worker was involved in an occupational accident and received a maximum permissible bone burden of ^{239}Pu, the 50-year committed dose equivalent to the bone would be greater than 1000 rem. As can be seen, in all cases, the calculated 50-year committed dose equivalents to the population for the severe natural phenomena scenarios considered in this report are far lower than the collective dose equivalent from 50 years of exposure to either natural background radiation or medical x-rays.

Existing guidelines on acceptable levels of soil contamination from Pu can be found to range from 0.01 $\mu Ci/m^2$ to 270 $\mu Ci/m^2$ (Selby et al. 1975; EPA 1977; Martin and Bloom 1975; Healy 1977; U.S. Code 1976; Healy 1974; Guthrie and Nichols 1964; Hazle and Crist 1975; Kathren 1968; Dunster 1962). The EPA has proposed a guideline of 0.2 $\mu Ci/m^2$ for plutonium in the general environment (EPA 1977). This guideline is based on annual doses of one mrad to the lung from inhalation and three mrad to the bone from ingestion. If the broad range of current guidelines are normalized to these lung and bone doses and the same resuspension factor is used, the guidelines are all in reasonable agreement with 0.2 $\mu Ci/m^2$. The predicted ground plutonium contamination levels for all events considered here are well below the EPA proposed guideline at all significant locations.

The maximum predicted offsite ground deposition of beta-gamma emitters for any of the events considered in this study is 2.4×10^{-4} $\mu Ci/m^2$ (Tornado Case IV). This is about two orders of magnitude below the background ^{90}Sr contamination produced as a result of fallout from past nuclear weapons tests (ANSI 1978).

APPENDIX A

EVALUATION OF ENVIRONMENTAL PATHWAYS BY WHICH PLUTONIUM MAY REACH PEOPLE FROM AN ACCIDENTAL AIRBORNE RELEASE

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EVALUATION OF ENVIRONMENTAL PATHWAYS BY WHICH PLUTONIUM MAY REACH PEOPLE FROM AN ACCIDENTAL AIRBORNE RELEASE

Twelve environmental exposure modes for an accidental airborne release are considered for evaluation. Three are from exposure to the radioactive cloud, and four result from radioactive material deposited on the ground. The remaining five are via the waterborne pathway, assuming radioactive material was deposited onto a nearby surface body of water. For the Babcock & Wilcox study, it is assumed that irrigation does not occur.

The following exposure modes are included in the study:

1. inhalation during the initial cloud passage,
2. inhalation of resuspended radioactive material,
3. direct exposure from cloud submersion,
4. direct exposure to radioactive material deposited on the ground,
5. ingestion of leafy vegetables, beef, milk, water and fish,
6. direct exposure from swimming and boating in contaminated water, and
7. external exposure to radioactive material concentrated in the shoreline sediment.

One isotope of plutonium is considered, ^{239}Pu, but the conclusions from this evaluation apply to most of the other isotopes, as well as a typical mixture of plutonium isotopes. The dose models used to evaluate the exposure modes are taken from Regulatory Guide 1.109, Revision 1 (1977) and are modified accordingly for an accidental release. In the evaluation, doses are calculated to a hypothetical maximum adult individual for 50 years of exposure.

AIRBORNE PATHWAYS

Airborne Release Assumptions and Dispersion

A normalized plutonium release of 1 μg ^{239}Pu is assumed, and an arbitrary average accident exposure coefficient (E/Q) of 1 x 10^{-3} μg · sec/m^3 per μg at the location of the maximum exposed individual is chosen. It is assumed that the particle size of the plutonium released is in the respirable range, less than 10 μm in diameter.

Inhalation

The committed dose equivalent from radioactive material inhaled during passage of the initial cloud is calculated by:

$$DC_i = Q(E/Q)(DCF)_i \qquad \text{(A-1)}$$

where

- DC_i • committed dose equivalent to organ i (rem)
- Q • total quantity of radioactive material released during the accident (μg)
- (E/Q) • accident atmospheric exposure coefficient (μg · sec/m^3 per μg)
- $(DCF)_i$ • committed dose equivalent factor for organ i (rem per μg · sec/m^3)

The committed dose equivalent factors for acute inhalation of ^{239}Pu were calculated using the computer code DACRIN (Houston et al. 1975). This code incorporates the ICRP Task Group Lung Model to calculate the dose to the lungs and other organs of interest. The organ masses were modified to reflect the changes reported in ICRP-23 (1975). The 50-year committed dose equivalent factors per unit mass exposure for ^{239}Pu particles, with an activity median aerodynamic diameter (AMAD) of one micrometer, are listed in Table A.1 for the total body, lungs, bone, and the lower large intestine (GI-LLI), along with the calculated committed dose equivalents. The translocation classes which minimize the contribution from the inhalation pathway are used. Cloud depletion is not considered. The location of the maximum exposed individual would

TABLE A.1. Fifty-Year Committed Dose Equivalents from Inhalation of 1 μm AMAD ^{239}Pu Particles

Organ	Translocation Class	Committed Dose Equivalent Factors (rem per μg · sec/m^3)	Committed Dose Equivalent[a] (rem)
Total Body	Y	5.6E-04[b]	5.6E-07
Lungs	W	9.9E-04	9.9E-07
Bone	Y	1.2E-02	1.2E-05
GI-LLI	W	7.3E-07	7.3E-10

(a)At location where E/Q = 1 x 10^{-3} μg · sec/m^3 per μg.
(b)5.6E-04 is identical to 5.6 x 10^{-4}.

probably be a few hundred meters from the point of release, and the inclusion of cloud depletion would only lower the doses by a few percent (USNRC Guide 1.111 1977, Gudiksen 1976).

