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Benchmarking of RESRAD-OFFSITE: Transition from RESRAD (onsite) to RESRAD-OFFSITE and Comparison of the RESRAD-OFFSITE Predictions with Peer Codes

Environmental Science Division

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by
C. Yu, E. Gnanapragasam, J.-J. Cheng, and B. Biwer
Environmental Science Division, Argonne National Laboratory

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NOTATION

The following is a list of the acronyms, initialisms, and abbreviations (including units of measure) used in this document. Acronyms and abbreviations used only in tables and figures are defined in the respective tables and figures.

GENERAL ACRONYMS AND ABBREVIATIONS

BIOMOVS II	Biosphere Model Validation Study II
CAP88-PC	Clean Air Act Assessment Package-1988
EPA	U.S. Environmental Protection Agency
FGR	Federal Guidance Report
ISCLT3	Industrial Source Complex-Long Term
NREL	National Renewable Energy Laboratory
RESRAD	Residual Radioactivity (model)

CHEMICALS

C-14	carbon-14
CO_2	carbon dioxide
Co-60	cobalt-60
Cs-137	cesium-137
H-3	hydrogen-3
HTO	tritiated water
I-129	iodine-129
K-40	potassium-40
Kr-85	krypton-85
Np-237	neptunium-237
Pu-239	plutonium-239
Ra-226	radium-226
Ra-228	radium-228
Sr-90	strontium-90
Th-230	thorium-230
U-234	uranium-234
U-238	uranium-238

UNITS OF MEASURE

cal	calorie(s)
cm	centimeter(s)
cm^3	cubic centimeter(s)
d	day(s)
g	gram(s)
h	hour(s)
K	degree(s) Kelvin
kg	kilogram(s)
L	liter(s)
m	meter(s)
m^2	square meter(s)
m^3	cubic meter(s)
mrem	millirem(s)
pCi	picocurie(s)
s	second(s)
yr	year(s)
μm	micrometer(s)

BENCHMARKING OF RESRAD-OFFSITE: TRANSITION FROM RESRAD (ONSITE) TO RESRAD-OFFSITE AND COMPARISON OF THE RESRAD-OFFSITE PREDICTIONS WITH PEER CODES

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C. Yu, E. Gnanapragasam, J.-J. Cheng, and B. Biwer

ABSTRACT

The main purpose of this report is to document the benchmarking results and verification of the RESRAD-OFFSITE code as part of the quality assurance requirements of the RESRAD development program. This documentation will enable the U.S. Department of Energy (DOE) and its contractors, and the U.S. Nuclear Regulatory Commission (NRC) and its licensees and other stakeholders to use the quality-assured version of the code to perform dose analysis in a risk-informed and technically defensible manner to demonstrate compliance with the NRC's License Termination Rule, Title 10, Part 20, Subpart E, of the *Code of Federal Regulations* (10 CFR Part 20, Subpart E); DOE's 10 CFR Part 834, Order 5400.5, "Radiation Protection of the Public and the Environment"; and other Federal and State regulatory requirements as appropriate.

The other purpose of this report is to document the differences and similarities between the RESRAD (onsite) and RESRAD-OFFSITE codes so that users (dose analysts and risk assessors) can make a smooth transition from use of the RESRAD (onsite) code to use of the RESRAD-OFFSITE code for performing both onsite and offsite dose analyses.

The evolution of the RESRAD-OFFSITE code from the RESRAD (onsite) code is described in Chapter 1 to help the dose analyst and risk assessor make a smooth conceptual transition from the use of one code to that of the other. Chapter 2 provides a comparison of the predictions of RESRAD (onsite) and RESRAD-OFFSITE for an onsite exposure scenario. Chapter 3 documents the results of benchmarking RESRAD-OFFSITE's atmospheric transport and

dispersion submodel against the U.S. Environmental Protection Agency's (EPA's) CAP88-PC (Clean Air Act Assessment Package-1988) and ISCLT3 (Industrial Source Complex-Long Term) models. Chapter 4 documents the comparison results of the predictions of the RESRAD-OFFSITE code and its submodels with the predictions of peer models.

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1 INTRODUCTION

The RESRAD-OFFSITE code is an extension of the “original” RESRAD code, which was designed for evaluation of radiological doses to an onsite receptor (Yu et al. 1993, 2001). To prevent potential confusion of these two code names, the “original” RESRAD code is denoted as RESRAD (onsite) where appropriate, although RESRAD-OFFSITE can model both onsite and offsite receptors. The purpose of this report is two-fold. First, benchmarking of RESRAD-OFFSITE partially satisfies the quality assurance/quality control (QA/QC) requirements of the RESRAD program. Second, this report documents the differences of RESRAD (onsite) and RESRAD-OFFSITE and helps users understand the similarities and differences for a smooth transition from RESRAD (onsite) to RESRAD-OFFSITE.

This report documents the comparison of the predictions of the RESRAD-OFFSITE code and the submodels used in RESRAD-OFFSITE with the predictions of peer models. The evolution of the RESRAD-OFFSITE code from the RESRAD (onsite) code is described in this chapter. Chapter 2 provides a comparison of the predictions of RESRAD-OFFSITE and RESRAD (onsite) for an onsite exposure scenario. In Chapter 3, the atmospheric transport submodel is benchmarked against the CAP88-PC (Clean Air Act Assessment Package-1988) (Parks 1992) and ISCLT3 (Industrial Source Complex-Long Term) (EPA 1995) models. In Chapter 4, groundwater transport submodel predictions are compared with those published in the literature for national and international peer codes.

1.1 RESRAD (ONSITE)

RESRAD (onsite) is a computer code that evaluates the radiological dose and excess cancer risk to an individual who is exposed while residing and/or working in an area where the soil is contaminated with radionuclides (Yu et al. 2001). RESRAD was developed by the Environmental Assessment Division of Argonne National Laboratory (Argonne) in the 1980s and has been widely used to perform assessments of contaminated sites since its release in 1989. Since then, the RESRAD (onsite) code has undergone continuous improvement in response to feedback from users and sponsors. The RESRAD team has participated in many national and international model intercomparison studies in which both hypothetical and actual contaminated site-based scenarios were analyzed using RESRAD (onsite). The evolution of the RESRAD-

OFFSITE code from RESRAD (onsite) began during the Biosphere Modeling Validation Study II (BIOMOVS II), in which models were compared (Gnanapragasam and Yu 1997).

1.2 RESRAD-OFFSITE

RESRAD-OFFSITE (Yu et al. 2001) is a computer code that evaluates the radiological dose and excess cancer risk to an individual who is exposed while residing and/or working in or near an area where the soil is contaminated by radionuclides. It evolved from RESRAD (onsite) during the BIOMOVS II model comparison, first by the addition of an offsite soil accumulation submodel (BIOMOVS II 1995) and then by the inclusion of an advective-dispersive groundwater transport submodel (BIOMOVS II 1996). The ability to accept a time series for the release from the contaminated soil was also added during this study. The advective-dispersive groundwater transport submodel was improved to better predict the transport of progeny produced in transit during participation in the multimedia model comparison study (Gnanapragasam et al. 2000). Since then, an atmospheric transport submodel and a surface water body accumulation submodel have been added. Many of the submodels in RESRAD (onsite) were modified during the addition of these submodels. The computational algorithm of the RESRAD-OFFSITE code also changed from that of RESRAD (onsite). RESRAD (onsite) numerically evaluates the analytical expressions for concentration, dose, and risk at any desired time since the site survey; RESRAD-OFFSITE uses numerical methods to compute the concentration, dose, and risk progressively over time.

1.3 SAME OR SIMILAR SUBMODELS IN RESRAD (ONSITE) AND RESRAD-OFFSITE

This section identifies the submodels in RESRAD-OFFSITE that are essentially the same as the corresponding ones in RESRAD (onsite). It also describes the differences in those submodels, which serve as a starting point for investigating the differences in the predictions of the two codes.

1.3.1 Groundwater Release Submodel

The release to groundwater is the only release that RESRAD (onsite) explicitly considers. This is a first-order release model in which the flux of radionuclides released to the infiltrating water at any time is in direct proportion to the radionuclide inventory in the contaminated soil at that time. The same model was retained in RESRAD-OFFSITE, although the radionuclide inventory at any time is adjusted differently because of the modifications to the surface soil mixing submodel.

1.3.2 Surface Soil Mixing Submodel

The surface soil mixing submodel in RESRAD (onsite) ignores the contaminants that were removed by erosion of the initially uncontaminated mixing layer. Although this model is appropriate for RESRAD (onsite) because it does not address the surface soil release to offsite location, it is not suitable for RESRAD-OFFSITE, which models the accumulation of the eroded material in a surface water body and offsite soils. The new model in RESRAD-OFFSITE maintains mass balance of contaminants.

1.3.3 Dust Release Model

Although RESRAD (onsite) does not explicitly model a release to the atmosphere, it does model the effects of a dust release (inhalation, foliar deposition) by using the concept of a mass loading factor. In RESRAD-OFFSITE, this concept has been extended to provide a release to the atmospheric transport model.

1.3.4 Exposure Models

All the exposure models in RESRAD (onsite) — direct external radiation, inhalation of dust and radon, ingestion of vegetables, meat, milk, aquatic food and soil — were retained in RESRAD-OFFSITE, with minor changes. In RESRAD-OFFSITE, these exposure models are applied at more locations and more contamination pathways — on primary contamination in agricultural and farmed areas because of contamination by irrigation and deposition of dust. The exposure models were changed to accommodate the numerical nature of the RESRAD-OFFSITE code and also to facilitate their application to the offsite locations.

1.3.5 Advective Groundwater Transport Model

The groundwater transport model in RESRAD (onsite) considers the effects of the different transport rates of the progeny nuclides that are produced in transit. The option of using this advective transport model was retained in RESRAD-OFFSITE, in addition to the option of considering the effects of dispersive transport. Although the basic concepts are the same for both codes, each code implements them differently. The concentrations of nuclides in well and surface water at any time are expressed analytically in RESRAD (onsite), although these expressions are evaluated numerically. In RESRAD-OFFSITE, the nuclide transport is modeled zone by zone (each unsaturated zone and then the saturated zone) by numerically calculating the flux across each zone progressively over time.

1.3.6 Comparing Predictions of RESRAD (Onsite) and RESRAD-OFFSITE

Because RESRAD-OFFSITE is capable of modeling both onsite and offsite exposure and because of the wide acceptance of RESRAD (onsite), the predictions of RESRAD-OFFSITE are first compared with those of RESRAD (onsite) for an onsite exposure scenario in Chapter 2. The differences in the predictions are identified, and ways of refining the inputs to achieve closer predictions are described and implemented.

1.4 ADDITIONAL SUBMODELS IN RESRAD-OFFSITE

As mentioned in Section 1.2, submodels to simulate the following were included in RESRAD-OFFSITE: atmospheric transport, advective-dispersive groundwater transport, accumulation in offsite soil, and accumulation in a surface water body. The performance of these models is not tested in the comparison with RESRAD (onsite) predictions because the latter does not model these processes. The predictions of the atmospheric transport submodel are compared with those of CAP88PC (Parks 1992) and ISCLT3 (EPA 1995) in Chapter 3. In Chapter 4, the predictions of the advective-dispersive groundwater transport model are compared with those in the literature.

2 COMPARISON OF RESRAD (ONSITE) AND RESRAD-OFFSITE RESULTS FOR AN ONSITE EXPOSURE SCENARIO

The purpose of this chapter is to compare the dose results calculated by RESRAD-OFFSITE with those calculated by RESRAD (onsite) for onsite radiation exposures. The comparison was implemented by designing an onsite exposure scenario and applying both computer codes to analyze the scenario. Although the input parameters used by the two computer codes differ in some aspects, the values for those parameters in each code were selected so that the physical conditions of the hypothetical contaminated site and exposure conditions of the receptor were represented as closely as possible. The scenario descriptions and parameters used by both codes are presented in Section 2.1. The results are compared and discussed in Section 2.2.

2.1 DESCRIPTION OF ONSITE EXPOSURE SCENARIO

The exposure scenario selected for the comparison considers an onsite residential farmer who builds a house and grows plant foods and raises livestock on a contaminated area. In addition, he draws water from an onsite well for drinking and household use, and from both an onsite well and an onsite pond for irrigation and for feeding livestock. Occasionally, the farmer catches fish from the onsite pond and consumes the catch. Applicable exposure pathways for this scenario include external radiation; inhalation of radon and dust particles; and ingestion of soil, plant foods, meat, milk, fish, and drinking water.

A total of 13 radionuclides were selected as contaminants of concern: carbon-14 (C-14), cobalt-60 (Co-60), cesium-137 (Cs-137), hydrogen-3 (H-3), potassium-40 (K-40), neptunium-237 (Np-237), plutonium-239 (Pu-239), radium-226 (Ra-226), radium-228 (Ra-228), strontium-90 (Sr-90), thorium-230 (Th-230), uranium-234 (U-234), and uranium-238 (U-238). These radionuclides were selected because they emit different types of radiation and have different critical pathways for exposure. The inclusion of H-3, C-14, and radon precursors allows the comparison of the special models (radon diffusion and emanation, evaporation of tritiated water [HTO] and carbon dioxide [CO_2], and translocation of H-3 and C-14 from soil to plants) implemented in the two codes.

2.1.1 RESRAD (Onsite) Input Parameter Values

Appendix A lists the values for the soil/water partitioning coefficient (Kd) and plant food, meat, milk, and fish transfer factors used by RESRAD (onsite) for this comparison. Appendix B lists the values for the remaining input parameters. Most parameters were assigned either the mean or median values corresponding to their generic distributions or the RESRAD (onsite) default values. When the generic distribution, documented in NUREG/CR-6697 (Yu et al. 2000), is described by a log normal or log uniform function, the median value of the distribution was calculated and used. For other types of distribution functions, the mean value was calculated and used. If the generic distribution was not available in NUREG/CR-6697, the RESRAD (onsite) default value was used.

The area of contamination was assumed to be 100 acres or 404,700 m^2. The thickness of the contaminated zone was assumed to be 15 cm. The maximum length of the contaminated area parallel to the groundwater flow direction was taken to be the square root of the area, that is, 636 m. There was no cover material on top of the contaminated soil. The erosion rate of the contaminated zone was set to zero. The maximum number of points for dose integration was set to 5 in order to match as closely as possible the number of points used in RESRAD-OFFSITE for the yearly dose calculation in this case.

2.1.2 RESRAD-OFFSITE Input Parameter Values

To analyze offsite exposures, RESRAD-OFFSITE requires information on additional parameters other than those used by RESRAD (onsite). The onsite exposure scenario was modeled by the proper choice of input parameters, as discussed below.

In RESRAD (onsite), the entire areas or a portion of the agricultural areas for leafy and nonleafy vegetables and of the livestock feed areas for pasture, silage, and grain are assumed to be within the range of the contaminated site. Therefore, it is assumed that these areas have the same soil properties as the contaminated site. In RESRAD-OFFSITE, however, the entire agricultural and livestock feed areas can be located off the range of the contaminated site at different distances and can have different soil properties. The fractions of the agricultural and livestock feed areas over the contaminated zone were set to 1 in RESRAD-OFFSITE in order to simulate the onsite scenario. In addition, the soil properties applicable to the contaminated zone were specified for the agricultural and livestock feed growing areas.

The performance of the air dispersion model in RESRAD-OFFSITE is compared with its peers in Chapter 3. The RESRAD-OFFSITE code turns off the air dispersion pathway to a receptor area if that area overlaps the primary contamination. Because all the receptor areas are within the primary contamination for this onsite scenario, the air dispersion pathway is not active in this comparison. The air dispersion pathway can also be turned off by specifying a zero value for the deposition velocity of dust. For the purpose of this comparison, the offsite components of the external radiation and inhalation pathways were turned off by setting the fractions of time spent near the contaminated site and near the agricultural and livestock feed areas to zero.

The groundwater transport model in RESRAD (onsite) was extended in RESRAD-OFFSITE to consider potential contamination in an offsite surface water body and an offsite well. To be consistent with the RESRAD (onsite) analysis, the distance in the direction parallel to the groundwater flow from the edge of the contaminated site to the well or surface water body was set to 0 m.

In addition to extending the RESRAD (onsite) analysis to consider exposures at offsite locations, RESRAD-OFFSITE also refines some analyses for onsite exposures. This required some changes in the input parameters. For the benchmarking study, values for the different parameters were selected very carefully so that the physical conditions of the contaminated site simulated by RESRAD-OFFSITE would be the same as those simulated by RESRAD (onsite).

The transport models for the unsaturated and saturated zones in RESRAD (onsite) consider ingrowth and decay of radionuclides as well as retardation of radionuclides caused by adsorption to soil particles. Longitudinal and lateral dispersion of radionuclides is not considered. The analytic expressions for the radionuclide concentrations in groundwater are evaluated numerically. RESRAD-OFFSITE, on the other hand, implements numerical methods to consider longitudinal and lateral dispersion, in addition to radiological ingrowth and decay and adsorption. To accomplish this, input for dispersivity is required. Both the unsaturated and saturated zones can be subdivided into smaller zones to improve the predictions of progeny transport. To match the RESRAD (onsite) transport models, the dispersivities in RESRAD-OFFSITE were set to 0 and the unsaturated and saturated zones were not subdivided.

The differentiation of the livestock feed areas, for grains and for pasture and silage, respectively, is something new with RESRAD-OFFSITE. Because RESRAD (onsite) does not make this differentiation, when RESRAD-OFFSITE was used, the settings for growth and yield properties of these two types of fodder were identical. The total consumption of fodder for meat cattle was assumed to constitute 20% pasture and silage and 80% grains; for milk cows, the total consumption constituted 80% pasture and silage and 20% grains.

The soil erodibility factor in RESRAD-OFFSITE was set to 0 for the contaminated site and all the farming and livestock feed areas. This setting would result in a soil erosion rate of 0 m/yr.

For the agriculture and livestock feed areas, rather than input for total porosity, RESRAD-OFFSITE requires input for volumetric water content. The volumetric water content was calculated by using the equation for the saturation ratio in the RESRAD manual (Yu et al. 2001), then multiplying the saturation ratio by the total porosity specified for the contaminated zone.

RESRAD-OFFSITE implements a different approach for calculating the radionuclide concentration in a surface water body. The approach considers the contributions from surface runoff and the interception of groundwater flow. Radionuclides that are eroded from the ground surface could flow to a surface water body, carried by runoff water. The fraction of the eroded radionuclides that ends up in the surface water body was characterized by the sediment delivery ratio parameter. For the benchmarking study, a value of 0 was assigned to this parameter, because RESRAD (onsite) does not consider this transport mechanism. To consider the interception of groundwater flow, the depth of the aquifer contributing to the surface water body must be specified. Because RESRAD (onsite) uses the value that is input for the well pump intake depth for this purpose, it was assigned the same value in RESRAD-OFFSITE.

RESRAD (onsite) calculates the surface water concentration by diluting the groundwater concentration with the ratio of the area of the contaminated zone to the watershed area of the surface water body. RESRAD-OFFSITE calculates the amount of radionuclides flowing to the surface water body through the runoff and groundwater interception mechanisms, then performs a mass balance analysis to determine the surface water concentrations. For the mass balance analysis, the following parameters are used: (1) volume of the surface water body, (2) mean residence time of water in the surface water body, and (3) the Kd values of radionuclides in the sediment of the surface water body. Because of this fundamental difference in the modeling approach, RESRAD-OFFSITE defaults were used for the volume of the surface water body parameter and for the mean residence time parameter. The Kd’s in the sediment were set the same as those in all other soil layers.

RESRAD (onsite) can be easily instructed to calculate time-integrated doses and risks. The user simply has to specify a value greater than 1 for the “maximum number of integration points” parameter. To match this capability, specific values were assigned to some of the RESRAD-OFFSITE parameters. While running RESRAD-OFFSITE, the maximum number of graphic points (4,096) was specified. With the maximum time period set to 1,023 years and the exposure duration set to 1 year, the time horizon for dose analysis would be 1,024 years. Under the option of linear spacing, there would be five time points in each one-year period. A trapezoidal integration of the instantaneous dose rate at these five time points would be performed and reported as the time-integrated dose for the one-year period in RESRAD-OFFSITE. This specific arrangement was chosen so that the time integration method used by RESRAD (onsite) for calculating annual dose could be matched by RESRAD-OFFSITE to the extent possible. For this benchmarking study, the maximum number of time integration points used by RESRAD (onsite) was set to 5 using the Simpson integration method.

Appendix C lists all the RESRAD-OFFSITE parameters and their input values used in this benchmarking study.

2.2 COMPARISON OF TEMPORAL PREDICTIONS FOR RADIOLOGICAL DOSE AND CONCENTRATION

After the calculations, dose results were extracted from the summary reports and graphic outputs. Tables 2.1 through 2.7 compare pathway doses obtained from RESRAD (onsite) and RESRAD-OFFSITE. Figures 2.1 through 2.4 compare the well water concentrations for K-40, Np-237, C-14, and H-3, respectively. The comparisons indicated the following: (1) there are inconsistencies in the C-14 and H-3 doses; (2) for the other radionuclides, the RESRAD (onsite) and RESRAD-OFFSITE doses are almost identical for the water-independent pathways except for the inhalation pathway; (3) for the first few years, radon doses for U-238 are very small and differ slightly between RESRAD (onsite) and RESRAD-OFFSITE; and (4) there are inconsistencies in the water-dependent pathway doses. The inconsistencies between the RESRAD (onsite) and RESRAD-OFFSITE results are highlighted in bold in the tables.

Special models were incorporated into RESRAD (onsite) and RESRAD-OFFSITE to analyze radiation doses resulting from evasion and partitioning of C-14 and H-3 to surrounding environmental media. Because of the special models, the inconsistencies in the dose results for

TABLE 2.1 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Pathway Doses at t = 0 Year[a]

	Water-Independent Pathways													
	External		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	**4.82E-07**	**7.18E-07**	**9.25E-05**	**1.38E-04**	0.00E+00	0.00E+00	**8.73E-02**	**1.48E-01**	**1.89E-01**	**3.23E-01**	**2.06E-02**	**4.34E-02**	**1.75E-06**	**2.60E-06**
Co-60	5.42E+00	5.42E+00	**1.89E-06**	**1.81E-06**	0.00E+00	0.00E+00	1.64E-02	1.64E-02	1.14E-01	1.14E-01	3.69E-03	3.69E-03	2.48E-04	2.48E-04
Cs-137	1.28E+00	1.28E+00	**2.91E-07**	**2.78E-07**	0.00E+00	0.00E+00	1.61E-02	1.60E-02	2.69E-01	2.69E-01	2.70E-02	2.70E-02	4.88E-04	4.88E-04
H-3	0.00E+00	0.00E+00	**9.98E-05**	**1.29E-04**	0.00E+00	0.00E+00	**2.23E-04**	**2.94E-04**	**3.34E-04**	**3.70E-04**	**8.19E-05**	**1.06E-04**	**7.49E-08**	**9.65E-08**
K-40	3.33E-01	3.33E-01	**1.03E-07**	**9.83E-08**	0.00E+00	0.00E+00	4.11E-02	4.10E-02	1.32E-01	1.32E-01	2.09E-02	2.10E-02	1.65E-04	1.65E-04
Np-237	4.25E-01	4.25E-01	**4.82E-03**	**4.60E-03**	0.00E+00	0.00E+00	6.98E-01	6.98E-01	3.78E-01	3.80E-01	1.95E-03	1.96E-03	4.23E-02	4.23E-02
Pu-239	1.21E-04	1.21E-04	**3.96E-03**	**3.78E-03**	0.00E+00	0.00E+00	2.88E-02	2.88E-02	2.40E-02	2.39E-02	1.30E-04	1.30E-04	3.49E-02	3.49E-02
Ra-226	4.08E+00	4.08E+00	**8.20E-05**	**7.82E-05**	3.39E+01	3.39E+01	4.37E-01	4.37E-01	1.54E-01	1.54E-01	7.40E-02	7.40E-02	1.41E-02	1.41E-02
Ra-228	2.65E+00	2.64E+00	**5.38E-04**	**5.10E-04**	8.74E-02	8.70E-02	4.45E-01	4.45E-01	1.50E-01	1.50E-01	7.43E-02	7.43E-02	1.46E-02	1.46E-02
Sr-90	9.52E-03	9.52E-03	**1.18E-05**	**1.12E-05**	0.00E+00	0.00E+00	3.62E-01	3.62E-01	5.71E-01	5.71E-01	5.21E-02	5.22E-02	1.47E-03	1.47E-03
Th-230	1.39E-03	1.39E-03	**3.01E-03**	**2.88E-03**	7.34E-03	7.34E-03	4.55E-03	4.54E-03	3.74E-03	3.74E-03	1.15E-04	1.15E-04	5.42E-03	5.41E-03
U-234	1.69E-04	1.69E-04	**1.22E-03**	**1.16E-03**	**2.20E-08**	**2.27E-08**	4.59E-03	4.58E-03	1.55E-02	1.55E-02	4.18E-03	4.19E-03	2.78E-03	2.78E-03
U-238	5.74E-02	5.74E-02	**1.09E-03**	**1.04E-03**	**1.56E-14**	**1.26E-13**	4.36E-03	4.35E-03	1.47E-02	1.47E-02	3.98E-03	3.98E-03	2.64E-03	2.64E-03

	Water-Dependent Pathways													
	Water		Fish		Radon		Plant		Meat		Milk		Total	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**2.97E-01**	**5.15E-01**
Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.55E+00	5.55E+00
Cs-137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.59E+00	1.59E+00
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**7.39E-04**	**8.99E-04**
K-40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.27E-01	5.27E-01
Np-237	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.55E+00	1.55E+00
Pu-239	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.19E-02	9.16E-02
Ra-226	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.87E+01	3.87E+01
Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.42E+00	3.41E+00
Sr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.96E-01	9.96E-01
Th-230	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.56E-02	2.54E-02
U-234	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.84E-02	2.84E-02
U-238	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.42E-02	8.41E-02

[a] The differences are highlighted in bold.

