United States
Nuclear Regulatory Commission

Policy and Guidance Directive PG-8-08

Scenarios for Assessing Potential Doses Associated with Residual Radioactivity

Division of Waste Management
Office of Nuclear Material Safety and Safeguards

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Enclosure

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Associated with Residual Radioactivity

Introduction

NRC defines "decommission" in 10 CFR Parts 30, 40, and 70 as "to remove (as a facility) safely from service and *reduce residual radioactivity to a level that permits* release of the property for unrestricted use and termination of license" [emphasis added; see §§30.4, 40.4, and 70.4]. Currently, NRC is using criteria from existing guidance documents to determine the adequacy of site decommissioning actions until new radiological criteria for decommissioning are established through NRC's Enhanced Participatory Rulemaking. This rulemaking should be completed by May 1995. In the interim, licensees should decommission facilities in accordance with concentration criteria established in existing NRC guidance documents with emphasis on achieving residual contamination levels that are as low as is reasonably achievable (ALARA). Documents listing the existing criteria are identified in the Action Plan to Ensure Timely Cleanup of Site Decommissioning Management Plan Sites (57 *FR* 13389; April 16, 1992) and in Table 1.

In some situations, however, criteria have not already been established for radionuclides that may be present as volume contamination specifically in soils at licensed nuclear facilities and other sites with significant contamination. In other situations, a licensee may attempt to justify alternate criteria (above or below existing criteria) on the basis of ALARA considerations or site-specific conditions. The NRC staff commonly evaluates the acceptability of residual contamination levels in such situations by considering potential doses to individuals from exposure to the contamination. The objective of these evaluations is to ensure that residual contamination has been sufficiently reduced to satisfy the definition of "decommission" in NRC's requirements before the license is terminated and the site is released for unrestricted use.

This Policy and Guidance Directive has been developed to foster consistency in the exposure scenarios used for NRC dose assessments associated with residual radioactivity for decommissioning. In addition, by describing standard scenarios to be considered in such dose assessments, the Directive also seeks to ensure that the dose assessments are sufficiently protective of potential future residents that may be exposed to residual radioactive contamination after termination of the license and release of the site for unrestricted use.

The NRC staff anticipates that alternative exposure scenarios may be appropriate based on site-specific factors that affect the likelihood and extent of potential future exposure to residual radioactive contamination. For example, exposure scenarios for certain sites may exclude exposures via agricultural pathways, if agricultural land uses are clearly incompatible with existing and anticipated future conditions at the sites. As another example, exposures via ingestion of contaminated groundwater may be discounted if the affected groundwater is of such poor quality as to preclude human consumption.

Table 1. Interim Cleanup Criteria[#]

1. Options 1 and 2 of the Branch Technical Position *Disposal or Onsite Storage of Thorium or Uranium Wastes from Past Operations*, (46 FR 52601; October 23, 1981).[1]

2. *Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material*, Policy and Guidance Directive FC 83-23, Division of Industrial and Medical Nuclear Safety, November 4, 1983 (as revised in 1987).[2]

3. *Termination of Operating Licenses for Nuclear Reactors*, Regulatory Guide 1.86, June 1974, Table 1, for surface contamination of reactor facility structures and components.[3] Also ^{60}Co, ^{137}Cs, and ^{152}Eu that may exist in concrete, components, and structures should be removed so the indoor exposure rate is less than 5 microroentgen per hour above natural background at 1 meter, with an overall dose objective of less than 10 millirem per year (cf. Letter to Stanford University from James R. Miller, Chief, Standardization and Special Projects Branch, Division of Licensing, Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, April [illegible], 1982, Docket No. 50-141).[4]

4. The Environmental Protection Agency's (EPA's) *Interim Primary Drinking Water Regulations*, 40 CFR Part 141 (41 FR 38404; July 9, 1976).[5] In accordance with FC 83-23, the maximum contaminant levels for radionuclides in public drinking water as established by EPA should be used as reference standards for protection of groundwater and surface water resources.

5. EPA's *Persons Exposed to Transuranium Elements in the Environment* (42 FR 60956, November 30, 1977).[6] This document provides guidelines for acceptable levels of transuranic elements in soil.

[#]These criteria will be applied on a site-specific basis with emphasis on keeping residual contamination levels as low as is reasonably achievable (ALARA).