Resuspension is an important aspect to be considered when calculating the dose from inhalation of plutonium. The airborne concentration from resuspended material can be predicted using a resuspension factor, k. The resuspension factor is defined as the resuspended air concentration divided by the surface deposition. Reasonable values for k between 10^{-4} m^{-1} and 10^{-13} m^{-1} have been measured and reported (Anspaugh 1975, Cohen 1977, Hanson 1975, FES 1974, Selby 1975, Bennett 1975, EPA 1977, Martin and Bloom 1975, Sehmel 1977, Healy 1977, and Anspaugh 1976). Until a more general model is available, which considers all the important variables affecting the resuspension process, Anspaugh (1975) recommends using a simple time-dependent model to predict the average airborne concentration of a resuspended contaminant:

$$K(t) = 10^{-4} \exp(-0.15t^{\frac{1}{2}}) + 10^{-9} \qquad \text{(A-2)}$$

where

K • resuspension factor (m^{-1})

t • time since the material was deposited on the ground (days)

The second term was added based upon the assumption that there may be no further measurable decrease in the resuspension process after 17 years, which is the longest period post deposition that measurements have been reported. This time-dependent model accounts for the observed decrease in air concentrations which has been noted to occur in the absence of a significant net loss of the deposited contaminant.

The resuspension factor was integrated over 50 years to include the total potential intake from resuspended plutonium. It was determined that 78% of the total 50-year exposure from resuspension occurs in the first year and 99% occurs in the first five years. To simplify the calculation, it is assumed that the total 50 years of exposure to resuspended plutonium is received during the first year, and the particle size is in the respirable range. The committed dose environment factor remains relatively constant over the first five years. Thus, bringing this term out of the integral does not affect the results. When Equation A-2 is integrated over 50 years, the total exposure to resuspended material is calculated to be 8.9×10^{-3} days/meter.

The committed dose equivalent from inhalation of resuspended material is calculated by:

$$HC_i = W(DCF)_i(8.64 \times 10^4) \int_0^{T_d} K(t)\, dt \qquad (A-3)$$

where

W • surface concentration of radioactive material initially deposited from the cloud onto the ground ($\mu g/m^2$)

T_d • dose commitment time (days);
$T_d = 1.83 \times 10^4$ days (50 years in this study)

$(DCF)_i$ • 50-year committed dose equivalent factor for organ i (rem per μg · sec/m^3)

8.64×10^4 • constant which converts days to seconds (sec/day)

The terms K and DC_i have already been defined.

The initial ground deposition concentration for an accidental release of plutonium is calculated using the following equation:

$$W = E\ V_d \qquad \text{(A-4)}$$

where

E • exposure (μg · sec/m^3), the product of Q and E/Q as defined earlier

V_d • deposition velocity (m/sec)

A deposition velocity of 1×10^{-3} m/sec was chosen as is used in the computer code FOOD (Baker 1977).

Chronic committed dose equivalent factors were calculated for one year of inhalation of ^{239}Pu using DACRIN (Houston et al. 1975). The organ masses were modified to reflect the changes reported in ICRP-23 (1975) as before. The 50-year committed dose equivalent factors per unit mass inhaled during the first year for ^{239}Pu particles with an AMAD of one micrometer are listed in Table A.2 for the total body, lungs, bone, and GI-LLI, along with the calculated committed dose equivalents. The translocation classes which minimize the contribution from inhalation are used to be consistent with Table A.1.

TABLE A.2. Fifty-Year Committed Dose Equivalents from 50 Years' Inhalation of 1 μm AMAD Resuspended ^{239}Pu Particles

Organ	Translocation Class	Committed Dose Equivalent Factors (rem per μg · sec/m^3)	Committed Dose Equivalent[a] (rem)
Total Body	Y	4.6E-04	3.5E-07
Lungs	W	8.1E-04	6.2E-07
Bone	Y	9.7E-03	7.5E-06
GI-LLI	W	5.9E-07	4.5E-10

(a)At the same location where initial inhalation was calculated.

Cloud Submersion

A semi-infinite cloud model is used for calculating the external doses from cloud submersion during cloud passage. The doses are calculated with the following equation:

$$D_i = E_T(DF)_i \, S_F \qquad \text{(A-5)}$$

where

- E_T • sum of the initial exposure from initial cloud passage and resuspended radioactive material (μg · sec/m^3)
- $(DF)_i$ • dose factor for cloud submersion for organ i (rem per μg · sec/m^3)
- S_F • attenuation factor which accounts for shielding provided by residential structures (dimensionless)

The total exposure is calculated by:

$$E_T = E + W(8.64 \times 10^4) \int_0^{T_d} K(t)\, dt \qquad \text{(A-6)}$$

where all terms have already been defined.

The total exposure to the airborne particulate, E_T, is calculated to be 1.8×10^{-3} μg-sec/m^3. A value of 0.70 is used for the attenuation factor, S_F (USNRC Guide 1.109 1977).

Doses for submersion in a semi-infinite cloud of ^{239}Pu were calculated using dose factors taken from Soldat (1974) and converted to dose per unit mass. The calculated doses and dose factors are given in Table A.3.

TABLE A.3. Air Submersion Doses from Exposure to ^{239}Pu

Organ	Dose Factor (rem per μg · sec/m^3)	Dose (rem)
Total Body	9.6E-13	1.2E-15
Skin	1.3E-11	1.6E-14

Ground Exposure

Dose from external exposure to radioactive material deposited on the ground is calculated by:

$$D_i = W(DF)_i \, S_F \, T \qquad \text{(A-7)}$$

where

- $(DF)_i$ • dose rate factor for organ i (rem/hr per μg/m^2)
- S_F • attenuation factor defined in Equation A-5 (dimensionless)
- T • time of exposure (hours)

W has been defined previously (μg/m^2).