TABLE 2.2 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Pathway Doses at t = 3 Years[a]

	Water-Independent Pathways													
	External		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	0.00E+00	7.81E-36	0.00E+00	1.50E-33	0.00E+00	0.00E+00	**2.51E-30**	**3.22E-29**	**6.09E-29**	**5.82E-27**	**2.98E-30**	**6.32E-29**	0.00E+00	2.83E-35
Co-60	3.59E+00	3.59E+00	**1.26E-06**	**1.20E-06**	0.00E+00	0.00E+00	1.09E-02	1.08E-02	7.56E-02	7.56E-02	2.45E-03	2.45E-03	1.65E-04	1.65E-04
Cs-137	1.18E+00	1.18E+00	**2.70E-07**	**2.57E-07**	0.00E+00	0.00E+00	1.49E-02	1.49E-02	2.49E-01	2.49E-01	2.50E-02	2.50E-02	4.51E-04	4.51E-04
H-3	0.00E+00	0.00E+00	**9.45E-17**	**1.22E-16**	0.00E+00	0.00E+00	**2.64E-16**	**4.33E-16**	**7.27E-16**	**1.86E-15**	**1.49E-16**	**2.85E-16**	**7.09E-20**	**9.13E-20**
K-40	1.74E-01	1.74E-01	**5.38E-08**	**5.13E-08**	0.00E+00	0.00E+00	2.14E-02	2.14E-02	6.91E-02	6.94E-02	1.09E-02	1.10E-02	8.62E-05	8.62E-05
Np-237	3.43E-01	3.43E-01	**3.89E-03**	**3.71E-03**	0.00E+00	0.00E+00	5.63E-01	5.63E-01	3.05E-01	3.07E-01	1.57E-03	1.58E-03	3.41E-02	3.41E-02
Pu-239	1.20E-04	1.20E-04	**3.95E-03**	**3.77E-03**	0.00E+00	0.00E+00	2.87E-02	2.86E-02	2.39E-02	2.39E-02	1.29E-04	1.29E-04	3.48E-02	3.48E-02
Ra-226	4.07E+00	4.07E+00	**1.00E-04**	**9.54E-05**	3.38E+01	3.38E+01	4.53E-01	4.53E-01	2.28E-01	2.28E-01	8.15E-02	8.15E-02	2.02E-02	2.02E-02
Ra-228	3.46E+00	3.46E+00	**1.81E-03**	**1.73E-03**	3.16E-01	3.16E-01	3.13E-01	3.13E-01	1.07E-01	1.07E-01	5.18E-02	5.18E-02	1.38E-02	1.38E-02
Sr-90	7.90E-03	7.90E-03	**9.75E-06**	**9.30E-06**	0.00E+00	0.00E+00	3.01E-01	3.01E-01	4.74E-01	4.74E-01	4.33E-02	4.33E-02	1.22E-03	1.22E-03
Th-230	6.69E-03	6.69E-03	**3.01E-03**	**2.87E-03**	5.13E-02	5.13E-02	5.13E-03	5.12E-03	3.98E-03	3.98E-03	2.16E-04	2.16E-04	5.43E-03	5.43E-03
U-234	1.64E-04	1.64E-04	**1.18E-03**	**1.13E-03**	8.05E-07	8.06E-07	4.45E-03	4.45E-03	1.51E-02	1.51E-02	4.06E-03	4.07E-03	2.70E-03	2.70E-03
U-238	5.58E-02	5.57E-02	**1.05E-03**	**1.01E-03**	**2.68E-12**	**3.43E-12**	4.23E-03	4.23E-03	1.43E-02	1.43E-02	3.86E-03	3.87E-03	2.57E-03	2.57E-03

	Water-Dependent Pathways													
	Water		Fish		Radon		Plant		Meat		Milk		Total	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**6.64E-29**	**5.92E-27**
Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.68E+00	3.68E+00
Cs-137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.47E+00	1.47E+00
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**1.23E-15**	**2.70E-15**
K-40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.75E-01	2.76E-01
Np-237	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.25E+00	1.25E+00
Pu-239	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.16E-02	9.13E-02
Ra-226	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.87E+01	3.87E+01
Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.27E+00	4.26E+00
Sr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.27E-01	8.27E-01
Th-230	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.58E-02	7.56E-02
U-234	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.76E-02	2.76E-02
U-238	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.18E-02	8.17E-02

[a] The differences are highlighted in bold.

TABLE 2.3 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Pathway Doses at t = 30 Years[a]

	Water-Independent Pathways													
	External		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co-60	8.96E-02	8.96E-02	**3.13E-08**	**2.99E-08**	0.00E+00	0.00E+00	2.70E-04	2.70E-04	1.88E-03	1.88E-03	6.09E-05	6.09E-05	4.11E-06	4.11E-06
Cs-137	5.87E-01	5.87E-01	**1.34E-07**	**1.28E-07**	0.00E+00	0.00E+00	7.39E-03	7.39E-03	1.24E-01	1.24E-01	1.24E-02	1.24E-02	2.24E-04	2.24E-04
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
K-40	4.97E-04	4.97E-04	**1.54E-10**	**1.47E-10**	0.00E+00	0.00E+00	6.13E-05	6.13E-05	1.98E-04	1.99E-04	3.13E-05	3.14E-05	2.46E-07	2.46E-07
Np-237	4.94E-02	4.94E-02	**5.60E-04**	**5.34E-04**	0.00E+00	0.00E+00	8.11E-02	8.11E-02	4.39E-02	4.42E-02	2.27E-04	2.28E-04	4.91E-03	4.91E-03
Pu-239	1.16E-04	1.16E-04	**3.81E-03**	**3.63E-03**	0.00E+00	0.00E+00	2.77E-02	2.76E-02	2.30E-02	2.30E-02	1.25E-04	1.25E-04	3.36E-02	3.36E-02
Ra-226	3.99E+00	3.99E+00	**2.06E-04**	**1.96E-04**	3.31E+01	3.31E+01	5.40E-01	5.40E-01	6.79E-01	6.79E-01	1.25E-01	1.25E-01	5.58E-02	5.58E-02
Ra-228	1.91E-01	1.91E-01	**1.21E-04**	**1.15E-04**	2.12E-02	2.12E-02	1.21E-02	1.21E-02	4.18E-03	4.17E-03	1.98E-03	1.98E-03	6.56E-04	6.56E-04
Sr-90	1.48E-03	1.48E-03	**1.82E-06**	**1.74E-06**	0.00E+00	0.00E+00	5.62E-02	5.62E-02	8.86E-02	8.87E-02	8.09E-03	8.10E-03	2.27E-04	2.27E-04
Th-230	5.37E-02	5.37E-02	**3.00E-03**	**2.86E-03**	4.41E-01	4.41E-01	1.10E-02	1.10E-02	9.63E-03	9.63E-03	1.46E-03	1.45E-03	5.88E-03	5.88E-03
U-234	1.33E-04	1.33E-04	**9.07E-04**	**8.65E-04**	5.52E-05	5.52E-05	3.42E-03	3.42E-03	1.16E-02	1.16E-02	3.12E-03	3.12E-03	2.08E-03	2.08E-03
U-238	4.28E-02	4.28E-02	**8.10E-04**	**7.73E-04**	1.52E-09	1.52E-09	3.25E-03	3.25E-03	1.10E-02	1.10E-02	2.97E-03	2.97E-03	1.97E-03	1.97E-03

	Water-Dependent Pathways													
	Water		Fish		Radon		Plant		Meat		Milk		Total	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.18E-02	9.18E-02
Cs-137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.31E-01	7.31E-01
H-3	**8.05E-05**	**1.23E-04**	**6.37E-06**	**4.45E-08**	0.00E+00	0.00E+00	**6.03E-06**	**1.11E-05**	**1.23E-05**	**1.89E-05**	**1.36E-05**	**1.67E-05**	**1.19E-04**	**1.70E-04**
K-40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.87E-04	7.89E-04
Np-237	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-01	1.80E-01
Pu-239	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.84E-02	8.81E-02
Ra-226	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.85E+01	3.85E+01
Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.31E-01	2.31E-01
Sr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.55E-01	1.55E-01
Th-230	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.26E-01	5.26E-01
U-234	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.13E-02	2.13E-02
U-238	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.28E-02	6.28E-02

[a] The differences are highlighted in bold.

TABLE 2.4 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Pathway Doses at t = 300 Years[a]

	Water-Independent Pathways													
	External		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co-60	8.27E-18	8.27E-18	**2.89E-24**	**2.75E-24**	0.00E+00	0.00E+00	2.50E-20	2.49E-20	1.74E-19	1.74E-19	5.62E-21	5.62E-21	3.79E-22	3.79E-22
Cs-137	5.43E-04	5.43E-04	**1.24E-10**	**1.18E-10**	0.00E+00	0.00E+00	6.84E-06	6.84E-06	1.14E-04	1.14E-04	1.15E-05	1.15E-05	2.08E-07	2.08E-07
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
K-40	1.82E-29	1.82E-29	0.00E+00	5.38E-36	0.00E+00	0.00E+00	2.25E-30	2.25E-30	7.25E-30	7.28E-30	1.15E-30	1.15E-30	0.00E+00	9.04E-33
Np-237	3.32E-07	3.30E-07	**1.51E-08**	**1.43E-08**	0.00E+00	0.00E+00	3.50E-08	3.49E-08	7.38E-08	7.38E-08	1.64E-08	1.64E-08	3.15E-08	3.13E-08
Pu-239	8.11E-05	8.11E-05	**2.67E-03**	**2.54E-03**	0.00E+00	0.00E+00	1.94E-02	1.93E-02	1.61E-02	1.61E-02	8.72E-05	8.72E-05	2.35E-02	2.35E-02
Ra-226	3.23E+00	3.23E+00	**2.34E-04**	**2.23E-04**	2.68E+01	2.68E+01	4.97E-01	4.97E-01	8.33E-01	8.33E-01	1.29E-01	1.29E-01	6.76E-02	6.76E-02
Ra-228	1.27E-15	1.27E-15	**8.07E-19**	**7.69E-19**	1.42E-16	1.42E-16	8.04E-17	8.04E-17	2.78E-17	2.78E-17	1.32E-17	1.32E-17	4.37E-18	4.37E-18
Sr-90	7.66E-11	7.66E-11	**9.45E-14**	**9.01E-14**	0.00E+00	0.00E+00	2.91E-09	2.91E-09	4.60E-09	4.60E-09	4.20E-10	4.20E-10	1.18E-11	1.18E-11
Th-230	4.59E-01	4.59E-01	**2.85E-03**	**2.72E-03**	3.80E+00	3.80E+00	7.22E-02	7.21E-02	1.10E-01	1.10E-01	1.72E-02	1.72E-02	1.37E-02	1.37E-02
U-234	3.04E-04	3.04E-04	**6.72E-05**	**6.41E-05**	2.45E-03	2.45E-03	2.91E-04	2.91E-04	8.94E-04	8.94E-04	2.33E-04	2.34E-04	1.58E-04	1.58E-04
U-238	3.06E-03	3.06E-03	**5.79E-05**	**5.52E-05**	4.38E-07	4.37E-07	2.32E-04	2.32E-04	7.85E-04	7.86E-04	2.12E-04	2.12E-04	1.41E-04	1.41E-04

	Water-Dependent Pathways													
	Water		Fish		Radon		Plant		Meat		Milk		Total	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.47E-18	8.47E-18
Cs-137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.76E-04	6.76E-04
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
K-40	**1.39E-02**	**0.00E+00**	**1.10E+00**	**0.00E+00**	0.00E+00	0.00E+00	**6.10E-04**	**0.00E+00**	**1.56E-02**	**0.00E+00**	**5.07E-03**	**0.00E+00**	**1.13E+00**	**2.89E-29**
Np-237	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.04E-07	5.01E-07
Pu-239	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.18E-02	6.16E-02
Ra-226	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.16E+01	3.16E+01
Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.54E-15	1.54E-15
Sr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.02E-09	8.02E-09
Th-230	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.48E+00	4.47E+00
U-234	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.39E-03	4.40E-03
U-238	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.49E-03	4.49E-03

[a] The differences are highlighted in bold.

TABLE 2.5 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Pathway Doses at t = 500 Years[a]

	Water-Independent Pathways													
	External		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co-60	1.10E-29	1.10E-29	0.00E+00	3.65E-36	0.00E+00	0.00E+00	0.00E+00	3.31E-32	0.00E+00	2.30E-31	0.00E+00	7.45E-33	0.00E+00	5.02E-34
Cs-137	3.08E-06	3.08E-06	**7.03E-13**	**6.70E-13**	0.00E+00	0.00E+00	3.87E-08	3.87E-08	6.48E-07	6.48E-07	6.52E-08	6.52E-08	1.18E-09	1.18E-09
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
K-40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np-237	3.30E-07	3.28E-07	**1.11E-08**	**1.05E-08**	0.00E+00	0.00E+00	1.96E-08	1.95E-08	2.26E-08	2.25E-08	2.65E-09	2.65E-09	2.23E-08	2.21E-08
Pu-239	6.23E-05	6.23E-05	**2.05E-03**	**1.95E-03**	0.00E+00	0.00E+00	1.49E-02	1.48E-02	1.24E-02	1.24E-02	6.70E-05	6.70E-05	1.80E-02	1.80E-02
Ra-226	2.76E+00	2.76E+00	**2.00E-04**	**1.91E-04**	2.29E+01	2.29E+01	4.25E-01	4.25E-01	7.13E-01	7.13E-01	1.10E-01	1.10E-01	5.78E-02	5.78E-02
Ra-228	4.01E-26	4.01E-26	**2.52E-29**	**2.43E-29**	4.47E-27	4.47E-27	2.54E-27	2.54E-27	8.78E-28	8.78E-28	4.17E-28	4.17E-28	1.38E-28	1.38E-28
Sr-90	3.08E-16	3.08E-16	**3.79E-19**	**3.62E-19**	0.00E+00	0.00E+00	1.17E-14	1.17E-14	1.84E-14	1.85E-14	1.68E-15	1.69E-15	4.73E-17	4.73E-17
Th-230	6.92E-01	6.92E-01	**2.75E-03**	**2.62E-03**	5.74E+00	5.74E+00	1.08E-01	1.08E-01	1.70E-01	1.70E-01	2.66E-02	2.66E-02	1.84E-02	1.84E-02
U-234	5.29E-04	5.29E-04	**1.17E-05**	**1.12E-05**	4.38E-03	4.38E-03	1.17E-04	1.17E-04	2.45E-04	2.45E-04	5.16E-05	5.16E-05	3.57E-05	3.57E-05
U-238	4.33E-04	4.33E-04	**8.20E-06**	**7.82E-06**	9.91E-07	9.91E-07	3.29E-05	3.29E-05	1.11E-04	1.11E-04	3.00E-05	3.01E-05	2.00E-05	2.00E-05

	Water-Dependent Pathways													
	Water		Fish		Radon		Plant		Meat		Milk		Total	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	**3.75E-06**	**0.00E+00**	**1.45E-02**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**7.45E-06**	**0.00E+00**	**5.11E-06**	**0.00E+00**	**1.83E-06**	**0.00E+00**	**1.45E-02**	**0.00E+00**
Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-29	1.13E-29
Cs-137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.83E-06	3.83E-06
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
K-40	**1.41E-02**	**1.15E-02**	**1.11E+00**	**4.16E-03**	0.00E+00	**0.00E+00**	**6.18E-04**	**4.37E-03**	**1.58E-02**	**7.96E-02**	**5.14E-03**	**1.38E-02**	**1.15E+00**	**1.13E-01**
Np-237	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.08E-07	4.05E-07
Pu-239	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.74E-02	4.73E-02
Ra-226	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.70E+01	2.70E+01
Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.86E-26	4.86E-26
Sr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.22E-14	3.22E-14
Th-230	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.76E+00	6.76E+00
U-234	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.37E-03	5.37E-03
U-238	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.36E-04	6.36E-04

[a] The differences are highlighted in bold.

TABLE 2.6 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Pathway Doses at t = 750 Years[a]

	Water-Independent Pathways													
	External		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	4.78E-09	4.78E-09	**1.09E-15**	**1.04E-15**	0.00E+00	0.00E+00	6.02E-11	6.01E-11	1.01E-09	1.01E-09	1.01E-10	1.01E-10	1.83E-12	1.83E-12
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
K-40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np-237	3.08E-07	3.06E-07	**9.79E-09**	**9.29E-09**	0.00E+00	0.00E+00	1.62E-08	1.61E-08	1.40E-08	1.40E-08	5.57E-10	5.55E-10	1.95E-08	1.94E-08
Pu-239	4.47E-05	4.47E-05	**1.47E-03**	**1.40E-03**	0.00E+00	0.00E+00	1.07E-02	1.07E-02	8.88E-03	8.88E-03	4.81E-05	4.81E-05	1.30E-02	1.30E-02
Ra-226	2.27E+00	2.27E+00	**1.64E-04**	**1.57E-04**	1.89E+01	1.88E+01	3.50E-01	3.49E-01	5.86E-01	5.86E-01	9.06E-02	9.06E-02	4.75E-02	4.75E-02
Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sr-90	5.53E-23	5.53E-23	**6.82E-26**	**6.50E-26**	0.00E+00	0.00E+00	2.10E-21	2.10E-21	3.31E-21	3.32E-21	3.03E-22	3.03E-22	8.50E-24	8.50E-24
Th-230	9.20E-01	9.20E-01	**2.62E-03**	**2.50E-03**	7.63E+00	7.63E+00	1.43E-01	1.43E-01	2.30E-01	2.30E-01	3.57E-02	3.57E-02	2.30E-02	2.30E-02
U-234	7.63E-04	7.63E-04	**3.25E-06**	**3.10E-06**	6.33E-03	6.33E-03	1.22E-04	1.22E-04	2.00E-04	2.00E-04	3.22E-05	3.22E-05	2.13E-05	2.13E-05
U-238	3.78E-05	3.78E-05	**7.13E-07**	**6.80E-07**	1.61E-06	1.61E-06	2.89E-06	2.89E-06	9.71E-06	9.72E-06	2.62E-06	2.62E-06	1.74E-06	1.74E-06

	Water-Dependent Pathways													
	Water		Fish		Radon		Plant		Meat		Milk		Total	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	**3.64E-06**	**1.41E-05**	**1.41E-02**	**2.50E-04**	0.00E+00	0.00E+00	**7.24E-06**	**1.05E-03**	**4.99E-06**	**1.31E-03**	**1.78E-06**	**2.09E-04**	**1.41E-02**	**2.83E-03**
Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.95E-09	5.95E-09
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
K-40	1.13E-11	1.15E-02	**8.96E-10**	**4.16E-03**	0.00E+00	0.00E+00	**4.98E-13**	**4.38E-03**	**1.30E-11**	**7.97E-02**	**4.16E-12**	**1.38E-02**	**9.25E-10**	**1.14E-01**
Np-237	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.68E-07	3.65E-07
Pu-239	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.41E-02	3.41E-02
Ra-226	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.22E+01	2.21E+01
Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.78E-21	5.79E-21
Th-230	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.98E+00	8.98E+00
U-234	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.47E-03	7.47E-03
U-238	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.70E-05	5.71E-05

[a] The differences are highlighted in bold.

TABLE 2.7 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Pathway Doses at t = 1,023 Years[a]

	Water-Independent Pathways													
	External		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	4.10E-12	4.09E-12	**9.35E-19**	**8.92E-19**	0.00E+00	0.00E+00	5.15E-14	5.15E-14	8.62E-13	8.62E-13	8.67E-14	8.68E-14	1.57E-15	1.57E-15
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
K-40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np-237	2.84E-07	2.82E-07	**8.97E-09**	**8.51E-09**	0.00E+00	0.00E+00	1.48E-08	1.46E-08	1.23E-08	1.22E-08	3.45E-10	3.44E-10	1.79E-08	1.78E-08
Pu-239	3.12E-05	3.12E-05	**1.02E-03**	**9.77E-04**	0.00E+00	0.00E+00	7.45E-03	7.43E-03	6.19E-03	6.19E-03	3.35E-05	3.35E-05	9.03E-03	9.03E-03
Ra-226	1.84E+00	1.83E+00	**1.33E-04**	**1.27E-04**	1.52E+01	1.52E+01	2.82E-01	2.82E-01	4.73E-01	4.73E-01	7.32E-02	7.32E-02	3.84E-02	3.84E-02
Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sr-90	2.38E-30	2.38E-30	0.00E+00	2.80E-33	0.00E+00	0.00E+00	9.05E-29	9.05E-29	1.43E-28	1.43E-28	1.30E-29	1.30E-29	0.00E+00	3.66E-31
Th-230	1.10E+00	1.10E+00	**2.49E-03**	**2.37E-03**	9.13E+00	9.13E+00	1.71E-01	1.71E-01	2.77E-01	2.77E-01	4.30E-02	4.30E-02	2.66E-02	2.66E-02
U-234	9.54E-04	9.54E-04	**2.39E-06**	**2.28E-06**	7.91E-03	7.91E-03	1.48E-04	1.48E-04	2.40E-04	2.40E-04	3.73E-05	3.73E-05	2.34E-05	2.34E-05
U-238	2.86E-06	2.86E-06	**5.01E-08**	**4.78E-08**	2.13E-06	2.13E-06	2.38E-07	2.38E-07	7.35E-07	7.35E-07	1.91E-07	1.91E-07	1.27E-07	1.27E-07

	Water-Dependent Pathways													
	Water		Fish		Radon		Plant		Meat		Milk		Total	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	**3.53E-06**	**1.37E-05**	**1.37E-02**	**2.42E-04**	0.00E+00	0.00E+00	**7.01E-06**	**1.02E-03**	**4.83E-06**	**1.26E-03**	**1.73E-06**	**2.03E-04**	**1.37E-02**	**2.74E-03**
Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.10E-12	5.09E-12
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
K-40	**0.00E+00**	**2.53E-25**	**0.00E+00**	**1.17E-25**	0.00E+00	0.00E+00	**0.00E+00**	**1.35E-16**	**0.00E+00**	**3.42E-16**	**0.00E+00**	**5.23E-17**	**0.00E+00**	**5.29E-16**
Np-237	**1.11E+00**	**9.23E-01**	**2.64E+00**	**9.99E-03**	0.00E+00	0.00E+00	**4.08E-02**	**2.14E-01**	**6.19E-02**	**3.02E-01**	**5.78E-04**	**1.51E-03**	**3.85E+00**	**1.45E+00**
Pu-239	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.38E-02	2.37E-02
Ra-226	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.79E+01	1.79E+01
Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.49E-28	2.49E-28
Th-230	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.08E+01	1.07E+01
U-234	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.31E-03	9.31E-03
U-238	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.33E-06	6.33E-06

[a] The differences are highlighted in bold.

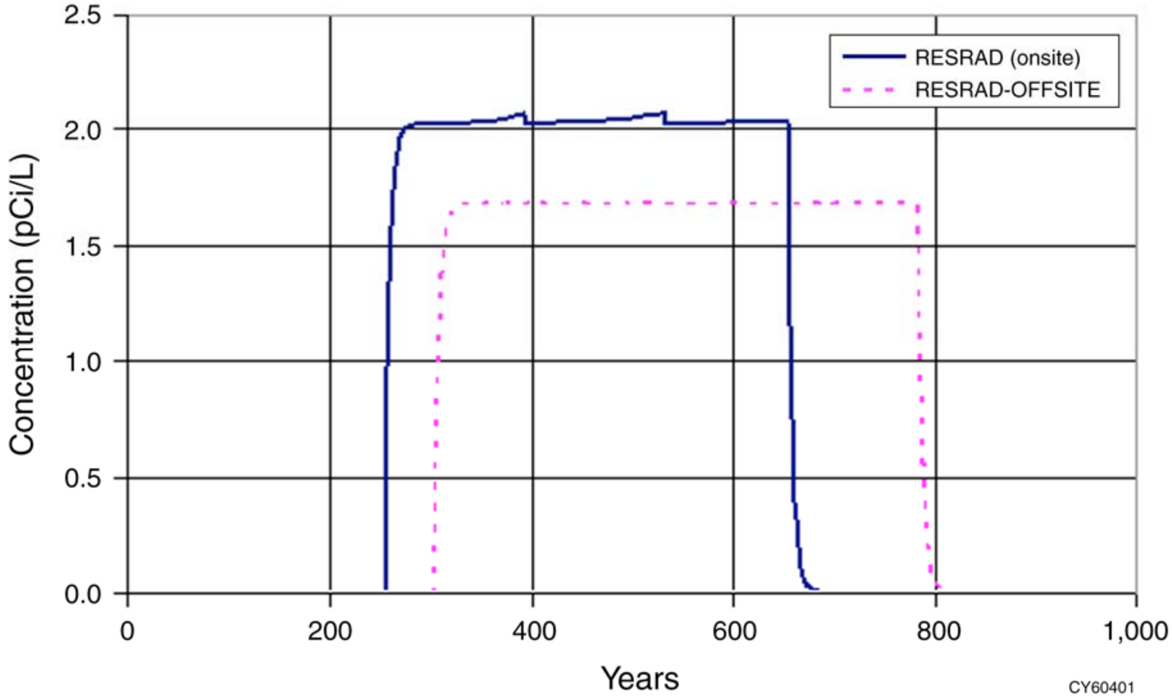

FIGURE 2.1 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Well Water K-40 Concentrations

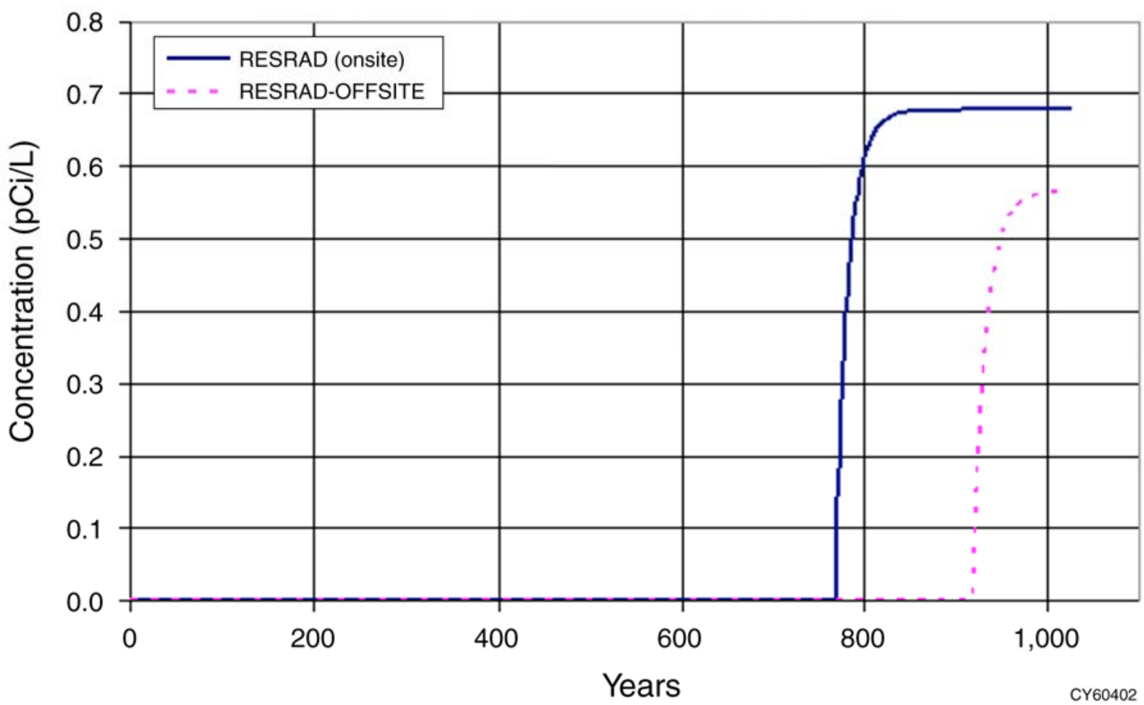

FIGURE 2.2 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Well Water Np-237 Concentrations

