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Preliminary Report on Operational Guidelines Developed for Use in Emergency Preparedness and Response to a Radiological Dispersal Device Incident

Prepared for U.S. Department of Energy, Office of Health, Safety and Security

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Preliminary Report on Operational Guidelines Developed for Use in Emergency Preparedness and Response to a Radiological Dispersal Device Incident

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FOREWORD

This report presents preliminary operational guidelines and supporting work products developed through the interagency Operational Guidelines Task Group (OGT). These operational guidelines were developed in concert with and are intended to support implementation of protective action guides (PAGs) for radiological dispersal devices (RDDs) defined in "Planning Guidance for Protection and Recovery Following Radiological Dispersal Device (RDD) and Improvised Nuclear Device (IND) Incidents" (73 FR 149).

This report consolidates preliminary operational guidelines and descriptions of their derivation, all ancillary work products, and a companion software tool (RESRAD-RDD) that facilitates their implementation into one reference source document. It is intended for use and comment by Federal agencies, State and local governments, and emergency planning and response subject matter experts regarding emergency preparedness planning and response initiatives for an RDD incident. The report principally focuses on the technical derivation and presentation of the operational guidelines with some accompanying general end-user guidance. The guidelines and guidance presented in this report can be used in trial applications during controlled practice exercises simulating emergency planning and response to an RDD. They are appropriate for use in developing preliminary event-specific operational guidelines and guidance. The report and operational guidelines are preliminary and do not represent the official policy, methods, or guidance of the agencies that participated in the OGT.

The preliminary operational guidelines are categorized into seven groups on the basis of their intended application within early, intermediate, and long-term recovery phases of emergency response. We anticipate that these operational guidelines will be updated and refined by interested government agencies in response to comments and lessons learned from their review, consideration, and trial application. This review, comment, and trial application process will facilitate the development of more detailed end-user guidance and the selection of a final set of operational guidelines that may be more or less inclusive of the preliminary operational guidelines presented in this report. These and updated versions of the operational guidelines and associated guidance will be made available through the Department of Energy's OGT public Web site (http://ogcms.energy.gov) as they become finalized for public distribution, use, and comment.

Comments in the form of recommendations, pertinent data, and lessons learned that may improve the methods employed for deriving operational guidelines, the resulting preliminary operational guidelines and general end-user guidance presented in this report, and the companion software tool should be sent to:

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The preliminary operational guidelines, ancillary work products, and companion software tool presented in this report were developed through the interagency Operational Guidelines Task Group (OGT). The OGT is a technical support element of the Consequence Management, Site Restoration/Cleanup, and Decontamination Subgroup (CMS) that developed the protective action guides for radiological dispersal devices (RDDs) defined in "Planning Guidance for Protection and Recovery Following Radiological Dispersal Device (RDD) and Improvised Nuclear Device (IND) Incidents" (73 FR 149).

We thank the following individuals for their participation in the OGT. Their technical expertise and contributions, persistence, and willingness to work through a consensus-based process in a team environment were invaluable to the successful development of the operational guidelines and guidance presented in this report.

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Stephen Domotor	U.S. Department of Energy, OGT Chair
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Robert Whitcomb	Centers for Disease Control and Prevention
Charley Yu	Argonne National Laboratory, RESRAD Team Leader

* OGT participant's organization listing at the time of operational guidelines development.

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Fred Baes, Oak Ridge National Laboratory	OGT Web site development and maintenance.
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Doug Tynan, U.S. Dept. of Energy	Coordination of funding and related project administration.
Andrew Wallo, U.S. Dept. of Energy	Development of the conceptual framework and definitions for the operational guidelines.
Charley Yu and RESRAD Team, Argonne National Laboratory	Exposure pathway modeling for operational guidelines and development of the RESRAD-RDD software. The RESRAD Team members who contributed to this report and the RESRAD-RDD software include Jing-Jy Cheng, Sunita Kamboj, and Tim Klett. Emmanuel Gnanapragasam provided technical review of the final report and the RESRAD-RDD software. S.Y. Chen provided management support throughout the project.
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ACRONYMS AND ABBREVIATIONS

The following is a list of the acronyms, initialisms, abbreviations, and units of measure used in this document. Some acronyms and abbreviations used only in tables, figures, equations, or as reference callouts are defined in the respective tables, figures, equations, and reference lists.

ACRONYMS, INITIALISMS, AND ABBREVIATIONS

AC	air-conditioning
ANL	Argonne National Laboratory
ANSI/HPS	American National Standards Institute/Health Physics Society
CDC	Centers for Disease Control and Prevention
CDE	committed dose equivalent
CED	committed effective dose
CEDE	committed effective dose equivalent
CFR	*Code of Federal Regulations*
CMS	Consequence Management, Site Restoration/Cleanup and Decontamination Subgroup
DCF	dose conversion factor
DHS	Department of Homeland Security
DIL	derived intervention level
DM&A	Dade Moeller and Associates
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DRL	derived response level
DSR	dose-to-source ratio
EPA	U.S. Environmental Protection Agency
FDA	U.S. Food and Drug Administration
FGR	Federal Guidance Report
FR	*Federal Register*
FRMAC	Federal Radiological Monitoring and Assessment Center
HVAC	heating, ventilating, and air-conditioning
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IND	improvised nuclear device
ISCORS	Interagency Steering Committee on Radiation Standards

KI	potassium iodide
MEI	maximally exposed individual
NCRP	National Council on Radiation Protection and Measurements
NIST	National Institute of Standards and Technology
NRC	U.S. Nuclear Regulatory Commission
OGT	Operational Guidelines Task Group
PAG	protective action guide
POTW	publicly owned treatment works
PV	planning value
RDD	radiological dispersal device
TED	total effective dose
TEDE	total effective dose equivalent
WCF	weathering correction factor

UNITS OF MEASURE

Bq	becquerel(s)
cm	centimeter(s)
d	day(s)
dpm	disintegration(s) per minute
g	gram(s)
h	hour(s)
kg	kilogram(s)
km	kilometer(s)
L	liter(s)
m	meter(s)
m^2	square meter(s)
m^3	cubic meter(s)
MB	megabyte(s)
min	minute(s)
mrem	millirem(s)
mSv	millisievert(s)
pCi	picocurie(s)
µCi	microcurie(s)
s	second(s)
Sv	sievert(s)
rem	roentgen equivalent man
R	roentgen(s)
yr	year(s)

EXECUTIVE SUMMARY

This report provides preliminary operational guidelines and descriptions of their derivation, all ancillary work products, and a companion software tool (RESRAD-RDD) that facilitates their implementation into one reference source document. It is intended for trial use and comment by Federal agencies, State and local governments, and emergency planning and response subject matter experts regarding emergency preparedness planning and response initiatives in the event of a radiological dispersal device (RDD) incident. The methods and guidelines presented in this report can be used in trial applications during controlled practice exercises simulating emergency planning and response to an RDD. They are appropriate for use in developing preliminary event-specific operational guidelines and guidance. The report principally focuses on the technical derivation and presentation of the operational guidelines with some accompanying general end-user guidance. The report and operational guidelines are preliminary and do not represent the official policy, methods, or guidance of the agencies that participated in the OGT.

This Executive Summary provides essential information resulting from the operational guidelines development initiative, and should prove useful as an end-user primer that facilitates the application of operational guideline groups and subgroups detailed in this report. It summarizes the purpose of operational guidelines and their use in facilitating decisions on protective actions for RDDs, the relationship of operational guidelines to protective action guides (PAGs) and other guidelines, the framework of operational guideline groups and subgroups, and the RESRAD-RDD software tool. The Department of Energy's OGT public Web site (http://ogcms.energy.gov) is available as a resource for users interested in a more general summary concerning the operational guidelines development initiative and its relationship to interagency planning guidance for protection and recovery following an RDD incident.

ES.1 PURPOSE OF OPERATIONAL GUIDELINES AND THEIR USE IN FACILITATING DECISIONS ON PROTECTIVE ACTIONS FOR RDDS

The primary purpose of the operational guidelines is to support implementation of the Department of Homeland Security's (DHS) protective action guides (PAGs) for RDDs published in "Planning Guidance for Protection and Recovery Following Radiological Dispersal Device (RDD) and Improvised Nuclear Device (IND) Incidents" (*Federal Register*, 73 FR 149). As cited in the DHS PAGs, by agreement with the Environmental Protection Agency (EPA), the

DHS PAG guidance and its substance will be incorporated without change into the revision of the 1992 *EPA Manual of Protective Action Guides and Protective Actions for Nuclear Incidents* (the EPA PAG Manual; currently EPA 400-R-92-001). As such, the operational guidelines presented in this report will also support implementation of the EPA PAG Manual.

A PAG is the projected dose to a reference individual from an accidental or deliberate release of radioactive material at which a specific protective action (e.g., sheltering or evacuation of the public and restriction of water and food consumption) to reduce or avoid that dose is recommended. Protective actions are designed to be taken before the anticipated dose is realized. The PAGs are not regulatory limits or firm distinctions between safe and unsafe. Rather, they are guidelines for determining if protective actions for public and worker safety are warranted for a specific radiological incident. Tables ES-1 and ES-2, taken from *Federal Register* 73 FR 149, present the PAGs and Emergency Worker Guidelines appropriate for use in various phases of emergency preparedness and in response to an RDD incident.

The PAGs and Emergency Worker Guidelines are dose-based, and because it is often difficult to readily measure the dose, a need existed for operational measurements of radiation levels, or concentrations in various media, that could be related to the PAGs to facilitate decisions regarding the need for protective actions. The operational guidelines were developed for this purpose and involve prederived levels of radioactivity or radionuclide concentrations in various media that can be measured in the field and compared to the PAGs to quickly determine if protective actions are warranted. For example, in the hours and days following an incident, there could be an urgent need for decisions about evacuation or relocation of the public. Determinations regarding critical infrastructures such as access to roads and medical facilities, as well as restoration of power, water, and sewer facilities, may also have to be made. Although some values already exist (e.g., derived response levels [DRLs] from the Federal Radiological Monitoring and Assessment Center [FRMAC] for generic cases, from the EPA for water, and derived intervention levels [DILs] from the U.S. Food and Drug Administration [FDA] for food) that could potentially serve as operational guidelines, many more were needed for handling various situations.

The operational guidelines presented in this report were derived by the Operational Guidelines Task Group (OGT) established by the U.S. Department of Energy (DOE) in response to House Report 108-076, "Making Emergency Wartime Supplemental Appropriations for the Fiscal Year 2003, and for Other Purposes" that directed DOE "to develop standards for the cleanup of contamination resulting from a potential RDD event." The OGT consists of regulatory and subject matter experts in radiological and nuclear preparedness and response from many

TABLE ES-1 Protective Action Guidelines for RDD and IND Incidents

Phase	Protective Action Recommendation	Protective Action Guide
Early	Sheltering-in-place or evacuation of the public[a]	1 to 5 rem (0.01-0.05 Sv) projected dose[b]
	Administration of prophylactic drugs – potassium iodide[c, d]; administration of other prophylactic or decorporation agents[e]	5 rem (0.05 Sv) projected dose to child's thyroid[c, d]
Intermediate	Relocation of the public	2 rem (0.02 Sv) projected dose first year; subsequent years, 0.5 rem/yr (0.005 Sv/yr) projected dose[b]
	Food interdiction	0.5 rem (0.005 Sv) projected dose, or 5 rem (0.05 Sv) to any individual organ or tissue in the first year, whichever is limiting
	Drinking water interdiction	0.5 rem (0.005 Sv) projected dose in the first year

a Should normally begin at 1 rem (0.01 Sv); take whichever action (or combination of actions) results in the lowest exposure for the majority of the population. Sheltering may begin at lower levels, if advantageous.

b Total effective dose equivalent (TEDE) is the sum of the effective dose equivalent from external radiation exposure and the committed effective dose equivalent from internal radiation exposure.

c Provides thyroid protection from radioactive iodine only.

d Committed dose equivalent (CDE). FDA understands that a potassium iodide (KI) administration program that sets different projected thyroid radioactive dose thresholds for treatment of different population groups may be logistically impractical to implement during a radiological emergency. If emergency planners reach this conclusion, FDA recommends that KI be administered to both children and adults at the lowest intervention threshold (i.e., >5 rem (0.05 Sv) projected internal thyroid dose in children) (FDA 2001).

e For other information on other radiological prophylactics and medical countermeasures, refer to http://www.fda.gov/cder/drugprepare/default.htm, http:/www.bt.cdc.gov/radiation, or http://www.orau.gov/reacts.

TABLE ES-2 Emergency Worker Guidelines in the Early Phase 1[a]

Total Effective Dose Equivalent (TEDE) Guideline[b]	Activity	Condition
5 rem (0.05 Sv)	All occupational exposures.	All reasonably achievable actions have been taken to minimize dose.
10 rem (0.1 Sv)	Protecting valuable property necessary for public welfare (e.g., a power plant).	• All appropriate actions and controls have been implemented; however, exceeding 5 rem (0.05 Sv) is unavoidable. • Responders have been fully informed of the risks of exposures they may experience. • Dose >5 rem (0.05 Sv) is on a voluntary basis. • Appropriate respiratory protection and other personal protection is provided and used. • Monitoring available to project or measure dose.
25 rem (0.25 Sv)[c]	Lifesaving or protection of large populations. It is highly unlikely that doses would reach this level in an RDD incident; however, worker doses higher than 25 rem (0.25 Sv) are conceivable in a catastrophic incident such as an IND incident.	• All appropriate actions and controls have been implemented; however, exceeding 5 rem (0.05 Sv) is unavoidable. • Responders have been fully informed of the risks of exposures they may experience. • Dose >5 rem (0.05 Sv) is on a voluntary basis. • Appropriate respiratory protection and other personal protection are provided and used. • Monitoring available to project or measure dose.

[a] In the intermediate and late phases, standard worker protections, including the 5 rem occupational dose limit, would normally apply.

[b] The projected sum of the effective dose equivalent from external radiation exposure and committed effective dose equivalent from internal radiation exposure.

[c] EPA's 1992 PAG Manual states, "Situations may also rarely occur in which a dose in excess of 25 rem for emergency exposure would be unavoidable in order to carry out a lifesaving operation or avoid extensive exposure of large populations." Similarly, the National Council on Radiation Protection and Measurements (NCRP) and International Commission on Radiological Protection (ICRP) raise the possibility that emergency responders might receive an equivalent dose that approaches or exceeds 50 rem (0.5 Sv) to a large portion of the body in a short time (NCRP 1993). If lifesaving emergency responder doses approach or exceed 50 rem (0.5 Sv) emergency responders must be made fully aware of both the acute and the chronic (cancer) risks of such exposure.

agencies and organizations. The operational guidelines are organized into seven groups that are generally categorized by the phase of emergency response in which they would be implemented or used for planning purposes. Individual groups are further categorized into subgroups, as appropriate. Operational guidelines were derived for 11 radionuclides: Am-241, Cf-252, Cm-244, Co-60, Cs-137, Ir-192, Po-210, Pu-238, Pu-239, Ra-226, and Sr-90. Table ES-3 provides a summary of the operational guideline groups and subgroups.

ES.2 RELATIONSHIP OF OPERATIONAL GUIDELINES TO PAGS AND OTHER GUIDELINES

As previously noted, the operational guidelines in this report complement related guidelines called DRLs published by the FRMAC. The DRLs support implementation of the EPA PAG Manual (EPA 400-R-92-001). The operational guidelines presented here and the FRMAC DRLs are analogous, but have been developed to address different audiences.

TABLE ES-3 Operational Guidelines: Groups and Subgroups

Groups	Subgroups
A. Access control during emergency response operations	1. Life- and property-saving measures 2. Emergency worker demarcation
B. Early-phase protective action	1. Evacuation 2. Sheltering
C. Relocation from different areas and critical infrastructure utilization in relocation areas	1. Residential areas 2. Commercial and industrial areas 3. Other areas, such as parks and monuments 4. Hospitals and other health care facilities 5. Critical transport facilities 6. Water and sewer facilities 7. Power and fuel facilities
D. Temporary access to relocation areas for essential activities	1. Worker access to businesses for essential actions 2. Public access to residences for retrieval of property, pets, records
E. Transportation and access routes	1. Bridges 2. Streets and thoroughfares 3. Sidewalks and walkways
F. Release of property from radiologically controlled areas	1. Personal property, except wastes 2. Waste 3. Hazardous waste 4. Real property, such as lands and buildings
G. Food consumption	1. Early-phase food guidelines 2. Early-phase soil guidelines 3. Intermediate-phase soil guidelines 4. Intermediate- to late-phase soil guidelines

The DHS PAGs were promulgated to extend the scope of existing federal guidance (EPA's PAGs) to specifically address RDDs and INDs. The EPA PAGs were designed to be generic to all radiological accidents or incidents, although principally designed for nuclear power plant accidents. The two sets of PAGs are generally compatible; a revised version of the EPA PAGs (currently in draft) subsumes the DHS PAGs and is fully compatible.