Exposure Scenarios

In evaluating potential doses from residual radioactivity, the NRC staff typically assesses the acceptability of the doses by constructing a source-term & exposure scenario and executing a computer model or analytical solution that simulates the release and transport of radionuclides and radiation in the environment. These assessments are performed on a site-specific basis and reflect differences in the characteristics of the residual radioactivity (e.g., nature, types, extent, and concentrations of radioactive contaminants) and of the environment (e.g, soil, surface water, groundwater, and air at the site). Unless there is a compelling reason to exclude specific exposure pathways based on these characteristics, a uniform set of exposure scenarios should be considered in evaluating whether residual radioactivity has been sufficiently reduced in accordance with NRC regulations.

Extensive environmental pathways modeling since the 1970s has demonstrated that a combination of several exposure pathways generally bound potential doses to potential future residents from residual radioactivity. For example, NRC's 1982 Generic Environmental Impact Statement in support of the low-level radioactive waste disposal requirements in 10 CFR Part 61 identified several scenarios that were considered conservative representations of how potential future residents could be exposed to radioactive materials, including the intruder-farmer, intruder-construction, and intruder-discovery scenarios (cf. *Final Environmental Impact Statement on 10 CFR Part 61, Licensing Requirements for Land Disposal of Radioactive Waste*, NUREG-0945, November 1982)[7]. These scenarios have evolved since then and are applied widely by NRC, the Department of Energy, the Environmental Protection Agency, State agencies, industry, and academia in evaluating the health risks associated with both radiological and non-radiological contamination[8, 9, 10, 11, 12, 13, 14].

Based on this experience, NRC has developed a comprehensive methodology for translating residual radioactive contamination levels into doses in NUREG/CR-5512[10]. The methodology presented in NUREG/CR-5512 includes four primary exposure scenarios:

(1) Building Renovation Scenario (surface contamination),

(2) Building Occupancy Scenario (surface contamination),

(3) Drinking Water Scenario (Groundwater Contamination), and

(4) Residential Scenario (volume contamination).

Although the methodology has been developed to estimate doses from residual radioactive contamination for each of these scenarios, computer codes and alternative calculational tools have only been developed to estimate doses to potential residents from volume contamination (i.e., where the radioactive materials are dispersed throughout material such as soil or concrete).

Computer codes are not currently available to estimate doses from surface contamination (rather than volume contamination). NRC anticipates completion of a computer code, entitled D&D SCREEN, that will assess doses from both surface and volume contamination based on the methodology presented in NUREG/CR-5512 by early 1995. Until enhanced computational capabilities are available to assess doses associated with surface contamination, the surface contamination limits in Table 1 of NRC Regulatory Guide 1.86 or Policy and Guidance Directive FC 83-23 will be employed to appropriately constrain residual radioactive contamination on surfaces and structures[3,4].

In addition, the exposure scenarios and calculational methodology described in NUREG/CR-5512 are intended to be applied for screening purposes to determine whether more detailed analyses must be performed. The foreword to NUREG/CR-5512 states that the intent of the scenarios contained therein is to account for the vast majority of potential uses of lands and structures and to overestimate the most probable annual dose while discounting a small fraction of highly unlikely uses that would result in higher doses. NUREG/CR-5512 also recognizes that customized, site-specific modeling may be necessary to evaluate and optimize radiation protection measures and determine whether residual radioactivity levels are ALARA. The scenarios described in this Policy Directive are intended to guide these more customized analyses.

Source Term

The common source term is assumed to be an uncovered contaminated soil zone of typically cylindrical shape. The radionuclide contaminants are assumed to be homogeneously distributed within the contaminated zone. The contaminated soil is assumed to be underlain by an uncontaminated unsaturated zone and a saturated zone. The starting point of radionuclide releases is the contaminated (soil) zone. Radionuclides are assumed to be released from the soil by surface erosion activities (e.g., wind, resuspension), plant uptake, direct ingestion, gaseous emanation (e.g., radon emanation), infiltration, and leaching. In addition, potential future resident could be exposed to direct gamma radiation emitted by radiological constituents. Contaminants may also be transported to groundwater through combined activities of water infiltration, leaching, and dispersion.

Standard Scenarios

Considering the above source-term, the following exposure scenarios should be analyzed in determining potential doses associated with residual radioactivity (volume contamination):

(A) Direct exposure to external radiation and inhalation of airborne radioactive material from contaminated soil to onsite worker,

(B) Direct exposure to external radiation, and inhalation and ingestion of airborne radioactive material to onsite resident who works off-site, and

(C) Direct exposure to external radiation and inhalation and ingestion of radioactive material to an individual who lives on the site, ingests groundwater produced from beneath the site, and ingests food grown on site.