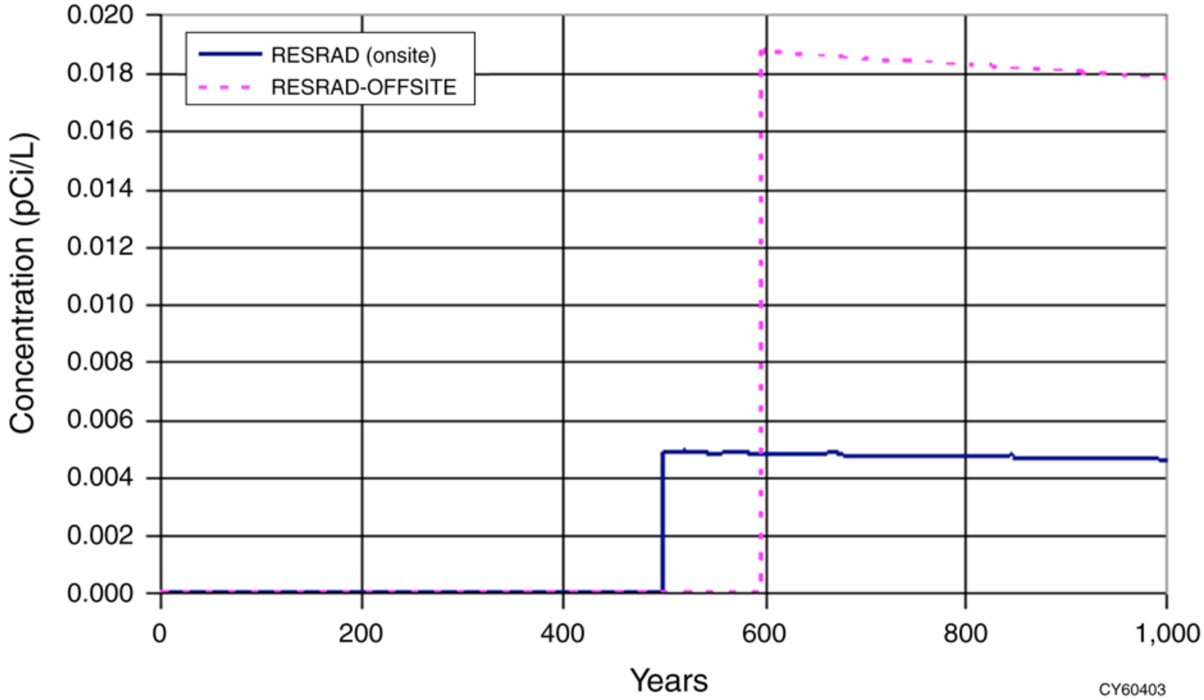

FIGURE 2.3 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Well Water C-14 Concentrations

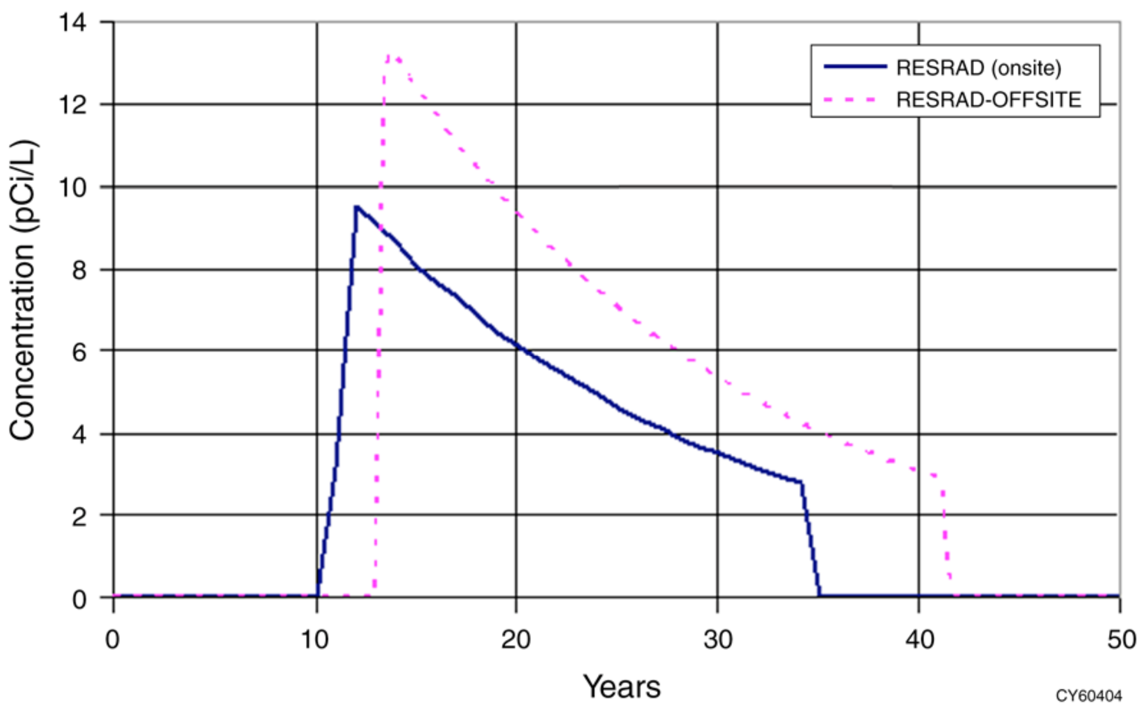

FIGURE 2.4 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Well Water H-3 Concentrations

C-14 and H-3 differ from those for other radionuclides. To explore the causes of the inconsistencies, separate analyses were conducted for these two radionuclides, and special settings were used for some input parameters. The special settings and the analytical results are discussed in Section 2.2.2. For all the other radionuclides, the cause of discrepancies and analytical results are discussed in Section 2.2.1.

2.2.1 Analysis of Results

When inhalation doses were compared, a constant ratio (1.05) between the RESRAD (onsite) and RESRAD-OFFSITE results was found across all radionuclides (except for C-14 and H-3). This is because of the difference in the area factor used to calculate the inhalation doses. The area factor was estimated by interpolating a set of coefficients that are functions of dust particle size and wind speed (see Table 4 of Chang et al. 1998). The default size of respirable dust particles considered in RESRAD (onsite) and RESRAD-OFFSITE is 1 μm. When estimating the area factor, RESRAD-OFFSITE uses the two coefficients that bracket the wind speed of 4.24 m/s (input value) and correspond to a particle size of 1 μm. RESRAD (onsite), on the other hand, uses four coefficients to obtain the area factor; in addition to the two coefficients RESRAD-OFFSITE uses, it also uses the two coefficients that correspond to a particle size of 2 μm. Both codes use the single point area factor values for wind speeds of 0, 1, 2, 5, and 10 m/s. When a wind speed of 5 m/s is used, the predictions of the two codes agree as shown in Tables 2.8 through 2.11.

The radon doses for U-238 at *t* = 0 and 3 years differ between RESRAD (onsite) and RESRAD-OFFSITE (Tables 2.1 and 2.2). At these two time periods, although the differences are obvious, the magnitude of the radon doses is very small: less than 1×10^{-11} mrem/yr. As time increases and the radon doses become more significant, the differences between the RESRAD (onsite) and RESRAD-OFFSITE results diminish (Tables 2.3 through 2.7). The differences at early times were caused by the different integration methods used to calculate annual doses (see discussions in Section 2.1). The good agreement in radon doses at later times proves that the same radon model was implemented in RESRAD (onsite) and RESRAD-OFFSITE for the analysis of onsite scenario.

Inconsistencies in the surface water concentrations, as displayed by the different radiation doses for the fish ingestion pathway in Tables 2.3 through 2.7, are expected because RESRAD

TABLE 2.8 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Pathway Doses at t = 300 Years, Calculated with Revised Input Parameters[a]

	Water-Independent Pathways													
	External		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co-60	8.27E-18	8.27E-18	2.40E-24	2.39E-24	0.00E+00	0.00E+00	2.50E-20	2.49E-20	1.74E-19	1.74E-19	5.62E-21	5.62E-21	3.79E-22	3.79E-22
Cs-137	5.43E-04	5.43E-04	1.03E-10	1.03E-10	0.00E+00	0.00E+00	6.84E-06	6.84E-06	1.14E-04	1.14E-04	1.15E-05	1.15E-05	2.08E-07	2.08E-07
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
K-40	1.82E-29	1.82E-29	0.00E+00	4.68E-36	0.00E+00	0.00E+00	2.25E-30	2.25E-30	7.25E-30	7.28E-30	1.15E-30	1.15E-30	0.00E+00	9.04E-33
Np-237	3.32E-07	3.30E-07	1.25E-08	1.25E-08	0.00E+00	0.00E+00	3.50E-08	3.49E-08	7.38E-08	7.38E-08	1.64E-08	1.64E-08	3.15E-08	3.13E-08
Pu-239	8.11E-05	8.11E-05	2.21E-03	2.21E-03	0.00E+00	0.00E+00	1.94E-02	1.93E-02	1.61E-02	1.61E-02	8.72E-05	8.72E-05	2.35E-02	2.35E-02
Ra-226	3.23E+00	3.23E+00	1.94E-04	1.94E-04	2.67E+01	2.67E+01	4.97E-01	4.97E-01	8.33E-01	8.33E-01	1.29E-01	1.29E-01	6.76E-02	6.76E-02
Ra-228	1.27E-15	1.27E-15	6.69E-19	6.69E-19	1.30E-16	1.30E-16	8.04E-17	8.04E-17	2.78E-17	2.78E-17	1.32E-17	1.32E-17	4.37E-18	4.37E-18
Sr-90	7.66E-11	7.66E-11	7.83E-14	7.83E-14	0.00E+00	0.00E+00	2.91E-09	2.91E-09	4.60E-09	4.60E-09	4.20E-10	4.20E-10	1.18E-11	1.18E-11
Th-230	4.59E-01	4.59E-01	2.37E-03	2.37E-03	3.79E+00	3.79E+00	7.22E-02	7.21E-02	1.10E-01	1.10E-01	1.72E-02	1.72E-02	1.37E-02	1.37E-02
U-234	3.04E-04	3.04E-04	5.57E-05	5.57E-05	2.44E-03	2.44E-03	2.91E-04	2.91E-04	8.94E-04	8.94E-04	2.33E-04	2.34E-04	1.58E-04	1.58E-04
U-238	3.06E-03	3.06E-03	4.80E-05	4.80E-05	4.36E-07	4.36E-07	2.32E-04	2.32E-04	7.85E-04	7.86E-04	2.12E-04	2.12E-04	1.41E-04	1.41E-04

	Water-Dependent Pathways													
	Water		Fish		Radon		Plant		Meat		Milk		Total	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.47E-18	8.47E-18
Cs-137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.76E-04	6.76E-04
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
K-40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.89E-29	2.89E-29
Np-237	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.01E-07	4.99E-07
Pu-239	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.14E-02	6.13E-02
Ra-226	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.15E+01	3.15E+01
Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.53E-15	1.53E-15
Sr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.02E-09	8.02E-09
Th-230	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.46E+00	4.46E+00
U-234	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.37E-03	4.38E-03
U-238	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.48E-03	4.48E-03

[a] The input parameters were the same as those listed in Appendices A and B, except that (1) the effective porosity of the unsaturated and saturated zones was set to 0.425, the same as the total porosity; (2) the groundwater fraction of livestock water and irrigation water was 1; and (3) the wind speed was set to 5 m/s.

TABLE 2.9 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Pathway Doses at t = 500 Years, Calculated with Revised Input Parameters[a]

	Water-Independent Pathways													
	External		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co-60	1.10E-29	1.10E-29	0.00E+00	3.17E-36	0.00E+00	0.00E+00	0.00E+00	3.31E-32	0.00E+00	2.30E-31	0.00E+00	7.45E-33	0.00E+00	5.02E-34
Cs-137	3.08E-06	3.08E-06	5.83E-13	5.83E-13	0.00E+00	0.00E+00	3.87E-08	3.87E-08	6.48E-07	6.48E-07	6.52E-08	6.52E-08	1.18E-09	1.18E-09
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
K-40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np-237	3.30E-07	3.28E-07	9.18E-09	9.13E-09	0.00E+00	0.00E+00	1.96E-08	1.95E-08	2.26E-08	2.25E-08	2.65E-09	2.65E-09	2.23E-08	2.21E-08
Pu-239	6.23E-05	6.23E-05	1.70E-03	1.70E-03	0.00E+00	0.00E+00	1.49E-02	1.48E-02	1.24E-02	1.24E-02	6.70E-05	6.70E-05	1.80E-02	1.80E-02
Ra-226	2.76E+00	2.76E+00	1.66E-04	1.66E-04	2.28E+01	2.28E+01	4.25E-01	4.25E-01	7.12E-01	7.13E-01	1.10E-01	1.10E-01	5.78E-02	5.78E-02
Ra-228	4.01E-26	4.01E-26	2.09E-29	2.11E-29	4.11E-27	4.11E-27	2.54E-27	2.54E-27	8.78E-28	8.78E-28	4.17E-28	4.17E-28	1.38E-28	1.38E-28
Sr-90	3.08E-16	3.08E-16	3.15E-19	3.15E-19	0.00E+00	0.00E+00	1.17E-14	1.17E-14	1.84E-14	1.85E-14	1.68E-15	1.69E-15	4.73E-17	4.73E-17
Th-230	6.92E-01	6.92E-01	2.28E-03	2.28E-03	5.72E+00	5.72E+00	1.08E-01	1.08E-01	1.70E-01	1.70E-01	2.66E-02	2.66E-02	1.84E-02	1.84E-02
U-234	5.29E-04	5.29E-04	9.70E-06	9.70E-06	4.36E-03	4.36E-03	1.17E-04	1.17E-04	2.45E-04	2.45E-04	5.16E-05	5.16E-05	3.57E-05	3.57E-05
U-238	4.33E-04	4.33E-04	6.80E-06	6.80E-06	9.88E-07	9.88E-07	3.29E-05	3.29E-05	1.11E-04	1.11E-04	3.00E-05	3.01E-05	2.00E-05	2.00E-05

	Water-Dependent Pathways													
	Water		Fish		Radon		Plant		Meat		Milk		Total	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.10E-29	1.13E-29
Cs-137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.83E-06	3.83E-06
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
K-40	1.17E-02	1.15E-02	**9.22E-01**	**4.16E-03**	0.00E+00	0.00E+00	**7.28E-04**	**8.73E-03**	**1.86E-02**	**1.59E-01**	**6.06E-03**	**2.76E-02**	**9.59E-01**	**2.11E-01**
Np-237	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.06E-07	4.04E-07
Pu-239	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.71E-02	4.70E-02
Ra-226	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.69E+01	2.69E+01
Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.82E-26	4.82E-26
Sr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.22E-14	3.22E-14
Th-230	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.74E+00	6.74E+00
U-234	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.35E-03	5.35E-03
U-238	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.35E-04	6.35E-04

[a] The input parameters were the same as those listed in Appendices A and B, except that (1) the effective porosity of the unsaturated and saturated zones was set to 0.425, the same as the total porosity; (2) the groundwater fraction of livestock water and irrigation water was 1; and (3) the wind speed was set to 5 m/s. Differences are highlighted in bold.

TABLE 2.10 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Pathway Doses at t = 750 Years, Calculated with Revised Input Parameters[a]

	Water-Independent Pathways													
	External		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	4.78E-09	4.78E-09	9.05E-16	9.05E-16	0.00E+00	0.00E+00	6.02E-11	6.01E-11	1.01E-09	1.01E-09	1.01E-10	1.01E-10	1.83E-12	1.83E-12
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
K-40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np-237	3.08E-07	3.06E-07	8.12E-09	8.08E-09	0.00E+00	0.00E+00	1.62E-08	1.61E-08	1.40E-08	1.40E-08	5.57E-10	5.55E-10	1.95E-08	1.94E-08
Pu-239	4.47E-05	4.47E-05	1.22E-03	1.22E-03	0.00E+00	0.00E+00	1.07E-02	1.07E-02	8.88E-03	8.88E-03	4.81E-05	4.81E-05	1.30E-02	1.30E-02
Ra-226	2.27E+00	2.27E+00	1.36E-04	1.36E-04	1.88E+01	1.88E+01	3.50E-01	3.49E-01	5.86E-01	5.86E-01	9.06E-02	9.06E-02	4.75E-02	4.75E-02
Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sr-90	5.53E-23	5.53E-23	5.65E-26	5.65E-26	0.00E+00	0.00E+00	2.10E-21	2.10E-21	3.31E-21	3.32E-21	3.03E-22	3.03E-22	8.50E-24	8.50E-24
Th-230	9.20E-01	9.20E-01	2.18E-03	2.17E-03	7.60E+00	7.60E+00	1.43E-01	1.43E-01	2.30E-01	2.30E-01	3.57E-02	3.57E-02	2.30E-02	2.30E-02
U-234	7.63E-04	7.63E-04	2.70E-06	2.70E-06	6.31E-03	6.31E-03	1.22E-04	1.22E-04	2.00E-04	2.00E-04	3.22E-05	3.22E-05	2.13E-05	2.13E-05
U-238	3.78E-05	3.78E-05	5.91E-07	5.91E-07	1.61E-06	1.60E-06	2.89E-06	2.89E-06	9.71E-06	9.72E-06	2.62E-06	2.62E-06	1.74E-06	1.74E-06

	Water-Dependent Pathways													
	Water		Fish		Radon		Plant		Meat		Milk		Total	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	**3.06E-06**	**1.41E-05**	**1.19E-02**	**2.50E-04**	0.00E+00	0.00E+00	**7.36E-06**	**1.79E-03**	**5.22E-06**	**2.21E-03**	**2.01E-06**	**3.56E-04**	**1.19E-02**	**4.62E-03**
Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.95E-09	5.95E-09
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
K-40	1.17E-02	1.15E-02	**9.25E-01**	**4.16E-03**	0.00E+00	0.00E+00	**7.31E-04**	**8.74E-03**	**1.87E-02**	**1.59E-01**	**6.08E-03**	**2.76E-02**	**9.62E-01**	**2.11E-01**
Np-237	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.66E-07	3.64E-07
Pu-239	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.38E-02	3.39E-02
Ra-226	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.21E+01	2.21E+01
Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.78E-21	5.79E-21
Th-230	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.95E+00	8.95E+00
U-234	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.45E-03	7.45E-03
U-238	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.69E-05	5.70E-05

[a] The input parameters were the same as those listed in Appendices A and B, except that (1) the effective porosity of the unsaturated and saturated zones was set to 0.425, the same as the total porosity; (2) the groundwater fraction of livestock water and irrigation water was 1; and (3) the wind speed was set to 5 m/s. Differences are highlighted in bold.

TABLE 2.11 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Pathway Doses at t = 1,023 Years, Calculated with Revised Input Parameters[a]

	Water-Independent Pathways													
	External		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	4.10E-12	4.09E-12	7.75E-19	7.75E-19	0.00E+00	0.00E+00	5.15E-14	5.15E-14	8.62E-13	8.62E-13	8.67E-14	8.68E-14	1.57E-15	1.57E-15
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
K-40	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Np-237	2.84E-07	2.82E-07	7.44E-09	7.40E-09	0.00E+00	0.00E+00	1.48E-08	1.46E-08	1.23E-08	1.22E-08	3.45E-10	3.44E-10	1.79E-08	1.78E-08
Pu-239	3.12E-05	3.12E-05	8.49E-04	8.49E-04	0.00E+00	0.00E+00	7.45E-03	7.43E-03	6.19E-03	6.19E-03	3.35E-05	3.35E-05	9.03E-03	9.03E-03
Ra-226	1.84E+00	1.83E+00	1.10E-04	1.10E-04	1.52E+01	1.52E+01	2.82E-01	2.82E-01	4.73E-01	4.73E-01	7.32E-02	7.32E-02	3.84E-02	3.84E-02
Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sr-90	2.38E-30	2.38E-30	0.00E+00	2.43E-33	0.00E+00	0.00E+00	9.05E-29	9.05E-29	1.43E-28	1.43E-28	1.30E-29	1.30E-29	0.00E+00	3.66E-31
Th-230	1.10E+00	1.10E+00	2.06E-03	2.06E-03	9.10E+00	9.10E+00	1.71E-01	1.71E-01	2.77E-01	2.77E-01	4.30E-02	4.30E-02	2.66E-02	2.66E-02
U-234	9.54E-04	9.54E-04	1.98E-06	1.98E-06	7.88E-03	7.88E-03	1.48E-04	1.48E-04	2.40E-04	2.40E-04	3.73E-05	3.73E-05	2.34E-05	2.34E-05
U-238	2.86E-06	2.86E-06	4.16E-08	4.16E-08	2.12E-06	2.12E-06	2.38E-07	2.38E-07	7.35E-07	7.35E-07	1.91E-07	1.91E-07	1.27E-07	1.27E-07

	Water-Dependent Pathways													
	Water		Fish		Radon		Plant		Meat		Milk		Total	
Nuclide	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE	RESRAD (Onsite)	RESRAD-OFFSITE
C-14	**2.93E-06**	**1.37E-05**	**1.14E-02**	**2.42E-04**	0.00E+00	0.00E+00	**7.05E-06**	**1.73E-03**	**5.00E-06**	**2.14E-03**	**1.93E-06**	**3.44E-04**	**1.14E-02**	**4.47E-03**
Co-60	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cs-137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.10E-12	5.09E-12
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
K-40	2.55E-25	2.53E-25	**2.03E-23**	**1.17E-25**	0.00E+00	0.00E+00	**1.60E-26**	**2.70E-16**	**4.20E-25**	**6.83E-16**	**1.34E-25**	**1.04E-16**	**2.11E-23**	**1.06E-15**
Np-237	9.26E-01	9.23E-01	**2.20E+00**	**9.99E-03**	0.00E+00	0.00E+00	**4.84E-02**	**4.27E-01**	**7.35E-02**	**6.03E-01**	**6.85E-04**	**3.01E-03**	**3.25E+00**	**1.97E+00**
Pu-239	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.36E-02	2.36E-02
Ra-226	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.79E+01	1.79E+01
Ra-228	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sr-90	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.49E-28	2.49E-28
Th-230	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.07E+01	1.07E+01
U-234	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.29E-03	9.28E-03
U-238	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.32E-06	6.31E-06

[a] The input parameters were the same as those listed in Appendices A and B, except that (1) the effective porosity of the unsaturated and saturated zones was set to 0.425, the same as the total porosity; (2) the groundwater fraction of livestock water and irrigation water was 1; and (3) the wind speed was set to 5 m/s. Differences are highlighted in bold.

(onsite) and RESRAD-OFFSITE use different approaches to account for dilution of groundwater after it flows to the surface water body. The approach RESRAD-OFFSITE uses is more sophisticated than the one RESRAD (onsite) uses and requires more site-specific data. However, there is no obvious way of adjusting the RESRAD-OFFSITE parameters to produce a dilution factor that is the same as that used by RESRAD (onsite); therefore, no attempt was made to bridge the inconsistencies in the dose results.

Figures 2.1 and 2.2 show the comparisons of the groundwater concentrations for K-40 and Np-237, respectively. For other radionuclides, except for C-14 and H-3, the breakthrough times are greater than the time frame considered in the analysis. As the figures indicate, the shapes of the concentration curves are identical for the same radionuclide. The curve of the RESRAD-OFFSITE results can be obtained by shifting that of the RESRAD results along the time horizon and reducing the peak value. The difference is the result of the different formulations (Equations 2.1 and 2.2) of advective transport speeds that the two codes use. Therefore, resolution of the inconsistency can be achieved by setting the effective porosity to the value of the total porosity in RESRAD-OFFSITE for both the unsaturated and saturated zones. After the two computer codes were rerun with this new setting, the groundwater concentrations calculated by RESRAD (onsite) and RESRAD-OFFSITE were in good agreement (see Figures 2.5 and 2.6[1]).

$$v_{nuclide} = \frac{V_{wfr}}{\theta_e (1 + \rho_b K_d / \theta_t)} = \frac{V_{wfr}}{\theta_t + \rho_b K_d} \frac{\theta_t}{\theta_e} \text{ [formulation used by RESRAD (onsite)]} \quad (2.1)$$

$$v_{nuclide} = \frac{V_{wfr}}{\theta_t + \rho_b K_d} \text{ (formulation used by RESRAD-OFFSITE)} \quad (2.2)$$

where

$v_{nuclide}$ = velocity at which the nuclide is transported by groundwater; that is, the advective transport velocity (m/s),

1 The input parameters were the same as those listed in Appendices A through C, except that (1) the deposition velocity of dust was set to 0 m/s in RESRAD-OFFSITE; (2) the effective porosity of the unsaturated and saturated zones was set to 0.425, the same as the total porosity; (3) the groundwater fraction of livestock water and irrigation water was 1; and (4) the wind speed was set to 5 m/s.