The FRMAC DRLs are derived for generic radiological disasters and are designed to address the early and initial portion of the intermediate phases of a radiological accident or incident. They are valid in general and most appropriate for a suburban or rural areas. The operational guidelines are derived specifically to address RDDs with an emphasis on issues unique to a dense urban area during the later intermediate and late phases, and to suburban and rural areas during the late phases, of response. The operational guidelines are immediately applicable to an RDD involving any of the 11 most likely radionuclides expected to be employed for an RDD (Am-241, Cf-252, Cm 244, Co 60, Cs 137, Ir-192, Po-210, Pu-238, Pu-239, Ra-226, and Sr-90). The FRMAC DRLs are adequate and appropriate for immediate application to any radiological event, including RDDs, especially if more than one radionuclide is involved or if the radionuclide is unknown. Differences will arise between these operational guidelines and FRMAC DRLs because of the tailoring of computations to make them less generic and more incident-specific.

ES.3 SUMMARY OF OPERATIONAL GUIDELINE GROUPS AND SUBGROUPS AND THEIR APPLICATION

The sections that follow present a summary of each operational guideline group and subgroup, with information on their intended use, corresponding PAGs, numerical values in the form of lookup tables, end-user guidance, and relevant information on the assumptions applied in their development.

ES.3.1 Group A: Access Control during Emergency Response Operations

Group A operational guidelines are designed to assist in decision making for protecting first responders and emergency workers in the early phase of response to an RDD incident. They can be used to limit access time to the incident area based on preliminary measurement data on contamination. Group A operational guidelines are presented as stay times for use by first responders in establishing radiological control boundaries and were calculated on the basis of a 5 rem dose criterion for emergency workers. Table ES-4 provides the most restrictive stay times that would result in a 5 rem dose for the specified activity concentration/exposure rate. For a different activity concentration/exposure rate or dose limit, the corresponding stay times can be obtained by scaling the values listed in Table ES-4 or using the RESRAD-RDD software.

Group A stay-time tables were generated on the basis of either air concentration or ground surface concentration in terms of one of the following measurements: (1) gross alpha, (2) gross β-γ, (3) γ exposure rate, and (4) radionuclide-specific activity.

Since little information would be known about the type and extent of contamination shortly after an incident, the following objectives were considered when developing the stay times: (1) the stay times are applicable immediately after an RDD incident, (2) they are independent of the location and type of release, and (3) they are simple to implement. Potential exposures to radiation were considered to result from (1) inhalation of airborne radioactive particulates, (2) external exposure due to air submersion, and (3) external exposure to materials deposited on the ground surface. For the first responders and workers who do not wear respirators, the radiation dose would also result from direct ingestion of contaminated dust particles. Two different types of respirators that provide different levels of protection were considered. Table ES-4 also illustrates the importance of having appropriate and adequate measurement data. Although early on it may not be possible to identify the actual radionuclide involved, it is extremely helpful to identify the principal type of radiation (i.e., whether the radionuclide or the radiological hazard is primarily from a beta/gamma emitter or an alpha emitter).

ES.3.2 Group B: Early-Phase Protective Action (Evacuation or Sheltering)

Group B operational guidelines are designed to help decision makers make timely protective action decisions, such as evacuating or sheltering the general public, in the early response phase (i.e., the first four days) following an RDD incident. The operational guidelines were derived by using two methodologies, the FRMAC methodology and the OGT methodology.[1] The FRMAC methodology is an emulation of FRMAC's published methods and

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[1] The FRMAC methodology described here is an emulation of the computational process used by FRMAC, but is not quite identical. The OGT emulation includes additional dose pathways (incidental soil/dust ingestion and external exposure to resuspended contamination), which are omitted in FRMAC's published methods. The

is designed specifically for this group and should be used in an emergency situation for evacuation and sheltering-in-place decisions. The OGT methodology presented in this group is for comparison and to demonstrate the use of the consistent method that was used for other groups. Group B operational guidelines correspond to a PAG of 1 rem (for the general public) or 5 rem (for early response workers). Column 2 of Table ES-5 lists the most restrictive operational guidelines developed for Group B. When the initial ground surface concentration exceeds the guideline value, evacuating or sheltering the general public in the contaminated area should be considered.

The FRMAC methodology, as emulated by OGT, assumed that an infinitely large outdoor ground surface was contaminated, and that the resuspension of deposited radionuclides on the ground surface results in air contamination. A receptor was assumed to incur radiation doses through (1) exposure to external radiation from the contaminated ground surface, (2) inhalation of contaminated air, (3) exposure to external radiation from submersion in resuspended contamination, and (4) ingestion of contamination deposited on the ground surface. Note that FRMAC's published methods omit the last two pathways (external exposure to resuspended contamination and incidental soil/dust ingestion). Adjustments to the outdoor external radiation and air concentration for radiation exposures incurred indoors were made with the use of a shielding factor and an indoor dust filtration factor.

In the OGT methodology, multiple contaminated surfaces were considered, including an outdoor ground surface measuring 10,000 m^2, as well as the exterior of a building (four walls and the roof). It was assumed that the RDD incident occurred in an urban environment where resuspension of deposited radionuclides on the ground surface was enhanced by light traffic, thereby increasing air contamination. Note that for other traffic conditions (e.g., reduced traffic or heavy traffic) the RESRAD-RDD software can be used to derive site-specific operational guidelines.

FRMAC method is designed primarily for the early-phase and initial portion of the intermediate-phase applications for any single or combination of radionuclides, whereas the OGT method can be used for all (early, intermediate, and late) phases involving any of the eleven selected radionuclides. The FRMAC method is currently being updated to match the new EPA PAG guidance. It is expected that both methods will produce similar (if not identical) operational guidelines.

TABLE ES-4 Group A Stay Times for Access Control during Emergency Response Operations

Available measurement	Activity/ Exposure[b]	Stay Times That Would Result in a 5 rem Dose[a]											
		Most restrictive	Am-241	Cf-252	Cm-244	Co-60	Cs-137	Ir-192	Po-210	Pu-238	Pu-239	Ra-226	Sr-90
Without Respirator													
Surface concentration	1 μCi/cm^2	47 min	59 min	4.4 h	1.7 h	16 h	61 h	48 h	6.4 h	52 min	47 min	5.9 h	130 h
Air concentration	1 μCi/m^3[c]	28 s	36 s	2.6 min	1 min	9.7 min	37 min	29 min	3.9 min	31 s	28 s	3.5 min	1.3 h
Exposure rate	1 mR/h[d]	36 s	4.4 h	360 h	12 min	7,100 h	6,400 h	7,100 h	36 s	6.2 min	2.6 min	1,900 h	2,800 h
With Full-Face Air-Purifying Respirator (protection factor = 100)													
Surface concentration	1 μCi/cm^2	16 h	95 h	74 h	170 h	16 h	68 h	48 h	2,200 h	88 h	80 h	22 h	340 h
Air concentration	1 μCi/m^3	9.8 min	57 min	45 min	1.7 h	9.8 min	41 min	29 min	22 h	53 min	48 min	13 min	3.4 h
Exposure rate	1 mR/h	3.5 h	420 h	6,000 h	21 h	7,100 h	7,100 h	7,100 h	3.5 h	10h	4.4 h	7,000 h	7,100 h
With Full-Face Continuous-Flow Atmosphere-Supplying Respirator (protection factor = 1,000)													
Surface concentration	1 μCi/cm^2	16 h	620 h	86 h	1,600 h	16 h	68 h	48 h	22,000 h	860 h	800 h	22 h	340 h
Air concentration	1 μCi/m^3	9.8 min	6.2 h	52 min	16 h	9.8 min	41 min	29 min	220 h	8.6 h	8 h	13 min	3.4 h
Exposure rate	1 mR/h	34 h	2,800 h	7,000 h	200 h	7,100 h	7,100 h	7,100 h	34 h	100 h	43 h	7,100 h	7,100 h

[a] For any other dose limit, the stay times can be appropriately adjusted. For example, if the dose limit is 25 rem, the table entries can be multiplied by 5.

[b] For any measured activity/exposure, the stay times should be appropriately adjusted. For example, in the case when a worker does not have any respirator, if the measured surface concentration is 5 μCi/cm^2 (Cs-137), the table entries need to be divided by 5 (61/5 = 12.2 h) to get the stay time that would result in a 5 rem dose.

[c] It is important to identify radionuclides as soon as possible or at least whether alpha or beta/gamma emitters are of primary concern. Until this is determined, respirator protection is essential to allow reasonable stay times.

[d] Exposure rate measurements are most useful for beta/gamma emitters. It is important to determine if the principal hazard is from alpha or beta/gamma emitters as soon as possible – as can be seen if it is confirmed that alpha is not a primary radiation of concern, then the most restrictive stay time goes from seconds to hours.

ES.3.3 Group C: Relocation

Group C is divided into two parts. Part 1 concerns relocation from areas impacted by an RDD incident. Part 2 concerns continuous utilization of critical infrastructure within relocation areas. These operational guidelines were developed to support decision making during the intermediate phase of response after an RDD incident. Group C operational guidelines correspond to a PAG of 5 rem/yr for occupational exposure, and for the general public, PAGs of 2 rem/yr for the first year and 0.5 rem/yr for subsequent years.

ES.3.3.1 Group C Part 1: Relocation from Residential, Commercial/Industrial, and Other Areas

The operational guidelines for Group C Part 1 can be used to delineate impacted areas that, if inhabited or occupied, could result in radiation doses exceeding the relocation PAGs. The impacted areas are divided into three categories for consideration: residential areas (subgroup C1), commercial/industrial areas (subgroup C2), and other areas (subgroup C3). The other areas in subgroup C3 include monuments, parks, cemeteries, and special areas that are not included under subgroups C1 and C2.

Column 3 of Table ES-5 lists the most restrictive operational guidelines calculated for Group C Part 1. These most restrictive operational guidelines correspond to the residential areas. For industrial/commercial and other areas, the less restrictive operational guidelines are listed in Table 5.10 of Chapter 5. If the initial ground surface concentration of an impacted area exceeds the operational guideline, access to that area should be limited.

For deriving the operational guidelines, radionuclides were assumed to be dispersed on an outdoor ground surface and inside and outside of a building, including the roof, the exterior walls, the interior walls, and the interior floor. Radionuclide concentrations on the surfaces decreased with time through weathering and radioactive decay. Due to human activities and vehicular traffic, some radionuclides on the surfaces were resuspended and became airborne. Therefore, potential radiation exposure incurred by a receptor could result from external radiation (through groundshine and submersion), inhalation, and ingestion.

ES.3.3.2 Group C Part 2: Critical Infrastructure Utilization in Relocation Areas

The operational guidelines for Group C Part 2 are intended as screening values so that facilities critical to the public welfare in a relocation area can continue to operate after an RDD incident. The critical infrastructures considered in Part 2 include hospitals and other health care facilities (subgroup C4), transport facilities (subgroup C5), water and sewer facilities (subgroup C6), and power and fuel facilities (subgroup C7). Optimization principles should be employed in evaluating options for the continued use of critical infrastructures such that the potential doses to workers and the public are considered within the context of the public need. For deriving operational guidelines for these circumstances, which are assumed to be relatively short in duration (less than a year), an occupational PAG of 5 rem in the first year was used for workers, and 2 rem in the first year was used for the general public. However, as with other protective action recommendations, these criteria may be adjusted on the basis of public welfare needs. The information presented in Chapter 6 and the RESRAD-RDD software tool described in Chapter 12 can be used to calculate operational guidelines based on other dose criteria.

Column 4 of Table ES-4 lists the most restrictive operational guidelines derived for the different critical infrastructures considered. These guidelines should be used for comparison with the measured initial ground surface concentrations taken from the impacted area where the infrastructure is located.

The radiation sources and exposure pathways considered for Group C Part 2 were the same as those for Group C Part 1.

TABLE ES-5 Operational Guidelines (pCi/m^2) for Groups B, C, and E[a]

	Group B	Group C	Group C	Group E	Group E	
Radionuclide	Evacuation/ Sheltering[b]	Relocation[c]	Critical Infrastructure Utilization[d]	Vehicle Access to Bridges and Streets/ Thoroughfares[e]	Restricted Access to Sidewalks/ Walkways[f]	Unrestricted Access to Sidewalks/ Walkways[f]
Am-241	4.1E+06	2.25E+06	2.23E+07	2.94E+08	2.72E+08	1.17E+07
Cf-252	2.0E+07	1.15E+07	1.04E+08	1.44E+09	1.09E+09	5.46E+07
Cm-244	6.9E+06	4.02E+06	3.75E+07	4.97E+08	4.61E+08	1.97E+07
Co-60	4.1E+08	5.54E+06	2.48E+08	1.82E+09	1.98E+09	5.29E+07
Cs-137	1.6E+09	1.83E+07	8.65E+08	7.56E+09	6.94E+09	1.66E+08
Ir-192	1.2E+09	1.93E+08	2.36E+09	1.78E+10	1.89E+10	9.47E+08
Po-210	6.3E+07	2.35E+07	1.25E+08	7.52E+09	1.04E+09	5.21E+07
Pu-238	3.6E+06	1.99E+06	1.94E+07	2.57E+08	2.38E+08	1.02E+07
Pu-239	3.3E+06	1.81E+06	1.78E+07	2.35E+08	2.18E+08	9.33E+06
Ra-226	3.8E+07	3.91E+06	1.04E+08	1.34E+09	9.17E+08	2.99E+07
Sr-90	1.6E+09	6.79E+07	1.74E+09	1.46E+11	1.43E+10	3.67E+08

[a] Although presented to 3 significant digits to maintain calculational accuracy, it is anticipated that they will be applied to only 1 significant digit in field application.

[b] For Group B, most operational guidelines are based on the OGT methodology, except for Co-60, Cs-137, and Ir-192 gamma emitters. For these radionuclides, FRMAC's assumption of an infinitely large area of contamination resulted in more restrictive operational guidelines for gamma emitters.

[c] The guideline values for relocation from the residential area are the most restrictive. The dose criteria for relocation are 2 rem the first year and 0.5 rem per year thereafter.

[d] Utilization of hospitals and other health care facilities resulted in the most restrictive guideline values for all radionuclides, except Co-60, Cs-137, Ir-192, Po-210, Ra-226, and Sr-90. For those, utilization of other facilities resulted in the most restrictive guideline values. The dose criteria used for critical infrastructure utilization are 5 rem for workers and 2 rem for the general public.

[e] The dose criteria used for unrestricted vehicle access to bridges and streets/thoroughfares are the relocation PAG (i.e., 2 rem in the first year and 0.5 rem per year thereafter), and for restricted access, the dose used is 5 rem per year. However, the restricted access resulted in more conservative guidelines; therefore, the same can be used for unrestricted access.

[f] The dose criteria used for unrestricted access are the relocation PAG (i.e., 2 rem in the first year and 0.5 rem per year thereafter). For restricted access, the dose used is 5 rem per year.

ES.3.4 Group D: Temporary Access to Relocation Areas for Essential Activities

The operational guidelines for Group D are developed to define protective actions or restrictions necessary to allow for temporary access to relocation areas. The guidelines are expressed in terms of stay times, which are total time periods during which the public or employees may access the contaminated areas and have reasonable assurance that their doses will be below the dose criterion used. The total time may be distributed over several visits or work periods in the area. Tables ES-6 and ES-7 list the stay times corresponding to a 500 mrem dose through outdoor and indoor exposure, respectively. They correspond to different initial concentration levels on the street ranging from 1×10^6 to 1×10^{11} pCi/m^2.

