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Hanford Dose Overview Program:

Comparison of AIRDOS-EPA and Hanford Site Dose Codes

R. L. Aaberg
B. A. Napier

November 1985

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

Battelle

PNL-5633

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

NTIS Price Codes
Microfiche A01

Printed Copy

Pages	Price Codes
001-025	A02
026-050	A03
051-075	A04
076-100	A05
101-125	A06
126-150	A07
151-175	A08
176-200	A09
201-225	A010
226-250	A011
251-275	A012
276-300	A013

PNL-5633
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SUMMARY

Radiation dose commitments for persons in the Hanford environs calculated using AIRDOS-EPA were compared with those calculated using a suite of Hanford codes: FOOD, PABLM, DACRIN, and KRONIC. Dose commitments to the population and to the maximally exposed individual (MI) based on annual releases of eight radionuclides from the N-Reactor, were calculated by these codes. Dose commitments from each pathway to the total body, lung, thyroid, and lower large intestine (LLI) are given as ratios for comparison of codes in Tables S.1 and S.2 for the population and MI, respectively.

The selection of the MI location by AIRDOS limits the applicability of calculations concerning the MI at the Hanford Site. AIRDOS selected a location for the MI that is uninhabited. The location of choice for the MI for the entire Hanford Site is at a defined distance and direction.

TABLE S.1. Comparison of Dose Commitments to the Population (Ratio Hanford/AIRDOS)

Pathway	Organ			
	Total Body	Lung	Thyroid	LLI
Ingestion	3.5	0.4	5.4	1.3
Inhalation	1.0	4.5	2.2	0.6
External (from ground)	0.5	0.7	0.7	0.6
Air Submersion	0.4	0.5	0.5	0.5

TABLE S.2. Comparison of Dose Commitments to the Maximally Exposed Individual (Ratio Hanford/AIRDOS)

Pathway	Organ			
	Total Body	Lung	Thyroid	LLI
Ingestion	5.1	1.3	1.2	3.1
Inhalation	1.0	3.6	0.8	0.1
External (from ground)	0.4	0.6	0.6	0.5
Air Submersion	1.2	1.6	1.5	1.4

Dose commitments from the ingestion pathway to the MI are similar. Total body dose commitments differ, possibly because organ weightings are different. For dose to the thyroid for population exposures, the codes FOOD and PABLM project that the dose from ^{131}I dominates. The difference in the magnitude of the doses computed by AIRDOS and the Hanford codes results from plume depletion, which is not considered in the Hanford codes, making them more conservative for dose assessment purposes.

Inhalation doses computed by DACRIN show good agreement with AIRDOS. Dose to the lung is higher, and dose to the LLI is lower due to differences in dose factors. DACRIN projects higher population doses because plume depletion is not addressed.

External doses calculated by AIRDOS and the Hanford codes show good agreement. External doses from ground deposition calculated by FOOD and PABLM are generally about one-half of that estimated by AIRDOS. This is due to a factor of D.5 correction for surface roughness included in the Hanford codes. Population doses calculated by the Hanford codes are greater than one-half the AIRDOS values because extra deposition from a non-depleting plume partially compensates for the surface-roughness correction.

Air submersion doses computed by KRONIC are higher for the MI than estimates by AIRDOS because KRONIC uses a finite cloud model and AIRDOS uses a semi-infinite cloud model.

In general, the Hanford codes produce results that are equivalent to or more conservative than AIRDOS.

ACKNOWLEDGMENTS

The authors wish to acknowledge those who helped with this study. Many thanks to D. L. Strenge and J. K. Soldat for reviewing the document and providing valuable suggestions; to V. L. Brouns for editing support; and to N. C. Van Houten, C. A. Davey, and A. Jewell for providing word processing support.

This research was supported by the Hanford Dose Overview Committee, R. L. Kathren, Chair.

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1.0 INTRODUCTION

The Environmental Protection Agency (EPA) gives National Emission Standards for Hazardous Air Pollutants and Standards for Radionuclides in 40 CFR 61. These standards limit radionuclide emissions from DOE facilities to an amount that results in a dose equivalent rate of 25 mrem/yr to the total body or 75 mrem/yr to the critical organ for any member of the public. (The standard excludes ^{220}Rn and ^{222}Rn and their respective decay products.) To determine compliance with the standard, radionuclide emission shall be determined and dose equivalents to members of the public are to be calculated using EPA-approved sampling procedures and EPA model AIRDOS-EPA, or other procedures EPA has determined to be suitable (40 CFR 61.93). The purpose of this study is to show that the codes used at the Hanford Site are functionally equivalent to AIRDOS-EPA.

This study compares AIRDOS-EPA to the exposure assessment used on the Hanford Site, as designated by the Hanford Dose Overview Program (McCormack, Ramsdell and Napier 1984). The Hanford Dose Overview Program, administered by Pacific Northwest Laboratory (PNL) for the U.S. Department of Energy (DOE), was established at the request of the DOE Richland Operations Office (DOE-RL) to provide a method of ensuring internal consistency of Hanford- Site-related environmental dose assessments.

Hanford environmental monitoring information from the N-Reactor at the Hanford Site 100 Area, located about 40 km north-northwest of Richland, Washington, is used as a basis for the comparison. Meteorological data and airborne emissions of radionuclides were input into the Hanford codes and AIRDOS to calculate environmental concentrations of radionuclides and doses resulting from various modes of exposure. Pathways considered include ingestion, inhalation, external exposure to deposited radionuclides, inhalation, and air-submersion. Items compared in this report include results of meteorological calculations, dose to the maximally exposed individual (MI), and dose to the population.

The Hanford environmental monitoring report of 1984 (Price et al. 1985) compares measured and calculated radionuclide concentrations for 1984 PUREX Plant operation. Measured concentrations of radionuclides in air and water and those calculated by the Hanford dose models were in reasonable agreement.

2.0 COMPARISON OF METEOROLOGICAL CALCULATIONS

Calculation of atmospheric dispersion is a very important part of calculation of doses from airborne releases. Dispersion determines the concentration of airborne material and, when combined with deposition velocity, determines ground concentrations of the material.

Meteorological calculations are performed differently in AIRDOS than in the Hanford codes. Most of the Hanford codes use output from other meteorological codes to determine dispersion characteristics at the site, while AIRDOS determines these dispersion parameters internally from extensive meteorological data.

The primary meteorological parameter used to calculate air concentrations is the normalized atmospheric dispersion factor, $\bar{\chi}/Q'$, with units of Ci/m^3 per Ci/sec. The value of $\bar{\chi}/Q'$ is predicted by atmospheric dispersion models that use site measurements of the occurrence frequency for wind speed, wind direction, and atmospheric stability (joint frequency data). The dispersion factor is multiplied by the release rate of material to the atmosphere to yield the air concentration of the material.