These exposure scenarios can be readily assessed using commonly available computer codes, such as the RESRAD code[11]. The RESRAD computer code is currently one of several codes used by the NRC staff to independently confirm estimated doses associated with residual radioactive contamination. Specific aspects of the scenarios depart from the residential scenario described in NUREG/CR-5512 based on specific features of the RESRAD code. For example, Scenario C is based on the assumption that the onsite resident withdraws groundwater from a well located at the downgradient edge of the contaminated area. This can be simulated using the Non-Dispersive option of the RESRAD computer code. In contrast, the methodology described in NUREG/CR-5512 assumes that the well is located in the middle of the contaminated area, which is analogous to the mass balance option of the RESRAD code. It should be pointed out that for small sites (e.g., contaminated surface area <1000 m^2), the mass balance option may be appropriately selected.

Another example of a difference between the scenarios considered in NUREG/CR-5512 and those described below is that the scenarios in this Directive consider exposure to radon and its decay products in indoor and outdoor air. The RESRAD computer code (versions 5.0 and higher) assesses potential exposures to radon and its decay products in indoor and outdoor air[15]. Sources of the radon considered by RESRAD include soil, well water, and building materials. RESRAD estimates indoor air concentrations based on the diffusion equation, assuming that advection is negligible and the flux of radon into the building occurs at steady-state. An indoor air exchange rate of 1/hour is typically assumed. In contrast, the methodology presented in NUREG/CR-5512 does not consider doses from exposure to radon produced via the decay of residual radioactive contamination (principally from the decay of ^{226}Ra and ^{224}Ra in the uranium and thorium decay chains).

The differences between the scenarios described in this Policy and Guidance Directive and those described in NUREG/CR-5512, with the exception of the doses from inhalation of radon, are not expected to result in significant disparities in estimated doses.

The exposure pathways for Scenarios A-C are summarized in Table 2. Scenario A is intended to represent typical exposures associated with the use of a contaminated site for light industrial purposes. Scenario B is intended to represent a homeowner, who spends most of the time onsite, but works at an offsite location. Scenario C represents the reasonable maximally exposed resident farmer, who resides, works, grows crops, and raises livestock onsite. Scenario C is the closest scenario to the residential scenario described in

NUREG/CR-5512[10].

Table 2. Summary of Exposure Pathways for Scenarios A - C

Pathway	Scenario A	Scenario B	Scenario C
External Exposure	Yes	Yes	Yes
Inhalation (Resuspension)	Yes	Yes	Yes
Radon Inhalation	Yes	Yes	Yes
Ingestion of Ground Water	No	Yes	Yes
Ingestion of Vegetables	No	Yes	Yes
Ingestion of Meat	No	No	Yes
Ingestion of Milk	No	No	Yes
Ingestion of Aquatic Food	No	No	Yes
Ingestion of Soil	No	Yes	Yes

In all three scenarios, except for radon diffusion, no credit has been given to shielding or containment provided by covers in reducing potential exposures to onsite residents. The scenarios allow limited credit for subflooring and foundations in estimating radon diffusion rates into a structure. Earthen covers placed over contaminated material may be effective in reducing exposures for some time by preventing resuspension of contamination, shielding gamma radiation, isolating plant roots from contaminated soil, and inhibiting or limiting infiltration into contaminated areas. Nevertheless, under the unrestricted use scenarios, it is conceivable that an individual would disrupt the earthen cover and expose contaminated material at the land surface. For example, construction of a home could include excavation of a foundation and distribution of contaminated soil at the land surface. Plants could then be grown in the contaminated soil resulting in uptake by the individual who consumes the vegetables, grains, or fruits. In addition, exposing the contaminated soil at the surface may cause resuspension of the contaminated material into the air onsite. Further, exposure of the contaminated material at the land surface would result in direct exposure from gamma radiation and increase the susceptibility of the material to leaching and transport through the unsaturated zone and into groundwater beneath the site.

The NRC staff will estimate potential doses associated with these exposure scenarios for up to 1000 years after completion of the decommissioning. Ingrowth of decay products of uranium, thorium, and other radionuclides with long half-lives will not be considered beyond 1000 years because of the large uncertainties associated with future conditions.