In deriving stay times, doses were estimated for different critical receptors that would be allowed temporary access in these contaminated areas. Potential exposure pathways considered for these receptors include direct external radiation from a contaminated street and building (roofs, walls, and floor), external radiation from submersion in contaminated air, inhalation of contaminated airborne dust particles and radon, and incidental ingestion of contaminated dust particles.

ES.3.5 Group E: Transportation and Access Routes

The operational guidelines for Group E are intended to assist in determining whether contaminated bridges, streets and thoroughfares, or sidewalks and walkways in a relocation area can remain open for unrestricted or restricted access. They consider regular or periodic access to the transportation routes and are applicable during the intermediate response phase after an RDD incident.

TABLE ES-6 Group D Stay Times for Access to Outdoor Locations

Radionuclide Concentration				Stay Time (continuous exposure time in hours) to Receive 0.5 rem (500 mrem)[a]										
pCi/cm^2	pCi/m^2	Bq/cm^2	Dpm/100 cm^2	Am-241	Cf-252	Cm-244	Co-60	Cs-137	Ir-192	Po-210	Pu-238	Pu-239	Ra-226	Sr-90
1.00E+02	1.00E+06	3.70E+00	2.22E+04	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760
1.00E+03	1.00E+07	3.70E+01	2.22E+05	3.00E+02	6.92E+03	1.99E+03	3.74E+03	> 8760	> 8760	1.05E+03	1.98E+02	1.55E+02	1.94E+03	> 8760
1.00E+04	1.00E+08	3.70E+02	2.22E+06	8.68E+00	4.57E+01	1.46E+01	2.72E+02	1.09E+03	1.42E+03	6.89E+01	7.57E+00	6.94E+00	7.82E+01	2.71E+03
1.00E+05	1.00E+09	3.70E+03	2.22E+07	8.68E-01	3.94E+00	1.46E+00	2.63E+01	9.60E+01	9.86E+01	6.21E+00	7.57E-01	6.94E-01	6.03E+00	1.90E+02
1.00E+06	1.00E+10	3.70E+04	2.22E+08	8.68E-02	3.94E-01	1.46E-01	2.63E+00	9.36E+00	9.61E+00	6.21E-01	7.57E-02	6.94E-02	6.03E-01	1.53E+01
1.00E+07	1.00E+11	3.70E+05	2.22E+09	8.68E-03	3.94E-02	1.46E-02	2.63E-01	9.36E-01	9.61E-01	6.21E-02	7.57E-03	6.94E-03	6.03E-02	1.53E+00

[a] A stay time >8,760 hours indicates that the dose criterion (in this case 0.5 rem in a year) used for the derivation of stay times at the specific concentrations will not be exceeded under continuous 24 hours/day, 365 days per year exposures (i.e., no protective actions are necessary to avert doses at or above the criterion. For concentrations and radionuclide combinations that exceed 8,760 hours, Chapter 7 should be used to determine the new stay times.

TABLE ES-7 Group D Stay Times for Access to Indoor Locations

Radionuclide Concentration				Stay Time (continuous exposure time in hours) to Receive 0.5 rem (500 mrem)[a]										
pCi/cm^2	pCi/m^2	Bq/cm^2	Dpm/100 cm^2	Am-241	Cf-252	Cm-244	Co-60	Cs-137	Ir-192	Po-210	Pu-238	Pu-239	Ra-226	Sr-90
1.00E+02	1.00E+06	3.70E+00	2.22E+04	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760
1.00E+03	1.00E+07	3.70E+01	2.22E+05	6.51E+02	7.39E+03	1.52E+03	> 8760	> 8760	> 8760	> 8760	5.17E+02	4.44E+02	6.23E+03	> 8760
1.00E+04	1.00E+08	3.70E+02	2.22E+06	1.80E+01	1.57E+02	3.26E+01	6.74E+02	3.53E+03	> 8760	6.06E+02	1.57E+01	1.44E+01	2.85E+02	> 8760
1.00E+05	1.00E+09	3.70E+03	2.22E+07	1.80E+00	8.41E+00	3.04E+00	6.38E+01	2.81E+02	2.47E+02	2.89E+01	1.57E+00	1.44E+00	1.46E+01	1.08E+03
1.00E+06	1.00E+10	3.70E+04	2.22E+08	1.80E-01	8.41E-01	3.04E-01	6.34E+00	2.65E+01	2.31E+01	2.80E+00	1.57E-01	1.44E-01	1.46E+00	6.63E+01
1.00E+07	1.00E+11	3.70E+05	2.22E+09	1.80E-02	8.41E-02	3.04E-02	6.34E-01	2.65E+00	2.31E+00	2.80E-01	1.57E-02	1.44E-02	1.46E-01	5.77E+00

[a] A stay time >8,760 hours indicates that the dose criterion (in this case 0.5 rem in a year) used for the derivation of stay times at the specific concentrations will not be exceeded under continuous 24 hours/day, 365 days per year exposures (i.e., no protective actions are necessary to avert doses at or above the criterion. For concentrations and radionuclide combinations that exceed 8,760 hours, Chapter 7 should be used to determine the new stay times.

The derived operational guidelines (expressed as ground surface concentrations) are listed in columns 5, 6, and 7 of Table ES-5. The operational guidelines derived for contaminated bridges are similar to those derived for contaminated streets/thoroughfares. The operational guidelines derived for contaminated sidewalks/walkways to allow for personal access are more restrictive than those derived for contaminated bridges and streets/thoroughfares to allow for vehicle access. The operational guidelines in Table ES-5 were derived using a PAG of 5 rem/yr for occupational exposure and PAGs of 2 rem/yr for the first year and 0.5 rem/yr for subsequent years for the general public. Operational guidelines using dose criteria different than these PAGs can be computed using procedures in Chapter 8 or using the RESRAD-RDD software tool described in Chapter 12.

In considering the use of bridges and streets/thoroughfares, it was assumed that the receptor would be inside a vehicle while driving through these areas and would not come in physical contact with the contamination on the ground. Potential radiation doses would result from external radiation (from the contaminated bridges and streets/thoroughfares), inhalation, and air submersion. The contaminated bridges and streets/thoroughfares were considered to be located in an urban environment.

For contaminated sidewalks/walkways, potential exposures were also considered under the conditions of restricted and unrestricted use. Like the contaminated bridges and streets/thoroughfares, the contaminated sidewalks/walkways were also considered to be in an urban environment. In addition to external radiation, inhalation, and air submersion, exposure to the contaminated sidewalks/walkways could also result from ingestion of contaminated dust particles.

ES.3.6 Group F-4: Release of Real Property from Radiologically Controlled Areas

The operational guidelines for Group F-4 were developed for use in releasing real properties — soils and buildings — located within radiologically controlled areas after an RDD incident. The real properties were assumed to be released in the late response phase, when the major cleanup/remediation activities that occurred during the early and intermediate phases were completed. For Group F, the operational guideline is to be derived using an optimization process employing site- or event-specific information. As an example, the operational guidelines in Table ES-8 are based on dose criteria for optimization of 0.1 rem and 0.004 rem for illustration purposes. The guideline values listed in Table ES-8 correspond to initial soil and building concentrations. The residual concentrations in the soils column provides limiting concentrations a residential farm use scenario, and the residual concentrations in buildings column is for a residential building scenario. Concentrations will vary with scenario. See Chapter 9 for concentrations for other scenarios (urban resident, worker, commercial building, etc.).

The operational guidelines for soil were derived by using the RESRAD code (Yu et al. 2001) and considering only soil contamination. The operational guidelines for buildings were derived by using the RESRAD-BUILD code (Yu et al. 2003) and considered only building contamination, existing on the interior floor, on the inside and outside of the surrounding four walls, and on the roof.

Because of the uncertainty concerning the location of an RDD incident and the affected population, probabilistic analyses were conducted to derive the operational guidelines. The 50th percentile and the mean plus two standard deviations (mean + 2σ) of the peak dose-to-source ratios (DSRs) were used. For site- and event-specific analyses required by the optimization process to derive operational guidelines for cleanup, RESRAD codes may be used in either a deterministic mode to assess a reasonably conservative use scenario or in the probabilistic mode to address likely exposures and uncertainties.

TABLE ES-8 Group F-4 Operational Guidelines for Residual Concentrations in Soils (pCi/g) and Buildings (pCi/m^2) Obtained by Using the Mean + 2σ Values from Peak Dose-to-Source Ratio Distributions

	Residual Concentrations in Soils		Residual Concentrations in Buildings	
Radionuclides	100 mrem/yr	4 mrem/yr	100 mrem/yr	4 mrem/yr
Am-241	9.80E+02	3.92E+01	4.1E+04	1.6E+03
Cf-252	5.13E+01	2.05E+00	5.5E+04	2.2E+03
Cm-244	2.44E+03	9.77E+01	7.5E+04	3.0E+03
Co-60	9.28E+00	3.71E-01	4.6E+05	1.8E+04
Cs-137	3.70E+01	1.48E+00	1.9E+06	7.5E+04
Ir-192	1.01E+02	4.05E+00	1.7E+06	6.7E+04
Po-210	1.87E+02	7.48E+00	1.1E+06	4.4E+04
Pu-238	1.11E+03	4.43E+01	3.7E+04	1.5E+03
Pu-239	1.01E+03	4.04E+01	3.2E+04	1.3E+03
Ra-226	1.63E+00	6.53E-02	1.6E+05	6.4E+03
Sr-90	2.89E+01	1.16E+00	8.2E+06	3.3E+05

ES.3.7 Group G: Food Consumption

Group G concerns potential radiation exposures from food consumption after an RDD incident. Operational guidelines for four subgroups were derived. Table ES-9 lists the final operational guidelines for all subgroups. Operational guidelines for subgroups 1 and 2 can be used for making decisions regarding the embargo of food products produced from areas impacted during an RDD incident. Operational guidelines for subgroups 3 and 4 can be used to determine whether agricultural activities should be permitted in the impacted areas after an RDD incident.

The first subgroup of operational guidelines was derived by using a methodology consistent with the one used by the U.S. Food and Drug Administration (FDA) for developing the derived intervention levels (DILs) for foods after a nuclear accident. It considers potential radiation exposure from food ingestion and is based on a food PAG of either 5 rem/yr committed equivalent dose to an individual organ or tissue, or 500 mrem/yr committed effective dose (CED), whichever is more limiting. To differentiate from the published FDA DILs, the derived food concentration values that use the FDA methodology are called planning values (PVs). These PVs are used as Group G, subgroup 1, operational guidelines.

TABLE ES-9 Group G Food Planning Values (PVs) for Subgroup 1 and Soil Operational Guidelines for Subgroups 2–4

	Food PVs (pCi/kg)	Soil Operational Guidelines (pCi/m^2)		
Radionuclide	Subgroup 1	Subgroup 2[a]	Subgroup 3[b]	Subgroup 4[c]
Am-241	1.30E+02	1.30E+03	6.49E+06	2.41E+09
Cf-252	9.72E+01	9.73E+02	4.95E+06	5.96E+09
Cm-244	1.84E+02	1.84E+03	9.21E+06	2.55E+09
Co-60	2.00E+04	2.00E+05	3.48E+07	1.57E+09
Cs-137	3.78E+04	1.34E+05	7.39E+07	5.70E+08
Ir-192	7.56E+04	7.63E+05	7.53E+08	5.34E+10
Po-210	4.05E+01	4.07E+02	1.74E+06	4.07E+08
Pu-238	1.59E+02	1.59E+03	7.98E+06	2.08E+09
Pu-239	1.46E+02	1.46E+03	7.30E+06	1.91E+09
Ra-226	5.40E+01	5.40E+02	2.86E+05	5.35E+07
Sr-90	2.97E+03	2.97E+04	2.27E+06	5.60E+07

[a] Subgroup 2 soil operational guidelines are derived from the subgroup 1 PVs.

[b] Subgroup 3 soil operational guidelines are derived from the subgroup 1 PVs.

[c] Subgroup 4 soil operational guidelines are derived on the basis of the 500 mrem per year dose (CED).

In deriving subgroup 2 operational guidelines, the PVs for subgroup 1 were applied for comparison with calculated concentrations in crops harvested or animal products produced after an RDD incident. The operational guidelines were developed by considering crops or fodder (consumed by livestock) that had been growing during the RDD incident and became contaminated by radionuclides deposited to foliage and the ground surface from a passing contamination plume generated in the incident. The operational guidelines are expressed in terms of concentrations in surface soil that would result in plant/milk concentrations equivalent to the PVs of subgroup 1. Subgroup 2 operational guidelines are intended for use in the early phase of response after an RDD incident.

Subgroup 3 soil operational guidelines consider crops and fodder planted after an RDD incident, and are intended for use in the intermediate phase of response after the incident. Concentrations in plants and animal products were related to soil concentrations and were compared with PVs to derive the operational guidelines.

In subgroup 4, plant and animal product concentrations were also linked to soil concentrations. However, unlike subgroup 3, which compares plant and animal product concentrations with PVs, the plant and animal product concentrations were converted to radiation doses through consumption. A PAG of 500 mrem/yr (CED) was then used for comparison with the calculated doses. Subgroup 4 operational guidelines are intended for use in the intermediate-to-late phase of response after an RDD incident.

ES.3.8 Additional Operational Guidelines and the RESRAD-RDD Companion Software Tool

During the development of RDD operational guidelines for Groups A through G, some additional exposure scenarios were analyzed, and the corresponding operational guidelines were derived. These potential exposure scenarios included flushing contaminated streets, cleaning contaminated vehicles, and releasing contaminated vehicles. These scenarios are discussed in Chapter 11 of the main report; however, they are not included in the companion software.

The methodology and parameters used in calculating operational guidelines for Groups A through G were initially coded in Microsoft Excel® spreadsheets to make it easy for OGT members to calculate the stay times and operational guidelines. A user-friendly graphical user interface was developed later so that the software tool (RESRAD-RDD) could be used by emergency first responders and dose/risk assessors. It is anticipated that this tool could be used in conjunction with or integrated within other tools available for radiological emergency response (e.g., FRMAC's Turbo FRMAC) and with other radiological dose and risk assessment tools for humans (e.g., RESRAD-OFFSITE [Yu et al. 2007], for evaluating doses to receptors located away from the location of an RDD incident), and with dose assessment tools for animals and plants (e.g., RESRAD-BIOTA [ISCORS 2004], for evaluating potential ecological impacts to aquatic and terrestrial biota resulting from RDD-related radionuclides during the intermediate- to long-term recovery phase).

ES.4 REFERENCES

DHS (U.S. Department of Homeland Security), 2008, "Planning Guidance for Protection and Recovery Following Radiological Dispersal Device (RDD) and Improvised Nuclear Device (IND) Incidences," *Federal Register* 73 (149):45029–45048, August 1.

EPA (U.S. Environmental Protection Agency), 1992, *Manual of Protective Action Guides and Protective Actions for Nuclear Incidents*, EPA 400-R-92-001, Washington, D.C.

FDA (U.S. Food and Drug Administration), 2001, "Guidance: Potassium Iodide as a Thyroid Blocking Agent in Radiation Emergencies, "*Federal Register* 66:64046, Dec. 11.

ISCORS (Interagency Steering Committee on Radiation Standards), 2004, *User's Guide, Version 1, RESRAD-BIOTA: A Tool for Implementing a Graded Approach to Biota Dose Evaluation*, Technical Report 2004-02, DOE/EH-0676, January.

Yu, C., et al., 2001, *User's Manual for RESRAD Version 6*, ANL/EAD-4, Argonne National Laboratory, Argonne, Ill.

Yu, C., et al., 2003, *User's Manual for RESRAD-BUILD Version 3*, ANL/EAD/03-1, Argonne National Laboratory, Argonne, Ill.

Yu, C., et al., 2007, *User's Manual for RESRAD-OFFSITE Version 2,* ANL/EVS/TM/07-1, DOE/HS-0005, NUREG/CR-6937, June.