Data on wind speed and direction are collected at each operating area and combined with atmospheric stability data collected at the Hanford Meteorology Station to provide input for the sector-averaged Gaussian model used to calculate dispersion factors. The 100 Area (N-Reactor) elevated release addressed in this report is based on an 89-m effective stack height (61-m stack plus plume rise).

All of the Hanford dose codes may use pre-calculated dispersion factors. The dispersion factors may represent the location of the MI or the distribution population within the study area. Alternately, the inhalation (DACRIN) and air submersion (KRONIC) codes may calculate dispersion factors.

AIRDOS includes atmospheric dispersion models that calculate values $\bar{\chi}/Q'$ given a large quantity of input data. Meteorological data required to run AIRDOS include: wind-direction frequency (16 directions), and reciprocalaveraged wind speeds, true-average wind speeds, and frequencies for Pasquill stability categories, each for seven Pasquill categories in 16 directions (Moore et al. 1979).

AIRDOS computes a table value of $\bar{\chi}/Q'$ for each radionuclide, corrected for decay and deposition during dispersion, whereas KRONIC and DACRIN consider decay in-transit, but not depletion. FOOD and PABLM use $\bar{\chi}/Q'$ for a non-decaying plume.

Table 1 gives a comparison of dispersion factors for a non-depleting plume used by Hanford codes with dispersion factors calculated by AIRDOS for ^{3}H and ^{131}I. The values of $\bar{\chi}/Q'$ for the non-depleting plume are comparable with $\bar{\chi}/Q'$ values for ^{3}H, which has a long half-life and little deposition. Non-depleting dispersion factors are about 1.1 times higher at 4 km, and are closer to the ^{3}H values at greater distances. In contrast, dispersion factors for radionuclides such as ^{131}I, which have a shorter half-life and greater deposition velocity, are much different for depleting and non-depleting plumes. Non-depleting plume $\bar{\chi}/Q'$ values at 72 km are three to six times the values for $\bar{\chi}/Q'$ for ^{131}I given by AIRDOS.

The population-weighted dispersion factor, PM, with units of person-sec/m^3, is used to compute population dose within the 80-km assessment area. The 1983 PM determined for Hanford 100-Area elevated releases is 1.43×10^{-3} person-sec/m^3. This compares favorably with a value of 1.33×10^{-3} computed using ^{3}H dispersion factors from AIRDOS. Population-weighted factors based on other isotopes may be considerably different. Table 2 gives a comparison of PM between Hanford and AIRDOS for the radionuclides in emissions from 100N.

In AIRDOS, dry deposition, scavenging by rain, and radioactive decay deplete the airborne plume as it is blown downwind. Depletion is accounted for by substituting a reduced release rate Q" for the original release rate Q'. The source depletion models maintain material balance as a plume is blown downwind from a source. The Hanford codes do not subtract for deposition, resulting in a higher estimate of doses. They also do not include resuspension, which tends to compensate for depletion.

TABLE 1. Comparison of Annual Average Dispersion Factors With and Without Radiological Decay and Plume Depletion[a] (sec/m^3)

Code/Radionuclide	Dispersion Factor 4 km	12 km	56 km	72 km
Hanford:				
All	8.06×10^{-8}	2.52×10^{-8}	4.32×10^{-9}	3.19×10^{-9}
AIRDOS-EPA:				
^{3}H	7.21×10^{-8}	2.38×10^{-8}	4.02×10^{-9}	3.03×10^{-9}
^{131}I	6.61×10^{-8}	1.75×10^{-8}	1.11×10^{-8}	5.89×10^{-10}

(a) North sector used as an example.

TABLE 2. Population-Weighted Dispersion Factor, PM, Based on Hanford Meteorological Data

Code	Radionuclide	PM (sec/m^3)	Fraction of Non-Depleting
Hanford	All	1.43×10^{-3}	1.0
AIRDOS	^{3}H	1.33×10^{-3}	0.93
	^{90}Sr	1.20×10^{-3}	0.84
	^{131}I	4.74×10^{-4}	0.33

Differences in PM result from a combination of radiological decay and plume depletion. AIRDOS was run with and without deposition (i.e., ^{3}H and ^{131}I) and with and without decay (i.e., ^{3}H and ^{131}I) and the results led to these conclusions. In FOOD, radiological decay is not considered until the material is deposited on the ground.

3.0 COMPARISON OF DOSE CALCULATIONS

This section compares 50-year dose commitments calculated by AIRDOS to those calculated by the standard Hanford dose codes.[a] The gaseous emissions from the Hanford Site N-Reactor stack during 1983, which are given in Table 3, are used as the source term for the dose calculations.

In this section, each dose pathway considered by AIRDOS is compared with its Hanford counterpart. Assumptions, methods, and dose factors from AIRDOS and the Hanford codes are discussed.

Pathways considered by AIRDOS include ingestion, inhalation, ground surface (external), air submersion, and swimming. The Hanford codes include the same pathways, with the exception of swimming in water contaminated from an airborne source (which has a negligible contribution to dose). FOOD and PABLM are used to compute doses from ingestion pathways and external exposure to contaminated ground.

TABLE 3. Radionuclides Released with Gaseous Effluents from the N-Reactor During CY 1983 (Price et al. 1984)

Radionuclide	Emission (Ci)
^{3}H	9.9×10^{0}
^{41}Ar	1.2×10^{5}
^{60}Co	6.3×10^{-3}
^{87}Kr	4.3×10^{2}
^{90}Sr	7.0×10^{-4}
^{131}I	3.4×10^{-1}
^{133}I	7.2×10^{-1}
^{138}Cs	5.4×10^{2}

(a) Dose commitment from ingestion and inhalation is specified in AIRDOS-EPA documentation, but the output titles say "Annual Dose" rather than "Dose Commitment."

Doses from the swimming pathway, as well as from ingestion of drinking water and irrigated crops, are computed in FOOD for waterborne contamination. Airborne deposition onto surface water is not considered in this comparison. DACRIN computes internal doses from inhalation, and KRONIC computes external doses from air submersion.

3.1 INGESTION DOSES: AIRDOS VS. FOOD

Ingestion doses from airborne releases are estimated from the deposition pattern, transfer factors, local food production and consumption, and ingestion dose factors. FOOD and PABLM are both used for dose assessments, but the calculations are somewhat different. FOOD computes a dose from one year of uptake following a specified deposition period and a variable dose commitment period. PABLM uses uptake from one year of operation, plus uptake from residual contamination for a variable commitment period (50 years is used in the Hanford Annual Reports). Dose factors used in AIRDOS are for a commitment period of 50 years. The optional build-up time in AIRDOS for residual deposition is for comparison with PABLM or FOOD.