Scenario A - Worker

Scenario A is designed to represent typical exposures to a worker on site. The residence time at the site is limited to 2000 hours (23% of time) per year (8 hours/day x 5 days/week x 50 weeks/year). Approximately 20% of that time (400 hours; 4% of the year) is spent outdoors on the site. The individual does not drink water from onsite or produce food for his or her personal consumption. This scenario assumes that the worker does not consume any plant foods, milk, meat, aquatic food, or water from the site. The scenario does not account for potential dilution of the contaminated soil or structures that may occur during construction or renovation of a facility to prepare for commercial use of the site.

In estimating the exposure to workers, the source term is assumed to be a contaminated zone beneath the building which extends outdoors where the worker spends 20% of available time. The walls, floor, and foundation of the building are assumed to reduce external exposure by 33%. The indoor dust level is assumed to be 50% of the dust level that exists outside the building. If the residual radioactive contamination decays to form radon (i.e., uranium or thorium decay chains), the scenario includes doses from indoor and outdoor radon exposure using conventional assumptions, as described above, about the construction and air-exchange characteristics of the structure.

Scenario B - Resident

Scenario B represents a typical residential exposure scenario for a homeowner who spends most of the time onsite. Consequently, the residence times for this scenario are considerably longer than those for Scenario A. These longer residence times probably increase estimated doses greater than would be typically expected because most people spend more than 25% of their time away from home. In addition to the exposure pathways given in Scenario A, this resident also ingests drinking water, produced from a groundwater well onsite, as well as food (e.g., vegetables, grain, and fruits), grown at garden onsite to supplement the diet.

The exposed resident is assumed to spend 40% of the time indoors on the site, 10% outdoors on the site, and 50% away from the site. As in Scenario A, the walls, floor, and foundation of the house reduce external exposure by 33% and the indoor dust level is assumed to be 50% of the outdoor dust level in air. The resident obtains drinking water from a well installed at the site boundary immediately downgradient from the contaminated area and uses this water to irrigate a small vegetable garden on site. The scenario assumes that the house garden produces 25% of the resident's annual vegetable, grain, and fruit diet. The resident does not consume any meat, milk, or aquatic food produced on site. If the residual radioactive contamination decays to form radon (i.e., uranium or thorium decay chains), the scenario includes doses from indoor and outdoor radon exposure using conventional assumptions about the construction and air-exchange characteristics of the structure.

Scenario C - Resident Farmer

Scenario C is intended to represent the maximum reasonably exposed individual. Because the scenario is based on "prudently conservative" assumptions that tend to overestimate potential doses, use of this scenario should result in estimated doses that will be greater than the exposure to future residents most of the time. In comparison to Scenario B, the individual in Scenario C spends much longer time outside the residence, grows and ingests a larger percentage of vegetables from the onsite garden, consumes meat and milk produced onsite, and consumes aquatic food from a neighboring pond near the site.

The resident spends 55% of the time indoors on site, 21% outdoors on site (5 hours per day for 365 days) and 24% of the time away from the site. The gardening is assumed to occur in the contaminated area. A maximum of 50% of the resident's vegetable, grain, and fruit diet is assumed to be produced from the garden. The maximum fraction of contaminated diet (50%) could be reduced if the contaminated area is less than 1,000 m^2. Certain codes (e.g., RESRAD) assume that the fraction of contaminated diet could vary from 50% to 0% as the contaminated area decreases from 1000 to 0 m^2. The fraction of the diet should be decreased linearly in proportion to the size of the contaminated area. This scenario also assumes that all of the resident's milk and 50% of the meat diet are produced on site. This diet fraction (meat and milk) may vary as a function of the contaminated area of the site. Dust levels in outdoor air in the vicinity of the garden are representative for earth moving areas because of tilling, planting, harvesting, and other activities that may increase suspension of soil particles in the air.

Vegetables, fruits, and grains are irrigated with water drawn from a well at the site boundary, immediately downgradient of the contaminated area. Well water is also used to water the livestock on site. All of the resident's drinking water is produced from the well on site. No surface water is assumed to occur on site except for a pond (or lake) which contains aquatic food for the residential consumption. As with other food products, the fraction of aquatic food onsite varies in a linear proportion with the contaminated area.

The walls, foundation, and floor of the resident's house reduce external exposure by 33%. Indoor dust levels in air are assumed to be 50% of the outdoor dust level. If the residual radioactive contamination decays to form radon (i.e., uranium or thorium decay chains), the scenario includes doses from indoor and outdoor radon exposure using conventional assumptions about the construction and air-exchange characteristics of the residence.