1 INTRODUCTION

The government's ability to respond to a radiological terrorist incident has been a central focus since the terrorist attacks in New York City on September 11, 2001. At the direction of the White House Office of Science and Technology Policy, the interagency Consequence Management, Site Restoration/Cleanup and Decontamination Subgroup (CMS) of the Radiological Dispersal Device (RDD)/Improvised Nuclear Device (IND) Preparedness Working Group has addressed this need. The CMS identified protective action guides (PAGs) appropriate for early and intermediate phases of response; provided a risk management framework for addressing long-term cleanup and recovery that incorporates the principles of optimization, stakeholder involvement, and shared accountability; and highlighted needs and concepts for operational guidelines to implement the PAGs. These PAGs and recommendations were reviewed by the Federal agencies and approved for government use as "Planning Guidance for Protection and Recovery Following Radiological Dispersal Device (RDD) and Improvised Nuclear Device (IND) Incidents" (*Federal Register*, 73 FR 149).

1.1 NEED FOR OPERATIONAL GUIDELINES

The basis and need for operational guidelines is discussed in Section 1.1.1, and the process used to develop operational guidelines is described in Section 1.1.2.

1.1.1 Basis and Need for Operational Guidelines

The primary purpose of the operational guidelines is to support implementation of the Department of Homeland Security's (DHS) PAGs for RDDs published in the *Federal Register* (73 FR 149). As cited in the DHS PAGs, by agreement with the Environmental Protection Agency (EPA), the DHS PAG guidance and its substance will be incorporated without change into the revision of the 1992 *EPA Manual of Protective Action Guides and Protective Actions for Nuclear Incidents* (the EPA PAG Manual; currently EPA 400-R-92-001). As such, the operational guidelines presented in this report will also support implementation of the EPA PAG Manual.

A PAG is the projected dose to a reference individual from an accidental or deliberate release of radioactive material at which a specific protective action (e.g., sheltering or evacuation of the public and restriction of water and food consumption) to reduce or avoid that dose is recommended. Protective actions are designed to be taken before the anticipated dose is realized. The PAGs are not regulatory limits or firm distinctions between safe and unsafe. Rather, they are guidelines for determining if protective actions for public and worker safety are warranted for a specific radiological incident. Tables 1.1 and 1.2, taken from *Federal Register* 73 FR 149, present the PAGs and Emergency Worker Guidelines appropriate for use in various phases of emergency preparedness and in response to an RDD. For context, Figure 1.1 depicts the relationship between possible routes of exposure from an RDD incident, protective measures, and time frames for exposure effects relative to the early, intermediate, and late or long-term recovery phases of the emergency response.

TABLE 1.1 Protective Action Guidelines for RDD and IND Incidents

Phase	Protective Action Recommendation	Protective Action Guide
Early	Sheltering-in-place or evacuation of the public[a]	1 to 5 rem (0.01-0.05 Sv) projected dose[b]
	Administration of prophylactic drugs – potassium iodide[c, d]; administration of other prophylactic or decorporation agents[e]	5 rem (0.05 Sv) projected dose to child's thyroid[c, d]
Intermediate	Relocation of the public	2 rem (0.02 Sv) projected dose first year; subsequent years, 0.5 rem/yr (0.005 Sv/yr) projected dose[b]
	Food interdiction	0.5 rem (0.005 Sv) projected dose, or 5 rem (0.05 Sv) to any individual organ or tissue in the first year, whichever is limiting
	Drinking water interdiction	0.5 rem (0.005 Sv) projected dose in the first year

[a] Should normally begin at 1 rem (0.01 Sv); take whichever action (or combination of actions) that results in the lowest exposure for the majority of the population. Sheltering may begin at lower levels, if advantageous.

[b] Total effective dose equivalent (TEDE). The sum of the effective dose equivalent from external radiation exposure and the committed effective dose equivalent from internal radiation exposure.

[c] Provides thyroid protection from radioactive iodine only.

[d] Committed dose equivalent (CDE). The FDA understands that a potassium iodide (KI) administration program that sets different projected thyroid radioactive dose thresholds for treatment of different population groups may be logistically impractical to implement during a radiological emergency. If emergency planners reach this conclusion, FDA recommends that KI be administered to both children and adults at the lowest intervention threshold (i.e., >5 rem (0.05 Sv) projected internal thyroid dose in children) (FDA 2001).

[e] For other information on other radiological prophylactics and medical countermeasures, refer to http://www.fda.gov/cder/drugprepare/default.htm, http:/www.bt.cdc.gov/radiation, or http://www.orau.gov/reacts.

TABLE 1.2 Emergency Worker Guidelines in the Early Phase 1[a]

Total Effective Dose Equivalent (TEDE) Guideline[b]	Activity	Condition
5 rem (0.05 Sv)	All occupational exposures.	All reasonably achievable actions have been taken to minimize dose.
10 rem (0.1 Sv)	Protecting valuable property necessary for public welfare (e.g., a power plant).	• All appropriate actions and controls have been implemented; however, exceeding 5 rem (0.05 Sv) is unavoidable. • Responders have been fully informed of the risks of exposures they may experience. • Dose >5 rem (0.05 Sv) is on a voluntary basis. • Appropriate respiratory protection and other personal protection is provided and used. • Monitoring available to project or measure dose.
25 rem (0.25 Sv)[c]	Lifesaving or protection of large populations. It is highly unlikely that doses would reach this level in an RDD incident; however, worker doses higher than 25 rem (0.25 Sv) are conceivable in a catastrophic incident such as an IND incident.	• All appropriate actions and controls have been implemented; however, exceeding 5 rem (0.05 Sv) is unavoidable. • Responders have been fully informed of the risks of exposures they may experience. • Dose >5 rem (0.05 Sv) is on a voluntary basis. • Appropriate respiratory protection and other personal protection are provided and used. • Monitoring available to project or measure dose.

[a] In the intermediate and late phases, standard worker protections, including the 5 rem occupational dose limit, would normally apply.

[b] The projected sum of the effective dose equivalent from external radiation exposure and committed effective dose equivalent from internal radiation exposure.

[c] EPA's 1992 PAG Manual states, "Situations may also rarely occur in which a dose in excess of 25 rem for emergency exposure would be unavoidable in order to carry out a lifesaving operation or avoid extensive exposure of large populations." Similarly, the National Council on Radiation Protection and Measurements (NCRP) and International Commission on Radiological Protection (ICRP) raise the possibility that emergency responders might receive an equivalent dose that approaches or exceeds 50 rem (0.5 Sv) to a large portion of the body in a short time (NCRP 1993). If lifesaving emergency responder doses approach or exceed 50 rem (0.5 Sv) emergency responders must be made fully aware of both the acute and the chronic (cancer) risks of such exposure.

The PAGs and Emergency Worker Guidelines are dose-based, and it is often difficult to readily measure the dose. Therefore, a need exists for operational measurements of radiation levels, or concentrations in various media, that can be related to the PAGs to facilitate decisions regarding the need for protective actions. As a result, operational guidelines are prederived levels of radioactivity or radionuclide concentrations in various media that can be measured in the field and compared to the PAGs to quickly determine if protective actions are warranted. For example, in the hours and days following an incident, there could be an urgent need for decisions about evacuation or relocation of the public. Determinations regarding critical infrastructures such as access to roads and medical facilities, as well as restoration of power, water, and sewer facilities, may also have to be made. Although some values already exist (e.g., derived response levels [DRLs] from the Federal Radiological Monitoring and Assessment Center [FRMAC] for generic cases, from the U.S. Environmental Protection Agency [EPA] for water, and derived intervention levels [DILs] from the U.S. Food and Drug Administration [FDA] for food) that could potentially serve as operational guidelines, many more were needed for handling various situations.

1.1.2 Relationship of Operational Guidelines to PAGs and Other Guidelines

The operational guidelines in this report complement related guidelines called DRLs published by FRMAC. The DRLs support implementation of the current EPA PAG Manual. The operational guidelines presented here and the FRMAC DRLs are analogous, but have been developed to address different audiences.

The DHS PAGs were promulgated to extend the scope of existing federal guidance (EPA's PAGs) to specifically address RDDs and INDs. The EPA PAGs were designed to be generic to all radiological accidents or incidents, although they were principally designed for nuclear power plant accidents. The two sets of PAGs are generally compatible; a revised version of the EPA PAGs (currently in draft) subsume the DHS PAGs and are fully compatible.

The FRMAC DRLs are derived for generic radiological disasters and are designed to address the early phase and initial portion of the intermediate phase of a radiological accident or incident. They are valid in general and most appropriate for suburban or rural areas. The operational guidelines are derived specifically to address RDDs with an emphasis on issues unique to a dense urban area during the later portion of the intermediate phase and the late phase, and to suburban and rural areas during the late phases, of response. The operational guidelines are immediately applicable to an RDD involving any of the 11 most likely radionuclides expected to be employed for an RDD (Am-241, Cf-252, Cm 244, Co 60, Cs 137, Ir-192, Po-210, Pu-238, Pu-239, Ra-226, and Sr-90). The FRMAC DRLs are adequate and appropriate for immediate application to any radiological event, including RDDs, especially if more than one radionuclide is involved or if the radionuclide is unknown. Differences will arise between these operational guidelines and FRMAC DRLs because of the tailoring of computations to make them less generic and more incident-specific.

1.1.3 Operational Guidelines Development Process

Appropriations language from House Report 108-076, "Making Emergency Wartime Supplemental Appropriations for the Fiscal Year 2003, and for Other Purposes," directed the U.S. Department of Energy (DOE) "to develop standards for the cleanup of contamination resulting from a potential RDD event" (U.S. Congress 2003). In response to this direction and the needs highlighted above, DOE (working through DHS) established the interagency Operational Guidelines Task Group (OGT), a technical support element of the CMS, to develop preliminary operational guidelines for a wide range of property types (e.g., vehicles, roads and bridges, residential and commercial buildings and lands, and special use areas such as parks and monuments) likely to be affected by an RDD incident. The strategic objective of the operational guidelines initiative was to provide numerical guidelines, along with end-user guidance and assistance tools for implementation, that could be incorporated into Federal and State planning and response documents and used by decision makers and first responders in emergency preparedness and emergency response activities.

The OGT consists of regulatory and subject matter experts in radiological and nuclear preparedness and response from many agencies and organizations, including the EPA, U.S. Nuclear Regulatory Commission (NRC), U.S. Department of Defense (DOD), Centers for Disease Control and Prevention (CDC), National Institute of Standards and Technology (NIST), DOE, FRMAC, Washington State Department of Health, and others. The OGT also included health physicists and radiological dose and risk assessment modelers from Argonne National Laboratory (ANL) as a core technical resource, with additional health physics support from Dade Moeller and Associates (DM&A). The OGT coordinated its work through conference calls,

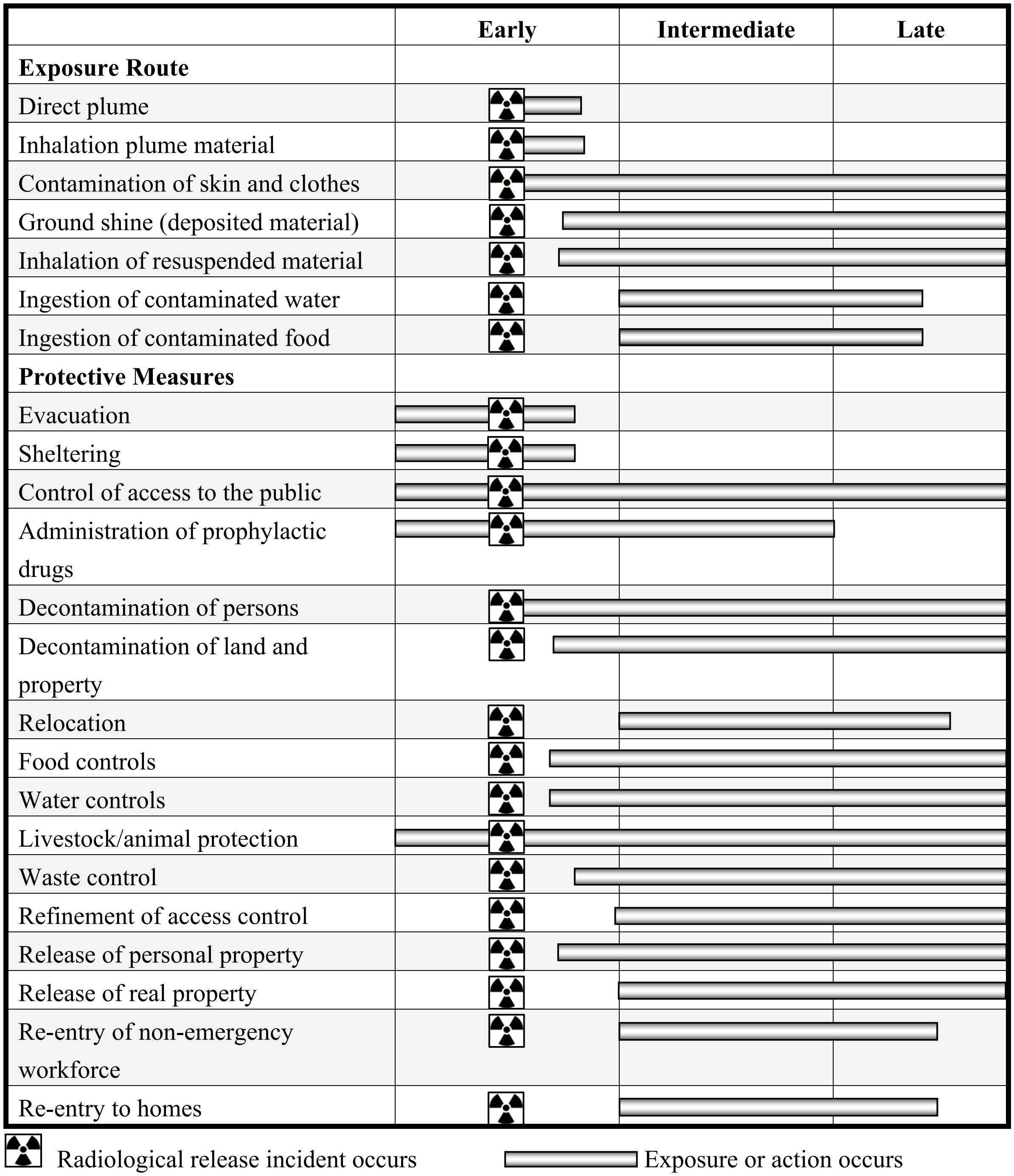

FIGURE 1.1 Relationships among Exposure Routes, Protective Measures, and Time Frames for Effects[1,2]

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1 For some activities, the figure indicates that protective actions may be taken before a release occurs. This would be the case if authorities have prior warning about a potential RDD/IND incident.

2 In certain circumstances, food and water interdiction may occur in early phases. In addition, some exposure routes (e.g., ingestion of contaminated food) may occur earlier than depicted in the figure, depending on the unique characteristics of the incident.

formal meetings, and use of the OGT Web site. A set of core guiding principles was agreed upon by the OGT as a foundation for the consensus-based approach used to develop the guidelines (Table 1.3). Individual OGT members volunteered to serve as "lead coordinators" for each of the operational guidelines groups and subgroups being developed. Lead coordinators generally served as the primary OGT points of contact for facilitating the review and comment of draft operational guidelines products by all OGT members, and leading and summarizing discussions within the OGT on the resolution of comments and refinement of work products, with a goal of achieving a consensus among all OGT members on the appropriate operational guidelines.

TABLE 1.3 Guiding Principles Used to Focus the Development of Operational Guidelines within the OGT

1. Be consistent with PAGs developed through Federal consensus.
2. Strive for consistency with PAGs to be incorporated into the revision of the EPA PAG Manual (EPA 1992).
3. Strive for consistency with available methodologies from FRMAC.
4. Document the rationale and benefits of approaches that might be different from or represent refinements to FRMAC methodologies. Use these to foster improvements to available FRMAC methodologies.
5. Apply the current state of science in radiation protection appropriate for addressing an RDD.
6. Apply a consensus-based process, obtain independent technical peer review, and seek public comment on key products and resources.
7. Respect the views and contributions of fellow OGT members as well as the integrity of OGT work products.

1.2 OPERATIONAL GUIDELINE GROUPS AND SUBGROUPS

The operational guidelines are organized into seven groups that are generally categorized by the phase of emergency response in which they would be implemented or used for planning purposes. Individual groups are further categorized into subgroups as appropriate. Table 1.4 provides a summary of the operational guideline groups and subgroups. A detailed overview of these groups and subgroups is provided below.