The assumption is made that the ground concentration of plutonium is constant (radiological decay is insignificant and was ignored), and the exposure time, T, is 50 years or 4.38×10^5 hours. A value of 0.70 is used for S_F (USNRC Guide 1.109 1977).

The dose rate factors were again taken from Soldat et al. (1974) and converted to dose per unit mass. The calculated dose factors and doses are listed in Table A.4.

TABLE A.4. Fifty Years of External Exposure to ^{239}Pu Deposited on the Ground

Organ	Dose Rate Factor (rem/hour per μg/m²)	Dose (rem)
Total Body	4.9E-11	1.5E-11
Skin	4.8E-10	1.5E-10

Crop Ingestion

The internal committed dose equivalent received from ingestion of contaminated vegetation is calculated by Equation A-8.

$$DC_i = C_p\, U_p\, (DCF)_i \qquad \text{(A-8)}$$

where

- U_p • consumption rate for vegetation (kg/yr)
- $(DCF)_i$ • 50-year committed dose equivalent factor for organ i from chronic ingestion of ^{239}Pu (rem per μg ingested per year)
- C_p • radionuclide concentration in the edible portion of the vegetation (μg/kg):

$$C_p = \frac{W\, V_d\, r\, T_r\, (8.64 \times 10^4)\, \exp(-\lambda_e t_2)}{Y} \left[10^{-4} \int_{T_1}^{T_2} \exp(\lambda_e s - 0.15\sqrt{s})\, ds + \frac{10^{-9}}{\lambda_e} \exp(\lambda_e t_2) - \exp(\lambda_e t_1) \right] + \frac{C_o\, r\, T_r}{Y} \exp[-\lambda_e (t_2 - t_1)] \qquad \text{(A-9)}$$

where previously undefined symbols are defined by:

- r • fraction of deposited radionuclide retained by the vegetation (dimensionless)
- T_r • factor for translocation of externally deposited radionuclides to the edible parts of the vegetation (dimensionless)

- Y • vegetation yield (kg/m^2)
- 8.64×10^4 • constant which converts days to seconds (sec/days)
- λ_e • effective decay constant for removal of radionuclides on leaf or produce surfaces by weathering and radiological decay ($days^{-1}$)
- t_1 • time from the accident to the appearance of the vegetation (days)
- t_2 • time from the accident to harvest of the vegetation (days)
- C_o • the concentration of radioactive material initially deposited on the vegetation ($\mu g/m^2$); equals zero if the vegetation was not present at the time of the accident.

Equation A-9 accounts for the radioactive material initially deposited on the vegetation following the accident as well as the contribution from the deposit of resuspended environmental residual radioactive material.

The contribution from root uptake of plutonium is negligible compared to the plutonium deposited directly onto the vegetation (less than 1%), and is ignored. It is assumed that the accident occurred a few days before harvest during the beginning of the growing season. A five-month growing season and a 90-day growing period for vegetation are used.

The integral was evaluated numerically. It was determined that almost all of the plutonium deposited on the vegetation occurs during the first year. Therefore, the assumption was made that the total intake occurs during the first year. Fifty-year committed dose equivalent factors were used to calculate the resulting committed dose equivalents.

Values for r, Y and λ_e are taken from Regulatory Guide 1.109 as 0.2 for particulates, 2.0 kg/m^2 for leafy vegetables and produce, and 0.0495 $days^{-1}$, respectively. Values of 1, for leafy vegetables, and 0.1, for produce, are used for T_r (Baker et al. 1966). Consumption rates for the maximum individual are taken from Regulatory Guide 1.109 and adjusted for a five-month growing season. Consumption rates of 27 kg/yr, for leafy vegetables, and 217 kg/yr, for fruits, vegetables, and grain, were calculated. The average plutonium concentrations in the edible portion of leafy vegetables and produce are presented in Table A.5 for a five-year period.

TABLE A.5. Average ^{239}Pu Concentration Estimated in Leafy Vegetables and Produce for a Five-Year Period

Year[(a)]	Plutonium Concentration (μg/kg)	
	Leafy Vegetables	Produce
1	4.7E-08	4.7E-09
2	9.4E-10	9.4E-11
3	2.9E-10	2.9E-11
4	1.2E-10	1.2E-11
5	5.5E-11	5.5E-12

(a) Accident occurred during first year, a few days before the first harvest.

Fifty-year committed dose equivalent factors for a one-year chronic ingestion of ^{239}Pu were taken from NUREG-0172 (Hoenes and Soldat 1977), modified using updated organ masses from ICRP-23 (1975) and biological half-lives from ICRP-19 (1972), and converted to a unit mass intake. Committed dose equivalent factors and committed dose equivalents were calculated and are included in Table A.6.