Table 3 presents a summary of major parameters, for each of the above three scenarios, corresponding to residence times, fractions of food and diets from site, dust loading and shielding factors, and other specific exposure pathways.

Table 3. Summary of Major Scenario Parameters for Scenarios A - C

Parameter	Scenario A	Scenario B	Scenario C
Time Indoors	18%	40%	55%
Time Outdoors	5%	10%	21%
Time Off-Site	77%	50%	24%
Vegetable From Site	NO	25%	50%*
Fruit From Site	NO	25%	50%*
Grain From Site	NO	25%	50%*
Milk From Site	NO	NO	100%*
Meat From Site	NO	NO	50%*
Surface Water	NO	NO	NO
Aquatic Food	NO	NO	50%*
Drinking Water	NO	100%	100%
Indoor Dust Loading	50%	50%	50%
Indoor Shielding factor	33%	33%	33%
Radon	YES	YES	YES

* The fraction of diet will change with area of contaminated zone.

Application of the Scenarios

NRC staff should consider the projected doses for each of the three scenarios in decisions on the adequacy of decommissioning actions. In many decommissioning reviews, the criteria in the guidance documents listed in Table 1, other than the 1981 Branch Technical Position[1] (BTP) criteria, will be applied in a straightforward manner by comparing residual concentrations with the concentration criteria, using the procedures described in NUREG/CR-5849[16]. In these cases, there is no need to estimate doses using the scenarios described in this Policy and Guidance Directive. However, when projected doses are considered in lieu of or in addition to the established concentration criteria, NRC staff should review the licensee's estimated doses and develop independent estimates of the doses for Scenarios A - C.

Dose estimates are necessary in support of applying the 1981 BTP[1] criteria other than the Option 1 criteria or evaluating site-specific ALARA analyses. When BTP Option 2 criteria are applied, the potential doses should be estimated as a part of the analysis and evaluation of environmental and waste disposal characteristics, in accordance with 10 CFR 20.2002. This would include, for example, consideration of potential doses via groundwater transport and exposure.

The intent of using the three scenarios is to establish a range of doses to potential future residents or occupants at a former nuclear facility after the license has been terminated and the site has been released for unrestricted use. The three scenarios depict a reasonable range of combinations of potential exposure pathways. The scenarios are based on the expectation that for most industrial sites, future use of the property will continue to be for industrial purposes. Thus, Scenario A may represent the most probable exposure scenario at industrial sites in most instances. However, given that former industrial sites have sometimes been converted back to residential uses, Scenario B represents a more conservative scenario that depicts typical exposures to potential residents, most of whom will work off site. Scenario C provides a reasonable upper estimate of the doses to potential future residents, who not only live on the site, but also produce a large proportion of their food (fruits, vegetables, grains, meat, and milk) on site and consume groundwater from the site.

Where the applicant or licensee has proposed that residual concentrations of radioactive materials will be ALARA, the staff should consider the combination of the three dose estimates in evaluating the merits of the proposal. The range of dose estimates provide a measure of the uncertainties associated with the decision and allow weighing of various factors in the ALARA analysis. For example, if the existing and projected future uses of the site are most likely industrial based on a variety of factors described below, the NRC staff may place greater emphasis on the dose estimates for Scenario A. Alternatively, if there is no particular reason to believe that industrial use of the site is highly unlikely, the staff should place more weight on considering doses for Scenario B and C in reviewing the ALARA analysis.

Scenario Parameters

Default physical and statistical parameter values for Scenarios A-C are listed in Appendix A. These values are essentially the default parameter values used in either the RESRAD code and NUREG/CR-5512[10]. They have been modified slightly to reflect the occupancy times and specific exposure pathways as discussed above and to be generally consistent with the default parameter values selected for the resident and water use scenarios described in

NUREG/CR-5512[10]. Appendix B compares the default parameter values for the RESRAD code with the values described in NUREG/CR-5512 for the residential scenario. Staff should use the default parameters listed in Appendix A, unless alternative values are justified based on site-specific information. For example, use of site-specific values is preferable for parameters such as the hydraulic conductivity of the saturated zone and the thickness of the unsaturated zone. The NRC staff should also use the sensitivity analysis feature of the RESRAD code (or other codes) to determine the sensitivity of the projected doses to reasonable variations in the input parameters (e.g., thickness of contaminated zone, thickness of unsaturated zone, depth of well intake).