TABLE 1.4 Operational Guidelines: Groups and Subgroups

Groups	Subgroups
A. Access control during emergency response operations	1. Life- and property-saving measures 2. Emergency worker demarcation
B. Early-phase protective action	1. Evacuation 2. Sheltering
C. Relocation from different areas and critical infrastructure utilization in relocation areas	1. Residential areas 2. Commercial and industrial areas 3. Other areas, such as parks and monuments 4. Hospitals and other health care facilities 5. Critical transport facilities 6. Water and sewer facilities 7. Power and fuel facilities
D. Temporary access to relocation areas for essential activities	1. Worker access to businesses for essential actions 2. Public access to residences for retrieval of property, pets, records
E. Transportation and access routes	1. Bridges 2. Streets and thoroughfares 3. Sidewalks and walkways
F. Release of property from radiologically controlled areas	1. Personal property, except wastes 2. Waste 3. Hazardous waste 4. Real property, such as lands and buildings
G. Food consumption	1. Early-phase food guidelines 2. Early-phase soil guidelines 3. Intermediate-phase soil guidelines 4. Intermediate- to late-phase soil guidelines

1.2.1 Group A: Access Control during Emergency Response Operations

These operational guidelines are designed to assist responders in decision making for worker health and safety in the early to intermediate phases of response to an RDD incident when the situation has not been fully stabilized or characterized. They are designed to guide responders in establishing radiological control zones or boundaries for the areas directly impacted by the RDD incident where first responders and emergency response personnel are working. They are not intended to restrict emergency responder access, but rather to inform responders of potential radiological hazards existing in the areas and to provide tools to those persons who are responsible for radiation protection during response activities. These operational guidelines may be used to restrict the access of nonessential personnel and members of the public to specific areas. Examples of operational guidelines developed in this group include life- and property-saving measures and emergency worker zone demarcation.

Group A operational guidelines are expressed as a series of reference “stay time” tables for responders who may have access to only limited health physics information and personal protective equipment at the time of the response. For example, the health physics information could include or be limited to measurements of the external exposure rate, gross alpha surface contamination, beta/gamma surface contamination, and/or air concentration. Radionuclide-specific correction factors as well as radionuclide-specific and respiratory protection-specific tables are provided. A detailed discussion about these stay time tables is provided in Chapter 3.

1.2.2 Group B: Early-Phase Protective Action (Evacuation or Sheltering)

These operational guidelines are designed to help decision makers make timely protective action decisions, such as evacuation or sheltering of the general public in the early response phase (i.e., the first four days following the incident). Group B operational guidelines are typically expressed as limiting concentrations of radioactivity in ground surface soil. Group B operational guidelines are discussed in Chapter 4.

1.2.3 Group C: Relocation from Different Areas and Critical Infrastructure Utilization in Relocation Areas

These operational guidelines are intended for early- to intermediate-phase protective actions. They are designed for use in deciding whether to relocate the public from affected areas for a protracted period of time. Screening values are provided to delineate areas that exceed the relocation PAGs. These areas include residential areas, commercial/industrial areas, and other areas such as parks, cemeteries, and monuments. Group C operational guidelines also ensure that facilities critical to the public welfare can continue to operate, if needed. These facilities include hospitals, airports, railroads and ports, water and sewer facilities, and power and fuel facilities. These operational guidelines are typically expressed as soil or street-surface contamination concentrations (e.g., pCi/m^2). Group C operational guidelines are discussed in Chapters 5 and 6.

1.2.4 Group D: Temporary Access to Relocation Areas for Essential Activities

Group D operational guidelines pertain to intermediate-phase protective actions. They are designed to assist in determining the protective action decisions or restrictions necessary to allow for temporary access to relocation areas. For example, the public or owners/employees of businesses may need temporary access to residences or commercial, agricultural, or industrial facilities in order to retrieve essential records, conduct maintenance to protect facilities, prevent environmental damage, attend to animals, or retrieve pets. These operational guidelines describe the level at which these actions can be taken without radiological supervision. The public or employees may occasionally access (i.e., a few days per month) areas that do not exceed these guidelines. Temporary access to relocation areas that exceed these levels should be permitted only under the supervision or with the permission of radiation protection personnel. Examples of these operational guidelines include worker access to businesses for essential actions and public access to residences for retrieval of critical property, pets, or records. They are typically expressed in terms of stay times during which the public or employees may access the areas without receiving the prescribed dose. Group D operational guidelines are discussed in Chapter 7.

1.2.5 Group E: Transportation and Access Routes

These operational guidelines apply to intermediate-phase protective actions. They are designed to assist in determining whether transportation routes (e.g., bridges, highways, streets) or access ways (e.g., sidewalks and walkways) may be used by the public for general, limited, or restricted use. The relocation PAGs serve as the basis for the operational guidelines for general access. For example, operational guidelines may be defined for industrial or commercial use of various roads, bridges, or access ways. These may be necessary to allow for access between nonrelocation areas via a highway that passes through a relocation area or for access to emergency recovery activities in the immediate area of an incident. These operational guidelines assume regular or periodic use and are not appropriate for one-time events, such as evacuation or relocation actions. They are typically expressed as surface contamination concentrations (e.g., pCi/m^2). Group E operational guidelines are discussed in Chapter 8.

1.2.6 Group F: Release of Property from Radiologically Controlled Areas

Group F operational guidelines are intended for intermediate to long-term recovery-phase protective actions. During response and recovery operations, property and wastes (e.g., vehicles, equipment, debris and nonradiological wastes, hazardous waste, buildings and land, etc.) must be cleared from radiologically controlled areas (relocation areas). These operational guidelines support such actions. Because retrieval of cleared or released properties will be difficult, wherever practicable, these levels should be similar to those likely to define late-phase goals. For this reason, they should not be applied to property that will remain in use in controlled areas. These operational guidelines should also be used for screening property that was located outside the controlled area. In general, the operational guidelines in this group provide reasonable assurance that the cleared property is acceptable for long-term unrestricted use (or designated disposition, in the case of wastes) without further reassessment. Property includes personal property, debris and waste, hazardous waste, and real property (i.e., buildings and lands). The operational guidelines for release of real property are discussed in Chapter 9. The operational guidelines for release of contaminated vehicles are discussed in Chapter 11.

It is noteworthy to highlight that, in particular, operational guidelines for real property (subgroup F4, buildings and lands) are designed to support implementation of the CMS's risk management framework, as presented in the PAGs for RDD and IND incidents (73 FR 149). The CMS risk management framework for addressing long-term cleanup and recovery incorporates the principles of optimization, stakeholder involvement, and shared accountability. Subgroup F4 guidelines are unique in that there is no one specific predefined numerical criterion (e.g., expressed in terms of dose or risk) on which to base protective action decisions. These guidelines are intended to be applied in the optimization process, which will likely consider the magnitude and extent of the contamination and the radionuclide(s) involved, proposed long-term land and building use in the affected areas, degree of need for expedited recovery, public welfare issues, cost impacts for each proposed cleanup option, ecological considerations, and other factors. Group F4 operational guidelines are provided as reference values (e.g., soil and building surface concentrations or risks) that can be used as a starting point for evaluating optimization process attributes and impacts relative to a range of dose or risk-based benchmarks (e.g., 500, 100, 25, or 4 millirem per year; comparative lifetime risk ranges, and others) that could be considered as part of recovery phase options. Thus, they are not regulatory dose limits or criteria, but serve as concentration values that provide perspective and aid in the optimization analyses.

1.2.7 Group G: Food Consumption

Group G operational guidelines apply to early through long-term recovery phase protective actions, as needed. They are designed to aid in decision making about the need for placing restrictions on consumption of potentially contaminated foods or on agricultural activities during and following an RDD incident.

Four subgroups of operational guidelines were developed, which are intended for use in conjunction with operational guidelines for other groups. Subgroup G.1 guidelines pertain to the early response phase immediately after the RDD incident. These guidelines can be used to screen against measured concentrations taken from previously harvested food or from animal products exposed during the incident. Subgroup G.1 guidelines also can be used to determine the need for placing an embargo and consumption restrictions on contaminated foods. Subgroup G.2 guidelines also apply to the early phase of response, but they are intended for use in evaluating crops or animal products exposed during the RDD incident (e.g., after the plume has passed). They serve as a comparison with measured concentrations taken from surface soil in which plant foods and fodder had been growing during the incident. Subgroups G.3 and G.4 are intended for the intermediate to long-term recovery phases and can be used for placing land use restrictions on agricultural activities after an RDD incident. They can be used to determine if crops can be grown on residually contaminated soil to produce a harvest that would be acceptable for public consumption. These operational guidelines are discussed in detail in Chapter 10.

1.3 MODELING OF RDD SCENARIOS AND DERIVATION OF OPERATIONAL GUIDELINES

The core methodology and modeling employed in deriving the operational guidelines was developed through a consensus-based process that involved all OGT members. Operational guidelines (Groups A-G), which correspond to specific PAGs, were derived for 11 potential RDD radionuclides: Am-241, Cf-252, Cm-244, Co-60, Cs-137, Ir-192, Po-210, Pu-238, Pu-239, Ra-226, and Sr-90. These radionuclides were determined by a joint DOE and NRC study to be the most likely sources available for potential terrorist use in an RDD (DOE/NRC 2003*).* For the early response phase (Group A), a straightforward concentration method or an exposure-to-dose conversion method was used to derive stay time tables. For the late response phase (Group F), the probabilistic RESRAD and RESRAD-BUILD programs (Yu et al. 2001, 2003) were used to derive property release criteria. The concepts and overarching methodology used to derive operational guidelines for RDD-related radionuclides could also be generally applied, with modifications, to radionuclides associated with an IND.

The methodology developed for the intermediate response phase (Groups B-E) assumes that an outdoor RDD event would contaminate streets, soils, and building surfaces with radioactive materials. Building interiors would also be contaminated as a result of air exchange and human traffic. The methodology can be modified for an indoor RDD event by considering different source partitioning factors. The model considers decay, weathering, a time-dependent resuspension factor, and concentration ratios (partitioning factors) between contaminated areas. A set of exposure pathways was considered in the model: external exposure from contaminants on streets, soils, and buildings; inhalation of dust particles; external exposure from submersion; ingestion of dust particles and plant foods; and indoor radon inhalation. Operational guidelines for each group were derived by using a systematic approach in which (1) applicable scenarios for each group were defined, (2) appropriate receptors for each scenario were identified, and (3) the receptor doses from applicable exposure pathways were estimated. A detailed discussion of the specific methodologies and approaches used to derive the operational guidelines is provided in Chapter 2.

1.4 ADDITIONAL EXPOSURE SCENARIOS AND OPERATIONAL GUIDELINES

Chapter 11 presents additional RDD incident scenarios that were analyzed to support the derivation of the operational guideline groups and subgroups described earlier. Two of these additional scenarios involve the use of water to flush streets and clean vehicles. Accordingly, operational guidelines for street flushing and cleaning contaminated vehicles are provided.

1.5 COMPANION SOFTWARE TOOL FOR FACILITATING IMPLEMENTATION OF OPERATIONAL GUIDELINES

A companion software tool, RESRAD-RDD, was developed to facilitate application of the default set of operational guidelines and to allow calculation of incident-specific operational guidelines through application of user-specified assumptions and environmental transfer parameters that correspond to exposure pathways for incident-specific analyses. The software tool utilizes elements of other codes already within the RESRAD family of codes, along with newly derived models and supporting parameters specific to the RDD scenarios used to determine the operational guidelines. A detailed overview of the RESRAD-RDD software tool and a general user's guide is provided in Chapter 12 of this report.

1.6 COORDINATION OF OGT AND DEVELOPMENT OF OPERATIONAL GUIDELINES WITH FRMAC AND FRMAC ASSESSMENT METHODS

Consistent with the OGT's guiding principles, development efforts for the operational guidelines were coordinated with FRMAC on several occasions. Coordination was achieved through participation of FRMAC representatives in OGT conference calls and meetings, and through OGT representation in a FRMAC Assessment Working Group meeting. Coordination between the DOE's Office of Emergency Response and Office of Nuclear Safety, Quality Assurance, and Environment helped to foster FRMAC–OGT relationships and ensure harmonization of approaches and tools for emergency response being developed through these initiatives. The goals of the coordination were (1) to identify areas of consistency between OGT methods and operational guidelines with existing FRMAC assessment methods for response to more traditional radiological incidents (e.g., nuclear power plant accidents), and (2) to determine the rationale and benefits of OGT approaches that might differ from, or represent refinements to, FRMAC methodologies, which might be applied in future improvements to currently available FRMAC methodologies.

A key activity that resulted from this coordination and set of goals was a methods comparison exercise that involved independent OGT and FRMAC analysis of mutually agreed upon, predefined assessment scenarios, sample data, and decision-support questions that could likely be expected in the event of a radiological incident. The OGT analysis of and results from the OGT/FRMAC methods comparison exercise is provided in Chapter 13 of this report.

Draft versions of this report were coordinated through the Office of Emergency Response and FRMAC for comments. A complete discussion and analysis of review comments received is provided in Chapter 14 of this report. Through this review and comment process, useful input was provided, especially on some of the parameters (e.g., breathing rates, resuspension factor, ground roughness factor, and soil ingestion rate) used in the OGT methodology. The general comments were positive, and no significant issues were identified.

The review cited that:

"The OGT report is seen as an important contribution to response readiness in three key ways:

- First, the OGT work addressed the problem of an RDD in a congested urban environment. FRMAC has prepared six generic 'Pre-Assessed Default Scenarios,' which provide 'operational guidelines' tailored to specific scenarios. The OGT work complements and supplements the recently published FRMAC Pre-Assessed Default Scenario for RDDs.

- Secondly, the OGT work addresses topics associated with the later Intermediate Phase and Late Phase. FRMAC has only addressed the Early Phase and initial portion of the Intermediate Phase. Thus the work of the groups is again quite complementary.

- Finally, OGT has illuminated new methods that will be very useful for analyzing more complex cases, particularly those found after the Early Phase. Clearly, RESRAD has an important role in radiological assessment in the later phases. It is expected that RESRAD-RDD will become an important FRMAC assessment tool."

The review also provided a comparison of OGT operational guidelines and FRMAC's default DRLs and pointed out that some differences are large for a few radionuclides. After examining the parameters and dose factors used in both methods, the differences can be reduced to minimum, and, in some cases, would be negligible, if the parameters and dose factors were made the same. Chapter 14 of this report has a detailed discussion on this comparison study.

Finally, review comments were provided on the OGT food operational guidelines presented in Chapter 10. These food operational guidelines are derived using current state-of-science methods and dose conversion factors. As suggested, Chapter 10 was sent to FDA for a final review, and no issues were identified by FDA.

1.7 REFERENCES

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2 RDD OPERATIONAL GUIDELINES METHODOLOGY: CONCEPTUAL MODEL AND SENSITIVE PARAMETERS

2.1 INTRODUCTION

This chapter describes the model used to assess doses after an RDD event and discusses the assumptions involved in its application. This model is applicable for deriving operational guidelines for Groups B–E (Chapters 4–8) in the early and intermediate response phases. To derive operation guidelines for Group F (release of real property from a radiologically controlled area) in the late response phase, the probabilistic RESRAD code (Yu et al. 2000, 2001) was used for soil contamination, and the probabilistic RESRAD-BUILD code (Yu et al. 2003) was used for building contamination. The probabilistic assessments were employed in part because of the relatively large uncertainties (e.g., for assumptions and parameter values) used in deriving the initial set of operational guidelines for Group F. These operational guidelines are intended for use as a starting point for consideration within the optimization process. Deterministic approaches using RESRAD or RESRAD-BUILD codes (or other models) can also be used, particularly when more detailed site- and incident-specific data are available.

The conceptual model developed here is mainly applicable to situations after the direct plume phase is over. It was assumed that surface concentrations of dispersed radionuclides were known (i.e., measured). The model was designed for flexibility and ease of application under a variety of conditions. It was developed specifically for the derivation of operational guidelines and/or stay time tables for Groups B–E.

The model assumes that an RDD event occurred outdoors and contaminated streets and soils, exterior walls and roofs of buildings, and interior walls and floors of buildings with radioactive materials. With some modifications, the model can also be used for an RDD event occurring inside a building. The model considers default concentration ratios (partitioning factors) between streets/soils and other contaminated areas, accounts for change in surface concentration over time (includes decay and weathering), and uses a time-dependent resuspension factor to calculate air concentration.