In estimating potential ingestion doses, the ground deposition rate of airborne materials is calculated from the air concentration and a deposition velocity. For this analysis, where AIRDOS and FOOD recommend the use of different deposition velocities (see Appendix A), the deposition velocities from the Hanford codes have been used.

A major difference between AIRDOS and FOOD is that AIRDOS considers plume depletion and FOOD does not. Depletion results in lower air concentrations and, hence, less deposition at long distances from the source of the plume for AIRDOS than for FOOD.

Translocation factors are used to determine what happens to the material after it is deposited onto soil and plant surfaces. In the Hanford codes 25% of the direct deposition is presumed to be retained on foliage; the same value was used in AIRDOS for this comparison. Both AIRDOS and FOOD use translocation factors to calculate the fraction of deposited activity that transfers from plant surfaces and the ground to the edible portion of the crop. For animal products such as milk and meat, consumption rates by animals and additional translocation factors are included. The recommended transfer coefficients for each are given in Appendix A. A value of 14 days is used for the weathering half-life for both AIRDOS and the Hanford codes.

A comparison of the transfer coefficients indicates that the ingestion-to-milk transfer for iodine factor, perhaps the most important value for this comparison, is the same (1.0×10^{-2} d/L) for both AIRDOS and FOOD. Most of the factors used in AIRDOS are within a factor of two or three of those in the Hanford transfer-factor library.

Local production and consumption rates for each foodstuff are used to estimate the intake of radionuclides. AIRDOS input parameters were adjusted to fit Hanford agriculture and ingestion patterns to correspond with calculation done for the Dose Overview Committee (McCormack, Ramsdell and Napier 1984). Consumption parameters used to calculate ingestion doses for MI and population (average) are given in Appendix A. There are two major differences between the diet presumed for Hanford residents and that recommended in the AIRDOS documentation. The Hanford dietary parameters include a higher average per capita milk consumption and the diet of the MI contains a larger quantity of locally produced fruit.

Dose conversion factors relate radionuclide intake to radiation dose. A table of dose conversion factors is not available in PABLM and FOOD; values are computed within the code. Dose factors used by the Hanford codes for a 50-year commitment from one year of uptake are, however, represented by Hoenes and Soldat (1977), which uses the same internal dosimetry model as does FOOD. These values are compared in Appendix A with the factors from Dunning et al. (1981) used in AIRDOS. Differences in dose commitment factors for the total body may be partially attributable to different definitions of "total body."

The treatment of ^{3}H is similar in AIRDOS and FOOD. For both AIRDOS and FOOD, concentrations in environmental media are assumed to be proportional to the ^{3}H in air.

Results--Ingestion Dose

Values of organ dose commitments to the population and to the MI are compared in Tables 4 and 5, respectively. The 50-year committed population dose to the total body calculated by FOOD and PABLM is about four times that calculated by AIRDOS. Higher dose commitments for ^{131}I (17 times higher) and ^{90}Sr (nine times higher) calculated with FOOD are from a combination of higher dose factors and deposition from a non-depleting plume.

Doses from iodine show the most difference among the codes. This difference is illustrated with thyroid dose from ^{131}I. FOOD indicates that the dominant dose commitment is the milk pathway, which is 3.2 out of 3.7 person-rem. The total dose commitment calculated with AIRDOS is 0.746 person-rem. The major difference is caused by plume depletion in AIRDOS from the high deposition velocity of iodine. Neglecting plume depletion in FOOD makes the population dose (average resident about 56 km from 100N) five times larger than the AIRDOS estimate, when the MI dose (4 km distance) is only 1.2 times larger.

TABLE 4. Dose to the Population from Ingestion (person-rem)

Code	Organ			
	Total Body	Lung	Thyroid	LLI
AIRDOS	4.0×10^{-3}	3.0×10^{-3}	6.9×10^{-1}	4.2×10^{-3}
FOOD	1.4×10^{-2}	1.3×10^{-3}	3.7×10^{0}	5.4×10^{-3}
PABLM	1.5×10^{-2}	1.3×10^{-3}	3.6×10^{0}	5.4×10^{-3}

TABLE 5. Dose to the Maximally Exposed Individual from Ingestion, at 4 km E (rem)

Code	Organ			
	Total Body	Lung	Thyroid	LLI
AIRDOS	6.5×10^{-7}	2.1×10^{-7}	7.0×10^{-4}	4.2×10^{-7}
FOOD	3.3×10^{-6}	2.8×10^{-7}	8.2×10^{-4}	1.3×10^{-6}
PABLM	3.6×10^{-6}	2.8×10^{-7}	8.2×10^{-4}	1.4×10^{-6}

Because AIRDOS does not allow for the user to input the actual location of the MI, the location normally input to the Hanford codes could not be used. The Hanford Site, with an area of almost 500 km^2, has many uninhabited sectors. AIRDOS chose a location for the MI in one such sector, 4 km east of the N-Reactor. This location was input to the FOOD and PABLM codes. The actual location of the MI, according to McCormack et al. (1984), is 53 km SSE of the N-Reactor. At this latter location the ambient concentrations from N-Area emissions are less than 2% of those indicated by the 4-km-distant MI.

3.2 INHALATION DOSES: AIRDOS VS. DACRIN

Downwind transport and diffusion of airborne effluents are calculated from data collected during long-term onsite measurement of wind speed, wind direction and atmospheric stability. Release rates of radionuclides to the atmosphere are used with the atmospheric dispersion model to calculate air concentrations at specified locations in the environment. Radiation doses resulting from inhalation are calculated directly from these air concentrations on the basis of an inhalation rate and duration of occupancy.

DACRIN computes dose internally, using the model of the respiratory tract adopted by the International Commission on Radiological Protection (ICRP) Task Group on Lung Dynamics (ICRP 1966). Information from various standard Hanford data libraries are used in these calculations. Inhalation dose factors may be obtained from DACRIN by inputting unit quantities of radioisotopes.

AIRDOS requires dose factors as input to calculate doses. AIRDOS uses all data in the form of input rather than in the form of data libraries, as with the Hanford codes.

Dose commitment in DACRIN is computed internally, but the dose commitment factors in both codes are based on the same model as the factors from Dunning et al. (1981). A comparison of dose factors from DACRIN and AIRDOS is included in Appendix A. In general, the inhalation dose factors for the two codes are within a factor of two of each other.