ALARA Considerations

If the calculated doses associated with the scenarios listed above are deemed to be unacceptable in comparison to the radiation protection limits for members of the public in 10 CFR Part 20, the staff will consider the following factors in assessing whether the proposed residual radioactivity levels are ALARA:

- Existing and projected future land uses at the site and in the immediate vicinity of the site (e.g., 1 km);
- Environmental characteristics that may substantially attenuate the transport of the radionuclide(s) or reduce the probability of human exposure to residual radioactive contamination;
- Potential dilution of the residual radioactive contamination by the processes that disturb the material and result in human exposure to the contamination;
- Classification of groundwater beneath and downgradient from the site in accordance with Comprehensive State Ground Water Protection Programs reviewed by the Environmental Protection Agency;
- Existence of durable institutional controls and engineered barriers that may prevent or significantly reduce the probability of human exposure to residual radioactive contamination (e.g., restrictive covenants, deed restrictions, zoning controls, drilling restrictions, and erosion protection);
- Environmental impacts associated with performing

additional remediation to further reduce contamination levels;

- Radiological and non-radiological risks to workers associated with remedial actions to reduce contamination levels;
- Radiological and non-radiological risks to members of the public associated with remediation actions to reduce contamination levels;
- Limitations of technologies for removing and measuring residual contamination;
- Incremental remediation costs and the associated risk from such activities; and
- Other relevant societal and socioeconomic considerations

ALARA evaluations of these factors may involve unique and controversial policy issues. The staff may need to consult with the Commission about these considerations and their application on a case-by-case basis. The time frame for such considerations will not exceed 1,000 years into the future.

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1. U.S. Nuclear Regulatory Commission, *Disposal or Onsite Storage of Thorium or Uranium Wastes from Past Operations*, Branch Technical Position (46 FR 52601; October 23, 1981).

2. U.S. Nuclear Regulatory Commission, *Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material*, Policy and Guidance Directive FC 83-23, Division of Industrial and Medical Nuclear Safety, November 4, 1983 (as revised in 1987).

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14. U.S. Environmental Protection Agency, *Risk Assessment Guidance for Superfund: Volume 1, Human Health Evaluation Manual (Part A)*, EPA/540/1-89/002, December 1989.

15. Argonne National Laboratory, *RESRAD Workshop*, June 1989, pp. 115-125.

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18. U.S. Nuclear Regulatory Commission, *Calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers*, Regulatory Guide 3.64, 1989.

19. Sheppard, M. I., and D. H. Thibault, "Default Soil Solid/Liquid Partition Coefficients, K_ds, for Four Major Soil Types: A Compendium," *Health Physics*, v. 59, pp. 471-482.

Appendix A: Default Physical and Statistical Parameter Values for Scenarios A, B, and C for Dose Assessments for Residual Radioactivity

Parameter	Scenario A	Scenario B	Scenario C	Unit
Cover density	NU##	NU	NU	g/cm^3
Contaminated zone density	1.63	1.63	1.63	g/cm^3
Unsaturated zone density	1.63	1.63	1.63	g/cm^3
Saturated zone density	1.63	1.63	1.63	g/cm^3
Foundation density	2.4	2.4	2.4	g/cm^3
Cover porosity	NU	NU	NU	-
Contaminated zone porosity	0.3	0.3	0.3	-
Unsaturated zone porosity	0.3	0.3	0.3	-
Saturated zone porosity	0.3	0.3	0.3	-
Foundation porosity	0.1	0.1	0.1	-
Contaminated zone effective porosity	0.2	0.2	0.2	-
Saturated zone effective porosity	0.2	0.2	0.2	-
Unsaturated zone effective porosity	0.2	0.2	0.2	-
Contaminated zone hydraulic conductivity	NU	10	10	m/yr
Unsaturated zone hydraulic conductivity	NU	10	10	m/yr
Saturated zone hydraulic conductivity	NU	100	100	m/yr
Cover Volumetric Water Content	NU	NU	NU	-
Foundation Volumetric Water Content	0.03	0.03	0.03	-
Cover Radon Diffusion Coefficient (effective)	NU	NU	NU	m^2/s
Contaminated Zone Radon Diffusion Coefficient	2×10^{6}	2×10^{6}	2×10^{6}	m^2/s
Foundation Radon Diffusion Coefficient	3×10^{7}	3×10^{7}	3×10^{7}	m^2/s