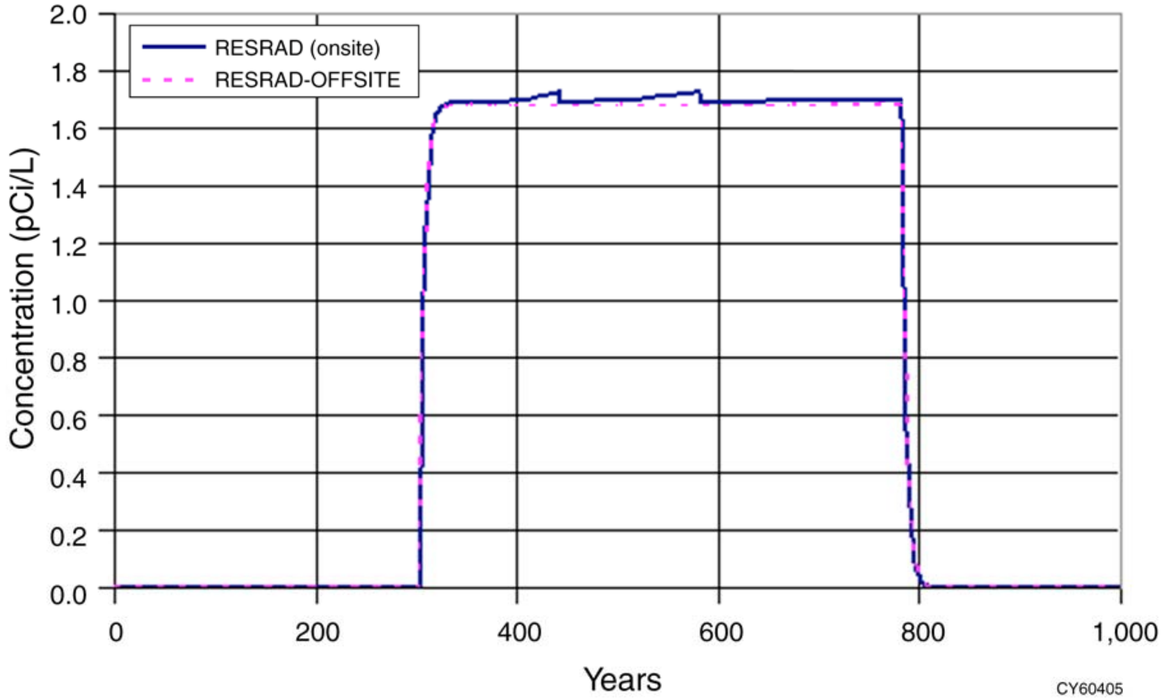

FIGURE 2.5 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Well Water K-40 Concentrations, Calculated with Revised Input Parameters

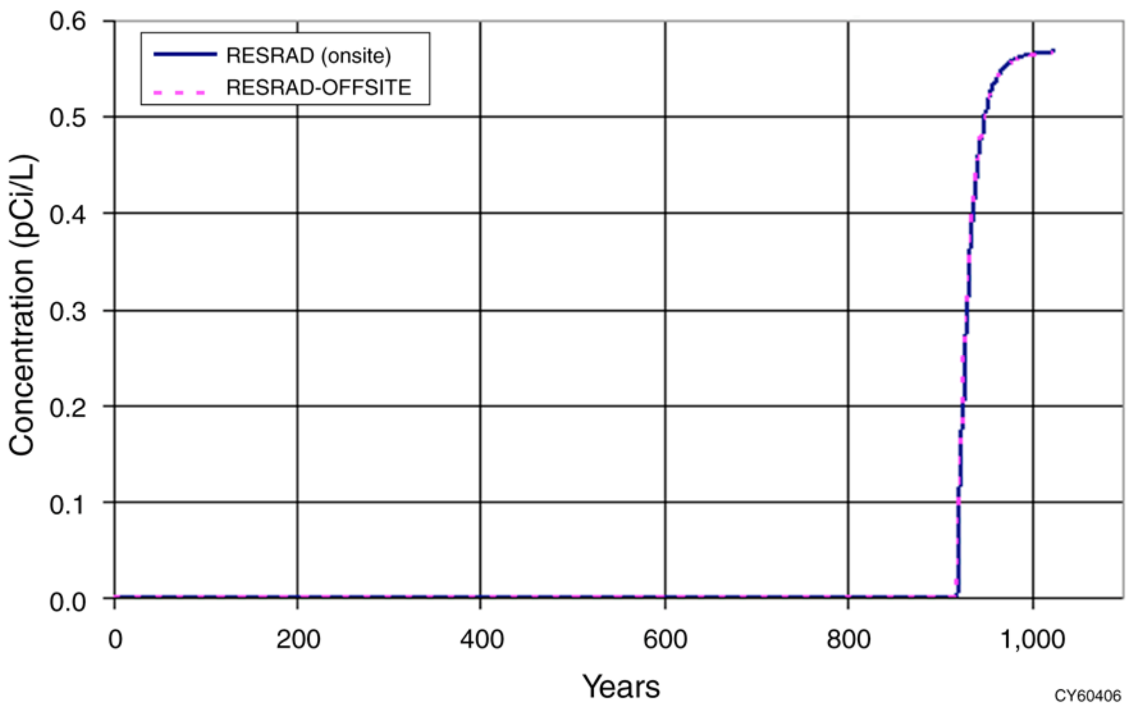

FIGURE 2.6 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Well Water Np-237 Concentrations, Calculated with Revised Input Parameters

V_{wfr} = volumetric flow rate per unit cross section of the aquifer, which is the product of the hydraulic conductivity and the hydraulic gradient (m/s),

ρ_b = dry bulk density of the soil that makes up the aquifer (g/cm^3),

K_d = distribution coefficient of the nuclide between the solid and aqueous phases of the aquifer (cm^3/g),

θ_t = total porosity of the aquifer, and

θ_e = effective porosity of the aquifer.

After the predictions for the concentrations in well water achieved agreement, the radiation doses from the water-dependent plant, meat, and milk pathways from RESRAD (onsite) and RESRAD-OFFSITE were compared again (see Tables 2.9, 2.10, and 2.11). The radiation doses calculated by RESRAD-OFFSITE were consistently greater than those of RESRAD (onsite). This is because of the accumulation of radionuclides deposited to the contaminated zone through the use of contaminated irrigation water (well water). RESRAD-OFFSITE accounts for this accumulation, whereas RESRAD (onsite) does not. As the results indicate, under certain conditions for some radionuclides, the impact of the accumulation to the total dose can be quite significant.

2.2.2 Special Consideration for C-14 and H-3

Figures 2.3 and 2.4 compare the groundwater C-14 and H-3 concentrations calculated by RESRAD (onsite) and RESRAD-OFFSITE when using the input parameters listed in Appendices A through C. By setting the effective porosity to the value of total porosity for the unsaturated and saturated zones, agreement was observed in the onset of groundwater contamination for C-14 and in the span of groundwater contamination for H-3 (see Figures 2.7 and 2.8). However, unlike the comparison of K-40 and Np-237 (Figures 2.5 and 2.6), in which the two curves coincide, C-14 and H-3 still exhibit large inconsistencies between the RESRAD (onsite) and RESRAD-OFFSITE results. The concentrations of C-14 and H-3 in the contaminated soil decrease rapidly because of evasion in the case of C-14, and because of both evasion and rapid leaching in the case of H-3. Thus the release to groundwater also decreases

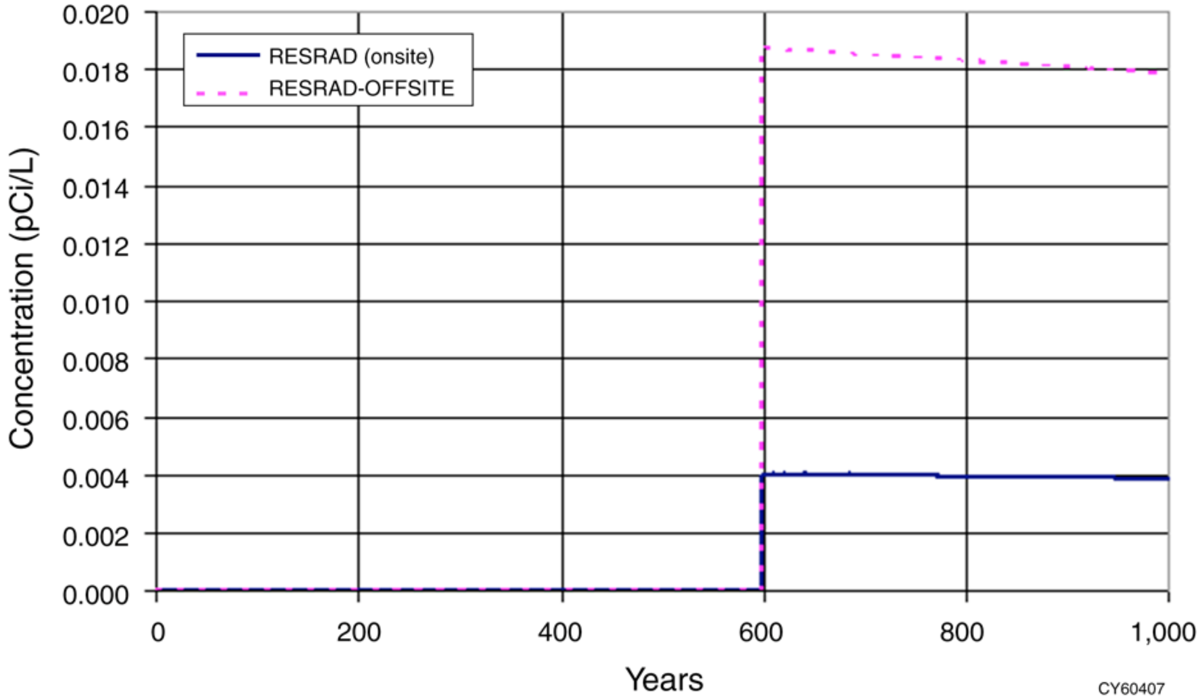

FIGURE 2.7 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Well Water C-14 Concentrations, Calculated with Revised Input Parameters

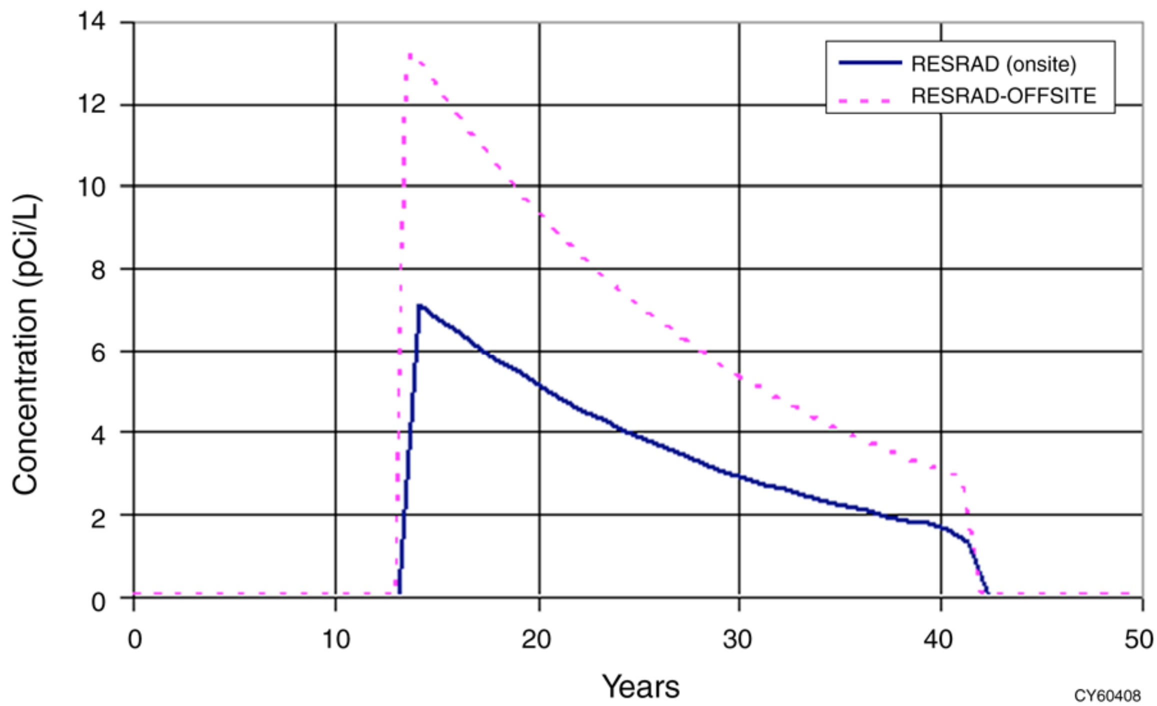

FIGURE 2.8 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Well Water H-3 Concentrations, Calculated with Revised Input Parameters

rapidly, as shown in Figures 2.9 and 2.10. As is evident from these figures, linear approximation between releases spaced at 1/4 of a year does not capture the variation in the release adequately, which causes the RESRAD-OFFSITE overpredictions shown in Figures 2.7 and 2.8. Much better agreement in the predictions is obtained when RESRAD-OFFSITE is run with a time interval of 1/16 of a year, as shown in Figures 2.11 and 2.12. The maximum number of time points in RESRAD-OFFSITE was increased to 22,000 in order to allow use of the finer time interval with large time horizons.

Because of the evasion due to vaporization and leaching, the soil concentrations of C-14 and H-3 decrease quickly; within 1 year, all the initial contamination is gone. For further comparisons, the time span for dose analysis was reduced from 1,024 to 2 years. This was accomplished by setting the maximum time period to 2 years for RESRAD (onsite) and to 1 year for RESRAD-OFFSITE. The maximum number of integration points for dose was increased to 17 in RESRAD (onsite), and the total number of graphic points was set to 128 for both codes. The minimum time increment was set to 1/64 of a year in RESRAD-OFFSITE. With the above settings, the two computer codes were executed again, and the dose results were obtained and compared. As Figures 2.13 and 2.14 show, the predictions of the two codes were close for the case in which water, animal feed, and human food are stored for a period of time before consumption. The predictions of the two codes were identical when these items are consumed as they are produced or extracted, that is, no storage time (Figures 2.15 and 2.16).

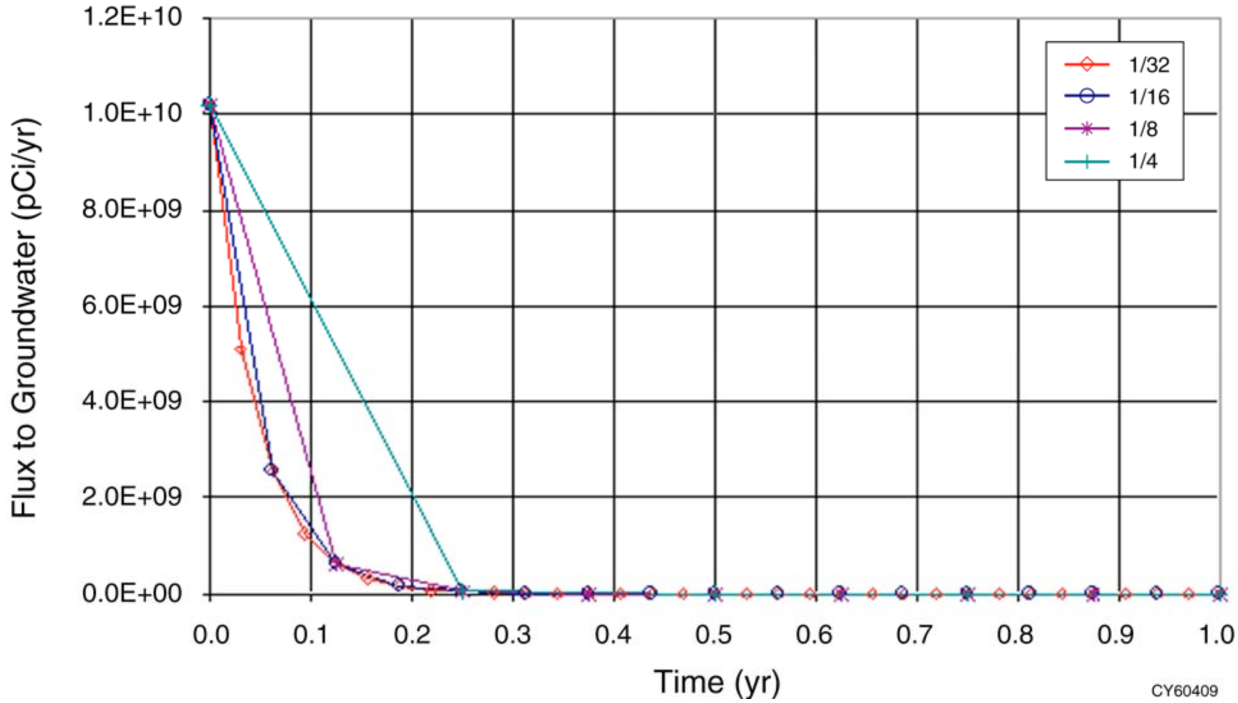

FIGURE 2.9 Variation of Release of C-14 to Groundwater with Time

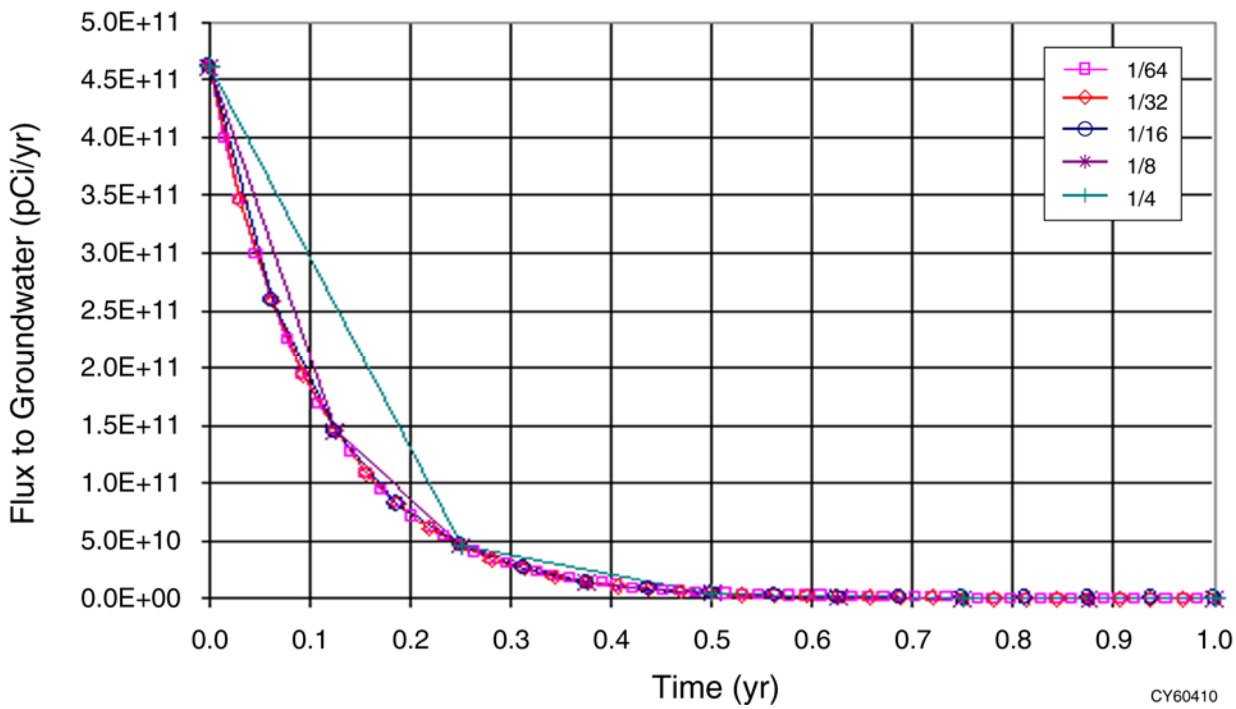

FIGURE 2.10 Variation of Release of H-3 to Groundwater with Time

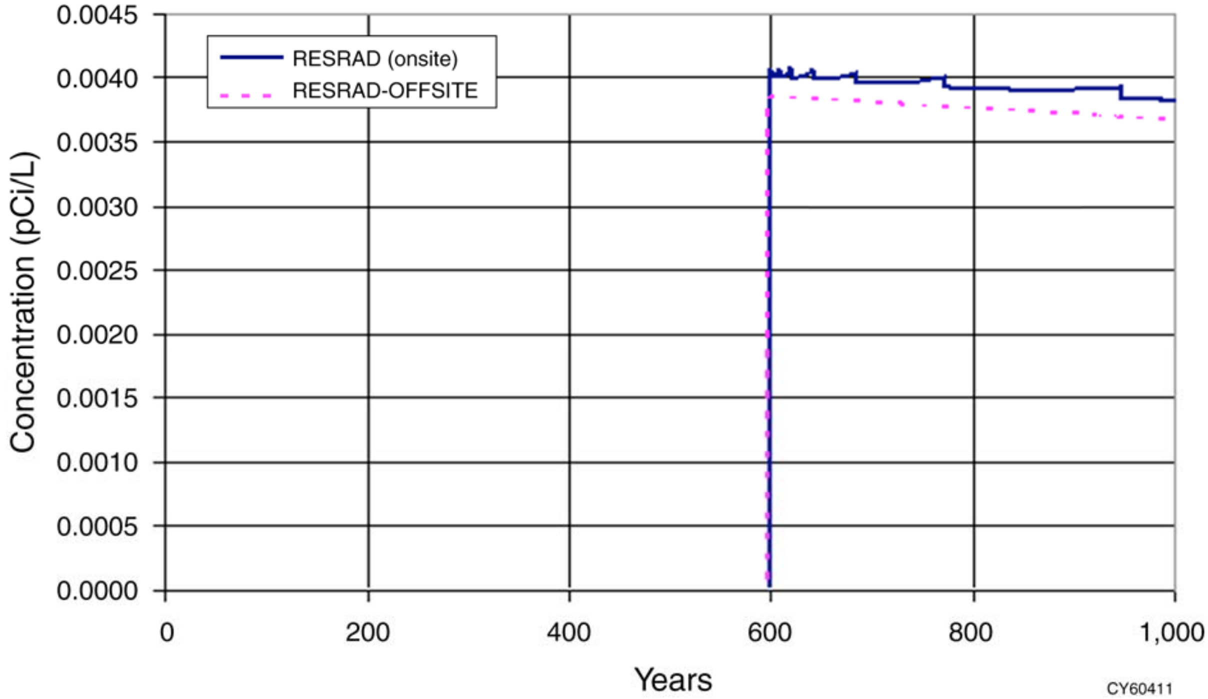

FIGURE 2.11 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Well Water C-14 Concentrations, Calculated with Revised Input Parameters and a 1/16-Year Time Interval

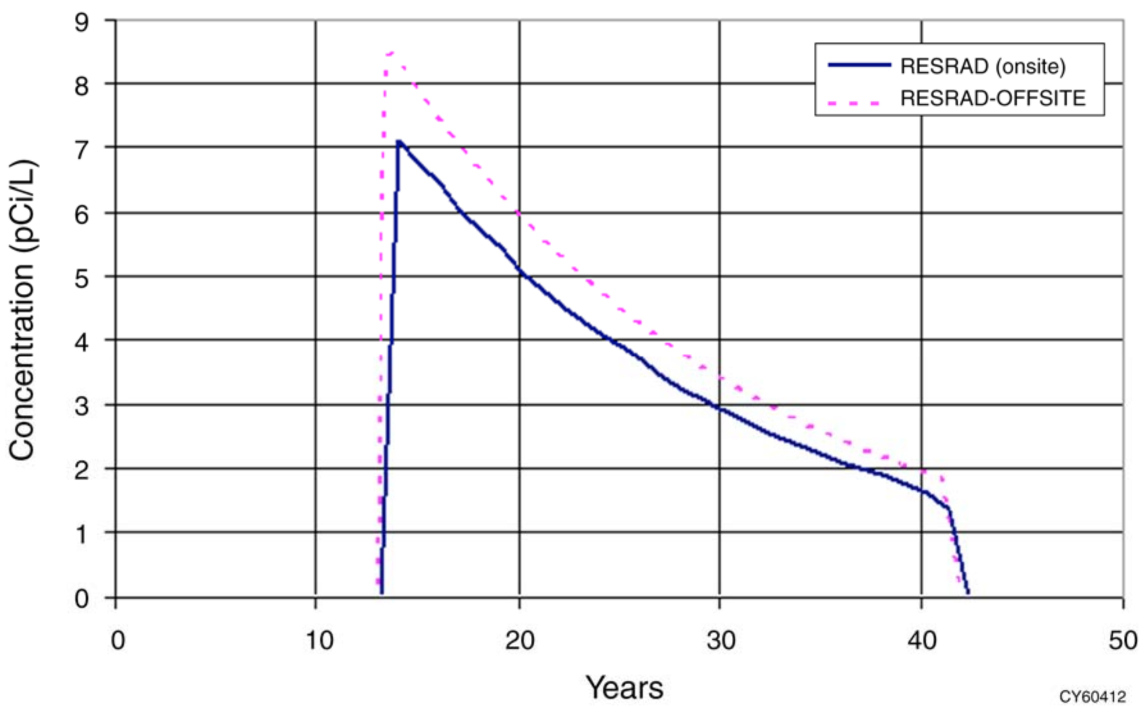

FIGURE 2.12 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Well Water H-3 Concentrations, Calculated with Revised Input Parameters and a 1/16-Year Time Interval

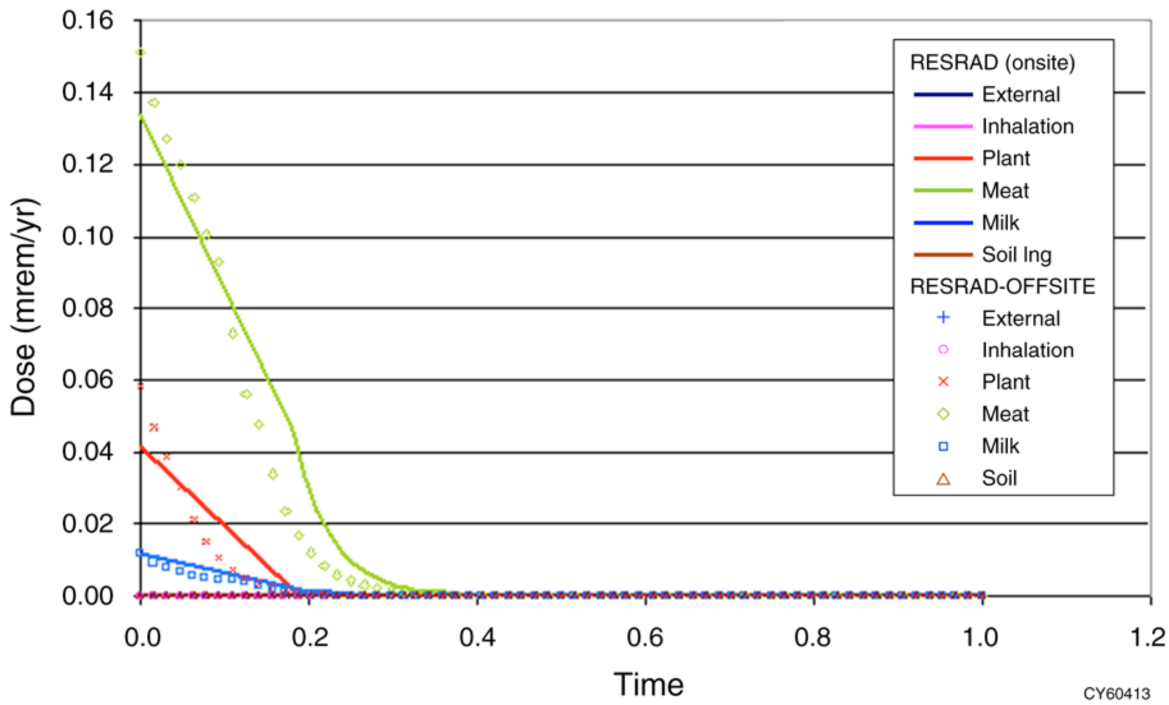

FIGURE 2.13 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Pathway Doses for C-14, Calculated with Revised Input Parameters and a 1/64-Year Time Interval and Storage Time