DACRIN accounts for deposition and decay in-transit; an average windspeed of 4.1 m/sec is used; in AIRDOS, a spectrum of windspeeds is generated to simulate an actual spectrum of windspeeds for travel time, decay, and deposition.

Results--Inhalation Dose

Dose commitments to the population and to the MI are given in Tables 6 and 7. Population doses to the total body are nearly identical, although contributions from various radionuclides differ (Appendix B). Other organ doses are generally within a factor of two.

3.3 EXTERNAL DOSES: AIRDOS VS. FOOD

External dose from direct exposure is calculated from the surface concentration of radionuclides deposited on the ground, and the duration of the exposure. In both the Hanford codes and AIRDOS, doses from gamma photons emitted from radionuclides on the ground are estimated using dose conversion factors derived for exposure at 1 meter above an infinite plane source.

TABLE 6. Fifty-Year Dose Commitment to the Population from Inhalation (person-rem)

Code	Organ			
	Total Body	Lung	Thyroid	LLI
AIRDOS	6.5×10^{-4}	3.1×10^{-3}	6.0×10^{-2}	4.9×10^{-4}
OACRIN	6.8×10^{-4}	1.4×10^{-2}	1.3×10^{-1}	2.8×10^{-4}

TABLE 7. Fifty-Year Oose Commitment to the Maximally Exposed Individual from Inhalation (rem)

Code	Organ			
	Total Body	Lung	Thyroid	LLI
AIRDOS	8.0×10^{-8}	4.4×10^{-7}	1.9×10^{-5}	4.8×10^{-7}
DACRIN	7.9×10^{-8}	1.6×10^{-6}	1.5×10^{-5}	3.2×10^{-8}

AIRDOS uses external dose correction factors (from input) to convert surface doses to doses for total body and reference organs. FOOD uses dose factors that are the same for total body and organs. External dose factors used in FOOD and PABLM include a factor of 0.5 for surface roughness. External dose factors (Appendix A) from FOOD vary from 0.2 to 1.3 times the corresponding dose factors from AIRDOS.

Results--External Dose

Ooses to the population and to the MI from external exposure are summarized in Tables 8 and 9. The dose to the population estimated by AIRDOS is 0.018 person-rem, mostly from ^{60}Co. Doses from FOOD and PABLM are 0.009 and 0.008 person-rem, respectively. Because the dose factors used in FOOD and PABLM include a correction for surface roughness, external doses estimated with FOOD are roughly one-half those from AIRDOS. This ratio may be different with different radionuclide source terms because dose factors for individual radionuclides vary.

TABLE 8. Dose to the Population from External Exposure to Ground (person-rem)

	Organ			
Code	Total Body	Lung	Thyroid	LLI
AIRDOS	1.8×10^{-2}	1.3×10^{-2}	1.3×10^{-2}	1.5×10^{-2}
FOOD	9.1×10^{-3}	9.1×10^{-3}	9.1×10^{-3}	9.1×10^{-3}
PABLM	7.8×10^{-3}	7.8×10^{-3}	7.8×10^{-3}	8.4×10^{-3}

TABLE 9. Dose to the Maximally Exposed Individual from External Exposure to Ground (rem)

	Organ			
Code	Total Body	Lung	Thyroid	LLI
AIRDOS	3.4×10^{-6}	2.5×10^{-6}	2.5×10^{-6}	2.9×10^{-6}
FOOD	1.5×10^{-6}	1.5×10^{-6}	1.5×10^{-6}	1.5×10^{-6}
PABLM	1.3×10^{-6}	1.3×10^{-6}	1.3×10^{-6}	1.3×10^{-6}

Immersion in a shallow body of water (i.e., swimming pool) is considered in AIRDOS. Since the only source of contamination is deposition onto the surface of the water, the additional external dose from that pathway is negligible. The Hanford codes are capable of computing doses for swimming and shoreline exposure, but only for waterborne effluents.

3.4 AIR SUBMERSION DOSES: AIRDOS VS. KRONIC

KRONIC is the Hanford code used to calculate air submersion doses from long-term releases to the atmosphere. The gamma dose is calculated with a finite cloud model. In KRONIC the photon emissions from radionuclides are divided into energy groups. The dose is computed for each group separately then combined into a total dose. (To determine the contribution from individual nuclides, separate cases must be run.)

AIRDOS lists the contribution by radionuclide. AIRDOS estimates external doses from submersion in air containing gamma-emitting radionuclides with a dose conversion factor calculated for an infinite cloud (rem-cm^3/μCi-hr). The code receives a skin-dose conversion factor as input data for each radionuclide for infinite cloud exposure. This skin-dose conversion factor is multiplied in the code by an external dose correction factor for total body and each reference organ, also supplied as input data for each radionuclide.

Ranges of dose factors expressed for AIRDOS cover the range of dose factors to various organs; lungs are usually on the low end of the range, and kidneys on the high end. The doses from KRONIC are based on a tissue depth of 5 cm.

AIRDOS was run with a "lid" height (maximum atmospheric mixing height) of 2000 m to compare with KRONIC, which has a maximum σ_z[(a)] of 2000 m.

Results--Air Submersion Dose

Doses to the population and to the MI are given in Tables 10 and 11. Organ doses from KRONIC are presumed to be the same as the total body dose,

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(a) σ_z is vertical crosswind standard deviation.

TABLE 10. Dose to the Population from Air Submersion (person-rem)

Code	Organ			
	Total Body	Lung	Thyroid	LLI
AIRDOS	6.1	4.7	4.8	5.1
KRONIC	2.5	2.5	2.5	2.5

TABLE 11. Dose to the Maximally Exposed Individual from Air Submersion (rem)

Code	Organ			
	Total Body	Lung	Thyroid	LLI
AIRDOS	3.5×10^{-3}	2.7×10^{-3}	2.8×10^{-3}	3.0×10^{-3}
KRONIC	4.3×10^{-3}	4.3×10^{-3}	4.3×10^{-3}	4.3×10^{-3}

i.e., equivalent to the dose at a 5-cm-tissue depth. The external dose from air submersion is primarily from ^{41}Ar, which dominates doses from N-Reactor gaseous effluents.

Air submersion dose to the population for the total body is estimated in AIROOS to be 6.1 person-rem, compared with 2.5 person-rem in KRONIC. Contributions from individual nuclides are generally within a factor of two of the AIRDOS population doses. Doses from iodine calculated by KRONIC are more than twa times greater, probably because plume depletion is not addressed in KRONIC as it is in AIRDOS. Oifferences in finite vs. semi-infinite cloud are not important for population dose, where the population-weighted average distance is about 56 km.