TABLE A.6. Fifty-Year Committed Dose Equivalents from 50 Years' Ingestion of Leafy Vegetables and Produce Contaminated with ^{239}Pu

Organ	Committed Dose Equivalent Factor (rem/50-year per μg ingested per year)	Committed Dose Equivalent (rem)
Total Body	1.2E-03	2.8E-09
Bone	4.5E-02	1.1E-07
GI-LLI	4.6E-03	1.1E-08

Ingestion of Milk and Beef

The internal committed dose equivalents from the ingestion of animal products (milk and beef) are calculated by:

$$DC_i = \left[\sum(CQ)\right] \; S \; U(DCF)_i \qquad \text{(A-10)}$$

where the summation of the product of the two terms, C and Q, represents the total radionuclide intake by the animal from consumption of contaminated forage, feed, and water, and

- C • radionuclide concentration in the animal's food, C_f (µg per kg forage or feed), or drinking water, C_w (µg per liter of water). Equation A-9 is used to determine values for C_f.
- Q • animals' consumption rate, Q_f (kg feed or forage/day), or Q_w (ℓ water/day)
- S • animal product transfer coefficient that relates the daily intake rate of an animal to the radionuclide concentration in milk, S_d (days/ℓ) and beef, S_b (days/kg)
- U • human consumption rate for milk, U_d (ℓ/year), or beef, U_b (kg/year)
- $(DCF)_i$ • chronic ingestion committed dose equivalent factor for organ i given in Table A.6 (rem/50-year per µg ingested per year)

The dose contribution from the ingestion of milk or beef contaminated by the animal's drinking water is addressed in the next section.

An eight-month grazing season is assumed for both beef cattle and milk cows. For the remaining four months, the animals are fed stored feed and grain, which were grown during the previous five-month growing season. The radionuclide concentration in the grain is calculated using Equation A-9. The same parameters used to calculate the concentration in produce are used for grain. It is assumed that the accident occurred a few days before the harvest, during the beginning of the growing season. A 90-day growing period is used.

To estimate the average radionuclide concentration deposited on the pasture from the initial accident and resuspended radioactive material, Equation A-9 was integrated with respect to t, evaluated over the eight-month grazing season using a 30-day buildup period (USNRC Guide 1.109 1977), and divided by the integration time period of 30 days. All other parameters remained unchanged, except that values of 1.0 (Baker et al. 1966) and 0.70 kg/m^2 (USNRC Guide 1.109 1977) were used for T_r and Y, respectively.

It was determined that almost all of the plutonium deposited on the grain and pasture occurs during the first year. Regulatory Guide 1.109 uses a value of 50 kg/day for feed or forage consumption for both beef cattle and milk cows. Values for S_d of 2.5×10^{-8} days/ℓ for milk and for S_b of 5.0×10^{-3} days/kg for beef are reported by Baker (1966). Values for the human consumption rates are taken from Regulatory Guide 1.109 as 310 ℓ of milk/year and 110 kg beef/year.

The average plutonium concentrations in the edible portion of the grain and in the fresh forage are presented in Table A.7 for a five-year period.

TABLE A.7. Average ^{239}Pu Concentration Estimated in Grain and Forage for a Five-Year Period

Year[(a)]	Plutonium Concentration (μg/kg)	
	Grain	Forage
1	4.7E-09	2.7E-08
2	9.5E-11	1.4E-09
3	2.9E-11	4.8E-10
4	1.2E-11	2.0E-10
5	5.5E-12	9.9E-11

(a)Accident occurred at beginning of first year, 90 days into the growing and grazing season.

Using the 50-year ingestion committed dose equivalent factors given in Table A.6, committed dose equivalents were calculated for the consumption of contaminated animal products and are presented in Table A.8.

TABLE A.8. Fifty-Year Committed Dose Equivalents from 50 Years' Ingestion of Milk and Beef Contaminated with ^{239}Pu

Organ	Committed Dose Equivalent (rem)	
	Milk	Beef
Total Body	9.8E-15	6.9E-10
Bone	3.7E-13	2.6E-08
GI-LLI	3.7E-14	2.7E-09

WATERBORNE PATHWAYS

To account for the contribution from radionuclides deposited onto a nearby surface body of water, a small lake one meter deep is assumed. Deposition over the lake is assumed to occur at the same rate as over land (USNRC Guide 1.111 1977). The plutonium is assumed to be soluble; however, it is most likely insoluble in water at normal pH levels. It is assumed that the radioactive particulates are uniformly mixed in the lake upon contact. A four-year removal half-life is used (Wahlgren and Marshall 1975).

A differential equation was set up with a dynamic source term (this includes the initial deposition onto the water and the contribution from deposited resuspended material) to reflect the changing water concentration. When this equation is solved for the water concentration, an expression is obtained similar to Equation A-9. Due to the slower removal process (four years versus 14 days for vegetation), and since the majority of the radioactive material deposited on the lake takes place during the first year, the water concentration curve approaches a simple exponential expression. The initial water concentration can be determined by extrapolating the curve back to time zero, which yields Equation A-11.

$$C_W = 1.86 \times 10^{-9} \exp(-\lambda t) \qquad \text{(A-11)}$$

where

- C_W • radionuclide concentration in water ($\mu g/\ell$)
- λ • removal constant for plutonium in the lake ($days^{-1}$); $\lambda = 0.693/1461\ days^{-1}$
- t • time since deposition onto the lake surface (days)
- 1.86×10^{-9} • extrapolated water concentration at $t = 0$ ($\mu g/\ell$)

Equation A-11 is much simpler than the complex solution obtained by solving the differential equation, and it only overestimates the water

concentration by a few percent over the 50-year period considered. Equation 11 was integrated to estimate the average radionuclide concentration in the water for each year.