To derive operational guidelines for each group (Groups B–E), different receptors were considered. The doses from different exposure pathways and contaminated areas were added to arrive at the total dose for an individual receptor. The RESRAD-BUILD computer code was used to calculate the external exposure and radon inhalation pathway doses. The dose for the critical receptor was used to derive the operational guideline for a particular group.

The operational guidelines were derived for 11 radionuclides: Am-241, Cf-252, Cm-244, Co-60, Cs-137, Ir-192, Po-210, Pu-238, Pu-239, Ra-226, and Sr-90. It was assumed that the short-lived progenies with half-lives <30 days are in equilibrium with the parent nuclide. For example, Sr-90 is assumed to be in equilibrium with its short-lived progeny Y-90. Calculations indicated that for Groups B–E, the long-lived progeny contribution to the dose for these 11 radionuclides would not be significant for at least the first 9 years after the RDD event. However, the radon dose from Ra-226 was computed separately. For Group B, which corresponds to operational guidelines for early phase protective actions (evacuation or sheltering), the PAGs are 1 rem (for the general public) or 5 rem (for early response workers). The early phase was defined as the first four days following the RDD event. For Groups C–E, the PAG for occupational exposure is 5 rem/yr. For the general public, the PAGs are 2 rem/yr for the first year and 0.5 rem/yr for subsequent years. Unless otherwise specified, the doses calculated were the average yearly dose for the first and second years. For Group F, the operational guideline is to be derived using an optimization process employing site- or event-specific information. As an example, the operational guidelines are derived on the basis of PAGs of 0.1 rem and 0.004 rem for illustration purposes.

2.2 CONCEPTUAL MODEL

The conceptual model of radiological contaminant transport following an RDD event is illustrated in Figure 2.1. It was assumed that the RDD event occurred outdoors. It was also assumed that the event resulted in surface contamination on the streets (in an urban/suburban environment) or soil (in a rural environment) and on the exterior walls and roof of residential/commercial building. In addition, the contaminants were assumed to get inside the residential/commercial building and be deposited on indoor floors and walls, either directly during the event through open windows or indirectly after the event through indoor/outdoor air exchange or through contaminants trapped to the bottom or on the surface of shoes of people who entered the building.

The model accepts input surface concentration ratios between outdoor walls, roof, indoor floor, and indoor walls, respectively, to soil/street. If the surface concentration ratios are not known, the model calculates dose values using the default relative ratios of 0.5, 1.0, 0.1, and 0.05

for surface concentrations for outdoor walls, roof, indoor floor, and indoor walls, respectively, to soil/street. These default concentration ratios are selected to yield reasonably conservative doses from other surfaces. For example, the indoor floor and outdoor street/soil concentration ratio of 10% assumes that outdoor contamination was tracked indoors by shoes and that windows were open when the outdoor RDD event occurred. The indoor wall concentration was assumed to be half (factor of 0.5) the concentration of the floor contamination, which is consistent with indoor deposition patterns (Raunemaa et al. 1989). The outdoor wall concentration was also assumed to be a factor of 0.5 of the soil/street contamination. The concentrations on outdoor walls actually could be much lower than the soil/street contamination level (Andersson et al. 2003). If data are available on the concentration ratios for various surfaces, these data can be input into RESRAD-RDD software for site-specific and incident-specific analysis.

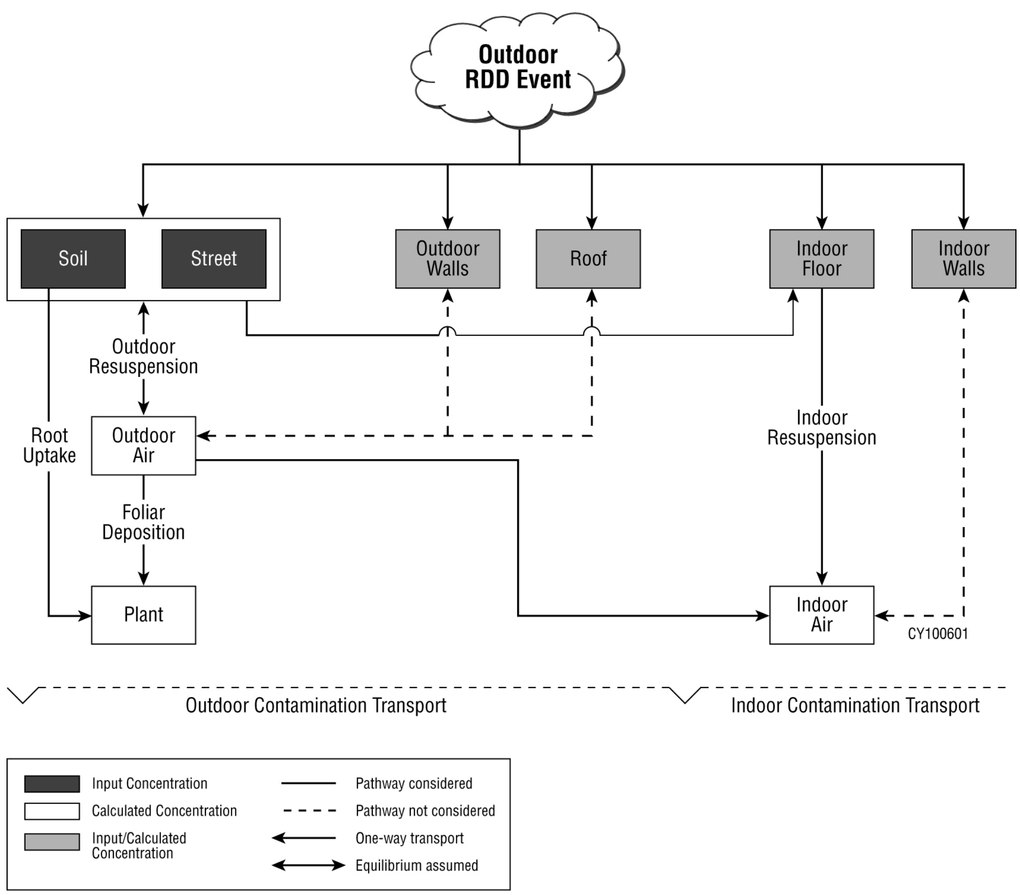

FIGURE 2.1 Conceptual Model of Environmental Transport after an RDD Event

At a minimum, soil/street surface concentration data should be available to use with this model. If data become available for other surfaces or surface measurements indicate other partitions, these other values can be used to obtain specific guidelines.

The surface contamination results in external exposure and inadvertent ingestion of contaminated dust particles deposited on the surface. The external dose was corrected by a factor that accounts for radioactive decay and weathering. In accordance with the specific scenarios developed for various operational groups, different dimensions were used for the commercial/residential buildings.

As shown in Figure 2.1, the secondary contamination sources include the outdoor air resulting from resuspension. A time-dependent resuspension factor accounting for weathering, source depletion, and radioactive decay was applied. In addition, the average resuspension factor was corrected to account for vehicular traffic. In accordance with the scenario defined for each operational group or subgroup, the resuspension factor was averaged over the appropriate time period, and the resulting outdoor air concentration was used to calculate the outdoor inhalation and submersion dose.

Another secondary contamination source shown in Figure 2.1 is indoor air contamination. It represents computed values and has two components. The exposure of a receptor inside the building is from the outdoor contaminated air, as well as through the resuspension of contaminated material deposited on the interior floors. A distribution function was developed for the indoor dust filtration factor (Yu et al. 2000). The dust filtration factor represents the fraction of outdoor contaminated dust that is available indoors. The median value (0.55) from this distribution was assumed for the ratio of indoor to outdoor air. The indoor resuspension factor was assumed to be constant at 10^{-6} m^{-1} (IAEA 2002; NRC 2001; EPA 1991). The calculated contaminated indoor air concentration was then used to compute the indoor inhalation and submersion dose. Plants also may get contaminated from foliar deposition and root uptake, but the dose contribution from the plant ingestion pathway was not included in deriving the operational guidelines for Groups B–E. However, plant ingestion pathways are included in Groups F4 and G.

2.3 EXPOSURE PATHWAYS

The model considers the following 13 exposure pathways for a receptor:

1. External exposure (groundshine) to contaminants on streets/soils while staying outdoors,

2. External exposure to contaminants on exterior walls while staying indoors,

3. External exposure to contaminants on roofs while staying indoors,

4. External exposure to contaminants on interior walls while staying indoors,

5. External exposure to contaminants on interior floors while staying indoors,

6. External exposure to contaminants on streets/soils while staying indoors,

7. Inhalation exposure while staying outdoors (resuspension of contaminants from streets/soils only),

8. Inhalation exposure while staying indoors (indoor air contamination results from both outdoor air contamination and resuspension from contaminants on interior floors),

9. Submersion in contaminated air while staying outdoors,

10. Submersion in contaminated air while staying indoors,

11. Ingestion of dust particles on streets/soils while staying outdoors,

12. Ingestion of dust particles while staying indoors (assumed to be from the floors or walls, whichever is more conservative), and

13. Radon inhalation while staying indoors.

The outdoor radon concentration was expected to be much smaller than indoor radon concentration because of the large dilution in an open environment. Therefore, the radiation dose from radon inhalation while staying outdoors was not included in the model.

The operational guidelines for Groups B–E were derived on the basis of appropriate exposure scenarios. The computations involved in the derivations were coded in a series of spreadsheets that are directed by a master sheet accepting input parameter values. These spreadsheets are the precursor of the RESRAD-RDD software. To obtain incident-specific operational guidelines for Groups B-E, the RESRAD-RDD user may input measured concentration ratios and adjust transfer factors as that information becomes available. The operational guidelines for Group F (release of real property) were obtained by using the RESRAD (onsite) code to simulate a subsistence farmer scenario for soil contamination and the RESRAD-BUILD code to simulate building occupancy scenarios for building contamination. A user's guide for the RESRAD-RDD software is presented in Chapter 12.

2.4 SENSITIVE PARAMETERS

The generic guidelines for each operational guideline group were developed on the basis of several assumptions and the corresponding parameter values. The common and most sensitive scenario parameters were as follows:

- Outdoor and indoor resuspension factors,
- Multiplication factor for outdoor resuspension, to account for vehicular traffic,
- Dust ingestion rate,
- Indoor/outdoor exposure duration and duration in different environments,
- Indoor/outdoor inhalation rates, and
- Building dimensions for external exposure.

The scenario-specific parameters used to derive the operational guidelines for each group (Groups B–E) are discussed in the subsequent chapters for each group. Probabilistic dose analysis was performed for Group F, and the default parameter distribution values in the RESRAD and RESRAD-BUILD codes were used. The 50th percentile and mean + 2σ values from peak dose/source ratio distributions were used to derive operational guideline values for Group F.

2.5 WEATHERING CORRECTION

Surface contamination would result in external exposure, inadvertent ingestion of contaminated dust particles deposited on the surface, and inhalation of contaminated air resulting from resuspension of dust particulates from contaminated surfaces.

It was observed from the Chernobyl accident data that in an urban environment, different surfaces have different initial retentions when compared with the reference surface and that they behave differently over time (Andersson et al. 2003). The reference surface was defined as an infinite smooth (surface with no roughness associated with it) air-ground interface with radionuclides deposited on the ground with no initial penetration. According to the Andersson et al. study, the weathering process and the effect of migration generally follow a two-class exponential behavior with time, as represented by Equation 2.1:

$$w(t) \quad = \quad a\, e^{-(bt)} + (1-a)\, e^{-(ct)}, \qquad (2.1)$$

where $w(t)$ is the activity fraction retained after weathering at time t, and a, b, and c are parameters for each surface. In this equation, there is a mobile fraction a with a shorter half-life ($\ln 2/b$) due to loose binding to the surface or due to the higher migration rate in the case of permeable surfaces. There is also a fixed fraction ($1 - a$) with a longer half-life ($\ln 2/c$) due to strong binding to the surface or the lower migration rate. Table 2.1 summarizes the values for these parameters for various media. The data were collected primarily for Cs-137, but are used as defaults for other radionuclides in the analysis. However, the user may input radionuclide-specific values in the RESRAD-RDD software if data are available. It is expected that the longer half-life ($\ln 2/c$) is more likely to be radionuclide dependent. For the short time period (less than a few years) considered in the derivation of operational guidelines and stay-time tables, this radionuclide dependency of the longer half-life may not be important.

TABLE 2.1 Weathering and Migration of Contaminants for Urban Surfaces

Surface	Mobile Fraction (*a*)	Shorter Half-Life (ln 2/*b*), yr	Longer Half-Life (ln 2/*c*), yr
Windows	0.8	0.2	2
Vertical walls	0.2	0.2	20
Roofs with tiles	0.5	1–4	25–50
Paved areas	0.5	0.2	2
Trees	0.8	0.2	2
Lawn	0.46	1.5	50

Source: Andersson et al. (2003).

External and ingestion pathway doses from different contaminated media (surfaces) were corrected by a factor that accounts for radioactive decay and weathering. The average weathering correction from time t_1 to t_2, which includes correction for radioactive decay, can be given by Equation 2.2:

$$\overline{WCF} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} [a\, e^{-(bt)} + (1-a) e^{-(ct)}] e^{-\lambda t} dt \ . \qquad (2.2)$$

The weathering correction factors reported by Andersson et al. (2003) are for outdoor surfaces. In the dose assessments, the weathering correction factors for the outdoor soil/street were also applied to the interior floor, and those for exterior walls were applied to interior walls, to consider the transport of contaminants by human activities (e.g., walking from outdoors to indoors) and air exchange.

The average weathering correction factors for different radionuclides were calculated for the first and second year, as well as for short durations (first 4 days, first 2 weeks, and 6 months) of exposure. The first 4-day period was considered because it was assumed in the operational decision making on evacuation or sheltering (Group B) that the early phase would last for 4 days. The time period of 6 months and 2 weeks was considered in the Group C dose assessment and guideline calculations. Table 2.2 provides the correction factors for various surfaces and radionuclides. The operational decision making on evacuation and sheltering (Group B) also involved guideline derivation based on the FRMAC methodology (Rhodes et al. 2003a).