The air submersion doses computed by KRONIC are higher for the MI than those estimated by AIRDOS because KRONIC uses a finite cloud model that accounts for the gamma dose from an overhead plume; AIRDOS uses a semi-infinite cloud model that uses ground-level concentration to calculate submersion doses. Differences for individual nuclides are generally within a factor of two.

Comparisons between dose factors for air submersion for AIRDOS and KRONIC would not be meaningful because the cloud models used are different. Far from the source of the plume (as in population dose), a semi-infinite cloud is a good model. Differences in contributions of individual nuclides to population dose for nuclides with a small deposition velocity may be attributed to differences in dose factors (Appendix B).

4.0 CONCLUSIONS

Comparison of doses calculated by AIRDOS and the Hanford codes for gaseous effluents released from the 100-N Area in 1983 (Price et al. 1984) shows that, for dose assessment purposes, the codes produce results that are comparable for dose assessment purposes. The Hanford codes are generally more conservative because plume depletion is not modeled.

4.1 MAXIMALLY EXPOSED INDIVIDUAL

A major difference in the MI doses calculated by the codes stems from the location of the MI in AIRDOS, which is 4 km east of 100N as opposed to the 53 km SSE selected by the Dose Overview Committee (McCormack, Ramsdell and Napier 1984). This comparison has been conducted on the assumption of an MI residing 4 km east of the site, although this is not the actual case.

4.2 INGESTION DOSES

Fifty-year dose commitments to comparable organs of the MI from ingestion calculated by the two codes were generally within a factor of three. Total body doses differ by a greater amount, possibly because of different organ weightings. Population doses estimated by the Hanford codes are generally higher because plume depletion makes a big difference at the greater distances where most of the population resides.

A combination of dose commitment factors and plume depletion accounts for most of the differences.

4.3 INHALATION DOSES

Inhalation doses from AIRDOS and DACRIN are, in most cases, within a factor of two.

4.4 EXTERNAL GROUND DOSES

Ratios of external doses calculated by AIRDOS and those produced by FOOD and PABLM vary from 0.4 to 0.7. The differences are partly explained by the surface roughness factor of 0.5; population doses from the Hanford codes are higher because plume depletion is ignored.

4.5 AIR SUBMERSION DOSES

Air submersion doses calculated by AIRDOS and KRONIC generally agree within a factor of two. Doses to the MI calculated by KRONIC are higher than those from AIRDOS because KRONIC uses a finite plume model.

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APPENDIX A

DOSE FACTORS AND INPUT PARAMETERS

APPENDIX A

DOSE FACTORS AND INPUT PARAMETERS

This Appendix documents and compares parameters used during the comparison of the AIRDOS-EPA and Hanford codes. Quantities documented include consumption parameters, transfer coefficients, and dose factors. Dose factors used by AIRDOS are compared with those in the Hanford External Dose Factor Library (GRNDFLIB) and those generated within the codes, based on the Hanford Radionuclide Master Data Library (RMDLIB) and Organ Data Library (ORGLIB).

A.1 INGESTION FACTORS: AIRDOS VS. FOOD

Information used in calculating doses from ingestion of contaminated foods are given in the following tables. Table A.1 gives deposition velocities recommended by AIRDOS and by FOOD. For this comparison, FOOD values have been used as input for both codes.

Transfer coefficients for plants, milk, and beef for both AIRDOS and the Hanford transfer factor library are given in Table A.2. Differences of a factor of three or greater are noted.

Consumption rates and holdup times used are given in Table A.3.

Table A.4 shows organ dose factors for ingestion used in AIRDOS and in FOOD. Differences of a factor of three or more are noted. Dose conversion factors for ingestion resulting from an annual intake of a radionuclide are

TABLE A.1. Deposition Velocities Recommended by AIRDOS and FOOD (cm/sec)

	Material		
Code	reactive gases[a]	small particles	unreactive gases[b]
AIRDOS	3.5	0.18	0.018
FOOD	1.0	0.1	---

(a) For example, ^{2}I, ^{2}Br.
(b) For example, noble gases.

TABLE A.2. Transfer Coefficients Used in AIRDOS and FOOD

Food Item/Code	Element			
	Co	Sr	I	Cs
Plants: Soil				
AIRDOS	---	2.9×10^{-1}	5.5×10^{-2}	9.3×10^{-3}
FOOD	9.4×10^{-3}	2.0×10^{-1}	2.0×10^{-2}	*2.0×10^{-3}
Milk: Feed				
AIRDOS	---	2.4×10^{-3}	1.0×10^{-2}	5.6×10^{-3}
FOOD	5.0×10^{-4}	1.5×10^{-3}	1.0×10^{-2}	5.0×10^{-3}
Beef: Feed				
AIRDOS	---	3.0×10^{-4}	7.0×10^{-3}	1.4×10^{-2}
FOOD	1.0×10^{-3}	3.0×10^{-4}	2.0×10^{-2}	3.0×10^{-2}

* Denotes that transfer coefficients differ by a factor of three or more.

TABLE A.3. Consumption Parameters Used in this Comparison

Food Item	Consumption Rate (kg/yr)		Holdup Time (days)	
	Maximum	Average	Maximum	Average
Leafy vegetables	30	15	1	14
Vegetables/grain	300	212	1-10[a]	14
Fruit	335	64	1-10[a]	14
Meat	98	78	15	34
Milk	274 (L/yr)	230 (L/yr)	1	4

(a) Range based on different vegetable types given in FOOD--longer end of range for grain, shorter for vegetables.

provided as input to AIRDOS. Dose conversion factors include contributions by both the radionuclides and its daughters growing in after intake. To designate this, +D has been used from data listings from the Hanford codes.

TABLE A.4. Representative Ingestion Dose Factors Used in AIRDOS and FOOD (mrem/50-yr per pCi ingested in first year)

	Radionuclide					
Organ/Code	^{3}H	^{60}Co	$^{90}Sr+D$	$^{131}I+D$	$^{133}I+D$	^{138}Cs
Total Body						
AIRDOS	8.3×10^{-8}	4.37×10^{-6}	9.45×10^{-5}	9.08×10^{-7}	2.65×10^{-7}	0.
FOOD	5.99×10^{-8}	4.92×10^{-6}	1.75×10^{-4}	*3.41×10^{-6}	7.53×10^{-7}	*5.4×10^{-8}
Thyroid						
AIRDOS	8.28×10^{-8}	3.10×10^{-6}	5.99×10^{-6}	1.80×10^{-3}	4.50×10^{-4}	0.
FOOD	5.99×10^{-8}	*0.	*0.	1.95×10^{-3}	3.63×10^{-4}	0.
LLI						
AIRDOS	1.43×10^{-7}	4.02×10^{-5}	7.78×10^{-5}	5.32×10^{-8}	3.98×10^{-8}	0.
FOOD	5.99×10^{-8}	4.02×10^{-5}	*2.97×10^{-4}	*1.57×10^{-6}	*2.22×10^{-6}	4.65×10^{-13}

* Denotes that dose factors differ by more than a factor of three.