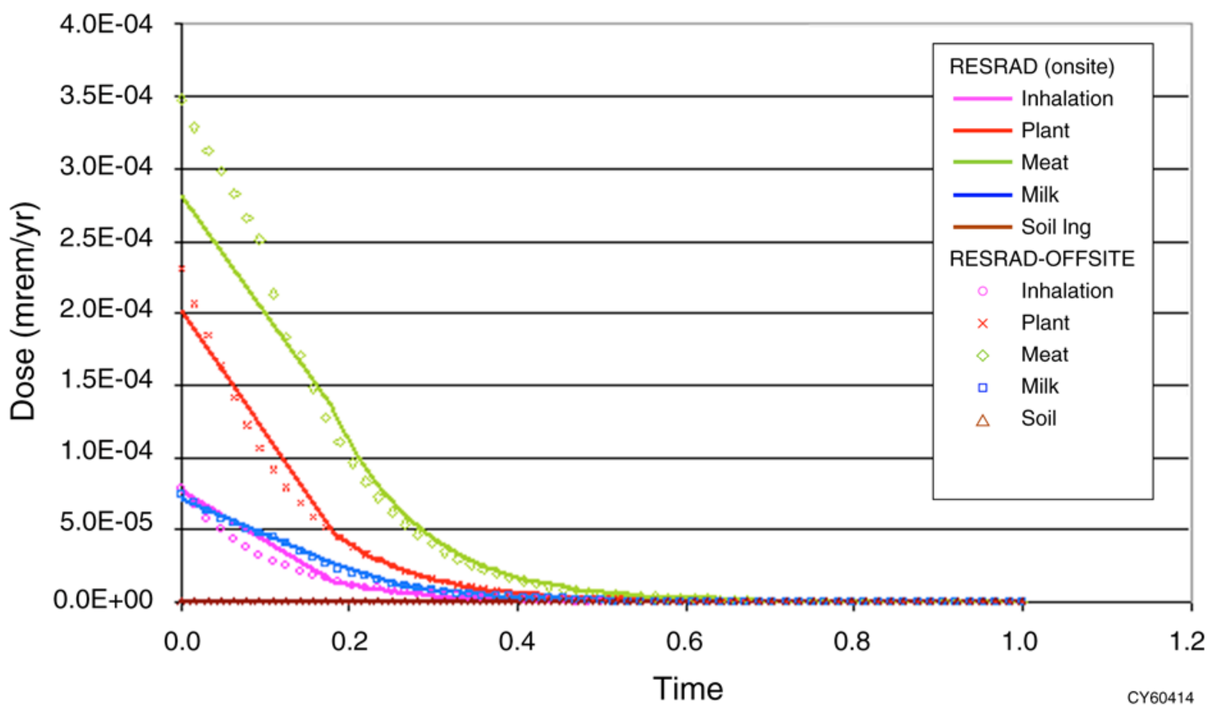

FIGURE 2.14 Comparison of RESRAD and RESRAD-OFFSITE Pathway Doses for H-3: Calculated with Revised Input Parameters and a 1/64-Year Time Interval and Storage Time

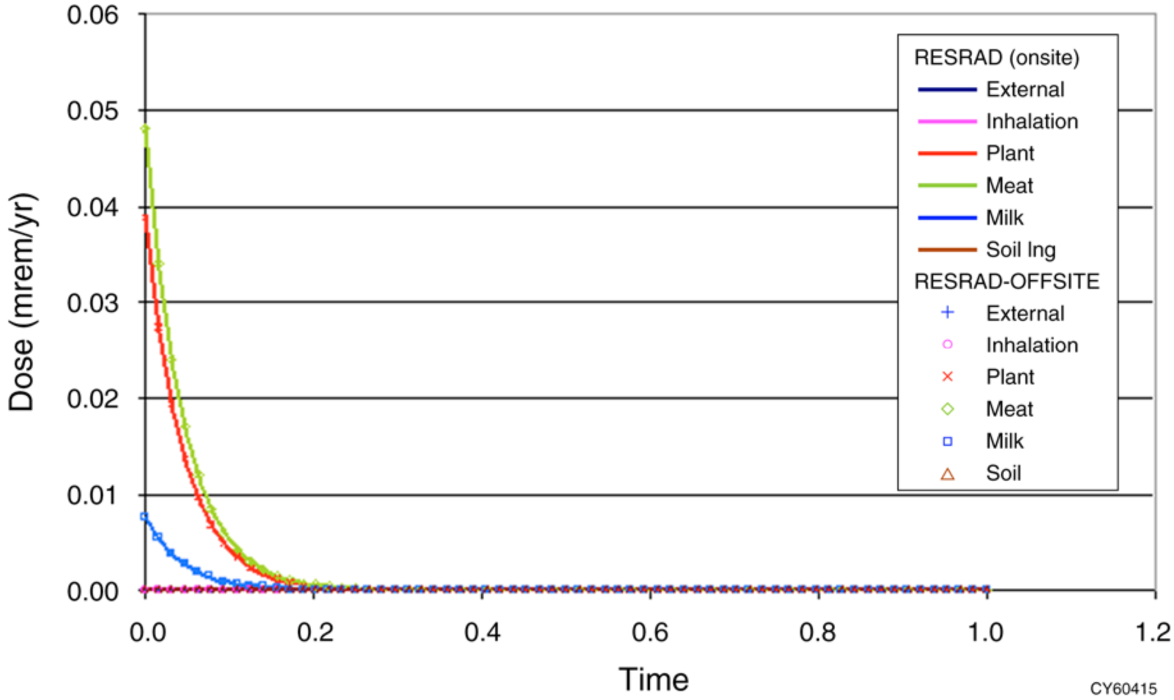

FIGURE 2.15 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Pathway Doses for C-14: Calculated with Revised Input Parameters, a 1/64-Year Time Interval, and No Storage Time

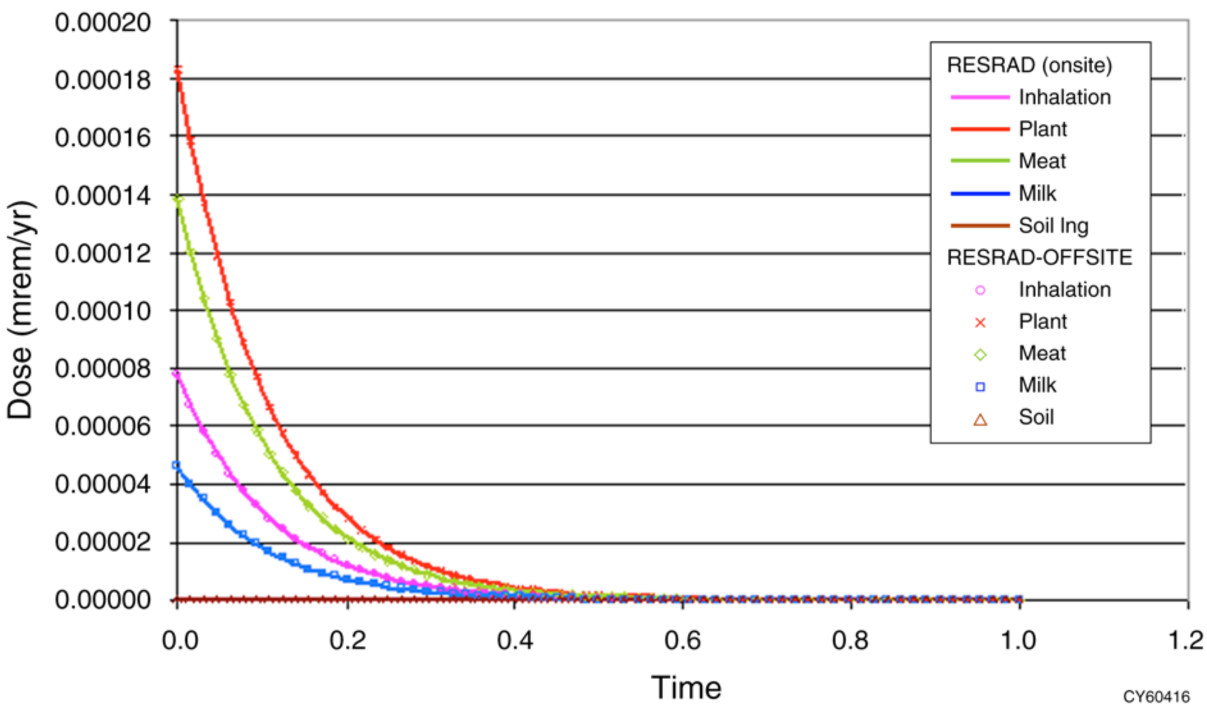

FIGURE 2.16 Comparison of RESRAD (Onsite) and RESRAD-OFFSITE Pathway Doses for H-3: Calculated with Revised Input Parameters, a 1/64-Year Time Interval, and No Storage Time

3 COMPARISON OF THE PREDICTIONS OF THE ATMOSPHERIC TRANSPORT MODEL WITH CAP88-PC AND ISCLT3

An area source air dispersion model was added to the RESRAD-OFFSITE computer code for the long-term analysis of downwind receptor impacts from area sources with chronic releases of radionuclides to the atmosphere (Biwer et al. 2003). The air dispersion model is based on the standard Gaussian plume point source formulation and was adapted for use as an area source implementation. This section presents results of air dispersion benchmark comparisons of RESRAD-OFFSITE with CAP88-PC (Parks 1992) and ISCLT3 (EPA 1995). A prior understanding of the Gaussian plume model as implemented in these models is assumed.

Section 3.1 looks at variations in the models considered in order to provide a basis for some of the differences noted in the benchmark comparisons presented in Section 3.2. In Sections 3.1 and 3.2, the primary components of the air dispersion model are investigated separately to better understand where the sources of any differences are in the model results. Results are presented for dispersion with and without plume rise and plume depletion (dry and/or wet deposition).

3.1 AREA SOURCE MODEL DESCRIPTIONS

This section provides a brief discussion of each model considered. The similarities and differences among the models are highlighted for a better understanding of the result comparisons in Section 3.2. For more detailed information on each model, please review the respective user's manuals — Biwer et al. (2003) for RESRAD-OFFSITE, Parks et al. (1992) for CAP88-PC, and EPA (1995) for ISCLT3.

3.1.1 Gaussian Plume Model

The Gaussian plume air dispersion model had its origins in the mid-1900s and remains a simple model that produces a relatively accurate result for the input data required (Slade 1968). The Gaussian model is a point source model that assumes the release of airborne material from a single point. Because most sources have an associated size (area/cross section/volume) at the release location, the Gaussian model is not considered to give reasonable results within a few hundred meters of the release location unless adjustments are made, such as in area and volume source adaptations.

The Gaussian plume model for continuous (chronic) releases is derived from the puff model for instantaneous (acute) releases (Slade 1968). The chronic form is used to derive the area source model in RESRAD-OFFSITE. Equation 3.1 (Equation 2.10 in Biwer et al. 2003) presents the basic Gaussian time-dependent dispersion equation for a discrete puff generated from a point source (Pasquill 1974):

$$C_a(i,x,y,z,t) = \frac{Q_{x_i}}{(2\pi)^{3/2}\sigma_y^2\sigma_z} exp\left(\frac{-r^2}{2\sigma_y^2}\right)\left[exp\left(\frac{-(z-H)^2}{2\sigma_z^2}\right) + exp\left(\frac{-(z+H)^2}{2\sigma_z^2}\right)\right], \quad (3.1)$$

where

$C_a(i,x,y,z,t)$	=	air concentration of radionuclide i at x,y,z from a release at $0,0,H$ at time t after release (Ci/m^3),
Q_{xi}	=	depleted source strength of nuclide i at distance x (Ci),
σ_y	=	horizontal dispersion coefficient,
σ_z	=	vertical dispersion coefficient,
r^2	=	$(x - u_H t)^2 + y^2$, assumes Gaussian symmetry, that is, $\sigma_x = \sigma_y$ (m^2),
x	=	downwind receptor distance from the release point (m),
y	=	crosswind distance from the plume centerline (m),
u_H	=	average wind speed at the effective release height (m/s),
t	=	time following release (s), and
H	=	effective release height (m).

Equation 3.1 is modified at greater distances where plume reflection occurs off a stable upper layer or mixing layer. At these distances, uniform mixing between the ground and the upper air layer is assumed, and the Gaussian form of the equation is lost.

The dispersion coefficients are characteristic of the size of the plume and become larger as the plume travels farther downwind. Several empirical formulations of the dispersion coefficients have been proposed. The most commonly used formulations are based on the Pasquill-Gifford curves (Eimutis and Konicek 1972) or those suggested by Briggs (1974) for rural (open country) or urban conditions. CAP88-PC implements the rural Briggs coefficients;

ISCLT3 contains options for use of the Pasquill-Gifford curves or the urban Briggs coefficients; and RESRAD-OFFSITE provides all three options.

The Gaussian dispersion model itself is often supplemented by other models when downwind air concentrations are being calculated. Factors considered include plume rise, buoyancy-induced dispersion, and plume depletion as a function of dry and wet deposition. Initial plume rise due to thermal buoyancy can be accounted for in RESRAD-OFFSITE, CAP88-PC, and ISCLT3. All three codes incorporate the buoyancy plume rise formulas suggested by Briggs (1969) as an option. Buoyancy-induced dispersion refers to growth of the plume during plume rise as a result of turbulent motion associated with plume release conditions and turbulent entrainment of ambient air. RESRAD-OFFSITE and ISCLT3 adjust the size of the dispersion coefficients according to the method suggested by Pasquill (1976) to account for this effect. CAP88-PC does not account for buoyancy-induced dispersion if buoyant plume rise is considered.

Except in the case of nonreactive gases, the total amount of contaminant in the plume decreases as the plume moves downwind because of chemical reaction, gravitational settling (dry deposition), and wet deposition (rainout, washout). Most radioactive contaminants are in the form of particulates that are depleted from the plume because of dry and wet deposition. All three codes have different algorithms to estimate plume depletion resulting from dry deposition. RESRAD-OFFSITE and CAP88-PC account for wet deposition with different algorithms. CAP88-PC considers radioactive decay during air dispersion. Plume depletion by radioactive decay is not considered in the current version of RESRAD-OFFSITE because air transit times are only on the order of seconds to minutes, much shorter than the intended evaluation period (months to years). ISCLT3 does not explicitly consider radioactive decay; it does, however, incorporate a decay term that could be used to model such decay.

3.1.2 Chronic Releases

The chronic implementation of the Gaussian puff model considers a continuous atmospheric release. For a receptor at ground level, the concentration downwind of a chronic source can be derived from Equation 3.1 by setting $z = 0$ and integrating over time from zero to infinity. The resulting equation calculates the chronic air concentration at a specific location downwind for a given set of meteorological conditions (i.e., weather stability category and wind speed and direction).

All three codes are capable of using a polar grid that segments wind direction into 16 sectors to specify wind direction and the frequency that the wind blows in any given sector. However, wind direction will still fluctuate with time within a given sector. Thus, it is appropriate to use the sector-average concentration in risk analysis. The sector-average concentration is obtained by integrating the chronic air concentration over the *y* (crosswind) direction from minus infinity to plus infinity, then dividing this by the distance that spans the sector at the given receptor distance (*x*) downwind. This formulation, as used in both RESRAD-OFFSITE and CAP88-PC, compresses the plume to within the sector boundaries.

The chronic sector-averaged air concentration in cases with and without plume reflection is given in Equations 3.2 and 3.3:

$$\overline{C_{sec}}(i,x) = \frac{Q_{x_i}}{0.49680 x \sigma_z u_H} exp\left(\frac{-H^2}{2\sigma_z^2}\right) \tag{3.2}$$

$$\overline{C_{sec}}(i,x) = \frac{Q_{x_i}}{0.397825 x L u_H} \ , \tag{3.3}$$

where

L = Lid or mixing height (m).

These are the same derivations as those used in RESRAD-OFFSITE and CAP88-PC. For cases in which there is no plume reflection, Equation 3.2 matches Equation 2.22 in Biwer et al. (2003) and Equation 12 in Parks (1992). For cases with plume reflection, Equation 3.3 matches Equation 2.24 in Biwer et al. (2003) and Equation 16 in Parks (1992). The treatment in ISCLT3 is similar but does not compress the plume into the sector and contains a smoothing function near sector boundaries.

3.1.3 Area Source Implementation

The development of the RESRAD-OFFSITE and CAP88-PC area source models is similar up to the derivation of a chronic sector-averaged air concentration, as discussed in Section 3.1.2. CAP88-PC treats the area source as an annular segment with the same area. At short distances, it is modeled as a circular area. At larger distances, where the ratio of the distance to the diameter is greater than 2.5, the area source is modeled as a point source. If the area source is 10 m in diameter or less, CAP88-PC also uses a point source model. In contrast, RESRAD-OFFSITE assumes a rectangular area source and uses the same methodology for all area sizes and distances. Each square meter of the source is treated as a point source, and the resulting average downwind normalized air concentration (χ/Q) values at the receptor location are summed and divided by the number of square meters in the source (averaged). This method avoids any area source approximations but does increase computation time. “Point” sources larger than 1 m^2 may be specified to reduce computation time at the sacrifice of some accuracy. All benchmark calculations employed the 1-m^2 setting unless otherwise noted. RESRAD-OFFSITE does not attempt to smooth results near sector boundaries as is done in ISCLT3; it does, however, individually determine the proper sector (direction) to use when applying the wind frequency data for each point source.

The area source in ISCLT3 is modeled as a rectangular area with a length-to-width aspect ratio of up to 10 to 1. The source can also be rotated with respect to a north-south and east-west orientation. Like RESRAD-OFFSITE, the downwind air concentration calculated by ISCLT3 is a double integral of the Gaussian equation in the upwind (x) and crosswind (y) directions. ISCLT3 also evaluates dispersion in adjoining sectors and uses smoothing routines related to the frequency of occurrence in each direction to adjust the calculated sector average concentration.

3.2 MODEL RESULT COMPARISONS

RESRAD-OFFSITE was compared with CAP88-PC and ISCLT3 in situations where the models required similar input data and were expected to provide the same result. Unless otherwise noted, a 10,000-m^2 area source, a 1,000-m lid height, and an ambient temperature of 285K were used. RESRAD-OFFSITE results were obtained by using the rural Briggs dispersion coefficients for all comparisons with CAP88-PC, because those coefficients are used by the latter code. Likewise, RESRAD-OFFSITE results were generated by using both the Pasquill-Gifford coefficients and the Briggs urban coefficients for comparisons with ISCLT3 results.

The simplest comparison made was for plume dispersion without buoyant plume rise or depletion of the plume, as might occur for nonreactive gases; this is referred to as the “simple model” below. Further comparisons that included effects such as plume rise, dry deposition, and wet deposition, were also made. The modeling endpoint is the normalized air concentration χ/Q (i.e., the air concentration divided by the release amount at the ground-level receptor location). A range of receptor locations from 100 to 80,000 m downwind of the release point (center of the source area) were evaluated. The downwind air concentration results for one specific direction are presented below. Results for other directions were similar except where noted.

3.2.1 Simple Model

Potential differences in the model results begin with any variations in the basic Gaussian plume model used. This section examines the differences found in the downwind concentrations when thermal buoyancy and depletion effects were not considered.

3.2.1.1 CAP88-PC

Version 1.0 of the CAP88-PC program was used. The downwind air concentration calculations and results remain the same in the updated beta 2.1 version and the beta 3.0 version.

Thermal buoyancy and wet deposition can be turned off by setting the appropriate input parameter values to zero. However, dry deposition is fixed in CAP88-PC for three categories of material: particulate matter, iodine, and nonreactive gases. Krypton-85 (Kr-85) was selected as the radioactive contaminant for this set of calculations because nonreactive gases have a predetermined deposition velocity of zero in CAP88-PC and because effects from radioactive decay would not be observed because of Kr-85's longer half-life. The corresponding values for thermal buoyancy and dry and wet deposition in RESRAD-OFFSITE were all set to zero.

The average wind speed used for each wind speed category in CAP88-PC is fixed. Therefore, the CAP88-PC wind speeds (0.772, 2.572, 4.373, 6.945, 9.774, and 11.882 m/s) were used in RESRAD-OFFSITE. The STAR joint frequency weather data file used in RESRAD-OFFSITE was converted by using the GETWIND utility program to the corresponding *.WND file for use with CAP88-PC.

Table 3.1 presents the first set of results of a comparison between the two codes. The left-hand columns in the table show the results for the area source releases. Good agreement is shown. The differences for all distances were approximately 6% or less, except for the 100-m

TABLE 3.1 Simple Model Comparison of RESRAD-OFFSITE with CAP88-PC

	Area Source			Point Source			Equation 3.2		
	χ/Q (s/m^3)			χ/Q (s/m^3)			χ/Q (s/m^3)		
Distance (m)	RESRAD-OFFSITE	CAP88-PC	Percent Difference	RESRAD-OFFSITE	CAP88-PC	Percent Difference	Briggs Rural	Modified Briggs	Percent Difference
100	2.1E-04	1.8E-04	-13	1.8E-04	1.8E-04	-4.1	1.8E-04	1.7E-04	-4.3
200	5.6E-05	5.4E-05	-4.8	5.4E-05	5.3E-05	-1.0	5.3E-05	5.2E-05	-1.1
250	3.7E-05	3.6E-05	-2.7	3.6E-05	3.6E-05	0.1	3.5E-05	3.5E-05	0.0
500	9.8E-06	9.9E-06	0.8	9.7E-06	9.9E-06	1.5	9.6E-06	9.8E-06	1.4
750	4.6E-06	4.6E-06	-0.2	4.6E-06	4.6E-06	0.1	4.6E-06	4.6E-06	0.0
1,000	2.8E-06	2.7E-06	-2.4	2.8E-06	2.7E-06	-2.3	2.7E-06	2.7E-06	-2.4
1,250	1.9E-06	1.9E-06	-0.5	1.9E-06	1.9E-06	-0.4	1.9E-06	1.8E-06	-0.5
1,500	1.4E-06	1.4E-06	0.8	1.4E-06	1.4E-06	0.8	1.4E-06	1.4E-06	0.7
1,750	1.1E-06	1.1E-06	1.3	1.1E-06	1.1E-06	1.3	1.1E-06	1.1E-06	1.2
2,000	8.5E-07	8.6E-07	1.3	8.5E-07	8.6E-07	1.3	8.4E-07	8.6E-07	1.3
2,250	7.0E-07	7.1E-07	1.1	7.0E-07	7.1E-07	1.1	7.0E-07	7.1E-07	1.0
2,500	6.0E-07	6.0E-07	0.6	6.0E-07	6.0E-07	0.6	5.9E-07	5.9E-07	0.5
2,750	5.1E-07	5.1E-07	-0.1	5.1E-07	5.1E-07	-0.1	5.1E-07	5.1E-07	-0.2
3,000	4.5E-07	4.4E-07	-0.9	4.5E-07	4.4E-07	-0.9	4.4E-07	4.4E-07	-1.0
4,000	2.9E-07	3.0E-07	2.8	2.9E-07	3.0E-07	2.8	2.9E-07	3.0E-07	2.7
5,000	2.1E-07	2.2E-07	4.0	2.1E-07	2.2E-07	4.0	2.1E-07	2.2E-07	3.9
6,000	1.6E-07	1.7E-07	4.2	1.6E-07	1.7E-07	4.2	1.6E-07	1.7E-07	4.1
7,000	1.3E-07	1.4E-07	3.7	1.3E-07	1.4E-07	3.7	1.3E-07	1.4E-07	3.6
8,000	1.1E-07	1.1E-07	2.8	1.1E-07	1.1E-07	2.8	1.1E-07	1.1E-07	2.8
9,000	9.4E-08	9.6E-08	2.0	9.4E-08	9.6E-08	2.0	9.4E-08	9.5E-08	1.9
10,000	8.2E-08	8.3E-08	0.9	8.2E-08	8.3E-08	0.9	8.2E-08	8.2E-08	0.8
20,000	3.5E-08	3.7E-08	5.9	3.5E-08	3.7E-08	5.9	3.5E-08	3.7E-08	5.9
30,000	2.2E-08	2.4E-08	6.3	2.2E-08	2.4E-08	6.3	2.2E-08	2.3E-08	6.3
40,000	1.6E-08	1.7E-08	5.7	1.6E-08	1.7E-08	5.7	1.6E-08	1.7E-08	5.6
50,000	1.3E-08	1.3E-08	4.7	1.3E-08	1.3E-08	4.7	1.2E-08	1.3E-08	4.6
60,000	1.0E-08	1.1E-08	3.7	1.0E-08	1.1E-08	3.7	1.0E-08	1.1E-08	3.6
70,000	8.8E-09	9.0E-09	2.8	8.8E-09	9.0E-09	2.8	8.7E-09	8.9E-09	2.7
80,000	7.6E-09	7.8E-09	1.9	7.6E-09	7.8E-09	1.9	7.5E-09	7.6E-09	1.8

receptor, for which a 13% difference was found. Because the RESRAD-OFFSITE and CAP88-PC implementations are identical through the chronic sector average derivation (Equations 3.2 and 3.3), these observed differences can be attributed to variations in the vertical dispersion coefficient and the actual area source methodology.

As a second step in this comparison, differences due to the area source methodology were removed by comparing point source results from RESRAD-OFFSITE and CAP88-PC, as shown in the middle columns in Table 3.1. RESRAD-OFFSITE was run by using a source area of 1 m^2, and the point source model in CAP88-PC was selected. For the distances evaluated beyond 500 m, the point sources gave the same results as the area sources, respectively, for each code. For these distances, the differences between codes can be entirely attributed to differences in the vertical dispersion coefficient, as shown in the following discussion.

The horizontal dispersion coefficient σ_y is absent in Equations 3.2 and 3.3 because of sector averaging. Thus, only the vertical dispersion coefficient σ_z is used in the chronic release calculations. The form of the vertical dispersion coefficient as given by Briggs (1974) is

$$\sigma_z = ax \left(1 + bx\right)^c \quad , \tag{3.4}$$

where a, b, and c are constants defined in Table 3.2 for open country (rural) conditions as used in RESRAD-OFFSITE. CAP88-PC uses the Briggs rural coefficients in a modified form,

$$\sigma_z = \frac{x^D}{F} , \tag{3.5}$$

to facilitate integrations over x, where D and F are constants as defined in Table 3.3.