TABLE 2.2 Average Correction Factors

Radionuclide	Streets	Soil	Exterior Walls	Roofs	Interior Floor for Buildings Surrounded by Streets	Interior Floor for Buildings Surrounded by Soils	Interior Walls	Outdoor Air above Streets	Outdoor Air above Soils
Average Correction Factor[a,b] for First Year									
Am-241	5.62E-01	9.04E-01	8.42E-01	9.55E-01	5.62E-01	9.04E-01	8.42E-01	1.60E-08	1.84E-08
Cf-252	5.05E-01	7.99E-01	7.44E-01	8.42E-01	5.05E-01	7.99E-01	7.44E-01	1.56E-08	1.78E-08
Cm-244	5.53E-01	8.88E-01	8.27E-01	9.38E-01	5.53E-01	8.88E-01	8.27E-01	1.59E-08	1.83E-08
Co-60	5.33E-01	8.49E-01	7.91E-01	8.96E-01	5.33E-01	8.49E-01	7.91E-01	1.58E-08	1.80E-08
Cs-137	5.57E-01	8.95E-01	8.33E-01	9.45E-01	5.57E-01	8.95E-01	8.33E-01	1.59E-08	1.83E-08
Ir-192	2.02E-01	2.68E-01	2.53E-01	2.76E-01	2.02E-01	2.68E-01	2.53E-01	1.29E-08	1.38E-08
Po-210	2.98E-01	4.27E-01	4.00E-01	4.44E-01	2.98E-01	4.27E-01	4.00E-01	1.39E-08	1.52E-08
Pu-238	5.60E-01	9.01E-01	8.39E-01	9.52E-01	5.60E-01	9.01E-01	8.39E-01	1.60E-08	1.83E-08
Pu-239	5.62E-01	9.05E-01	8.42E-01	9.56E-01	5.62E-01	9.05E-01	8.42E-01	1.60E-08	1.84E-08
Ra-226	5.62E-01	9.04E-01	8.42E-01	9.55E-01	5.62E-01	9.04E-01	8.42E-01	1.60E-08	1.84E-08
Sr-90	5.57E-01	8.94E-01	8.33E-01	9.45E-01	5.57E-01	8.94E-01	8.33E-01	1.59E-08	1.83E-08
Average Correction Factor[a,b] for Second Year									
Am-241	3.02E-01	7.59E-01	7.59E-01	8.74E-01	3.02E-01	7.59E-01	7.59E-01	5.87E-10	1.45E-09
Cf-252	2.07E-01	5.16E-01	5.15E-01	5.93E-01	2.07E-01	5.16E-01	5.15E-01	4.07E-10	1.00E-09
Cm-244	2.87E-01	7.19E-01	7.19E-01	8.27E-01	2.87E-01	7.19E-01	7.19E-01	5.58E-10	1.38E-09
Co-60	2.50E-01	6.26E-01	6.26E-01	7.20E-01	2.50E-01	6.26E-01	6.26E-01	4.89E-10	1.21E-09
Cs-137	2.93E-01	7.35E-01	7.35E-01	8.46E-01	2.93E-01	7.35E-01	7.35E-01	5.70E-10	1.41E-09
Ir-192	3.07E-03	7.30E-03	7.11E-03	8.27E-03	3.07E-03	7.30E-03	7.11E-03	6.97E-12	1.64E-11
Po-210	2.36E-02	5.73E-02	5.64E-02	6.53E-02	2.36E-02	5.73E-02	5.64E-02	5.03E-11	1.21E-10
Pu-238	3.00E-01	7.52E-01	7.52E-01	8.65E-01	3.00E-01	7.52E-01	7.52E-01	5.82E-10	1.44E-09
Pu-239	3.03E-01	7.61E-01	7.61E-01	8.76E-01	3.03E-01	7.61E-01	7.61E-01	5.89E-10	1.46E-09
Ra-226	3.03E-01	7.60E-01	7.61E-01	8.75E-01	3.03E-01	7.60E-01	7.61E-01	5.88E-10	1.46E-09
Sr-90	2.93E-01	7.34E-01	7.35E-01	8.45E-01	2.93E-01	7.34E-01	7.35E-01	5.69E-10	1.41E-09

TABLE 2.2 (Cont.)

Radionuclide	Streets	Soil	Exterior Walls	Roofs	Interior Floor for Buildings Surrounded by Streets	Interior Floor for Buildings Surrounded by Soils	Interior Walls	Outdoor Air above Streets	Outdoor Air above Soils
Average Correction Factor[a,b] for 6 Months									
Am-241	6.97E-01	9.49E-01	8.88E-01	9.77E-01	6.97E-01	9.49E-01	8.88E-01	3.04E-08	3.35E-08
Cf-252	6.58E-01	8.90E-01	8.34E-01	9.16E-01	6.58E-01	8.90E-01	8.34E-01	2.99E-08	3.29E-08
Cm-244	6.91E-01	9.40E-01	8.80E-01	9.68E-01	6.91E-01	9.40E-01	8.80E-01	3.03E-08	3.34E-08
Co-60	6.77E-01	9.19E-01	8.61E-01	9.46E-01	6.77E-01	9.19E-01	8.61E-01	3.01E-08	3.32E-08
Cs-137	6.94E-01	9.44E-01	8.83E-01	9.72E-01	6.94E-01	9.44E-01	8.83E-01	3.03E-08	3.35E-08
Ir-192	3.66E-01	4.62E-01	4.38E-01	4.72E-01	3.66E-01	4.62E-01	4.38E-01	2.57E-08	2.73E-08
Po-210	4.81E-01	6.27E-01	5.91E-01	6.43E-01	4.81E-01	6.27E-01	5.91E-01	2.75E-08	2.97E-08
Pu-238	6.96E-01	9.47E-01	8.87E-01	9.75E-01	6.96E-01	9.47E-01	8.87E-01	3.03E-08	3.35E-08
Pu-239	6.97E-01	9.49E-01	8.88E-01	9.77E-01	6.97E-01	9.49E-01	8.88E-01	3.04E-08	3.35E-08
Ra-226	6.97E-01	9.49E-01	8.88E-01	9.77E-01	6.97E-01	9.49E-01	8.88E-01	3.04E-08	3.35E-08
Sr-90	6.93E-01	9.43E-01	8.83E-01	9.72E-01	6.93E-01	9.43E-01	8.83E-01	3.03E-08	3.35E-08
Average Correction Factor[a,b] for 2 Weeks									
Am-241	9.65E-01	9.96E-01	9.87E-01	9.98E-01	9.65E-01	9.96E-01	9.87E-01	2.55E-07	2.59E-07
Cf-252	9.60E-01	9.91E-01	9.82E-01	9.93E-01	9.60E-01	9.91E-01	9.82E-01	2.54E-07	2.59E-07
Cm-244	9.64E-01	9.95E-01	9.86E-01	9.97E-01	9.64E-01	9.95E-01	9.86E-01	2.55E-07	2.59E-07
Co-60	9.62E-01	9.93E-01	9.84E-01	9.96E-01	9.62E-01	9.93E-01	9.84E-01	2.55E-07	2.59E-07
Cs-137	9.64E-01	9.95E-01	9.86E-01	9.98E-01	9.64E-01	9.95E-01	9.86E-01	2.55E-07	2.59E-07
Ir-192	9.05E-01	9.33E-01	9.25E-01	9.36E-01	9.05E-01	9.33E-01	9.25E-01	2.47E-07	2.51E-07
Po-210	9.32E-01	9.62E-01	9.53E-01	9.64E-01	9.32E-01	9.62E-01	9.53E-01	2.50E-07	2.55E-07
Pu-238	9.65E-01	9.96E-01	9.87E-01	9.98E-01	9.65E-01	9.96E-01	9.87E-01	2.55E-07	2.59E-07
Pu-239	9.65E-01	9.96E-01	9.87E-01	9.98E-01	9.65E-01	9.96E-01	9.87E-01	2.55E-07	2.59E-07
Ra-226	9.65E-01	9.96E-01	9.87E-01	9.98E-01	9.65E-01	9.96E-01	9.87E-01	2.55E-07	2.59E-07
Sr-90	9.64E-01	9.95E-01	9.86E-01	9.98E-01	9.64E-01	9.95E-01	9.86E-01	2.55E-07	2.59E-07

TABLE 2.2 (Cont.)

Radionuclide	Streets	Soil	Exterior Walls	Roofs	Interior Floor for Buildings Surrounded by Streets	Interior Floor for Buildings Surrounded by Soils	Interior Walls	Outdoor Air above Streets	Outdoor Air above Soils
Average Correction Factor[a,b] for 4 Days									
Am-241	9.90E-01	9.99E-01	9.96E-01	9.99E-01	9.90E-01	9.99E-01	9.96E-01	5.92E-07	5.96E-07
Cf-252	9.88E-01	9.97E-01	9.95E-01	9.98E-01	9.88E-01	9.97E-01	9.95E-01	5.91E-07	5.95E-07
Cm-244	9.89E-01	9.99E-01	9.96E-01	9.99E-01	9.89E-01	9.99E-01	9.96E-01	5.92E-07	5.96E-07
Co-60	9.89E-01	9.98E-01	9.95E-01	9.99E-01	9.89E-01	9.98E-01	9.95E-01	5.92E-07	5.96E-07
Cs-137	9.90E-01	9.99E-01	9.96E-01	9.99E-01	9.90E-01	9.99E-01	9.96E-01	5.92E-07	5.96E-07
Ir-192	9.71E-01	9.80E-01	9.78E-01	9.81E-01	9.71E-01	9.80E-01	9.78E-01	5.84E-07	5.88E-07
Po-210	9.80E-01	9.89E-01	9.86E-01	9.90E-01	9.80E-01	9.89E-01	9.86E-01	5.88E-07	5.92E-07
Pu-238	9.90E-01	9.99E-01	9.96E-01	9.99E-01	9.90E-01	9.99E-01	9.96E-01	5.92E-07	5.96E-07
Pu-239	9.90E-01	9.99E-01	9.96E-01	9.99E-01	9.90E-01	9.99E-01	9.96E-01	5.92E-07	5.96E-07
Ra-226	9.90E-01	9.99E-01	9.96E-01	9.99E-01	9.90E-01	9.99E-01	9.96E-01	5.92E-07	5.96E-07
Sr-90	9.90E-01	9.99E-01	9.96E-01	9.99E-01	9.90E-01	9.99E-01	9.96E-01	5.92E-07	5.96E-07
Average Correction Factor[a,b] for 4 Days (for FRMAC methodology)									
Am-241	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	5.97E-07	5.97E-07
Cf-252	9.98E-01	9.98E-01	9.98E-01	9.98E-01	9.98E-01	9.98E-01	9.98E-01	5.96E-07	5.96E-07
Cm-244	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	5.96E-07	5.96E-07
Co-60	9.98E-01	9.98E-01	9.98E-01	9.98E-01	9.98E-01	9.98E-01	9.98E-01	5.96E-07	5.96E-07
Cs-137	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	5.97E-07	5.97E-07
Ir-192	9.80E-01	9.80E-01	9.80E-01	9.80E-01	9.80E-01	9.80E-01	9.80E-01	5.88E-07	5.88E-07
Po-210	9.89E-01	9.89E-01	9.89E-01	9.89E-01	9.89E-01	9.89E-01	9.89E-01	5.92E-07	5.92E-07
Pu-238	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	5.97E-07	5.97E-07
Pu-239	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	5.97E-07	5.97E-07
Ra-226	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	5.97E-07	5.97E-07
Sr-90	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	9.99E-01	5.97E-07	5.97E-07

[a] Average correction factors are WCFs for streets, soils, exterior walls, roofs, interior floors, and interior walls. For outdoor air, they are products of the WCF for streets/soil and resuspension factor averaging over the considered period.

[b] Scientific notation: 5.62E-01 = 5.62×10^{-1}, or 0.562.

To simulate the FRMAC methodology, it was assumed that the mobile fraction (a) was 0.4 with half-life of 1.505 years and that the half-life for the fixed fraction $(1-a)$ was 49.5 years.

2.6 RESUSPENSION FACTOR CORRECTION

Walsh (2002) reviewed two types of resuspension methodologies — those using a resuspension factor and those using a dust-loading approach — and found that the resuspension factor methodology is appropriate for use with fresh deposits and, therefore, is applicable to emergency response. For these situations, Walsh (2002) recommends a time-dependent resuspension factor based on Garland's formula, modified to account for long-term outdoor resuspension, as shown in Equation 2.3:

$$RF_o(t) = \frac{A}{t} + B \,, \tag{2.3}$$

where t is time in days after deposition and the coefficients A (1.2×10^{-6}) and B (1×10^{-9} m^{-1}) were the initial and long-term resuspension factors, respectively. Equation 2.3 is applicable only for times greater than 1 day; during the first day, a resuspension factor of 1.2×10^{-6} m^{-1} was assumed.

However, somewhat different resuspension factor coefficients were used in the FRMAC methodology (Rhodes 2003a), which are based on National Council on Radiation Protection and Measurements (NCRP) recommendations (NCRP 1999). The FRMAC method defines the coefficient A as 1×10^{-6} (m^{-1}) for days 1 to 1,000 after plume deposition, which then changes to zero after 1,000 days; the coefficient B is initially zero for 1,000 days, then changes to 1×10^{-9} m^{-1} for longer times. To be consistent with the FRMAC methodology in the default case, it is assumed that the resuspension factor is fixed at 1×10^{-6} m^{-1} for the first day; for days 1 to 1,000, it varies with time as $1 \times 10^{-6}/t$ (m^{-1}); it then remains fixed at 1×10^{-9} m^{-1} after 1,000 days. The RESRAD-RDD software has the flexibility of accepting two user-defined coefficients, A and B, for use in resuspension factor calculations.

Combining with the average weathering correction factor discussed in Section 2.5, an average outdoor air concentration correction factor from time t_1 to t_2 that accounts for radioactive decay, resuspension, and source depletion due to weathering and leaching, can be defined as follows:

$$\overline{WCF \times RF_o} = \frac{\int_{t_1}^{t_2} RF_o(t)[a\,e^{-(bt)} + (1-a)e^{-(ct)}]e^{-\lambda t}\,dt}{t_2 - t_1} \quad . \tag{2.4}$$

This factor is used in the analyses to obtain an average outdoor air concentration of contaminants from a contaminated surface source (see Figure 2.1). As opposed to the integration in Equation 2.2, which has an analytic solution, the integration in Equation 2.4 was solved numerically by using the Gautschi and Cahill approximation (Gautschi and Cahill 1965). The results of the calculation for the first and second exposure years, as well as for the shorter durations of exposure (first 6 months, 2 weeks, and first 4 days) are also shown in Table 2.2.

In addition to the resuspension factors discussed above, a list of "rule of thumb" multiplication factors is given by Walsh (2002) to adjust for resuspended air concentrations resulting from variations in atmospheric conditions. The multiplication factors (Table 2.3) were used to adjust the average resuspension factors in accordance with the specific scenarios defined in deriving the operational guidelines for Groups B−E.

TABLE 2.3 Multiplication Factors to Be Applied to the Resuspension Factor Results

Condition	Multiplication Factor
Rural conditions, light-medium winds	1
Arid climate	10
Urban conditions, light traffic, light pedestrian activity[a]	10
Urban conditions, heavy traffic	100
Plowing in dry conditions	100

[a] Given that some countermeasures might restrict the movement of vehicles, this factor need not always be applied.

2.7 DOSE CALCULATION

It is assumed that a receptor could be exposed via up to 13 exposure pathways, as described in Section 2.3. To calculate doses, first the dose-to-source ratio (DSR) for each exposure pathway resulting from different contaminated media (street/soil, building roof, exterior walls of the building, interior floor of the building, and interior walls of the building) are calculated by using the relationships discussed previously among the media for each receptor in a group/subgroup. The doses from relevant pathways are then added to obtain the total dose for each receptor.

The dose conversion factors (DCFs) used to derive the default preliminary operational guidelines and stay times are International Commission on Radiological Protection (ICRP) Publication 60 (ICRP 1991)-based DCFs. However, in the RESRAD-RDD software, the user can select either ICRP Publication 30 (ICRP 1982)-based or ICRP 60 Publication (ICRP 1991)-based DCFs. For Group G, the ICRP Publication 72 (ICRP 1996) age-dependent DCFs were used for food consumption dose calculations. Some of the DCFs (e.g., the DCFs for the submersion external dose pathway) are calculated using the DCAL software (Eckerman et al. 2006). It should be noted that the inhalation DCF for Cf-252 is being updated by Eckerman (2008). The new inhalation DCF for Type F is about twice of the Type M DCF used in this report, which is based on ICRP 60 and 72 data. The RESRAD-RDD software is designed to accept new DCFs if data are available.

2.7.1 External Pathway Dose[3]

For pathway 1, a 10,000-m^2 homogenously contaminated surface area is assumed for outdoor external pathway dose calculations. An exception is made for operational guideline Group B, which involved guideline derivation based on the FRMAC methodology where it is assumed that an infinitely large ground surface is contaminated. The outdoor receptor is assumed to be at the center of the contaminated area. The RESRAD-BUILD computer code is used to calculate this external exposure pathway dose (Yu et al. 2003). The external pathway dose is also corrected for ground roughness; a correction factor of 0.82 based on the default value of Turbo FRMAC 2.0 was used.

For pathways 2−5, the indoor receptor is assumed to be located at the center of the contaminated building and is exposed to contamination on the floor, indoor walls, outdoor walls, and outdoor roof. The RESRAD-BUILD computer code is used to calculate this external dose (Yu et al. 2003), which is corrected for source configuration, receptor distance from the source,

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3 Pathway numbers correspond to the list of potential exposure pathways given in Section 2.3.

and shielding between the source and receptor. In accordance with the specific scenarios developed for various groups, different dimensions are used for the commercial/residential buildings. Table 2.4 lists different dimensions (geometries) used to calculate the external dose from different contaminated media (roof, exterior walls, interior walls, and interior floors).

For pathway 6, the external exposure to contaminants on streets/soils while staying indoors is calculated by using the dose conversion factor (DCF) from contaminated streets/soil (pathway 1) corrected by a shielding factor. The FRMAC provides shielding factors for a receptor inside the building from ground surface deposition for different types of structures (Rhodes 2003b). The values vary from 0.4 (one- and two-story wood frame house) to 0.005 (in the basement of a multistory structure). Table 2.4 provides the shielding factor used in different exposure configurations.