A.2 INHALATION DOSES: AIRDOS VS. DACRIN

Table A.5 compares inhalation dose factors computed with DACRIN to those contained in the AIRDOS documentation.

A.3 EXTERNAL EXPOSURE: AIRDOS VS. FOOD

External exposure to contaminated ground is based on dose factors given in Table A.6. The two sets of factors have two primary differences: FOOD has a factor of 0.5 built in to account for surface roughness, and dose factors for FOOD for all organs are assumed to be the same as those for the total body calculated at a 5-cm tissue depth.

TABLE A.5. Inhalation Dose Factors from AIRDOS and DACRIN (rem/µCi)

Organ/Code	Radionuclide ^{60}Co	^{90}Sr	^{131}I	^{133}I	^{138}Cs
Total Body:					
AIRDOS	8.2×10^{-3}	2.4×10^{-1}	6.1×10^{-4}	2.0×10^{-4}	---
DACRIN	3.0×10^{-3}	*1.7	*2.0×10^{-3}	3.8×10^{-4}	*1.4×10^{-5}
Lung:					
AIRDOS	1.3×10^{0}	9.9×10^{-3}	2.4×10^{-3}	3.2×10^{-3}	---
DACRIN	3.0×10^{0}	1.1×10^{-2}	2.4×10^{-3}	3.6×10^{-3}	*6.0×10^{-4}
Thyroid:					
AIRDOS	6.0×10^{-2}	1.5×10^{-2}	1.1×10^{0}	2.4×10^{-1}	---
DACRIN	* ---	* ---	1.1×10^{0}	1.9×10^{-1}	---
LLI:					
AIRDOS	2.8×10^{-2}	1.4×10^{-2}	3.4×10^{-5}	2.3×10^{-5}	---
DACRIN	2.4×10^{-2}	1.1×10^{-2}	*2.6×10^{-4}	*3.6×10^{-4}	4.9×10^{-11}

* Denotes that dose factors differ by more than a factor of three.

TABLE A.6. Dose Factors for External Exposure from FOOD and AIRDOS (rem/hr per $\mu Ci/cm^2$)

Radionuclide	Total body Food	Total body AIRDOS	Lungs AIRDOS	LLI AIRDOS
^{60}Co	1.7×10^{-1}	3.2×10^{-1}	2.4×10^{-1}	2.7×10^{-1}
^{90}Sr	0.0	9.0×10^{-7}	9.0×10^{-7}	9.0×10^{-7}
^{131}I	2.8×10^{-2}	2.2×10^{-2}	1.5×10^{-2}	1.8×10^{-2}
^{133}I	3.7×10^{-2}	7.7×10^{-2}	5.5×10^{-2}	6.6×10^{-2}
^{138}Cs	2.1×10^{-1}	2.7×10^{-1}	2.1×10^{-1}	2.3×10^{-1}

APPENDIX B

DOSE COMMITMENTS FROM N-REACTOR GASEOUS EFFLUENTS AS CALCULATED BY AIRDOS-EPA AND HANFORD CODES

APPENDIX B

DOSE COMMITMENTS FROM N-REACTOR GASEOUS EFFLUENTS AS CALCULATED BY AIRDOS-EPA AND HANFORD CODES

This Appendix contains the dose commitments calculated for gaseous releases from N-Reactor operations during 1983 as calculated by AIRDOS-EPA and Hanford codes. The dose commitments are presented in table form for the population and the MI, by pathway. Tables B.1 and B.2 are for ingestion; Tables B.3 and B.4 are for inhalation; Tables B.5 and B.6 are for external exposure; Tables B.7 and B.8 are for air submersion.

TABLE B.1. Fifty-Year Dose Commitments to the Population from Ingestion (person-rem)

Radionuclide	Organ/Code: Total Body		Lung		Thyroid		LLI	
	AIRDOS	FOOD	AIRDOS	FOOD	AIRDOS	FOOD	AIRDOS	FOOD
^{3}H	2.6×10^{-3}	1.3×10^{-3}	2.6×10^{-3}	1.3×10^{-3}	2.6×10^{-3}	1.3×10^{-3}	2.6×10^{-3}	1.3×10^{-3}
^{41}Ar	---(a)	---	---	---	---	---	---	---
^{60}Co	7.5×10^{-5}	2.3×10^{-5}	1.5×10^{-4}	---	5.3×10^{-5}	---	6.9×10^{-4}	2.2×10^{-4}
^{87}Kr	---	---	---	---	---	---	---	---
^{90}Sr	1.0×10^{-3}	6.7×10^{-3}	6.6×10^{-5}	---	6.6×10^{-5}	---	8.5×10^{-4}	5.0×10^{-4}
^{131}I	3.5×10^{-4}	6.4×10^{-3}	1.5×10^{-4}	---	6.9×10^{-1}	3.7×10^{0}	2.0×10^{-5}	3.3×10^{-3}
^{133}I	9.5×10^{-8}	2.5×10^{-5}	8.0×10^{-8}	---	1.6×10^{-4}	1.2×10^{-2}	1.4×10^{-8}	8.2×10^{-5}
^{138}Cs	---	---	---	---	---	---	---	---
TOTAL	4.0×10^{-3}	1.4×10^{-2}	3.0×10^{-3}	1.3×10^{-3}	6.9×10^{-1}	3.7×10^{0}	4.2×10^{-3}	5.4×10^{-3}

(a) Dash (-) indicates not applicable to pathway or value insignificant (less than 10^{-10}).