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##Not Used in Analysis

Appendix A: Continued

Parameter	Scenario A	Scenario B	Scenario C	Unit
Radon Emanation Coefficient	0.35###	0.35	0.35	-
Precipitation Rate	NU	1	1	m/yr
Runoff Coefficient	NU	0.2	0.2	-
Irrigation Rate	NU	0.76	0.76	m/yr
Evapotranspiration Coefficient	NU	0.5	0.5	-
Cover Erosion Rate	NU	NU	NU	m/yr
Contaminated Zone Erosion Rate	0.001	0.001	0.001	m/yr
Hydraulic Gradient	NU	0.02	0.02	-
Length of Contaminated Zone in Flow Direction	NU	100	100	m
Watershed Area	NU	1×10^6	1×10^6	m^2
Water Table Drop Rate	NU	0	0	m/yr
Well Intake Depth	NU	10	10	m
Radon Vertical Mixing Dimension	2	2	2	m
Average Annual Wind Speed	2	2	2	m/s
Average Air Exchange Rate	0.5	0.5	0.5	1/hr
Building Room Height	2.5	2.5	2.5	m
Unsaturated zone thickness (Uncontaminated)	1	1	1	m
Foundation Thickness	0.15	0.15	0.15	m
Foundation Depth Below Ground	1	1	1	m
Fraction of Indoor Time	0.18	0.40	0.55	-

###Based on NRC Regulatory Guide 3.64[18]

Appendix A: Continued

Parameter	Scenario A	Scenario B	Scenario C	Unit
Fraction of Outdoor Time	0.05	0.10	0.21	-
Area of Contaminated Zone	Variable	Variable	Variable	m^2
Cover Thickness	NU	NU	NU	m
Distribution Coefficients	Variable####	Variable	Variable	cm^3/g
Livestock Fodder Rate for Meat	NU	NU	68	kg/d
Livestock Fodder Rate for Milk	NU	NU	55	kg/d
Air-Mass Loading Factor	2×10^{4}	2×10^{4}	2×10^{4}	g/m^3
Milk Consumption	NU	NU	100	l/yr
Shielding Factor for Inhalation	0.50	0.50	0.50	-
Root Depth	NU	0.9	0.9	m
Soil Ingestion Rate	NU	10.0	18.25	g/yr
Contaminated Zone Thickness	2	2	2	m
Dilution Length for Airborne Dust	3	3	3	m
Fruit, Vegetable, and Grain Consumption Rate	NU	83	166	kg/yr
Inhalation Rate	10512	10512	10512	m^3/yr
Leafy Vegetable Ingestion Rate	NU	6	11	kg/yr
Livestock Water Intake Rate	NU	NU	50	l/d
Livestock Water Intake Rate	NU	NU	160	l/d
Shielding Factor for External Gamma	0.33	0.33	0.33	-
Drinking Water Intake Rate	NU	730	730	l/yr

####See generally the distribution coefficients provided in Sheppard and Thibualt (1990)[19].

Appendix A: Continued

Parameter	Scenario A	Scenario B	Scenario C	Unit
Fraction of Drinking Water from Site	0	1	1	-
Mass Loading from Foliar Deposition	NU	1×10^{4}	1×10^{4}	g/m^3
Depth of Soil Mixing Layer	NU	0.15	0.15	m
Drinking Water Fraction from Groundwater	0	1	1	-
Livestock Water Fraction from Groundwater	NU	NU	1	-
Irrigation Water Fraction from Groundwater	NU	1	1	-

Appendix B: Comparison between Default Parameter Values for the RESRAD Code and the Methodology in NUREG/CR-5512

Parameter	RESRAD[1]	NUREG/CR-5512[2]	LD-9301	Unit
Cover density	1.5	NU	NU	g/cm^3
Contaminated zone density	1.5	1.63	1.63	g/cm^3
Unsaturated zone density	1.5	1.63	1.63	g/cm^3
Saturated zone density	1.5	1.63	1.63	g/cm^3
Foundation density	2.4	NU	2.4	g/cm^3
Cover porosity	0.4	NU	NU	-
Contaminated zone porosity	0.4	0.3	0.3	-
Unsaturated zone porosity	0.4	0.3	0.3	-
Saturated zone porosity	0.4	0.3	0.3	-
Foundation porosity	0.1	-	0.1	-
Contaminated zone effective porosity	0.2	-	0.2	-
Saturated zone effective porosity	0.2	-	0.2	-
Unsaturated zone effective porosity	0.2	-	0.2	-
Contaminated zone hydraulic conductivity	10	-	10	m/yr
Unsaturated zone hydraulic conductivity	10	-	10	m/yr
Saturated zone hydraulic conductivity	100	-	100	m/yr
Cover Volumetric Water Content	0.05	-	0.05	-
Foundation Volumetric Water Content	0.03	-	0.03	-
Cover Radon Diffusion Coefficient (eff)	2×10^{6}	-	2×10^{6}	m^2/s
Contaminated Zone Radon Diffusion Coefficient	2×10^{6}	-	2×10^{6}	m^2/s
Foundation Radon Diffusion Coefficient	3×10^{7}	-	3×10^{7}	m^2/s