The two sets of coefficients were compared by using them in Equation 3.2, which should also match the point source results. A set of Excel spreadsheet calculations implementing Equation 3.2 were performed. The results are shown in the last three right-hand columns of Table 3.1. It can be seen that for distances greater than 500 m, the differences between the codes using Equation 3.2 exactly mirror (to within approximately 0.1%) the differences between the codes using the point sources. This excellent agreement demonstrates that the differences observed in the RESRAD-OFFSITE and CAP88-PC results for distances greater than 500 m are due to the differences in the vertical dispersion coefficients. The spreadsheet calculation results also serve to verify the correct operation of the codes in the region where a plume is not limited

TABLE 3.2 Briggs Rural Vertical Dispersion Coefficient (σ_z) Parameters

Weather Condition	Stability Class	a	b	c
Extremely unstable	A	0.20	0.0	0.0
Moderately unstable	B	0.12	0.0	0.0
Slightly unstable	C	0.08	0.0002	-0.5
Neutral	D	0.06	0.0015	-0.5
Moderately stable	E	0.03	0.0003	-1.0
Very stable	F	0.016	0.0003	-1.0

Source: Briggs (1974).

TABLE 3.3 Vertical Dispersion Coefficient Parameters as Used in CAP88-PC

Stability Class	Distance (m)	Parameter D	Parameter F
A	x ≤ 1,000	1	5.02
	1,000 < x ≤ 3,000	1	5.02
	3,000 < x ≤ 10,000	1	5.02
	x > 10,000	1	5.02
B	x ≤ 1,000	1	8.35
	1,000 < x ≤ 3,000	1	8.35
	3,000 < x ≤ 10,000	1	8.35
	x > 10,000	1	8.35
C	x ≤ 1,000	0.9540	10.015
	1,000 < x ≤ 3,000	0.8330	4.400
	3,000 < x ≤ 10,000	0.8330	4.400
	x > 10,000	0.5524	0.3320
D	x ≤ 1,000	0.8061	7.480
	1,000 < x ≤ 3,000	0.6715	2.950
	3,000 < x ≤10,000	0.5099	0.8100
	x > 10,000	0.5251	0.9300
E	x ≤ 1,000	0.8600	15.50
	1,000 < x ≤ 3,000	0.6290	3.150
	3,000 < x ≤ 10,000	0.4054	0.5240
	x > 10,000	0.1110	0.0349
F	x < = 1,000	0.8823	34.70
	1,000 < x ≤ 3,000	0.6321	6.132
	3,000 < x ≤ 10,000	0.3710	0.7640
	x > 10,000	0.1106	0.0694

by the atmospheric lid height, since the Equation 3.2 results are within round-off errors of the point source results for both codes. Differences between the two codes in impacts at close receptor distances due to the area source methodology are discussed further in Section 3.2.1.3.

3.2.1.2 ISCLT3

Version 96113 of ISCLT3 was used. The rural modeling option uses Pasquill-Gifford dispersion coefficients, and the urban modeling option uses the Briggs urban coefficients. ISCLT3 uses a different formulation for the Pasquill-Gifford coefficients than does RESRAD-OFFSITE, but both codes use the same formulation for the Briggs urban coefficients as originally proposed (Briggs 1974). Both dispersion options were compared with RESRAD-OFFSITE by using the appropriate coefficients. The default RESRAD-OFFSITE average wind speeds (0.89, 2.46, 4.47, 6.93, 9.61, and 12.52 m/s) were used for the six wind speed categories, with one exception: ISCLT3 does not accept a wind speed of less than 1. Thus, for the lowest wind speed category, a wind speed of 1.0 was used in both codes. The same STAR joint frequency distribution was used by both codes. Thermal buoyancy and dry/wet deposition input parameters were set to zero.

Table 3.4 presents the comparison of results. There was good agreement when the Pasquill-Gifford coefficients were used (left side of Table 3.4), with differences of less than 5% for all distances, including the closest distance of 100 m. However, differences of up to 109% (a factor of approximately 2) were observed when the Briggs urban coefficients were used. The explanation for these latter differences is uncertain, in part because both codes use the same form of the vertical dispersion coefficient, yet the Pasquill-Gifford comparison showed good agreement. Comparisons between plumes limited and not limited by a lid layer were investigated; however, better agreement was not reached when the Briggs urban coefficients were used.

3.2.1.3 Discussion

The CAP88-PC and ISCLT3 area source calculations use the principle of reciprocity in their calculations. The receptor and area source are effectively interchanged, and the average χ/Q value over the area calculated is based on a point source at the receptor location. This latter

TABLE 3.4 Simple Model Comparison of RESRAD-OFFSITE with ISCLT3

	Pasquill-Gifford Coefficients			Briggs Urban Coefficients		
	χ/Q (s/m³)			χ/Q (s/m³)		
Distance (m)	RESRAD-OFFSITE	ISCLT3	Percent Difference	RESRAD-OFFSITE	ISCLT3	Percent Difference
100	1.6E-04	1.6E-04	1.7	5.8E-05	6.3E-05	9.7
200	4.2E-05	4.1E-05	-1.5	1.2E-05	1.3E-05	9.5
250	2.8E-05	2.7E-05	-1.1	7.6E-06	8.5E-06	12
500	7.8E-06	7.8E-06	-0.2	1.9E-06	2.3E-06	22
750	3.8E-06	3.8E-06	-0.5	8.5E-07	1.1E-06	31
1,000	2.3E-06	2.3E-06	1.2	4.8E-07	6.7E-07	38
1,250	1.5E-06	1.6E-06	3.7	3.1E-07	4.5E-07	43
1,500	1.1E-06	1.2E-06	4.6	2.2E-07	3.3E-07	49
1,750	8.8E-07	9.2E-07	4.6	1.6E-07	2.5E-07	54
2,000	7.1E-07	7.4E-07	4.2	1.3E-07	2.0E-07	60
2,250	5.9E-07	6.1E-07	4.4	1.0E-07	1.7E-07	64
2,500	5.0E-07	5.2E-07	4.3	8.5E-08	1.4E-07	68
2,750	4.3E-07	4.5E-07	4.1	7.1E-08	1.2E-07	71
3,000	3.7E-07	3.9E-07	3.8	6.1E-08	1.1E-07	74
4,000	2.4E-07	2.5E-07	3.9	3.6E-08	6.7E-08	84
5,000	1.7E-07	1.8E-07	3.5	2.5E-08	4.7E-08	91
6,000	1.3E-07	1.4E-07	2.8	1.8E-08	3.6E-08	96
7,000	1.1E-07	1.1E-07	2.0	1.4E-08	2.8E-08	100
8,000	8.9E-08	9.0E-08	1.7	1.1E-08	2.3E-08	103
9,000	7.5E-08	7.6E-08	1.2	9.3E-09	1.9E-08	106
10,000	6.5E-08	6.5E-08	0.8	7.9E-09	1.6E-08	108
20,000	2.5E-08	2.5E-08	-1.2	2.9E-09	6.0E-09	109
30,000	1.4E-08	1.4E-08	-1.5	1.9E-09	3.4E-09	77
40,000	9.9E-09	9.8E-09	-0.8	1.4E-09	2.3E-09	59
50,000	7.4E-09	7.3E-09	-0.1	1.1E-09	1.7E-09	45
60,000	5.8E-09	5.8E-09	0.3	9.5E-10	1.3E-09	37
70,000	4.7E-09	4.8E-09	1.2	8.2E-10	1.1E-09	29
80,000	4.0E-09	4.1E-09	2.7	7.2E-10	8.9E-10	24

configuration is shown in Figure 3.1 and provides a good perspective on the wind directions involved. The larger differences in the results between RESRAD-OFFSITE and CAP88-PC at smaller distances (e.g., < 500 m) can be attributed to the area approximations made by CAP88-PC, since RESRAD-OFFSITE uses all relevant directions and frequencies in its calculations for each square meter point-to-point calculation. Agreement between the RESRAD-OFFSITE and ISCLT3 results was much better when the Pasquill-Gifford coefficients were used, as presented in Table 3.4, because both models account for wind direction across an undistorted source area.

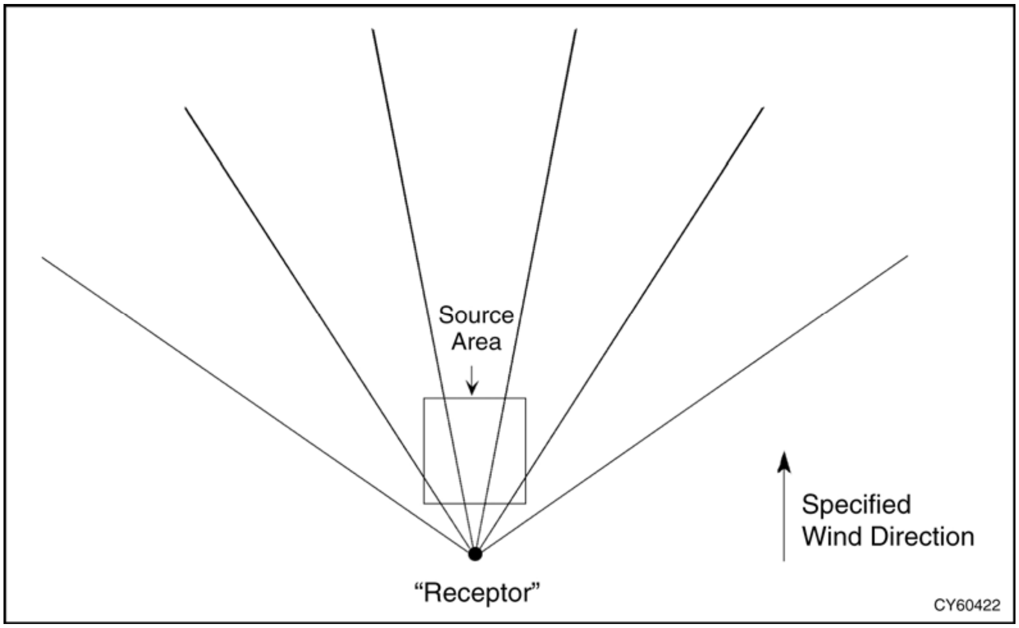

FIGURE 3.1 Relative Position of a Receptor 100 m from a 10,000-m^2 Source Area with the Wind Sector Grid Superimposed

At the 100-m receptor distance, large segments of the source area in the two sectors on either side of the specified sector affect the receptor, as shown in Figure 3.1. Figure 3.2 is a bar chart with the wind frequency for each direction in the sample meteorological joint frequency file used in the benchmark calculations. All comparisons to this point in the report have been based on calculations for a receptor to the north of the source area (wind blowing from the south). As Figure 3.2 shows, the wind blows from the south for about half the time that it blows from the south-southeast and for about twice the time that it blows from the south-southwest.

An extreme situation involves the receptor on the edge of a large source area for the 100-m receptor distance. Tables 3.5 and 3.6 present a comparison of RESRAD-OFFSITE with CAP88-PC and ISCLT3, respectively, using a 40,000-m^2 (200 m on a side) source area. In this case, the receptor is actually affected by wind blowing from half the sectors (wind from eight directions) on an annual basis. The receptor air concentrations at 100 m show a change in the difference between RESRAD-OFFSITE and CAP88-PC of -13% to 43% when comparing Tables 3.1 and 3.5. However, agreement between the RESRAD-OFFSITE results with those from ISCLT3 remains good, as seen in Tables 3.4 and 3.6, keeping within a 5% difference because both codes model the source area in a similar manner and account for wind direction.

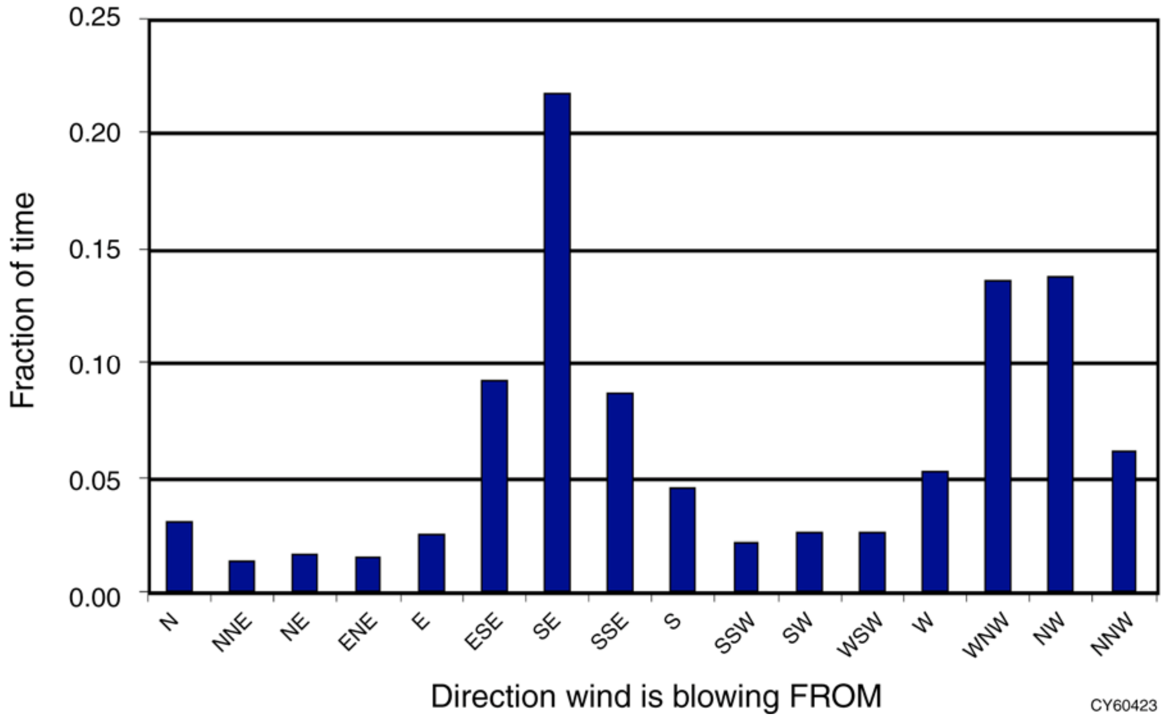

FIGURE 3.2 Summary of Sample Annual Wind Frequency Data Used in the Benchmark Calculations

TABLE 3.5 Simple Model Comparison of RESRAD-OFFSITE with CAP88-PC for a 40,000-m^2 Area Source

	Briggs Rural Coefficients		
	χ/Q (s/m^3)		
Distance (m)	RESRAD-OFFSITE	CAP88-PC	Percent Difference
100	2.4E-04	3.5E-04	43
200	6.5E-05	5.5E-05	-15
250	3.9E-05	3.6E-05	-7.0
500	1.0E-05	9.9E-06	-1.3
750	4.7E-06	4.6E-06	-1.3
1,000	2.8E-06	2.7E-06	-3.0
1,250	1.9E-06	1.9E-06	-0.8
1,500	1.4E-06	1.4E-06	0.5
1,750	1.1E-06	1.1E-06	1.1
2,000	8.5E-07	8.6E-07	1.2
2,250	7.1E-07	7.1E-07	0.9
2,500	6.0E-07	6.0E-07	0.5

TABLE 3.6 Simple Model Comparison of RESRAD-OFFSITE with ISCLT3 for a 40,000-m^2 Area Source

	Pasquill-Gifford Coefficients		
	χ/Q (s/m^3)		
Distance (m)	RESRAD-OFFSITE	ISCLT3	Percent Difference
100	2.2E-04	2.2E-04	2.0
200	4.9E-05	5.0E-05	1.8
250	2.9E-05	3.0E-05	-1.5
500	8.0E-06	7.9E-06	-1.3
750	3.8E-06	3.8E-06	-1.0
1,000	2.3E-06	2.3E-06	1.2
1,250	1.5E-06	1.6E-06	3.5
1,500	1.1E-06	1.2E-06	4.4
1,750	8.8E-07	9.2E-07	4.5
2,000	7.1E-07	7.4E-07	4.2
2,250	5.9E-07	6.1E-07	4.3
2,500	5.0E-07	5.2E-07	4.3

As shown in Figure 3.2, a greater neighboring sector wind differential would involve a receptor to the northwest of the source area (wind from the southeast). On an annual basis, winds blow in this direction over two times more often than toward adjoining sectors (toward the west-northwest or north-northwest). Tables 3.7 and 3.8 present an additional comparison of RESRAD-OFFSITE with CAP88-PC and ISCLT3, respectively, using a 40,000-m^2 area with a receptor to the northwest of the source area (wind blowing from the southeast). Again, a large difference, 38%, is noted between RESRAD-OFFSITE and CAP88-PC for the 100-m receptor with relatively good agreement, -4%, between RESRAD-OFFSITE and ISCLT3. However, there is a difference of up to 14% for a 500-m receptor in the latter case.

The average air concentrations calculated also depend on the frequency mix of wind speed and stability category for a specified direction. This latter consideration was not examined for this report when looking at the receptors toward the north and the northwest.

TABLE 3.7 Simple Model Comparison of RESRAD-OFFSITE with CAP88-PC for a 40,000-m^2 Area Source with the Receptor toward the Northwest

	Briggs Rural Coefficients		
	χ/Q (s/m^3)		
Distance (m)	RESRAD-OFFSITE	CAP88-PC	Percent Difference
100	2.6E-04	3.6E-04	-38
200	1.2E-04	1.1E-04	-7.0
250	8.5E-05	8.1E-05	-5.0
500	3.1E-05	3.2E-05	1.8
750	1.5E-05	1.5E-05	-1.2
1,000	9.0E-06	8.7E-06	-2.9
1,250	6.1E-06	6.0E-06	-0.7
1,500	4.4E-06	4.5E-06	0.6
1,750	3.4E-06	3.5E-06	1.1
2,000	2.8E-06	2.8E-06	1.2
2,250	2.3E-06	2.3E-06	1.0
2,500	1.9E-06	1.9E-06	0.5

TABLE 3.8 Simple Model Comparison of RESRAD-OFFSITE with ISCLT3 for a 40,000-m^2 Area Source with the Receptor toward the Northwest

	Pasquill-Gifford Coefficients		
	χ/Q (s/m^3)		
Distance (m)	RESRAD-OFFSITE	ISCLT3	Percent Difference
100	2.4E-04	2.3E-04	-4.0
200	9.5E-05	9.3E-05	-2.0
250	6.8E-05	6.6E-05	-2.0
500	2.7E-05	2.2E-05	-14
750	1.3E-05	1.1E-05	-12
1,000	7.8E-06	7.2E-06	-8
1,250	5.3E-06	5.0E-06	-5
1,500	3.9E-06	3.8E-06	-3.2
1,750	3.0E-06	2.9E-06	-2.3
2,000	2.4E-06	2.4E-06	-2.4
2,250	2.0E-06	2.0E-06	-2.0
2,500	1.7E-06	1.7E-06	-1.8

3.2.2 Dry Deposition

RESRAD-OFFSITE and CAP88-PC contain models for the depletion of the radioactive plume through dry deposition that are similar and that require the same type of input, primarily the deposition velocity of the radioactive material. The two codes were compared for plume depletion through dry deposition. A comparison of results with ISCLT3 was not considered, because ISCLT3 uses a different approach with significantly different input data requirements.

As mentioned in Section 3.2.1.1, CAP88-PC has fixed deposition velocities for three categories of radionuclides: gases (0.0 m/s), iodine (0.035 m/s), and particulates (0.0018 m/s). Iodine-129 (I-129) was selected as the radionuclide released for the dry deposition comparison because of its larger deposition velocity, which would highlight differences between the codes, and because of its relatively longer radioactive decay half-life, which would not affect the results. Good agreement between the codes was obtained for receptor distances of less than 10,000 m, as presented in the left half of Table 3.9. The differences in air concentration observed are similar to those obtained without deposition, as shown in Table 3.1.

At distances of 10,000 m and greater, the CAP88-PC results indicate an increasing amount of depletion with distances up to 80,000 m, where the RESRAD-OFFSITE air concentration is about 3 times larger than that from CAP88-PC. Increasing the lid height for the calculations only widened the gap at the farther receptor distances. CAP88-PC uses a set of stored depletion fractions for a given set release height, deposition velocity, and wind speed. It then converts the appropriate stored depletion fraction to the value for the actual deposition velocity and wind speed. It may be possible that this storage and conversion scheme may account for some of the observed differences between the two codes in air concentration at the farther receptor distances, similar to the effect observed when the modified rural Briggs vertical dispersion coefficients are used, as discussed in Section 3.2.1.1.

3.2.3 Wet Deposition

Comparison of the RESRAD-OFFSITE and CAP88-PC plume depletion results due to wet deposition were investigated in conjunction with dry deposition, because dry deposition cannot be excluded in CAP88-PC. As in the dry deposition case, benchmark results from the ISCLT3 wet deposition model were not investigated because ISCLT3 requires different inputs than those used for the other two codes. An annual precipitation rate of 1 m/yr was used.

TABLE 3.9 Simple Model Comparison of RESRAD-OFFSITE with CAP88-PC with Plume Depletion

	Dry Deposition Only			Dry and Wet Deposition		
	χ/Q (s/m^3)			χ/Q (s/m^3)		
Distance (m)	RESRAD-OFFSITE	CAP88-PC	Percent Difference	RESRAD-OFFSITE	CAP88-PC	Percent Difference
100	1.1E-04	9.2E-05	-15	1.1E-04	9.2E-05	-15
200	1.4E-05	1.5E-05	4.6	1.4E-05	1.5E-05	4.9
250	7.7E-06	8.2E-06	7.4	7.6E-06	8.2E-06	7.9
500	1.3E-06	1.4E-06	3.5	1.3E-06	1.4E-06	4.5
750	4.9E-07	5.1E-07	3.8	4.8E-07	5.1E-07	5.4
1,000	2.6E-07	2.6E-07	-1.6	2.5E-07	2.6E-07	0.4
1,250	1.6E-07	1.6E-07	0.7	1.5E-07	1.6E-07	3.4
1,500	1.0E-07	1.1E-07	2.0	1.0E-07	1.1E-07	5.4
1,750	7.3E-08	7.6E-08	3.6	7.0E-08	7.6E-08	7.7
2,000	5.6E-08	5.7E-08	0.7	5.3E-08	5.6E-08	5.1
2,250	4.4E-08	4.4E-08	1.6	4.1E-08	4.4E-08	6.5
2,500	3.5E-08	3.6E-08	2.5	3.3E-08	3.5E-08	8.1
2,750	2.8E-08	2.9E-08	2.8	2.6E-08	2.9E-08	9.0
3,000	2.3E-08	2.4E-08	3.0	2.2E-08	2.4E-08	9.7
4,000	1.3E-08	1.3E-08	2.5	1.1E-08	1.3E-08	12
5,000	7.9E-09	8.2E-09	3.8	6.9E-09	8.0E-09	15
6,000	5.4E-09	5.5E-09	2.7	4.6E-09	5.4E-09	16
7,000	3.8E-09	3.8E-09	-0.3	3.2E-09	3.7E-09	15
8,000	2.9E-09	2.9E-09	-1.1	2.4E-09	2.8E-09	17
9,000	2.3E-09	2.2E-09	-1.5	1.8E-09	2.2E-09	19
10,000	1.8E-09	1.8E-09	-4.4	1.4E-09	1.7E-09	18
20,000	4.4E-10	3.9E-10	-11	2.6E-10	3.6E-10	37
30,000	2.0E-10	1.4E-10	-29	9.4E-11	1.2E-10	31
40,000	1.2E-10	7.5E-11	-38	4.5E-11	6.2E-11	38
50,000	7.9E-11	4.1E-11	-48	2.2E-11	3.2E-11	42
60,000	5.4E-11	2.2E-11	-59	1.2E-11	1.6E-11	33
70,000	3.9E-11	1.5E-11	-62	6.7E-12	1.0E-11	50
80,000	3.0E-11	9.9E-12	-67	4.0E-12	6.5E-12	62

The right-hand side of Table 3.9 presents the results when plume depletion from both dry and wet deposition mechanisms is considered. Aside from the 100-m receptor, RESRAD-OFFSITE and CAP88-PC results remain within 10% of each other out to a receptor distance of approximately 3,000 m. Thereafter, the CAP88-PC results become increasingly larger than the RESRAD-OFFSITE results up to 80,000 m. Here the CAP88-PC results are about 1.5 times larger than the RESRAD-OFFSITE results. (They were one-third of the RESRAD-OFFSITE results when only dry deposition was considered.)

For the wet deposition case, even though the two codes use similar inputs, differences are expected because CAP88-PC uses an approximation for averaging the exponential terms with those for radioactive decay. The approximation involves only three wind speeds rather than the full set of six wind speeds. For further details, see Section 8.1.5 in Parks (1992).

3.2.4 Plume Rise

Thermal buoyancy from solar heating could result in plume rise from a source area. All three codes use plume rise formulas developed by Briggs (1969); however, the ISCLT3 formulation requires the use of a velocity term (for stack emissions) that cannot be circumvented. Thus the following comparison is between only RESRAD-OFFSITE and CAP88-PC. A heat release term of 90 cal/m^2-s was used. This value is consistent with heat fluxes from ground surfaces due to solar heating from direct sunlight during the summer months in the western United States on a clear day (NREL 2004).

The RESRAD-OFFSITE and CAP88-PC plume rise results agree (Table 3.10) to within about 15% or less for receptor distances of less than 500 m, similar to the baseline results without plume rise (Table 3.1). Inclusion of plume rise resulted in a relative increase of the CAP88-PC receptor air concentrations with respect to the corresponding RESRAD-OFFSITE air concentrations in the near field. This relative increase is expected because RESRAD-OFFSITE incorporates a buoyancy-induced dispersion adjustment to the vertical dispersion coefficient, which slightly increases the value of the coefficient, thus decreasing the air concentration result.