TABLE B.2. Fifty-Year Dose Commitments to the MI from Ingestion (rem)

Radionuclide	Organ/Code: Total Body		Lung		Thyroid		LLI	
	AIRDOS	FOOD	AIRDOS	FOOD	AIRDOS	FOOD	AIRDOS	FOOD
^{3}H	2.8×10^{-7}	2.8×10^{-7}	2.8×10^{-7}	2.8×10^{-7}	2.8×10^{-7}	2.8×10^{-7}	2.8×10^{-7}	2.8×10^{-7}
^{41}Ar	---(a)	---	---	---	---	---	---	---
^{60}Co	2.0×10^{-8}	5.3×10^{-9}	3.9×10^{-8}	---	1.4×10^{-8}	---	1.8×10^{-7}	5.0×10^{-8}
^{87}Kr	---	---	---	---	---	---	---	---
^{90}Sr	2.7×10^{-7}	1.6×10^{-6}	1.7×10^{-8}	---	1.7×10^{-8}	---	2.2×10^{-7}	1.2×10^{-7}
^{131}I	3.5×10^{-7}	1.4×10^{-6}	1.5×10^{-7}	---	7.0×10^{-4}	7.9×10^{-4}	2.1×10^{-8}	7.1×10^{-7}
^{133}I	1.4×10^{-9}	4.7×10^{-8}	1.2×10^{-9}	---	2.4×10^{-6}	2.2×10^{-5}	2.2×10^{-10}	1.5×10^{-7}
^{138}Cs	---	---	---	---	---	---	---	---
TOTAL	9.3×10^{-7}	3.3×10^{-6}	4.9×10^{-7}	2.8×10^{-7}	7.1×10^{-4}	8.2×10^{-4}	7.1×10^{-7}	1.3×10^{-6}

(a) Dash (-) indicates not applicable to pathway or value insignificant (less than 10^{-10}).

TABLE B.3. Fifty-Year Dose Commitments to the Population from Inhalation (person-rem)

Radionuclide	Organ/Code: Total Body AIRDOS	Total Body DACRIN	Lung AIRDOS	Lung DACRIN	Thyroid AIRDOS	Thyroid DACRIN	LLI AIRDOS	LLI DACRIN
^{3}H	4.1×10^{-4}	2.5×10^{-4}	4.1×10^{-4}	2.5×10^{-4}	4.1×10^{-4}	2.4×10^{-4}	4.4×10^{-4}	---(a)
^{41}Ar	---	---	---	---	---	---	---	---
^{60}Co	1.5×10^{-4}	6.5×10^{-6}	2.4×10^{-3}	6.5×10^{-3}	1.1×10^{-4}	---	5.3×10^{-5}	5.2×10^{-5}
^{87}Kr	---	---	---	---	---	---	---	---
^{90}Sr	4.9×10^{-5}	1.7×10^{-4}	2.0×10^{-6}	1.6×10^{-3}	3.0×10^{-6}	---	2.9×10^{-6}	1.0×10^{-5}
^{131}I	2.4×10^{-5}	1.8×10^{-4}	9.5×10^{-5}	2.7×10^{-3}	4.3×10^{-2}	1.0×10^{-1}	1.3×10^{-6}	7.8×10^{-5}
^{133}I	1.3×10^{-5}	5.4×10^{-5}	2.1×10^{-4}	2.1×10^{-3}	1.6×10^{-2}	2.7×10^{-2}	1.5×10^{-6}	1.4×10^{-4}
^{138}Cs	---	1.7×10^{-5}	---	7.0×10^{-4}	---	---	---	---
TOTAL	6.5×10^{-4}	6.8×10^{-4}	3.1×10^{-3}	1.4×10^{-2}	6.0×10^{-2}	1.3×10^{-1}	4.9×10^{-4}	2.8×10^{-4}

(a) Dash (-) indicates not applicable to pathway or value insignificant (less than 10^{-10}).

TABLE B.4. Fifty-Year Dose Commitments to the MI from Inhalation (rem)

Radionuclide	Organ/Code: Total Body AIRDOS	Total Body DACRIN	Lung AIRDOS	Lung DACRIN	Thyroid AIRDOS	Thyroid DACRIN	LLI AIRDOS	LLI DACRIN
^{3}H	4.4×10^{-8}	2.9×10^{-8}	4.4×10^{-8}	2.9×10^{-8}	4.4×10^{-8}	2.9×10^{-8}	4.7×10^{-7}	---(a)
^{41}Ar	---	---	---	---	---	---	---	---
^{60}Co	1.8×10^{-8}	7.4×10^{-10}	2.9×10^{-7}	7.4×10^{-7}	1.3×10^{-8}	---	6.4×10^{-9}	5.7×10^{-9}
^{87}Kr	---	---	---	---	---	---	---	---
^{90}Sr	6.0×10^{-9}	2.0×10^{-8}	2.5×10^{-10}	1.8×10^{-7}	3.7×10^{-10}	---	3.5×10^{-10}	1.2×10^{-9}
^{131}I	7.1×10^{-9}	2.0×10^{-8}	2.8×10^{-8}	3.1×10^{-7}	1.3×10^{-5}	1.2×10^{-5}	4.0×10^{-10}	9.1×10^{-9}
^{133}I	5.0×10^{-9}	6.2×10^{-9}	7.8×10^{-8}	2.4×10^{-7}	5.9×10^{-6}	3.1×10^{-6}	5.6×10^{-10}	1.6×10^{-8}
^{138}Cs	---	2.5×10^{-9}	---	1.1×10^{-7}	---	---	---	---
TOTAL	8.0×10^{-8}	7.9×10^{-8}	4.4×10^{-7}	1.6×10^{-6}	1.9×10^{-5}	1.5×10^{-5}	4.8×10^{-7}	3.2×10^{-8}

(a) Dash (-) indicates not applicable to pathway or value insignificant (less than 10^{-10}).

TABLE B.5. Fifty-Year Dose Commitments to the Population from External Exposure to Ground (person-rem)

Radionuclide	Organ/Code							
	Total Body		Lung		Thyroid		LLI	
	AIRDOS	FOOD	AIRDOS	FOOD	AIRDOS	FOOD	AIRDOS	FOOD
^{3}H	---[(a)]	---	---	---	---	---	---	---
^{41}Ar	---	---	---	---	---	---	---	---
^{60}Co	1.6×10^{-2}	3.3×10^{-3}	1.2×10^{-2}	3.3×10^{-3}	1.2×10^{-2}	3.3×10^{-3}	1.3×10^{-2}	3.3×10^{-3}
^{87}Kr	---	---	---	---	---	---	---	---
^{90}Sr	2.2×10^{-8}	---	2.2×10^{-8}	---	2.2×10^{-8}	---	2.2×10^{-8}	---
^{131}I	9.9×10^{-4}	1.3×10^{-3}	6.6×10^{-4}	1.3×10^{-3}	4.2×10^{-4}	1.3×10^{-3}	8.2×10^{-4}	1.3×10^{-3}
^{133}I	5.9×10^{-4}	3.8×10^{-4}	4.3×10^{-4}	3.8×10^{-4}	2.6×10^{-4}	3.8×10^{-4}	5.1×10^{-4}	3.8×10^{-4}
^{138}Cs	3.6×10^{-4}	4.2×10^{-3}	2.8×10^{-4}	4.2×10^{-3}	2.9×10^{-4}	4.2×10^{-3}	3.0×10^{-4}	4.2×10^{-3}
TOTAL	1.8×10^{-2}	9.2×10^{-3}	1.3×10^{-2}	9.1×10^{-3}	1.3×10^{-2}	9.1×10^{-3}	1.5×10^{-2}	9.1×10^{-3}

(a) Dash (-) indicates not applicable to pathway or value insignificant (less than 10^{-10}).