Ingestion of Animal Products

If the animals' drinking water supply was to come from the lake, a small fraction of the plutonium would eventually be transferred to the animals' milk or meat and be subsequently ingested by the maximum exposed individual. Since the potential radionuclide intake from this pathway occurs for approximately 30 years, ingestion committed dose equivalent factors must be calculated to account for the decreasing commitment time as the exposure time approaches the end of the 50-year exposure period. Committed dose equivalent factors for chronic ingestion of radionuclides are calculated with Equation A-12.

$$(DCF)_i = (2.92 \times 10^{-7})\, SA\, (F_w\, \varepsilon/m)(\tau^2) \left[\lambda_e t_1 + \exp(-\lambda_e t_2) - \exp(-\lambda \Delta t)\right] \quad \text{(A-12)}$$

where

- $(DCF)_i$ • committed dose equivalent factor for organ i (rem per μg ingested per year)
- SA • specific activity of the radionuclide (pCi/μg)
- F_w • fraction of the ingested radionuclide reaching organ i (dimensionless)
- ε • effective energy of the radionuclide in organ i [(MeV/dis)(rem/rad)]
- m • mass of organ i (g)
- τ • effective half-life of the radionuclide in organ i (days)
- λ_e • effective decay constant in organ i ($days^{-1}$); $\lambda_e = \ln 2/\tau$
- t_1 • duration of intake (days)

t_2 • time over which the dose commitment is calculated, including the duration of intake (days)

Δt • $(t_2 - t_1) \geq 0$

One- through 50-year ingestion committed dose equivalent factors were calculated for ^{239}Pu using parameter values found in ICRP-2 (1959), ICRP-23 (1975), and ICRP-19 (1972). The committed dose equivalent factor to the GI-LLI from ingestion does not change.

Committed dose equivalents were calculated using Equation A-10 for each year during the 50-year exposure period, using average yearly water concentrations and the appropriate dose commitment factor for that year. Baker (1966) and Regulatory Guide 1.109 use animal water consumption values of 60 ℓ/day for milk cows, and 50 ℓ/day for beef cattle. The total committed dose equivalents for the 50-year period to the maximum individual from ingestion of animal products for this exposure pathway are presented in Table A.9. The sum of the contributions from animal product ingestion for the airborne pathway and the waterborne pathway is also shown in Table A.9.

TABLE A.9. Fifty-Year Committed Dose Equivalents from 50 Years' Ingestion of Animal Products Contaminated with ^{239}Pu (waterborne pathway and waterborne plus air)

Organ	Committed Dose Equivalents (rem) from Waterborne Pathway		Total Committed Dose Equivalents (rem) from Airborne and Waterborne Pathways	
	Milk	Beef	Milk	Beef
Total Body	5.2E-15	3.1E-10	1.5E-14	1.0E-09
Bone	2.0E-13	1.2E-08	5.7E-13	3.8E-08
GI-LLI	2.3E-14	1.4E-09	6.0E-14	4.1E-09

Drinking Water Ingestion

The committed dose equivalent from consumption of contaminated drinking water is calculated by:

$$DC_i = \overline{C}_w \, U_w \, (DCF)_i \qquad \text{(A-13)}$$

where

- $\overline{C}_w$ • average radionuclide concentration in water during the year of interest (µg/ℓ); calculated earlier
- U_w • consumption rate (ℓ/year)
- $(DCF)_i$ • chronic ingestion committed dose equivalent factor for organ i (rem per µg ingested)

A water consumption rate of 730 ℓ/year is used (USNRC Guide 1.109 1977). Committed dose equivalent factors were calculated using Equation A-12. The dose calculations were taken out to 28 years, at which time the contribution to the total dose commitment from drinking water is insignificant. The resulting committed dose equivalents are listed in Table A.10.

TABLE A.10. Fifty-Year Committed Dose Equivalents from 50 Years' Consumption of Water Contaminated with ^{239}Pu

Organ	Committed Dose Equivalent (rem)
Total Body	8.3E-09
Bone	3.2E-07
GI-LLI	3.6E-08

Fish Ingestion

The equation used to estimate the dose from consumption of fish, assuming immediate transfer and equilibrium after deposition of the radionuclide onto the lake, is:

$$DC_i = \overline{C}_w \, B \, U_f \, (DCF)_i \qquad \text{(A-14)}$$

where

- $\overline{C}_w$ • average radionuclide concentration in the lake during the year of interest (µg/ℓ); calculated earlier

B • equilibrium bioaccumulation factor expressed as the ratio of the concentration in fish to the radionuclide concentration in water (ℓ/kg)

U_f • fish consumption rate (kg/year)

$(DCF)_i$ • same committed dose equivalent factor calculated for the ingestion of animal products and drinking water, for organ i (rem per μg ingested)

A fish consumption rate of 21 kg/year is used (USNRC Guide 1.109 1977) and the value for the bioaccumulation factor, B, is selected to be 3.5 ℓ/kg (Soldat et al. 1974). The duration of fish consumption is assumed to be 50 years. However, the contribution from the last 22 years of fish consumption is negligible.

The committed dose equivalents from fish consumption were calculated and are given in Table A.11.

TABLE A.11. Fifty-Year Committed Dose Equivalents from 50 Years' Consumption of Fish Contaminated with ^{239}Pu

Organ	Committed Dose Equivalent (rem)
Total Body	3.8E-10
Bone	3.2E-08
GI-LLI	3.6E-09

Swimming and Boating

The following equation is used to calculate the dose from swimming:

$$D_i = \overline{C}_w (DF)_i U T \qquad \text{(A-15)}$$

where

$\overline{C}_w$ • average radionuclide concentration in the lake during the period of exposure (μg/ℓ); calculated earlier

$(DF)_i$ • water immersion dose rate factor for organ i (rem/hr per μg/ℓ)

U • exposure rate (hours/year)

T • period of exposure (years)

The dose rate factors were taken from Soldat et al. (1975) and converted to dose per unit mass. Equation A-11 was integrated over a 50-year period and divided by 50 years to obtain an average radionuclide concentration in the lake during the period of exposure of 2.1×10^{-10} μg/ℓ. Using a value of 100 hrs/year for the exposure rate (Soldat et al. 1974), and assuming a 50-year exposure time, the doses from swimming were calculated and are listed, along with the dose rate factors, in Table A.12.