TABLE 3.10 Simple Model Comparison of RESRAD-OFFSITE with CAP88-PC with Plume Rise

	χ/Q (s/m^3)		
Distance (m)	RESRAD-OFFSITE	CAP88-PC	Percent Difference
100	6.1E-05	5.5E-05	-9.2
200	2.4E-05	2.8E-05	15
250	2.0E-05	2.2E-05	14
500	8.0E-06	8.5E-06	7.0
750	4.2E-06	4.3E-06	3.3
1,000	2.6E-06	2.6E-06	0.0
1,250	1.8E-06	1.8E-06	1.2
1,500	1.3E-06	1.4E-06	2.0
1,750	1.0E-06	1.1E-06	2.2
2,000	8.3E-07	8.5E-07	2.1
2,250	6.9E-07	7.0E-07	1.7
2,500	5.8E-07	5.9E-07	1.2

4 COMPARISON OF THE PREDICTIONS OF THE GROUNDWATER TRANSPORT MODEL WITH PREDICTIONS OF PEER MODELS

As radionuclides are transported through an aquifer or a partially saturated (or unsaturated) soil layer, some of the atoms will be transformed into their progeny continuously throughout the transport zone. Different radionuclides will travel at different speeds, depending on their interaction with the solid phase of the soil layer. In RESRAD-OFFSITE, this interaction is characterized by the distribution coefficient of the nuclide between the aqueous and solid phase of the soil. The groundwater transport algorithms in RESRAD-OFFSITE account for the effects of longitudinal and transverse dispersion when modeling the transport of atoms that enter and leave a transport zone as the same radionuclide. RESRAD-OFFSITE has algorithms that will consider either the longitudinal dispersion or the different rates of transport of the parent and progeny nuclides in order to model the transport of progeny produced in transit. Both algorithms account for transverse dispersion. If one or the other of these two processes is dominant, the choice of the algorithm is straightforward. When both processes are of comparable importance, RESRAD-OFFSITE offers the option of subdividing the transport zone into smaller subzones in order to better model the transport of the progeny produced in transit. When the transport zone is broken up into many smaller layers, the length of the region in which both processes must be modeled is reduced, and the significant transport processes will be considered over most of the transport path. The scheme was tested in RESRAD-OFFSITE during the multimedia model comparison study described in Gnanapragasam et al. (2000). The scheme was not fully automated at that time, and the number of subzones was limited. The subdivision scheme has been fully implemented in the current version of the code. While the computational code does not limit the number of subdivisions, it is prudent to place a limit on them to reduce the possibility of the build up of numerical errors. The interface, therefore, limits the number of subdivisions to 1024. Figures 4.1 through 4.5 show the predictions of the current RESRAD-OFFSITE code for the scenario described in Gnanapragasam et al. (2000). The first three figures correspond to Figures 4, 6, and 7 in Gnanapragasam et al. (2000) and show good agreement with those of the original study.

Care was exercised when subdividing the zones to ensure that numerical errors are not magnified as the computations for the successive subzones are performed. This was checked by comparing the predictions for the parent nuclide for the cases with and without subdivisions, as in Figure 4.1. Differences occur between the two predictions for the parent only because the time points were too far apart to capture the temporal variation in the flux across each subzone. In the case of Figure 4.1, the two curves coincide over most of the time horizon, but there is a reduction of about 1% near the peak in the predictions after subdivision. If an unacceptable deviation had been observed, the situation would have been reanalyzed by using a finer time interval. A time interval of 7 and 13/16 years was used to generate Figures 4.1 through 4.5.

An early prototype version of RESRAD-OFFSITE was used in the international model intercomparison study conducted by the Biospheric Model Validation Study II Working Group on Uranium Mill Tailings (BIOMOVS II 1996). The predictions of well water concentrations made by the prototype version of RESRAD-OFFSITE compared well with the predictions of the other participating codes. This study also helped check the predictions of the offsite soil accumulation submodel. Again, the predictions of the prototype version of RESRAD-OFFSITE compared well with those of the other participating codes.

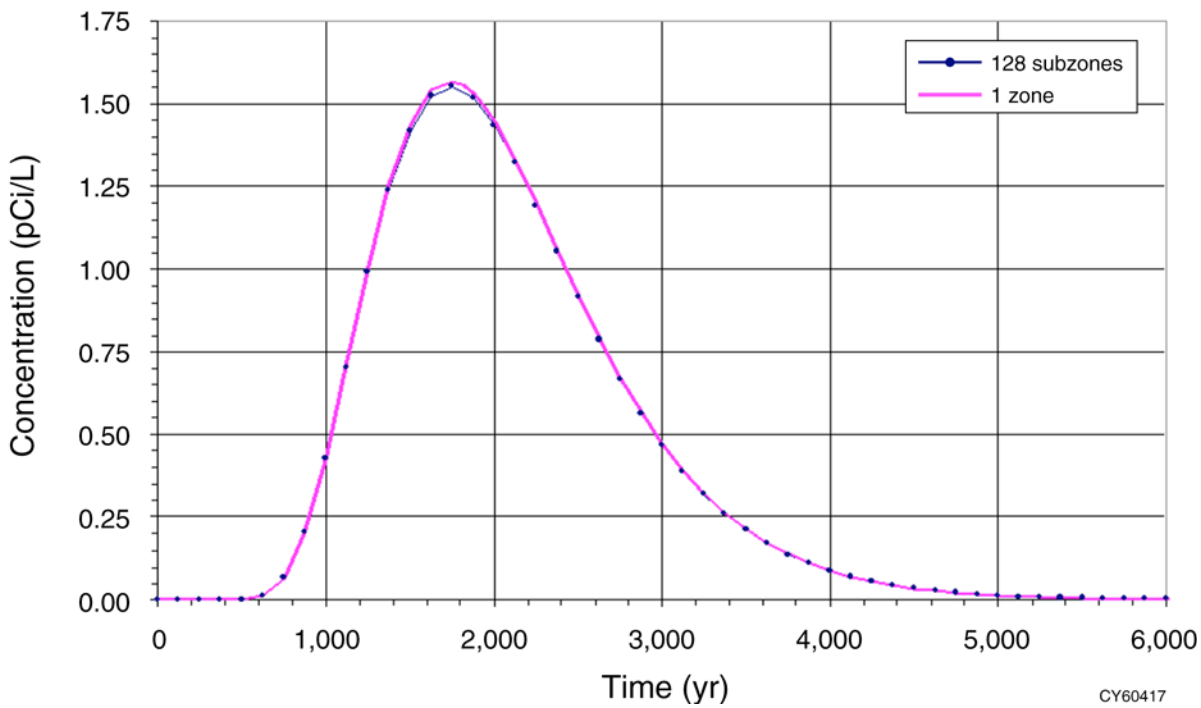

FIGURE 4.1 Temporal Variation of the U-234 Concentration in the Aquifer, at the Plume Centerline, and 10.4 km from the Center of the Source

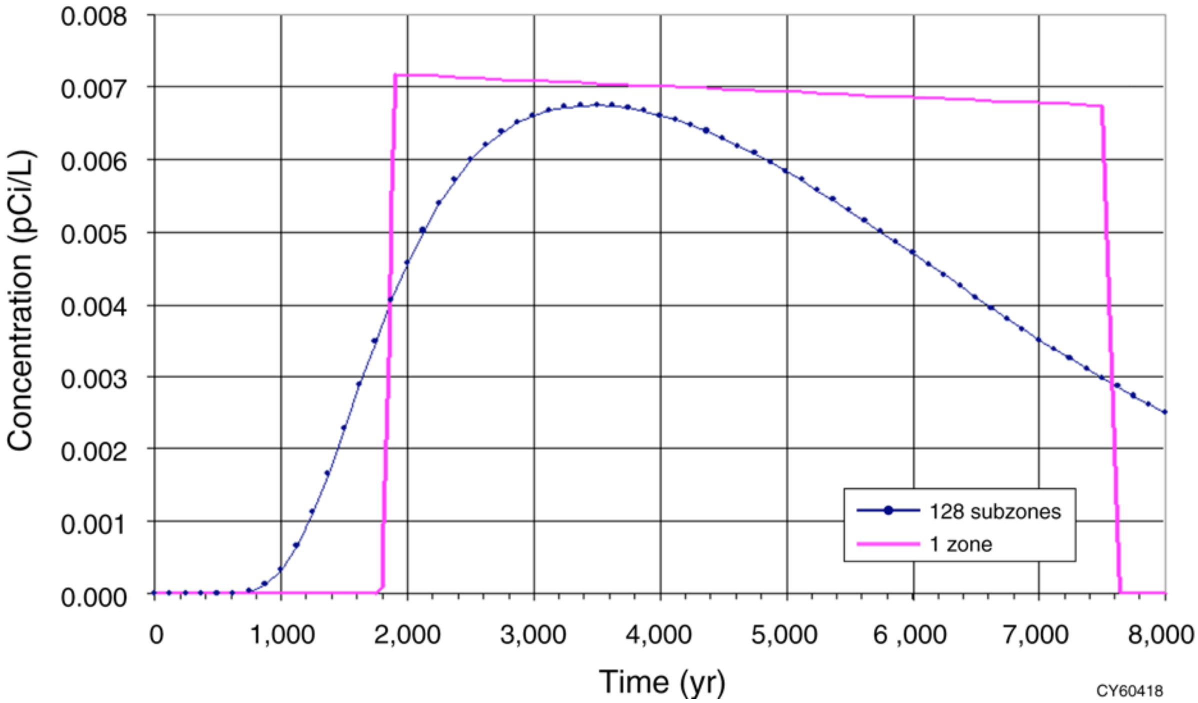

FIGURE 4.2 Temporal Variation of the Th-230 Concentration in the Aquifer, at the Plume Centerline, and 10.4 km from the Center of the Source

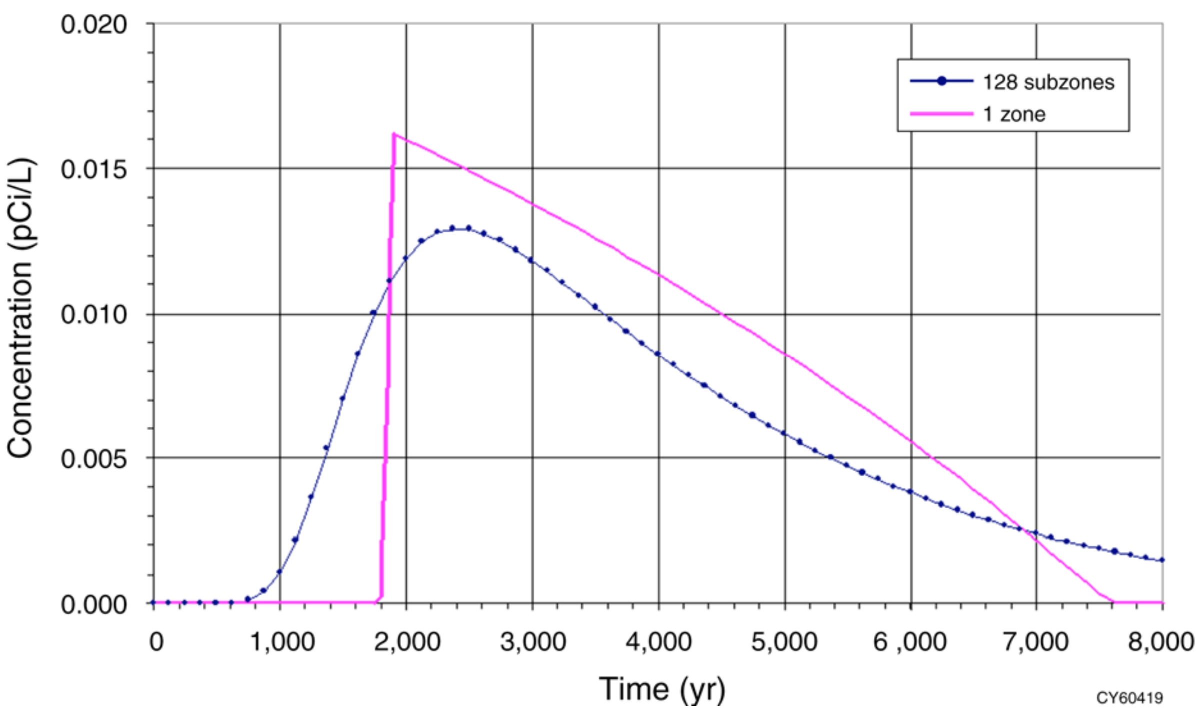

FIGURE 4.3 Temporal Variation of the Ra-226 Concentration in the Aquifer, at the Plume Centerline, and 10.4 km from the Center of the Source

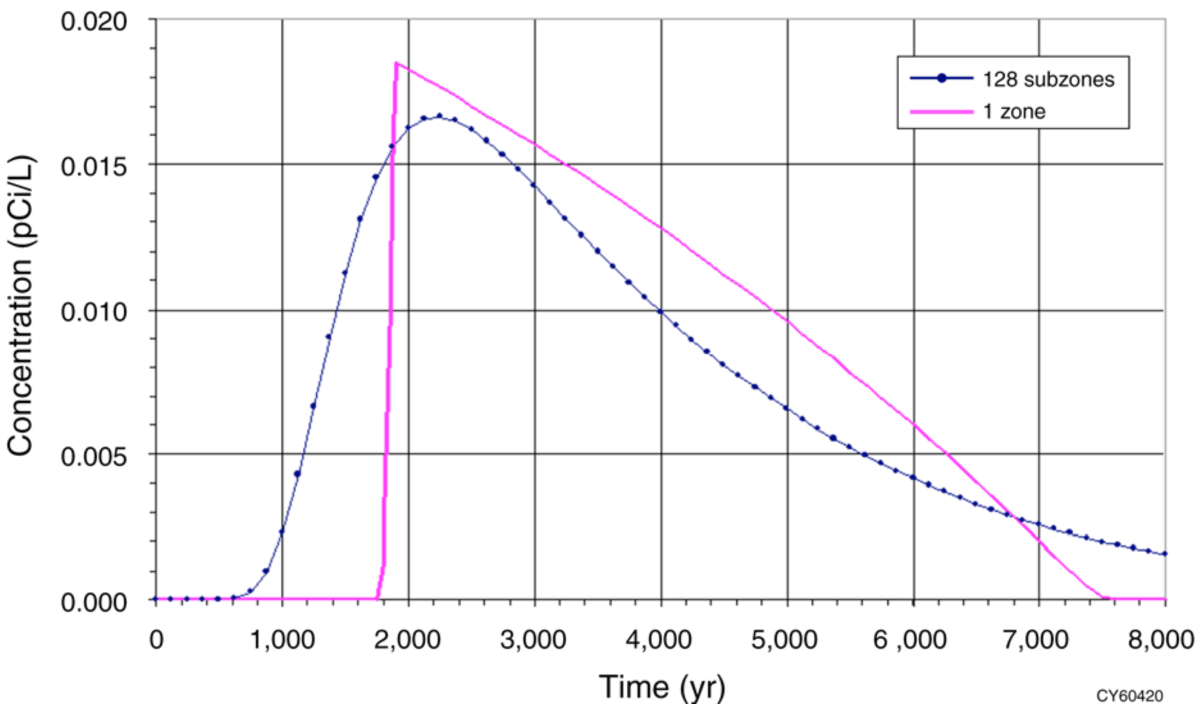

FIGURE 4.4 Temporal Variation of the Pb-210 Concentration in the Aquifer, at the Plume Centerline, and 10.4 km from the Center of the Source

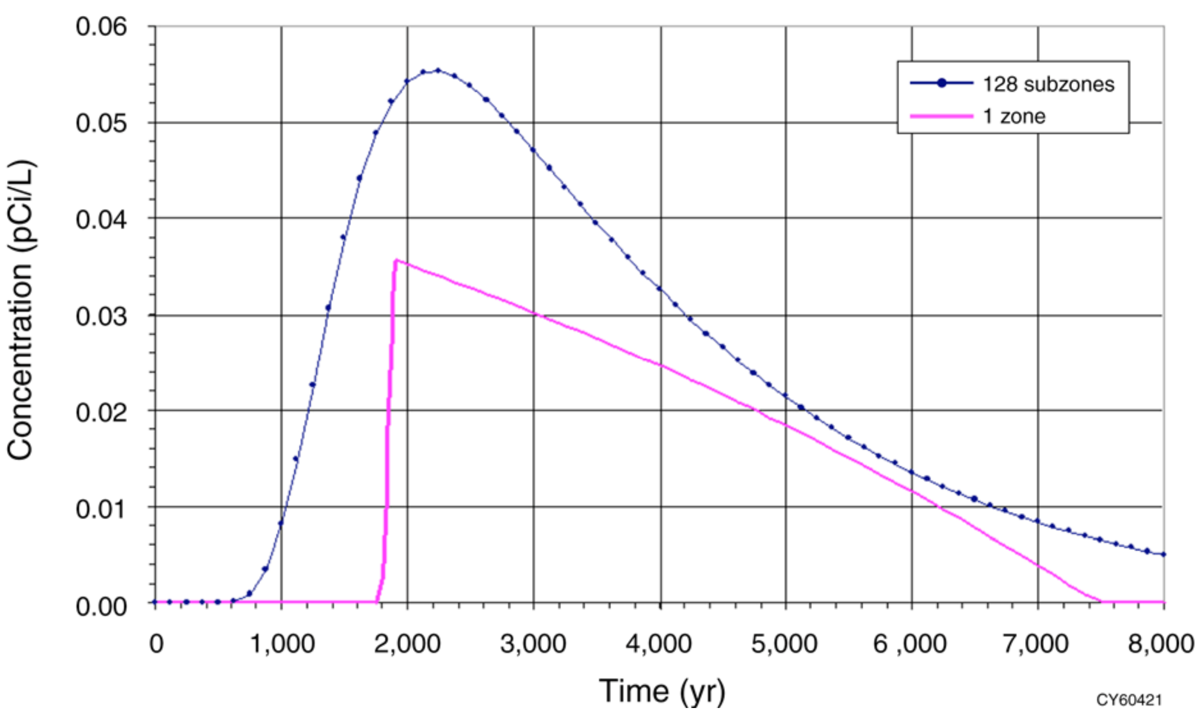

FIGURE 4.5 Temporal Variation of the Po-210 Concentration in the Aquifer, at the Plume Centerline, and 10.4 km from the Center of the Source

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APPENDIX A:

SOIL/WATER DISTRIBUTION COEFFICIENTS AND FOOD TRANSFER FACTORS

TABLE A-1 Soil/Water Distribution Coefficients (Kd's) and Food Transfer Factors[a]

		Transfer Factor			
Element	Kd (cm^3/g)	Plant	Meat (pCi/kg)/(pCi/d)	Milk (pCi/L)/(pCi/d)	Fish (L/kg)
Ac	825	1.0E-03	2.0E-05	2.0E-06	15
C	11	7.0E-01	3.0E-02	1.2E-02	49,000
Co	235	8.0E-02	3.0E-02	2.0E-03	300
Cs	446	4.0E-02	5.0E-02	1.0E-02	2,000
H	0.06	4.8	1.2E-02	1.0E-02	1
K	5.5	3.0E-01	2.0E-02	7.0E-03	1,000
Np	17	2.0E-02	1.0E-03	1.0E-05	30
Pa	380	1.0E-02	5.0E-06	5.0E-06	10
Pb	2,392	4.0E-03	8.0E-04	3.0E-04	300
Po	181	1.0E-03	5.0E-03	4.0E-04	100
Pu	953	1.0E-03	1.0E-04	1.0E-06	30
Ra	3,533	4.0E-02	1.0E-03	1.0E-03	50
Sr	32	3.0E-01	1.0E-02	2.0E-03	60
Th	5,884	1.0E-03	1.0E-04	5.0E-06	100
U	126	2.0E-03	8.0E-04	4.0E-04	10

[a] Median (geometric mean) of distributions.

APPENDIX B:

OTHER RESRAD (ONSITE) INPUT PARAMETERS

TABLE B-1 Other RESRAD (Onsite) Input Parameters

Input Parameter	Value	Comment
Title		
Title	Benchmark between RESRAD and RESRAD-OFFSITE	
Dose factor library	Benchmark	Created by modifying the FGR 13 morbidity database (Eckerman and Ryman 1993) with the soil/water distribution coefficients and transfer factors listed in Appendix A.
Cut-off half-life (180 or 30 days)	30 days	
Graphics Parameters		
Number of points	1,024	
Linear spacing/log spacing	Linear spacing	
Time integration parameters		
Maximum number of points for dose	5	Selected to be close to the number used by RESRAD-OFFSITE.
Maximum number of points for risk	1	Radiation doses are the targets for comparison.
User Preferences		
Use line draw character?	Yes	
Find peak pathway dose?	Yes	
Save all files after each run?	Yes	
Time-integrated probabilistic risk?	No	
Calculation times (yr)	1, 3, 10, 30, 100, 300, 500, 750, 1,023	
Basic radiation dose limit (mrem/yr)	25	
Source		
Nuclide concentration (pCi/g)	1 for C-14, Co-60, Cs-137, H-3, K-40, Np-237, Pu-239, Ra-226, Ra-228, Sr-90, Th-230, U-234, U-238	
Contaminated Zone Parameters		
Area of contaminated zone (m^2)	404,700	100 acres.
Thickness of contaminated zone (m)	0.15	
Length parallel to aquifer flow (m)	636	Square root of the area.

TABLE B-1 (Cont.)

Input Parameter	Value	Comment
Cover and Contaminated Zone Hydrological Data		
Cover depth (m)	0	No cover material.
Density of cover material (g/cm^3)	Not used	Not required when cover depth equals zero.
Cover erosion rate (m/yr)	Not used	Not required when cover depth equals zero.
Density of contaminated zone (g/cm^3)	1.52	Mean of distribution.
Contaminated zone erosion rate (m/yr)	0	
Contaminated zone total porosity	0.425	Mean of distribution.
Contaminated zone field capacity	0.2	RESRAD default.
Contaminated zone hydraulic conductivity (m/yr)	9.974	Median (geometric mean) of distribution.
Contaminated zone b parameter	2.895	Median (geometric mean) of distribution.
Humidity in air (g/m^3)	7.243	Median (geometric mean) of distribution.
Evapotranspiration coefficient	0.625	Mean of distribution.
Wind speed (m/s)	4.242	Median (geometric mean) of distribution.
Precipitation (m/yr)	1	RESRAD default.
Irrigation (m/yr)	0.2	RESRAD default.
Irrigation mode (overhead/ditch)	Overhead	RESRAD default.
Runoff coefficient	0.45	Mean of distribution.
Watershed area for nearby stream or pond (m^2)	1,000,000	RESRAD default.
Accuracy for water/soil computation	0.001	RESRAD default.
Saturated Zone Hydrological Data		
Density (g/cm^3)	1.52	Mean of distribution.
Effective porosity	0.355	Mean of distribution.
Total porosity	0.425	Mean of distribution.
Field capacity	0.2	RESRAD default.
Hydraulic conductivity (m/yr)	9.974	Median (geometric mean) of distribution.
Soil b parameter	Not used	Not required when the water table drop rate was set to 0.
Hydraulic gradient	0.00604	Median (geometric mean) of distribution.
Water table drop rate (m/yr)	0	
Well pump intake depth (m below water table)	15.33	Mean of distribution.
Model for water transportation (nondispersion/mass-balance)	Nondispersion	RESRAD default.
Well pumping rate (m^3/yr)	250	RESRAD default.
Unsaturated Zone Parameters		
Number of unsaturated zone strata	1	RESRAD default.
Thickness (m)	9.895	Median (geometric mean) of distribution.
Density (g/cm^3)	1.52	Mean of distribution.
Effective porosity	0.355	Mean of distribution.

TABLE B-1 (Cont.)

Input Parameter	Value	Comment
Unsaturated Zone Parameters (Cont.)		
Total porosity	0.425	Mean of distribution.
Field capacity	0.2	RESRAD default.
Hydraulic conductivity (m/yr)	9.974	Median (geometric mean) of distribution.
Soil b parameter	2.895	Median (geometric mean) of distribution.
Occupancy, Inhalation, and External Gamma Data		
Inhalation rate (m^3/yr)	8,627	Mean of distribution.
Mass loading for inhalation (g/m^3)	2.45E-05	Mean of distribution.
Exposure duration (yr)	1	
Indoor dust filtration factor	0.55	Mean of distribution.
External gamma shielding factor	0.27	Median (geometric mean) of distribution.
Indoor time fraction	0.651	Mean of distribution.
Outdoor time fraction	0.25	RESRAD default.
Shape of contaminated zone (circular/noncircular)	Circular	RESRAD default.
Ingestion Pathway Dietary Data		
Fruit, vegetable, and grain consumption (kg/yr)	210.33	Mean of distribution.
Leafy vegetable consumption (kg/yr)	22.667	Derived from EPA (1997).
Milk (L/yr)	120.67	Mean of distribution.
Meat and poultry (kg/yr)	222.1	Derived from EPA (1997).
Fish (kg/yr)	155.6	Derived from EPA (1997).
Other sea food (kg/yr)	0	
Soil ingestion (g/yr)	18.27	Mean of distribution.
Drinking water intake (L/yr)	409.5	Median (geometric mean) of distribution.
Contaminated Fractions		
Drinking water	0.9	Receptor spends some time offsite.
Household water	1	RESRAD default.
Livestock water	1	RESRAD default.
Irrigation water	1	RESRAD default.
Aquatic food	0.463	Mean of distribution.
Plant food	–1	Calculated by RESRAD from area factor, 0.5.
Meat	–1	Calculated by RESRAD from area factor, 1.
Milk	–1	Calculated by RESRAD from area factor, 1.
Ingestion Pathway, Nondietary Data		
Livestock fodder intake for meat (kg/d)	68	RESRAD default.
Livestock water intake for meat (L/d)	50	RESRAD default.
Livestock fodder intake for milk (kg/d)	55	RESRAD default.
Livestock water intake for milk (L/d)	160	RESRAD default.
Livestock intake of soil (kg/d)	0.5	RESRAD default.

TABLE B-1 (Cont.)

Input Parameter	Value	Comment
Ingestion Pathway, Nondietary Data (Cont.)		
Mass loading for foliar deposition (g/m^3)	0.0001	RESRAD default.
Depth of soil mixing layer (m)	0.25	Mean of distribution.
Depth of roots (m)	2.15	Mean of distribution.
Groundwater Fractional Usage		
Drinking water	1	RESRAD default.
Household water	1	RESRAD default.
Livestock water	0.5	To consider dose from surface water as well.
Irrigation water	0.5	To consider dose from surface water as well.
Nonleafy Plant Factors		
Wet weight crop yield (kg/m^2)	1.751	Median (geometric mean) of distribution.
Length of growing season (yr)	0.17	RESRAD default.
Translocation factor	0.1	RESRAD default.
Weathering removal constant (1/yr)	35.7	Mean of distribution.
Wet foliar interception fraction	0.25	RESRAD default.
Dry foliar interception fraction	0.25	RESRAD default.
Leafy Plant Factors		
Wet weight crop yield (kg/m^2)	1.5	RESRAD default.
Length of growing season (yr)	0.25	RESRAD default.
Translocation factor	1	RESRAD default.
Wet foliar interception fraction	0.56	Mean of distribution.
Dry foliar interception fraction	0.25	RESRAD default.
Fodder plant factors		
Wet weight crop yield (kg/m^2)	1.1	RESRAD default.
Length of growing season (yr)	0.08	RESRAD default.
Translocation factor	1	RESRAD default.
Wet foliar interception fraction	0.25	RESRAD default.
Dry foliar interception fraction	0.25	RESRAD default.
Radon Data		
Cover total porosity	Not used	No cover.
Cover volumetric water content	Not used	No cover.
Cover radon diffusion coefficient (m^2/s)	Not used	No cover.
Building foundation thickness (m)	0.15	RESRAD default.
Building foundation density (g/cm^3)	2.4	RESRAD default.
Building foundation total porosity	0.1	RESRAD default.
Building foundation volumetric water content	0.03	RESRAD default.
Building foundation radon diffusion coefficient (m^2/s)	3×10^{-7}	RESRAD default.
Contaminated zone radon diffusion coefficient (m^2/s)	2×10^{-6}	RESRAD default.
Radon vertical dimension of mixing (m)	2	RESRAD default.
Building air exchange rate (1/h)	0.5	RESRAD default.
Building room height (m)	2.5	RESRAD default.
Building indoor area factor	0	Value calculated by the code.