TABLE B.6. Fifty-Year Dose Commitments to the MI from External Exposure to Ground (rem)

Radionuclide	Total Body AIRDOS	Total Body FOOD	Lung AIRDOS	Lung FOOD	Thyroid AIRDOS	Thyroid FOOD	LLI AIRDOS	LLI FOOD
^{3}H	---[a]	---	---	---	---	---	---	---
^{41}Ar	---	---	---	---	---	---	---	---
^{60}Co	1.9×10^{-6}	5.6×10^{-7}	1.4×10^{-6}	5.6×10^{-7}	1.5×10^{-6}	5.6×10^{-7}	1.6×10^{-6}	5.6×10^{-7}
^{87}Kr	---	---	---	---	---	---	---	---
^{90}Sr	---	---	---	---	---	---	---	---
^{131}I	2.9×10^{-7}	2.1×10^{-7}	1.9×10^{-7}	2.1×10^{-7}	1.2×10^{-7}	2.1×10^{-7}	2.4×10^{-7}	2.1×10^{-7}
^{133}I	2.2×10^{-7}	6.4×10^{-8}	1.6×10^{-7}	6.4×10^{-8}	9.6×10^{-8}	6.4×10^{-8}	1.9×10^{-7}	6.4×10^{-8}
^{138}Cs	9.9×10^{-7}	6.9×10^{-7}	7.8×10^{-7}	6.9×10^{-7}	8.3×10^{-7}	6.9×10^{-7}	8.5×10^{-7}	6.9×10^{-7}
TOTAL	3.4×10^{-6}	1.5×10^{-6}	2.5×10^{-6}	1.5×10^{-6}	2.5×10^{-6}	1.5×10^{-6}	2.9×10^{-6}	1.5×10^{-6}

(a) Dash (-) indicates not applicable to pathway or value insignificant (less than 10^{-10}).

TABLE B.7. Fifty-Year Dose Commitments to the Population from Air Submersion (person-rem)

	Organ/Code							
	Total Body		Lung		Thyroid		LLI	
Radionuclide	AIRDOS	KRONIC	AIRDOS	KRONIC	AIRDOS	KRONIC	AIRDOS	KRONIC
^{3}H	---[(a)]	---	---	---	---	---	---	---
^{41}Ar	6.1×10^{0}	2.5×10^{0}	4.7×10^{0}	2.5×10^{0}	4.8×10^{0}	2.5×10^{0}	5.1×10^{0}	2.5×10^{0}
^{60}Co	3.7×10^{-6}	4.5×10^{-6}	2.8×10^{-6}	4.5×10^{-6}	2.9×10^{-6}	4.5×10^{-6}	3.1×10^{-6}	4.5×10^{-6}
^{87}Kr	9.2×10^{-3}	5.6×10^{-3}	7.2×10^{-3}	5.6×10^{-3}	7.6×10^{-3}	5.6×10^{-3}	8.1×10^{-3}	5.6×10^{-3}
^{90}Sr	---	---	---	---	---	---	---	---
^{131}I	1.1×10^{-5}	3.6×10^{-5}	7.0×10^{-6}	3.6×10^{-5}	4.5×10^{-6}	3.6×10^{-5}	8.7×10^{-6}	3.6×10^{-5}
^{133}I	2.8×10^{-5}	6.6×10^{-5}	2.0×10^{-5}	6.6×10^{-5}	1.3×10^{-5}	6.6×10^{-5}	2.4×10^{-5}	6.6×10^{-5}
^{138}Cs	7.4×10^{-3}	2.2×10^{-3}	5.9×10^{-3}	2.2×10^{-3}	6.3×10^{-3}	2.2×10^{-3}	6.4×10^{-3}	2.2×10^{-3}
TOTAL	6.1×10^{0}	2.5×10^{0}	4.7×10^{0}	2.5×10^{0}	4.8×10^{0}	2.5×10^{0}	5.1×10^{0}	2.5×10^{0}

(a) Dash (-) indicates not applicable to pathway or value insignificant (less than 10^{-10}).

TABLE B.8. Fifty-Year Dose Commitments to the MI from Air Submersion (rem)

	Organ/Code							
	Total Body		Lung		Thyroid		LLI	
Radionuclide	AIRDOS	KRONIC(a)	AIRDOS	KRONIC	AIRDOS	KRONIC	AIRDOS	KRONIC
^{3}H	---(b)	---	---	---	---	---	---	---
^{41}Ar	3.5×10^{-3}	4.3×10^{-3}	2.7×10^{-3}	4.3×10^{-3}	2.8×10^{-3}	4.3×10^{-3}	3.0×10^{-3}	4.3×10^{-3}
^{60}Co	4.5×10^{-10}	5.9×10^{-10}	3.4×10^{-10}	5.9×10^{-10}	3.5×10^{-10}	5.9×10^{-10}	3.8×10^{-10}	5.9×10^{-10}
^{87}Kr	7.3×10^{-6}	1.5×10^{-5}	5.7×10^{-6}	1.5×10^{-5}	6.0×10^{-6}	1.5×10^{-5}	6.4×10^{-6}	1.5 x 10-5
^{90}Sr	---	---	---	---	---	---	---	---
^{131}I	3.1×10^{-9}	5.1×10^{-9}	2.1×10^{-9}	5.1×10^{-9}	1.3×10^{-9}	5.1×10^{-9}	2.6×10^{-9}	5.1×10^{-9}
^{133}I	1.0×10^{-8}	1.3×10^{-8}	7.5×10^{-9}	1.3×10^{-8}	4.6×10^{-9}	1.3×10^{-8}	8.9×10^{-9}	1.3×10^{-8}
^{138}Cs	2.1×10^{-5}	1.7×10^{-5}	1.7×10^{-5}	1.7×10^{-5}	1.8×10^{-5}	1.7×10^{-5}	1.8×10^{-5}	1.7×10^{-5}
TOTAL	3.5×10^{-3}	4.3×10^{-3}	2.7×10^{-3}	4.3×10^{-3}	2.8×10^{-3}	4.3×10^{-3}	3.0×10^{-3}	4.3×10^{-3}

(a) Dose from KRONIC is for 5-cm tissue depth.
(b) Dash (-) indicates not applicable to pathway or value insignificant (less than 10^{-10}).

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