TABLE A.12. Fifty Years of External Exposure to ^{239}Pu from Swimming

Organ	Dose Rate Factor (rem/hour per μg/liter)	Dose (rem)
Total Body	7.4E-09	7.8E-15
Skin	1.1E-07	1.2E-13

The doses received from boating are calculated using Equation 15 and by dividing the dose rate factors by 2, to correct for the geometry (Soldat et al. 1974). The same values assumed for U and T, in the dose calculations for swimming, are used (Soldat et al. 1974). The doses for boating are given in Table A.13.

TABLE A.13. Fifty Years of External Exposure to ^{239}Pu from Boating

Organ	Dose (rem)
Total Body	3.9E-15
Skin	5.8E-14

Shoreline Exposure

The doses received from exposure to shoreline deposits are calculated by:

$$D_i = U\ (DF)_i\ \overline{C}_s\ T \qquad \text{(A-16)}$$

where

- U • exposure rate (hours/year)
- $(DF)_i$ • dose factor for organ i given in Table 4 (rem/hour per $\mu g/m^2$)
- $\overline{C}_s$ • average radionuclide surface concentration in the top 2.5 cm of shoreline sediments ($\mu g/m^2$)
- T • period of exposure (years)

A differential equation was set up to represent the buildup of radionuclide concentration in the shoreline sediments from the transport of the radionuclide particulates in the water adjacent to the sediment. The procedure is similar to that discussed in Regulatory Guide 1.109, Rev. 1, except that the water concentration is decreasing with time. Assuming a sediment surface density of 40 kg/m^2 (USNRC Guide 1.109 1977) and a water-to-sediment transfer coefficient of 7.2×10^{-2} ℓ/kg per hour (USNRC Guide 1.109 1977), ignoring radiological decay, and using Equation A-11 to predict the water concentration, the following equation for the sediment surface concentration is obtained:

$$C_s = C_s^o + (1.29 \times 10^{-7})\ S_w\ [1 - \exp(-\lambda t)]/\lambda \qquad \text{(A-17)}$$

where

- C_s^o • the surface concentration of radioactive material initially deposited from the cloud onto the sediments ($\mu g/m^2$); same as W defined in Equation A-4

1.29×10^{-7} • the extrapolated water concentration at t = 0, 1.86×10^{-9} µg/ℓ, times the water-to-sediment transfer coefficient, 7.2×10^{-2} ℓ/kg · hr, times the sediment surface density, 40 kg/m^2, times 24 hr/day (µg/m^2 per day)

S_w • shore-width factor that describes the geometry of the exposure (dimensionless)

λ • removal constant for plutonium in a lake, defined in Equation A-11 (days^{-1})

t • time since deposition onto the lake surface (days)

A shore-width factor of 0.3 is assumed for a lake shore (USNRC Guide 1.109 1977). Equation A-17 was integrated over a 50-year period and divided by 50 years to obtain an average radionuclide surface concentration in the sediments of 7.3×10^{-5} µg/m^2, during the period of exposure. Using an exposure rate of 50 hrs/year (Soldat et al. 1974), doses were calculated for a 50-year period and are listed in Table A.14.

TABLE A.14. Fifty Years of Shoreline Exposure to ^{239}Pu

Organ	Dose (rem)
Total Body	8.9E-11
Skin	8.8E-10

SUMMARY OF FIFTY-YEAR COMMITTED DOSE EQUIVALENTS FROM ALL MODES OF EXPOSURE

A summary of the 50-year committed dose equivalents from all modes of exposure is given in Table A.15. The inhalation exposure mode contributes greater than 98% of the total dose to the total body, lungs, and bone. All other exposure modes contribute less than 1%, except water consumption, which contributes 1.6% to the total bone dose. The assumptions used for this exposure mode were very conservative, and, in reality, this mode of exposure is not expected to contribute significantly. Therefore, for accidental airborne releases of plutonium, only inhalation from initial cloud passage and resuspension requires consideration. Resuspension could contribute as much as 39% of the total dose to the total body, lungs, and bone from inhalation, if all plutonium particles released and available for resuspension are in the respirable range.

The dose equivalents to the skin and GI-LLI are insignificant when compared to the lungs and bone dose, and can be ignored. Although ^{239}Pu was the only isotope considered, these conclusions apply to most isotopes of plutonium and a typical mixture of plutonium isotopes.

TABLE A.15. Fifty-Year Committed Dose Equivalents from an Acute Release of ^{239}Pu to the Atmosphere