TABLE B-1 (Cont.)

Input Parameter	Value	Comment
Radon Data (Cont.)		
Foundation depth below ground surface (m)	–1	Value calculated by the code to get the maximum flux rate.
Rn-222 emanation coefficient	0.25	RESRAD default.
Rn-220 emanation coefficient	0.15	RESRAD default.
Storage Times before Use Data		
Fruits, nonleafy vegetables, and grain (d)	14	RESRAD default.
Leafy vegetables (d)	1	RESRAD default.
Milk (d)	1	RESRAD default.
Meat (d)	20	RESRAD default.
Fish (d)	7	RESRAD default.
Crustacea and mollusks (d)	7	RESRAD default.
Well water (d)	1	RESRAD default.
Surface water (d)	1	RESRAD default.
Livestock fodder (d)	45	RESRAD default.
Carbon-14 Data		
C-12 concentration in local water (g/cm^3)	0.00002	RESRAD default.
C-12 concentration in contaminated soil (g/g)	0.03	RESRAD default.
Fraction of vegetation carbon adsorbed from soil	0.02	RESRAD default.
Fraction of vegetation carbon adsorbed from air	0.98	RESRAD default.
Thickness of evasion layer of C-14 in soil (m)	0.367	Mean of distribution.
C-14 evasion flux rate from soil (1/s)	0.0000007	RESRAD default.
C-12 evasion flux rate from soil (1/s)	1.00E-10	RESRAD default.
Grain fraction in livestock feed (balance is hay/fodder) for beef cattle	0.8	RESRAD default.
Grain fraction in livestock feed (balance is hay/fodder) for milk cow	0.2	RESRAD default.
Dose conversion factor correction factor for gaseous forms of C-14	88.94	RESRAD default.

Sources:

Eckerman, K.F., and J.C. Ryman, 1993, *External Exposure to Radionuclides in Air, Water, and Soil: Exposure to Dose Coefficients for General Application, Based on the 1987 Federal Radiation Protection Guidance*, EPA 402-R-93-081, Federal Guidance Report No. 12, prepared by Oak Ridge National Laboratory, Oak Ridge, Tenn., for U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

EPA (U.S. Environmental Protection Agency), 1997, *Exposure Factor Handbook*, EPA/600/P-95/002Fa, Office of Research and Development, National Center for Environmental Assessment, Washington, D.C.

APPENDIX C:

RESRAD-OFFSITE INPUT PARAMETERS

TABLE C-1 RESRAD-OFFSITE Input Parameters

Input Parameter	Value	Comment
Title		
Title	Benchmark between RESRAD and RESRAD-OFFSITE	
Intermediate time points	4,096	To have four time points for each year.
Linear spacing/log spacing	Linear	
Minimum time increment (yr)		Not applicable for linear spacing of time points
Dose and slope factor library	Benchmark	Created by modifying the FGR 13 morbidity database (Eckerman and Ryman 1993) with the soil/water transfer coefficients and transfer factors listed in Appendix A.
Cut-off half life (180 days, 30 days, 6 hours)	30 days	
Display update of computation progress	1 s	RESRAD-OFFSITE default.
Use line draw character?	Yes	
Preliminary Input		
Basic radiation dose limit (mrem/yr)	25	
Exposure duration (yr)	1	To make the time horizon extend to 1,024 years.
Number of unsaturated zones	1	
Radiological units	pCi for activity, mrem for dose	
Site Layout		
Bearing of X axis (degrees)	90	Standard convention.
X dimension of primary contamination (m)	636	Square root of the area.
Y dimension of primary contamination (m)	636	Square root of the area.
Fruit, grain and nonleafy vegetable plot		RESRAD-OFFSITE place holder values; places the receptor area within the primary contamination for this onsite scenario.
Smaller X coordinate (m)	34.375	
Larger X coordinate (m)	65.625	
Smaller Y coordinate (m)	234	
Larger Y coordinate (m)	266	
Leafy vegetable plot		RESRAD-OFFSITE place holder values; places the receptor area within the primary contamination for this onsite scenario.
Smaller X coordinate (m)	34.375	
Larger X coordinate (m)	65.625	
Smaller Y coordinate (m)	268	
Larger Y coordinate (m)	300	
Pasture and silage growing area		RESRAD-OFFSITE place holder values; places the receptor area within the primary contamination for this onsite scenario.
Smaller X coordinate (m)	0	
Larger X coordinate (m)	100	
Smaller Y coordinate (m)	450	
Larger Y coordinate (m)	550	

TABLE C-1 (Cont.)

Input Parameter	Value	Comment
Site Layout (Cont.)		
Livestock feed grain fields		RESRAD-OFFSITE place holder values; places the receptor area within the primary contamination for this onsite scenario.
Smaller X coordinate (m)	0	
Larger X coordinate (m)	100	
Smaller Y coordinate (m)	300	
Larger Y coordinate (m)	400	
Offsite dwelling site		RESRAD-OFFSITE place holder values. No offsite dwelling in this scenario.
Smaller X coordinate (m)	34.375	
Larger X coordinate (m)	65.625	
Smaller Y coordinate (m)	134	
Larger Y coordinate (m)	166	
Surface water body		Places the surface water body at the edge of the primary contamination for this onsite scenario.
Smaller X coordinate (m)	168	
Larger X coordinate (m)	468	
Smaller Y coordinate (m)	486	
Larger Y coordinate (m)	786	
Source		
Nuclide concentration (pCi/g)	1 for C-14, Co-60, Cs-137, H-3, K-40, Np-237, Pu-239, Ra-226, Ra-228, Sr-90, Th-230, U-234, U-238	
Source Release and Atmospheric Transport		
Release to groundwater, leach rate (1/yr)	0	
Deposition velocity (m/s)	0.001	Default, same as used in RESRAD, which is hardwired in the code.
Distribution Coefficients (cm^3/g)		
Contaminated zone	Values for all areas are the same. See Appendix A.	
Unsaturated zone		
Saturated zone		
Sediment in surface water body		
Fruit, grain, nonleafy fields		
Leafy vegetable fields		
Pasture, silage growing areas		
Livestock feed grain fields		
Transfer Factors		
Soil-to-plant transfer factor		
Fruit, grain, nonleafy vegetables	Values for different plants are the same. See Appendix A.	
Leafy vegetables		
Pasture, silage		
Livestock feed grain		
Intake-to-animal-product transfer factor		
Meat [(pCi/kg)/(pCi/d)]	See Appendix A.	
Milk [(pCi/L)/(pCi/d)]	See Appendix A.	

TABLE C-1 (Cont.)

Input Parameter	Value	Comment
Transfer Factors (cont.)		
Water-to-aquatic-food transfer factor		
Fish [(pCi/kg)/(pCi/L)]	See Appendix A.	
Crustacea [(pCi/kg)/(pCi/L)]	Default values.	
Reporting Times		
Times at which output is reported (yr)	1, 3, 10, 30, 100, 300, 500, 750, 1,023	The last time period, 1,023, would make the time horizon extend to 1,024 years.
Storage times		
Surface water (d)	1	RESRAD default.
Well water (d)	1	RESRAD default.
Fruits, grain, and nonleafy vegetables (d)	14	RESRAD default.
Leafy vegetables (d)	1	RESRAD default.
Livestock feed — pasture or silage (d)	45	RESRAD default.
Livestock feed — grain (d)	45	RESRAD default.
Meat (d)	20	RESRAD default.
Milk (d)	1	RESRAD default.
Fish (d)	7	RESRAD default.
Crustacea and mollusks (d)	7	RESRAD default.
Site Properties		
Precipitation (m/yr)	1	RESRAD default.
Wind speed (m/s)	4.242	Median (geometric mean) of distribution.
Primary Contamination		
Area of primary contamination (m^2)	Not a direct input	Computed using the X and Y dimensions in site layout.
Length of contamination parallel to aquifer flow (m)	636	Square root of the area.
Depth of soil mixing layer (m)	0.25	Mean of distribution.
Deposition velocity of dust (m/s)	0.001	RESRAD-OFFSITE default.
Irrigation applied per year (m/yr)	0.2	RESRAD default.
Evapotranspiration coefficient	0.625	Mean of distribution.
Runoff coefficient	0.45	Mean of distribution.
Rainfall erosion index	200	RESRAD-OFFSITE default.
Slope-length-steepness factor	1	RESRAD-OFFSITE default.
Cropping management factor	0.11	RESRAD-OFFSITE default.
Conservation practice factor	1	RESRAD-OFFSITE default.
Thickness of contaminated zone (m)	0.15	Value selected for scenario.
Total porosity of contaminated zone	0.425	Mean of distribution.
Erosion rate of contaminated zone (m/yr)	0	Calculated by RESRAD-OFFSITE.
Dry bulk density of contaminated zone (g/cm^3)	1.52	Mean of distribution.
Soil erodibility factor of contaminated zone (tons/acre)	0	To get an erosion rate of 0.
Field capacity of contaminated zone	0.2	RESRAD default.
Soil b parameter of contaminated zone	2.895	Median (geometric mean) of distribution.
Hydraulic conductivity of contaminated zone (m/yr)	9.974	Median (geometric mean) of distribution.

TABLE C-1 (Cont.)

Input Parameter	Value	Comment
Primary Contamination (Cont.)		
Cover thickness (m)	0	No cover material.
Total porosity of the cover material	Not used	
Erosion rate of cover depth (m/yr)	Not used	
Dry bulk density of the cover material (g/cm^3)	Not used	
Soil erodibility factor for cover (tons/acre)	Not used	
Volumetric water content of the cover material	Not used	
Agriculture Areas (applies to both fruit, grain, and nonleafy vegetable field and leafy vegetable field)		
Area (m^2)	Not an input	Computed using the coordinates in site layout.
Fraction of area directly over primary contamination	1	Onsite exposure.
Irrigation applied per year (m/yr)	0.2	RESRAD default.
Evapotranspiration coefficient	0.625	Mean of distribution.
Runoff coefficient	0.45	Mean of distribution.
Depth of soil mixing layer or plow layer (m)	0.25	Mean of distribution.
Volumetric water content	0.2839	Calculated on the basis of other input parameter values.
Erosion rate (m/yr)	0	Calculated by RESRAD-OFFSITE.
Dry bulk density of soil (g/cm^3)	1.52	Mean of distribution.
Soil erodibility factor (tons/acre)	0	To get an erosion rate of 0.
Slope-length-steepness factor	1	RESRAD-OFFSITE default.
Cropping management factor	0.11	RESRAD-OFFSITE default.
Conservation practice factor	1	RESRAD-OFFSITE default.
Livestock Feed Growing Areas (apply to both pasture and silage field and grain field)		
Area (m^2)	Not an input	Computed using the coordinates in site layout.
Fraction of area directly over primary contamination	1	Onsite exposure.
Irrigation applied per year (m/yr)	0.2	RESRAD default.
Evapotranspiration coefficient	0.625	Mean of distribution.
Runoff coefficient	0.45	Mean of distribution.
Depth of soil mixing layer or plow layer (m)	0.25	Mean of distribution.
Volumetric water content	0.2839	Calculated on the basis of other input parameter values.
Erosion rate (m/yr)	0	Calculated by RESRAD-OFFSITE.
Dry bulk density of soil (g/cm^3)	1.52	Mean of distribution.
Soil erodibility factor (tons/acre)	0	To get an erosion rate of 0.
Slope-length-steepness factor	1	RESRAD-OFFSITE default.
Cropping management factor	0.11	RESRAD-OFFSITE default.
Conservation practice factor	1	RESRAD-OFFSITE default.
Offsite dwelling area		
Area (m^2)	Not an input	Computed using the coordinates in site layout.

TABLE C-1 (Cont.)

Input Parameter	Value	Comment
Offsite dwelling area (Cont.)		
Irrigation applied per year (m/yr)	0.2	RESRAD-OFFSITE place holder values. No offsite dwelling in this scenario.
Evapotranspiration coefficient	0.5	
Runoff coefficient	0.2	
Depth of soil mixing layer or plow layer (m)	0.15	
Volumetric water content	0.3	
Erosion rate (m/yr)	0	
Dry bulk density of soil (g/cm^3)	1.5	
Soil erodibility factor (tons/acre)	0	
Slope-length-steepness factor	1	
Cropping management factor	0.11	
Conservation practice factor	1	
Atmospheric Transport		
Dispersion model coefficients (Pasquill-Gifford, Briggs rural, Briggs coefficients)	Briggs rural	RESRAD-OFFSITE place holder values, not used for an onsite scenario.
Wind speed terrain (rural, urban)	Rural	
Release height (m)	0	
Release heat flux (cal/s)	0	
Anemometer height (m)	10	
Ambient temperature (Kelvin)	285	
AM atmospheric mixing height (m)	400	
PM atmospheric mixing height (m)	1,600	
Elevation, relative six destination fields	10, 12, 20, 14, 6, 26	
Grid spacing for areal integration (m)	5	
Wind speed class 1–6 (m/s)	0.89, 2.46, 4.47, 6.93, 9.61, 12.52	
Joint frequency of wind speed classes 1 through 6 and Stability Classes A through F	1 or 0	
Groundwater Transport		
Distance in the direction parallel to the aquifer flow from the downgradient edge of the contamination to the well	0	Onsite well.
Distance in the direction parallel to the aquifer flow from the downgradient edge of the contamination to the surface water body	0	Onsite surface water body.
Distance in the direction perpendicular to the aquifer flow from the center of the contamination to the well	0	Onsite well.
Distance in the direction perpendicular to the aquifer flow from the center of the contamination to the near edge of the surface water body	-150	Corresponds to a square pond with an area of 90,000 m^2.
Distance in the direction perpendicular to the aquifer flow from the center of the contamination to the far edge of the surface water body	150	Corresponds to a square pond with an area of 90,000 m^2.
Convergence criterion (fractional accuracy desired)	0.001	RESRAD-OFFSITE default.
Number of main subzones in saturated stratum	1	To make consistent with RESRAD methodology.

TABLE C-1 (Cont.)

Input Parameter	Value	Comment
Groundwater Transport (cont.)		
Number of minor subzones in last main saturated zone subzone	1	Not user changeable
Number of main subzones in each unsaturated stratum	1	To make consistent with RESRAD methodology.
Number of minor subzones in last main unsaturated zone subzone	1	Not user changeable
Nuclide-specific retardation in all subzones, longitudinal dispersion in all but the subzone of transformation?	Yes	RESRAD-OFFSITE default.
Longitudinal dispersion in all subzones, nuclide-specific retardation in all but the subzone of transformation, parent retardation in zone of transformation?	No	RESRAD-OFFSITE default.
Longitudinal dispersion in all subzones, nuclide-specific retardation in all but the subzone of transformation, progeny retardation in zone of transformation?	No	RESRAD-OFFSITE default.
Unsaturated Zone		
Thickness (m)	9.895	Median (geometric mean) of distribution.
Dry bulk density (g/cm^3)	1.52	Mean of distribution.
Total porosity	0.425	Mean of distribution.
Effective porosity	0.355	Mean of distribution.
Field capacity	0.2	RESRAD default.
Hydraulic conductivity (m/yr)	9.974	Median (geometric mean) of distribution.
Soil b parameter	2.895	Median (geometric mean) of distribution.
Longitudinal dispersivity (m)	0	To make consistent with RESRAD methodology.
Surface Water Body		
Sediment delivery ratio	0	No runoff contribution to surface water.
Volume of surface water body (m^3)	150,000	RESRAD-OFFSITE place holder value.
Mean residence time of water in surface water body (yr)	1	
Saturated Zone Hydrological Data		
Thickness of saturated zone (m)	3,000	To ensure that ground water volumetric flow rate exceeds infiltration through primary contamination.
Dry bulk density of saturated zone (g/cm^3)	1.52	Mean of distribution.
Total porosity	0.425	Mean of distribution.
Effective porosity	0.355	Mean of distribution.
Hydraulic conductivity (m/yr)	9.974	Median (geometric mean) of distribution.
Hydraulic gradient	0.00604	Median (geometric mean) of distribution.

TABLE C-1 (Cont.)

Input Parameter	Value	Comment
Saturated Zone Hydrological Data (cont.)		
Longitudinal dispersivity (m)	0	To make consistent with RESRAD methodology.
Horizontal lateral dispersivity (m)	0	To make consistent with RESRAD methodology.
Disperse vertically?	No	To make consistent with RESRAD methodology.
Vertical lateral dispersivity (m)	Not used	
Do not disperse vertically?	Yes	To make consistent with RESRAD methodology.
Irrigation rate (value averaged over length of saturated zone) (m/yr)	0.2	Not used for onsite case.
Runoff coefficient (value averaged over length of saturated zone)	0.45	
Evapotranspiration coefficient (value averaged over length of saturated zone)	0.625	
Depth of aquifer contributing to well	15.33	Mean of distribution.
Depth of aquifer contributing to surface water body	15.33	To be consistent with RESRAD scenario.
Water Use Parameters		
Water for consumption by humans		
Quantify (L/yr)	409.5	Median (geometric mean) of distribution.
Fraction of water from surface body	0	No surface water.
Fraction of water from well	0.9	Receptor spends some time offsite.
Number of household individuals	4	RESRAD-OFFSITE place holder value.
Water for household purposes		
Quantify (L/d)	225	RESRAD-OFFSITE place holder value.
Fraction of water from surface body	0	No surface water.
Fraction of water from well	1	From groundwater.
Beef cattle		
Quantify (L/d)	50	RESRAD default.
Fraction of water from surface body	0.5	To consider surface water contamination.
Fraction of water from well	0.5	To consider surface water contamination.
Number of cattle	2	RESRAD-OFFSITE place holder value.
Dairy cows		
Quantify (L/d)	160	RESRAD default.
Fraction of water from surface body	0.5	To consider surface water contamination.
Fraction of water from well	0.5	To consider surface water contamination.
Number of cows	2	RESRAD-OFFSITE place holder value.

TABLE C-1 (Cont.)

Input Parameter	Value	Comment
Water Use Parameters (Cont.)		
Irrigation per year (apply to fruit, grain, nonleafy vegetable field; leafy vegetable field; livestock pasture and silage field; and livestock grain field)		
Quantify (m/yr)	0.2	RESRAD default.
Fraction of water from surface body	0.5	To consider surface water contamination.
Fraction of water from well	0.5	To consider surface water contamination.
Well pumping rate (m^3/yr)	250	RESRAD default.
Ingestion Rates		
Consumption rate		
Drinking water (L/yr)	409.5	Median (geometric mean) of distribution.
Fish (kg/yr)	155.6	Derived from EPA (1997).
Other aquatic food (kg/yr)	0	
Fruit, grain, nonleafy vegetables (kg/yr)	210.33	Mean of distribution.
Leafy vegetables (kg/yr)	22.667	Derived from EPA (1997).
Meat (kg/yr)	222.1	Derived from EPA (1997).
Milk (L/yr)	120.67	Mean of distribution.
Soil (incidental) (g/yr)	18.27	Mean of distribution.
Fraction from affected area		
Drinking water	0.9	Receptor spends sometime offsite.
Fish	0.463	Mean of distribution.
Other aquatic food	0.5	RESRAD value for this scenario.
Fruit, grain, nonleafy vegetables	0.5	
Leafy vegetables	0.5	
Meat	1	
Milk	1	
Livestock Intake		
Water for meat cow (L/d)	50	RESRAD default.
Pasture and silage for meat cow (kg/d)	13.6	Pasture and silage account for 20% of the feed in RESRAD.
Grain for meat cow (kg/d)	54.4	Grain fraction for meat cattle feed is 80% in RESRAD.
Soil from pasture and silage for meat cow (kg/d)	0.1	RESRAD default, 0.5, apportioned on the basis of each feed component.
Soil from grain for meat cow (kg/d)	0.4	
Water for milk cow (L/d)	160	RESRAD default.
Pasture and silage for milk cow (kg/d)	44	Pasture and silage account for 80% of the feed in RESRAD.
Grain for milk cow (kg/d)	11	Grain fraction for meat cattle feed is 20% in RESRAD.
Soil from pasture and silage for milk cow (kg/d)	0.4	RESRAD default, 0.5, apportioned on the basis of each feed component.
Soil from grain for milk cow (kg/d)	0.1	

TABLE C-1 (Cont.)

Input Parameter	Value	Comment
Livestock Feed Factors (apply to both pasture and silage field and grain field)		
Wet weight crop yield (kg/m^2)	1.1	RESRAD default.
Duration of growing season (yr)	0.08	RESRAD default.
Foliage-to-food transfer coefficient	1	RESRAD default.
Weathering removal constant (1/yr)	35.7	Mean of distribution.
Foliar interception factor for irrigation	0.25	RESRAD default.
Foliar interception factor for dust	0.25	RESRAD default.
Root depth (m)	2.15	Mean of distribution.
Plant factors		
Fruit, grain, nonleafy vegetables		
Wet weight crop yield (kg/m^2)	1.75	Median (geometric mean) of distribution.
Duration of growing season (yr)	0.17	RESRAD default.
Foliage-to-food transfer coefficient	0.1	RESRAD default.
Weathering removal constant (1/yr)	35.7	Mean of distribution.
Foliar interception factor for irrigation	0.25	RESRAD default.
Foliar interception factor for dust	0.25	RESRAD default.
Root depth (m)	2.15	Mean of distribution.
Leafy vegetables		
Wet weight crop yield (kg/m^2)	1.5	RESRAD default.
Duration of growing season (yr)	0.25	RESRAD default.
Foliage-to-food transfer coefficient	1	RESRAD default.
Weathering removal constant (1/yr)	35.7	Mean of distribution.
Foliar interception factor for irrigation	0.25	RESRAD default.
Foliar interception factor for dust	0.56	Mean of distribution.
Root depth (m)	2.15	Mean of distribution.
Inhalation and External Gamma Data		
Inhalation rate (m^3/yr)	8,627	Mean of distribution.
Mass loading for inhalation (g/m^3)	2.45×10^{-5}	Mean of distribution.
Mean onsite mass loading (g/m^3)	0.0001	Set to the same value as for mass loading for foliar deposition.
Indoor dust filtration factor	0.55	Mean of distribution.
External gamma shielding factor	0.27	Median (geometric mean) of distribution.
External Radiation Shape and Area Factors		
Shape of the plane of the primary contamination	Circular	RESRAD default.
Scale (m)	1,300	
Onsite receptor location X (m)	650	The receptor is located at the center of the contaminated zone.
Onsite receptor location Y (m)	650	The receptor is located at the center of the contaminated zone.
Offsite receptor location X (m)	100	Not used for the onsite scenario.
Offsite receptor location Y(m)	100	

TABLE C-1 (Cont.)

Input Parameter	Value	Comment
Occupancy Factors		
Fraction of time spent on primary contamination — indoors	0.651	Mean of distribution.
Fraction of time spent on primary contamination — outdoors	0.25	RESRAD default.
Fraction of time spent offsite, within the range of radiation emanating from primary contamination — indoors	0	Consider onsite exposure only.
Fraction of time spent offsite, within the range of radiation emanating from primary contamination — outdoors	0	Consider onsite exposure only.
Occupancy Factors (Cont.)		
Fraction of time spent in farmed areas		
Fruit, grain, and nonleafy vegetable field	0	Included in time fraction spent onsite outdoors.
Leafy vegetable field	0	Included in time fraction spent onsite outdoors.
Pasture and silage field	0	Included in time fraction spent onsite outdoors.
Livestock grain field	0	Included in time fraction spent onsite outdoors.
Radon Data		
Effective radon diffusion coefficient of cover (m^2/s)	2×10^{-6}	RESRAD default.
Effective radon diffusion coefficient of contaminated zone (m^2/s)		RESRAD default.
Effective radon diffusion coefficient of floor (m^2/s)	3×10^{-7}	RESRAD default.
Thickness of floor and foundation (m)	0.15	RESRAD default.
Density of floor and foundation (m)	2.4	RESRAD default.
Total porosity of floor and foundation	0.1	RESRAD default.
Volumetric water content of floor and foundation	0.03	RESRAD default.
Depth of foundation below ground level (m)	-1	RESRAD default.
Radon vertical dimension of mixing (m)	2	RESRAD default.
Building room height (m)	2.5	RESRAD default.
Building air exchange rate (1/h)	0.5	RESRAD default.
Building indoor area factor	0	RESRAD default.
Rn-222 emanation coefficient	0.25	RESRAD default.
Rn-220 emanation coefficient	0.15	RESRAD default.
C-14 Data		
Thickness of evasion layer for C-14 in soil (m)	0.367	Mean of distribution.
C-14 evasion flux rate from soil	7×10^{-7}	RESRAD default.
C-12 evasion flux rate from soil	1×10^{-10}	RESRAD default.
Fraction of vegetation carbon absorbed from soil	0.02	RESRAD default.
Fraction of vegetation carbon absorbed from air	0.98	RESRAD default.
Mass Fraction of C-12		
Contaminated soil	0.03	RESRAD default.
Local water	0.00002	RESRAD default.

TABLE C-1 (Cont.)

Input Parameter	Value	Comment
Mass Fraction of C-12(cont.)		
Fruit, grain, nonleafy vegetables	0.4	Values hardwired in RESRAD.
Leafy vegetables	0.09	
Pasture and silage	0.09	
Grain	0.4	
Meat	0.24	
Milk	0.07	
Tritium Data		
Humidity in air (g/m^3)	7.243	Median (geometric mean) of distribution.
Mass fraction of water in		
Fruit, grain, and nonleafy vegetables	0.8	Values hardwired in RESRAD.
Leafy vegetables	0.8	
Pasture and silage	0.8	
Livestock grain	0.8	
Meat	0.6	
Milk	0.88	

Sources:

Eckerman, K.F., and J.C. Ryman, 1993, *External Exposure to Radionuclides in Air, Water, and Soil: Exposure to Dose Coefficients for General Application, Based on the 1987 Federal Radiation Protection Guidance*, EPA 402-R-93-081, Federal Guidance Report No. 12, prepared by Oak Ridge National Laboratory, Oak Ridge, Tenn., for U.S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C.

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Environmental Science Division
Argonne National Laboratory
9700 South Cass Avenue, Bldg. 900
Argonne, IL 60439-4832

www.anl.gov

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