Appendix B: Continued

Parameter	RESRAD	NUREG/CR-5512	LD-93-01	Unit
Radon Emanation Coefficient	0.25	-	0.35	-
Precipitation Rate	1	0.18*	1	m/yr
Runoff Coefficient	0.2	-	0.2	-
Irrigation Rate	0.2	0.76	0.76	m/yr
Evapotranspiration Coefficient	0.5	-	0.5	-
Cover Erosion Rate	0.001	-	0.001	m/yr
Contaminated Zone Erosion Rate	0.001	-	0.001	m/yr
Hydraulic Gradient	0.02	-	0.02	-
Length of Contaminated Zone in Flow Direction	100	-	100	m
Watershed Area	1×10^6	-	1×10^6	m^2
Water Table Drop Rate	0.001	-	0.001	m/yr
Well Intake Depth	10	-	10	m
Radon Vertical Mixing Dimension	2	-	2	m
Average Annual Wind Speed	2	-	2	m/s
Average Air Exchange Rate	0.5	-	0.5	1/hr
Building Room Height	2.5	-	2.5	m
Unsaturated zone thickness (Uncont.)	4	1	1	m
Foundation Thickness	0.15	-	0.15	m
Foundation Depth Below Ground	1	-	1	m
Fraction of Indoor Time	0.5	0.55	0.50	-

* This value is the infiltration rate selected in NUREG/CR-5512

Appendix B: Continued

Parameter	RESRAD	NUREG/CR-5512	LD-93-01	Unit
Fraction of Outdoor Time	0.25	0.21	0.21	-
Area of Contaminated Zone	10,000	2500	Variable	m^2
Cover Thickness	0	0	0	m
Distribution Coefficients	Variable	Variable	Variable	cm^3/g
Livestock Fodder Rate for Meat	68	44	68*	kg/d
Livestock Fodder Rate for Milk	55	67	55*	kg/d
Air Mass-Loading Factor	2×10^{-4}	1×10^{-4}	1×10^{-4}	g/m^3
Milk Consumption	92	100	100	l/yr
Shielding Factor for Inhalation	0.4	0.5	0.5	-
Root Depth	0.9	-	-	m
Soil Ingestion Rate	36.5	18.25	18.25	g/yr
Contaminated Zone Thickness	2	-	2	m
Dilution Length for Airborne Dust	3	-	3	m
Fruit, Vegetable, and Grain Consumption Rate	160	166	166*	kg/yr
Inhalation Rate	8400	10512	10512	m^3/yr
Leafy Vegetable Ingestion Rate	14	11	11	kg/yr
Livestock Water Intake Rate - Meat	50	50	50	l/d
Livestock Water Intake Rate - Milk	160	60	160	l/d
Shielding Factor for External Gamma	0.7	0.33	0.33	-
Drinking Water Intake Rate	510	730	730	l/yr

* Assuming an area of $\geq 10,000\ m^2$

Appendix B: Continued

Parameter	RESRAD	NUREG/CR-5512	LD-93-01	Unit
Fraction of Drinking Water from Site	1	1	1	-
Mass Loading for Foliar Deposition	1×10^{-4}	0.1	0.1	-
Depth of Soil Mixing Layer	0.15	0.15	0.15	m
Drinking Water Fraction from Groundwater	1	1	1	-
Livestock Water Fraction from Groundwater	1	1	1	-
Irrigation Water Fraction from Groundwater	1	1	1	-

1. Default parameter values for the RESRAD Code from *Data Collection Handbook for Establishing Residual Radioactive Material Guidelines with RESRAD* (draft), December 1992[17].

2. Default values for Residential Scenario from Kennedy, W.E., and Strenge, D. L., 1992, *Residual Radioactive Contamination from Decommissioning*, U.S. Nuclear Regulatory Commission, NUREG/CR-5512, Volume 1[10].