Exposure Mode	Fifty-Year Committed Dose Equivalents (rem) to the Following Organs:				
	Total Body	Skin	Lungs	Bone	GI-LLI
Initial Inhalation	5.6E-07 (61)		9.9E-07 (61)	1.2E-05 (60)	7.3E-10 (1.3)
Inhalation from Resuspension	3.5E-07 (38)		6.2E-07 (39)	7.5E-06 (38)	4.5E-10 (0.8)
Cloud Submersion	1.2E-15 (<0.1)	1.6E-14 (<0.1)	1.2E-15 (<0.1)	1.2E-15 (<0.1)	1.2E-15 (<0.1)
Ground Exposure	1.5E-11 (<0.1)	1.5E-10 (15)	1.5E-11 (<0.1)	1.5E-11 (<0.1)	1.5E-11 (<0.1)
Crop Consumption	2.8E-09 (0.3)			1.1E-07 (0.6)	1.1E-08 (20)
Milk Consumption	1.5E-14 (<0.1)			5.7E-13 (<0.1)	6.0E-14 (<0.1)
Beef Consumption	1.0E-09 (0.1)			3.8E-08 (0.2)	4.1E-09 (7.3)
Water Consumption	8.3E-09 (0.9)			3.2E-07 (1.6)	3.6E-08 (64)
Fish Consumption	8.3E-10 (<0.1)			3.2E-08 (0.2)	3.6E-09 (6.4)
Swimming	7.8E-15 (<0.1)	1.2E-13 (<0.1)	7.8E-15 (<0.1)	7.8E-15 (<0.1)	7.8E-15 (<0.1)
Boating	3.9E-15 (<0.1)	5.8E-14 (<0.1)	3.9E-15 (<0.1)	3.9E-15 (<0.1)	3.9E-15 (<0.1)
Shoreline Exposure	8.9E-11 (<0.1)	8.8E-10 (85)	8.9E-11 (<0.1)	8.9E-11 (<0.1)	8.9E-11 (0.2)
Totals	9.2E-07 (100)	1.0E-09 (100)	1.6E-06 (100)	2.0E-05 (100)	5.6E-08 (100)

( ) - percent contribution of pathway to total organ dose.

APPENDIX B

DOSE FACTORS FOR INHALATION, AND DOSE CALCULATION RESULTS FOR CLASS W PLUTONIUM

APPENDIX B

TABLE B.1. Fifty-Year Committed Dose Equivalent Factors from Acute Inhalation for Class W Material[a]

Isotope	(rem per μg inhaled) Total Body	Kidneys	Liver	Bone	Lungs
^{238}Pu	1.2E+3[b]	4.8E+3	1.5E+4	2.4E+4	9.2E+2
^{239}Pu	4.6E+0	1.9E+1	5.9E+1	9.7E+1	3.0E+0
^{240}Pu	1.7E+1	6.9E+1	2.2E+2	3.6E+2	1.1E+1
^{241}Pu	1.3E+2	6.1E+2	1.8E+3	3.2E+3	1.8E+0
^{242}Pu	2.8E-1	1.1E+0	3.6E+0	5.7E+0	1.8E-1
^{241}Am	2.0E+2	1.5E+3	3.2E+3	5.2E+3	1.7E+2

(a) Committed dose equivalent factors calculated using DACRIN for 1 μm AMAD size particles. Organ masses are those reported in ICRP-23.
(b) 1.2E+3 is identical to 1.2×10^3.

TABLE B.2. Fifty-Year Committed Dose Equivalent Factors from Acute Inhalation for Class Y Material

Isotope	(rem per μg inhaled) Total Body	Kidneys	Liver	Bone	Lungs
3238_{Pu}	4.3E+2	1.8E+3	5.8E+3	8.9E+3	9.0E+3
^{239}Pu	1.7E+0	7.1E+0	2.3E+1	3.7E+1	3.0E+1
^{240}Pu	6.3E+0	2.6E+1	8.3E+1	1.3E+2	1.1E+2
^{241}Pu	4.3E+1	2.0E+2	6.0E+2	1.1E+3	9.6E+1
^{242}Pu	1.0E-1	4.3E-1	1.4E+0	2.2E+0	1.8E+0
^{241}Am	7.8E+1	5.6E+2	1.2E+3	1.9E+3	1.7E+3

TABLE B.3. Fifty-Year Committed Dose Equivalent Factors from One-Year Chronic Inhalation for Class W Material

	(rem per μg inhaled in first year)				
Isotope	Total Body	Kidneys	Liver	Bone	Lungs
^{238}Pu	1.2E+3	4.8E+3	1.5E+4	2.4E+4	9.2E+2
^{239}Pu	4.5E+0	1.9E+1	5.8E+1	9.7E+1	3.0E+0
^{240}Pu	1.7E+1	6.8E+1	2.2E+2	3.6E+2	1.1E+1
^{241}Pu	1.3E+2	6.1E+2	1.8E+3	3.2E+3	1.8E+0
^{242}Pu	2.8E-1	1.1E+0	3.6E+0	5.7E+0	1.8E-1
^{241}Am	2.0E+2	1.5E+3	3.2E+3	5.1E+3	1.7E+2

TABLE B.4. Fifty-Year Committed Dose Equivalent Factors from One-Year Chronic Inhalation for Class Y Material

	(rem per μg inhaled in first year)				
Isotope	Total Body	Kidneys	Liver	Bone	Lungs
^{238}Pu	4.3E+2	1.8E+3	5.7E+3	8.8E+3	9.0E+3
^{239}Pu	1.7E+0	7.0E+0	2.2E+1	3.6E+1	3.0E+1
^{240}Pu	6.2E+0	2.6E+1	8.2E+1	1.3E+2	1.1E+2
^{241}Pu	4.3E+1	2.0E+2	6.0E+2	1.0E+3	9.6E+1
^{242}Pu	1.0E-1	4.3E-1	1.4E+0	2.1E+0	1.8E+0
^{241}Am	7.7E+1	5.6E+2	1.2E+3	1.9E+3	1.7E+3

TABLE B.5. Fifty-Year Committed Dose Equivalent Factors for ^{90}Sr

Organ of Reference	Rem per μg Inhaled in First Year
Total Body	4.2E+2
Bone	1.7E+3
Lung	7.8E+2

TABLE B.6. Fifty-Year Committed Dose Equivalents from Inhalation Following an Earthquake (Class W)

Organ of Reference	Committed Dose Equivalents for: Population (person-rem) Case I(b)	Case II	Case III	Case IV	Nearest Residence(a) (rem) Case I	Case II	Case III	Case IV
Total Body	4.3E-3	1.2E-2	1.7E-1	4.8E-1	1.7E-6	1.0E-5	6.5E-5	4.0E-4
Kidneys	3.5E-3	1.0E-2	1.4E-1	3.9E-1	1.3E-6	8.1E-6	5.3E-5	3.2E-4
Liver	1.1E-2	3.2E-2	4.3E-1	1.5E+0	4.2E-6	2.5E-5	1.7E-4	1.0E-3
Bone	3.2E-2	9.3E-2	1.2E+0	3.5E+0	1.2E-5	7.4E-5	4.9E-4	3.0E-3
Lungs	6.9E-3	2.0E-2	2.7E-1	7.6E-1	2.6E-6	1.6E-5	1.0E-4	6.4E-4

(a) Located 760 meters SW of the JN-1b Building.
(b) Case I - most likely release with most likely dispersion; Case II - most likely release with conservative dispersion; Case III - conservative release with most likely dispersion; Case IV - conservative release with conservative dispersion.

TABLE B.7. Fifty-Year Committed Dose Equivalents from Inhalation Following a 75-mph Straight-Line Wind (Class W)

Organ of Reference	Committed Dose Equivalents for: Population (person-rem) Case I	Case II	Case III	Case IV	Nearest Residence(a) (rem) Case I	Case II	Case III	Case IV
Total Body	1.6E-6	7.7E-6	1.7E-5	7.7E-5	3.8E-10	1.7E-9	3.5E-9	1.7E-8
Kidneys	1.4E-6	6.3E-6	1.4E-5	6.3E-5	3.1E-10	1.4E-9	2.9E-9	1.4E-8
Liver	4.3E-6	2.0E-5	4.3E-5	2.0E-4	9.8E-10	4.4E-9	9.1E-9	4.4E-8
Bone	1.2E-5	5.7E-5	1.3E-4	5.7E-4	2.8E-9	1.3E-8	2.6E-8	1.3E-7
Lungs	2.6E-6	1.2E-5	2.6E-5	1.2E-4	6.0E-10	2.7E-9	5.6E-9	2.7E-8

(a) Located 760 meters SW of the JN-1b Building.

TABLE B.8. Fifty-Year Committed Dose Equivalents from Inhalation Following a 95-mph Straight-Line Wind (Class W)

Organ of Reference	Committed Dose Equivalents for: Population (person-rem) Case I	Case II	Case III	Case IV	Nearest Residence(a) (rem) Case I	Case II	Case III	Case IV
Total Body	1.8E-6	9.3E-6	8.1E-4	4.8E-3	4.6E-10	2.4E-9	2.3E-7	1.5E-6
Kidneys	1.5E-6	7.7E-6	6.7E-4	4.0E-3	3.8E-10	2.0E-9	1.9E-7	1.2E-6
Liver	4.8E-6	2.4E-5	2.1E-3	1.2E-2	1.2E-9	6.3E-9	5.9E-7	3.9E-6
Bone	1.4E-5	7.0E-5	6.1E-3	3.6E-2	3.4E-9	1.8E-8	1.7E-6	1.1E-5
Lungs	2.9E-6	1.5E-5	1.3E-3	7.6E-3	7.3E-10	3.9E-9	3.6E-7	2.4E-6

(a) Located 760 meters SW of the JN-1b Building.

TABLE B.9. Fifty-Year Committed Dose Equivalents from Inhalation Following a 115-mph Straight-Line Wind (Class W)

Organ of Reference	Committed Dose Equivalents for: Population (person-rem)				Nearest Residence[a] (rem)			
	Case I	Case II	Case III	Case IV	Case I	Case II	Case III	Case IV
Total Body	9.3E-5	4.1E-4	2.3E-3	1.8E-2	2.1E-8	8.4E-8	7.0E-7	5.7E-6
Kidneys	1.1E-4	5.0E-4	2.9E-3	2.1E-2	2.5E-8	1.0E-7	8.6E-7	6.9E-6
Liver	3.6E-4	1.6E-3	9.0E-3	6.7E-2	7.9E-8	3.2E-7	2.7E-6	2.2E-5
Bone	8.5E-4	3.7E-3	2.1E-2	1.6E-1	1.9E-7	7.7E-7	6.4E-6	5.2E-5
Lungs	1.4E-4	6.1E-4	3.5E-3	2.6E-2	3.1E-8	1.2E-7	1.0E-6	8.4E-6

(a) Located 760 meters SW of the JN-1b Building.

TABLE B.10. Fifty-Year Committed Dose Equivalents from Inhalation Following a 300-mph Tornado (Class W)

Organ of Reference	Committed Dose Equivalents for: Population (person-rem)				Nearest Residence[a] (rem)			
	Case I	Case II	Case III	Case IV	Case I	Case II	Case III	Case IV
Total Body	3.4E-2	3.3E-1	1.3E+0	1.3E+1	4.4E-7	4.4E-6	1.8E-5	1.8E-4
Kidneys	2.7E-2	2.7E-1	1.1E+0	1.1E+1	3.6E-7	3.6E-6	1.4E-5	1.4E-4
Liver	8.6E-2	8.5E-1	3.4E+0	3.4E+1	1.1E-6	1.1E-5	4.5E-5	4.5E-4
Bone	2.5E-1	2.5E+0	1.0E+1	1.0E+2	3.3E-6	3.3E-5	1.3E-4	1.3E-3
Lungs	5.4E-2	5.4E-1	2.2E+0	2.2E+1	7.0E-7	7.0E-6	2.8E-5	2.8E-4

(a) Located 48,000 meters to 64,000 meters from the plant in the direction the tornado travels.

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