The dose from external exposure pathways (pathways 1-6) is calculated by using Equation 2.5. The receptor could spend some time outdoors and some time indoors inside the contaminated building and could be exposed to all contaminated media. The total external pathway dose would be the sum from all external exposure to these media. The RESRAD-BUILD computer code is used to calculate the dose conversion factors from these six exposure pathways, as shown in Equation 2.5:

$$pathway\ dose_{ext,n,g} = C_s \times P_n \times \overline{WCF_n} \times OF_{n,g} \times SF_{n,g} \times GRC_{n,g} \times DCF_{n,g}\ , \qquad (2.5)$$

where:

$pathway\ dose_{ext,\ n,g}$ = dose from external radiation pathways (mrem/yr);

C_s = concentration on streets/soil at $t = 0$ (pCi/m^2);

P_n = partitioning factor (concentration ratio between media n and streets/soil) at $t = 0$ (1 for street/soil and roof, 0.5 for exterior walls, 0.1 for interior floor, and 0.05 for interior walls);

$\overline{WCF_n}$ = average weathering and radiological decay correction factor (ratio of average concentration during the first or second year to the concentration at $t = 0$ for media n; see Equation 2.2 and Table 2.2);

n = index for media (1 and 6 for street/soil, 2 for roof, 3 for exterior walls, 4 for interior floor, and 5 for interior walls);

g = index for geometries (see Table 2.4 for different geometries for which external DCFs were calculated);

$OF_{n,g}$ = occupancy factor (time fraction);

$SF_{n,g}$ = shielding factor (1 for $n = 1$ to 5, for $n = 6$; see Table 2.4 for values for different geometries);

$GRC_{n,g}$ = ground roughness correction factor (0.82 for $n = 1$, 1.0 for $n = 2$ to 6); and

$DCF_{n,g}$ = external dose conversion factor (dose per unit exposure for 1 year from different contaminated media for receptor indoors and outdoors) (mrem/yr per pCi/m^2).

TABLE 2.4 Different Geometries Used in External Pathway Dose Calculations

Geometry	Receptor Location	Shielding Factor	Air Exchange Rate (h^{-1})	Floor Area (m^2)	Building Height (m)	Shielding Thickness (cm)	Shielding Material	Shielding Density (g/cm^3)
Rural house	Indoor	0.4	1.52	36	2.4	3.5	Concrete	1
Suburban house	Indoor	0.4	1	196	2.4	3.5	Concrete	1
Urban apartment	Indoor	0.2	0.63	100	2.4	10	Concrete	2.4
Store	Indoor	0.2	1.52	36	2.4	5	Concrete	2.4
Warehouse	Indoor	0.2	2	900	3.7	10	Concrete	2.4
Monument	Indoor	0.2	2	900	9.1	10	Concrete	2.4
Street/soil	Outdoor	1	NA[a]	10,000	NA	NA	NA	NA
Street/soil	Outdoor	1	NA	Infinitely large	NA	NA	NA	NA
Street	Inside vehicle	1	NA	10,000	NA	0.07	Steel	7.8
Bridge[b]	Inside vehicle	1	NA	10,000	NA	0.07	Steel	7.8
Subway station	Indoor	0.2	5	Rectangular (4 × 46)	4	5	Concrete	2.4
Rail car	Indoor	0.4	5	Rectangular (2.8 × 17)	2.4	0.1	Steel	7.8

[a] NA = not applicable.

[b] The bridge geometry includes two additional surface sources of 610 m^2 that are set perpendicular to the contaminated street to represent guard rails on a bridge.

2.7.2 Inhalation Pathway Dose

To calculate the dose from inhalation pathways, first, the air concentrations outdoors and indoors are calculated by using Equations 2.6 and 2.7. As discussed in Sections 2.5 and 2.6, a time-dependent resuspension factor and weathering correction are then applied.

$$C_o = C_s \times \overline{WCF_s \times RF_o} \times MF \,, \tag{2.6}$$

$$C_i = C_o \times SHF\ 1 + C_{floor} \times RF_i \times \overline{WCF_{floor}} \,, \tag{2.7}$$

where:

C_o = outdoor air concentration (pCi/m^3);

C_i = indoor air concentration (pCi/m^3);

C_s = concentration on streets/soil at $t = 0$ (pCi/m^2);

C_{floor} = concentration on interior floor at $t = 0$ (pCi/m^2);

$\overline{WCF_s \times RF_o}$ = average outdoor air concentration correction factor (weathering and radioactive decay included; see Equation 2.4) (m^{-1});

MF = multiplication factor to account for influence of meteorological conditions or traffic (see Table 2.3);

$SHF\ 1$ = indoor dust filtration factor = 0.55;

$\overline{WCF_{floor}}$ = weathering correction factor for interior floor, including radioactive decay; and

RF_i = indoor resuspension factor = 1×10^{-6} m^{-1}.

As shown in Equation 2.7, the indoor air concentration is calculated from contamination in outdoor air corrected by the indoor dust filtration factor and from contamination on the interior floor corrected by a resuspension factor. The outdoor (pathway 7) and indoor (pathway 8) doses from inhalation exposure can be calculated with Equations 2.8 and 2.9, respectively:

$$pathway\ dose_{inh-outdoor} = C_o \times OF_o \times IR_o \times DCF_{inh}\,, \tag{2.8}$$

$$pathway\ dose_{inh-indoor} = C_i \times OF_i \times IR_i \times DCF_{inh}\,, \tag{2.9}$$

where:

IR_o, IR_i = inhalation rate while staying outdoors or indoors, respectively (m^3/yr);

OF_o, OF_i = occupancy factor (time fraction spent outdoors or indoors, respectively); and

DCF_{inh} = inhalation dose conversion factors taken from ICRP 72 (ICRP 1996), which was ICRP 60 (ICRP 1991) based committed effective dose conversion factors (mrem/pCi).

2.7.3 Air Submersion Pathway Dose

The outdoor (pathway 9) and indoor (pathway 10) doses from air submersion exposure can be calculated with Equations 2.10 and 2.11, respectively. For pathway 9, the dose is calculated by using only outdoor air concentration; for pathway 10, the dose is calculated by using indoor air concentration:

$$pathway\ dose_{sub-outdoor} = C_o \times OF_o \times DCF_{sub}\,, \tag{2.10}$$

$$pathway\ dose_{sub-indoor} = C_i \times OF_i \times DCF_{sub}\,, \tag{2.11}$$

where:

DCF_{sub} = submersion dose conversion factor based on the effective dose calculated by DCAL software (Eckerman et al. 2006) (mrem/yr per pCi/m^3).

2.7.4 Dust Ingestion Pathway Dose

The outdoor (pathway 11) and indoor (pathway 12) doses from dust ingestion exposure are calculated using Equation 2.12. For pathway 11, the dose is calculated from contamination on the streets/soil. For pathway 12, the dose is calculated from the contamination on the interior floor or wall of the building, whichever is greater. An ingestion rate of 3×10^{-4} m^2/d is assumed for adults (residents and workers), which was obtained by reducing the value suggested in Rhodes et al. (2003a) by 50%. The reduction was made to respond to the FRMAC comments on the draft report (See Chapter 14) to avoid overly estimating the ingestion dose. This assumed value is within the range reported in the literature for secondary ingestion (Kennedy and Strenge 1992):

$$pathway\ dose_{ing} = C_s \times P \times WCF \times IngR \times OF \times DCF_{ing}, \qquad (2.12)$$

where:

$pathway\ dose_{ing}$ = dose from dust ingestion pathways (mrem/yr);

C_s = concentration on streets/soil at $t = 0$ (pCi/m^2);

P = partitioning factor (1 for pathway 11, and 0.1 for pathway 12);

WCF = weathering correction factor ($\overline{WCF_s}$ for pathway 11, and $\overline{WCF_{floor}}$ for pathway 12);

$IngR$ = ingestion rate (3×10^{-4} m^2/day); and

DCF_{ing} = ingestion dose conversion factor taken from ICRP 72 (ICRP 1996), which was ICRP 60 (ICRP 1991) based committed effective dose conversion factors (mrem/pCi).

2.7.5 Radon Inhalation Pathway Dose

The dose from the radon inhalation pathway (pathway 13) is calculated only for indoor exposure. The calculation uses the methodology described in the RESRAD-BUILD manual for surface sources (Yu et al. 2003). The radon emanation fraction is set at 0.1. The radon DSR (mrem/yr per pCi of radium on interior surfaces) is calculated for different building geometries with the RESRAD-BUILD code. The building geometries are listed in Table 2.4. The radon pathway dose for an indoor receptor can be calculated with Equation 2.13. First, the total radium activity corrected for weathering is calculated for a given building. The total activity is then multiplied by the corresponding DSR to get the radon inhalation pathway dose:

$$pathway\ dose_{radon\_inh\_g} = (\sum_{n} C_s \times P_n \times surface\ area_n \times WCF_n) \times OF_i \times DSR_g, \qquad (2.13)$$

where:

$pathway\ dose_{radon\_inh\_g}$ = dose from radon inhalation pathway in a given building (mrem/yr),

C_s = concentration on streets/soil at $t = 0$ (pCi/m^2);

P_n = partitioning factor (concentration ratio between indoor media n and streets/soil) at $t = 0$ (0.1 for interior floor [$n = 1$], and 0.05 for interior walls [n = 2–5]);

WCF_n = weathering correction factor (ratio of average concentration over the exposure duration to the concentration at $t = 0$ for a surface media, see Equation 2.2 and Table 2.2);

n = index for indoor media (1 interior floor and 2–5 for interior walls);

g = index for building geometry (see Table 2.4);

$surface\ area_n$ = area for surface media n (m^2);

OF_i = occupancy factor (time fraction spent indoors); and

DSR_g = dose-to-source ratio calculated by using RESRAD-BUILD for radon inhalation in the given building (mrem/yr per pCi Ra-226).

2.8 GUIDELINE DERIVATION

To derive operational guidelines for each group (Groups B–E), a systematic approach was applied. First, scenarios applicable to each group were defined. Each scenario identified appropriate receptors. Then, for each receptor, doses from all applicable exposure pathways and contaminated areas were computed in accordance with the methodology described in Section 2.7. Finally, the pathway doses were added to get the total dose for each individual receptor. The dose for the critical receptor (the receptor that gives the highest total dose) was used to derive the concentration guideline for that particular operational group, as shown in Equation 2.14:

$$Group\ Guideline = PAG / \sum_{p} (\ pathway\ dose\ )_p \ \ for\ the\ critical\ receptor, \qquad (2.14)$$

where PAG is the protective action guide (rem or rem/yr) and p is the index for each pathway, as discussed in Sections 2.3 and 2.7.[4]

The PAG for decision making on evacuation or sheltering in the early phase is 1 rem for the general public and 5 rem for the workers. After the early phase, the PAG for occupational exposure is set to 5 rem/yr, and the PAGs for the general public are set to 2 rem/yr for the first year and 0.5 rem/yr for subsequent years.

Unless otherwise stated, the operational guidelines are given in surface activity concentration deposited on soil or streets (pCi/m^2). Depending on the analyzed scenario within the operational group, other guidelines may be expressed in volume concentration (pCi/g), as for Group F, or in stay times (the maximum time a person could stay and still remain within the PAG) as for Groups A and D.

Table 2.5 provides brief descriptions for the receptors considered in different groups. Table 2.6 summarizes the exposure pathways considered applicable for each receptor. Table 2.7 lists the common and most important parameters assumed for the generic guideline derivation.

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4 The term PAG as used in this report for the derivation of operational guidelines includes official PAGs as documented in DHS (2008), but the definition is also used more broadly throughout the report to include dose criteria for workers and those dose criteria for the optimization process.

TABLE 2.5 Receptors and Group Descriptions

Receptor ID	Group Description	Receptor Description	Applicable PAGs (rem) First Year[a,b]	Applicable PAGs (rem) After First Year
B1-1	Evacuation – FRMAC Method	Receptor spending 100% time indoors	1, 5	
B1-2	Evacuation – FRMAC Method	Receptor spending time working outdoors	1, 5	
B1-3	Evacuation – FRMAC Method	Receptor spending 100% time outdoors	1, 5	
B2-1	Evacuation – OGT Method	Receptor spending 100% time indoors	1, 5	
B2-2	Evacuation – OGT Method	Receptor spending time working outdoors	1, 5	
B2-3	Evacuation – OGT Method	Receptor spending 100% time outdoors	1, 5	
C1-1	Relocation from Residential Areas (urban setting)	Resident spending 100% of the time indoors	2	0.5
C1-2	Relocation from Residential Areas (urban setting)	Adults working outside	2	0.5
C1-3	Relocation from Residential Areas (rural)	Resident spending 100% of the time indoors	2	0.5
C1-4	Relocation from Residential Areas (rural)	Adults working outside	2	0.5
C2-1	Relocation from Commercial/Industrial Areas	Indoor office worker	2	0.5
C2-2	Relocation from Commercial/Industrial Areas	Outdoor worker	2	0.5
C3-1	Relocation from Other Areas	Indoor worker at a monument or park	2	0.5
C3-2	Relocation from Other Areas	Outdoor worker at a monument or park	2	0.5
C4-1	Hospital and Other Health Care Facilities	Hospital outdoor worker	5	
C4-2	Hospital and Other Health Care Facilities	Hospital indoor worker	5	
C4-3	Hospital and Other Health Care Facilities	Patient staying in hospital	2	0.5
C5-1	Critical Transport Facilities	Ticket clerk staying inside	5	

TABLE 2.5 (Cont.)

Receptor ID	Group Description	Receptor Description	Applicable PAGs (rem) First Year[a,b]	After First Year
C5-2	Critical Transport Facilities	Baggage handler staying outside	5	
C5-3	Critical Transport Facilities	Passenger staying inside	2	0.5
C5-4	Critical Transport Facilities	Passenger staying both outside and inside	2	0.5
C6-1	Water and Sewer Facilities	Facility outdoor worker	5	
C6-2	Water and Sewer Facilities	Facility indoor worker	5	
C6-3	Water and Sewer Facilities	Contractor works indoors	2	0.5
C6-4	Water and Sewer Facilities	Contractor works outdoors	2	0.5
C7-1	Power and Fuel Facilities	Facility outdoor worker	5	
C7-2	Power and Fuel Facilities	Facility indoor worker	5	
C7-3	Power and Fuel Facilities	Contractor works indoors	2	0.5
C7-4	Power and Fuel Facilities	Contractor works outdoors	2	0.5
D1-1	Temporary Access to Relocation Area	Outdoor worker accessing essential business location	0.5	
D1-2	Temporary Access to Relocation Area	Indoor worker accessing essential business buildings	0.5	
D2-1	Temporary Access to Relocation Area	Public accessing residential area and staying outside	0.5	
D2-2	Temporary Access to Relocation Area	Public accessing residential area and staying inside	0.5	
E1-1	Bridges	Occupational workers drive through bridges under restricted condition	5	
E1-2	Bridges	Public drive through bridges under unrestricted condition	2	0.5
E2-1	Streets and Thoroughfares	Occupational workers drive through streets under restricted condition	5	

TABLE 2.5 (Cont.)

Receptor ID	Group Description	Receptor Description	Applicable PAGs (rem) First Year[a,b]	After First Year
E2-2	Streets and Thoroughfares	Public drive through streets under unrestricted condition	2	0.5
E3-1	Sidewalks and Walkways	Essential service worker under restricted condition	5	
E3-2	Sidewalks and Walkways	Volunteer collecting donations near streets	2	0.5
E3-3	Sidewalks and Walkways	Vendor selling merchandise away from streets	2	0.5
F4-1	Release of Real Property from Radiologically Controlled Area (Soil)	Subsistence farmer	0.1, 0.004	
F4-2	Release of Real Property from Radiologically Controlled Area (Soil)	Urban resident	0.1, 0.004	
F4-3	Release of Real Property from Radiologically Controlled Area (Soil)	Indoor worker	0.1, 0.004	
F4-4	Release of Real Property from Radiologically Controlled Area (Soil)	Outdoor worker	0.1, 0.004	
F4-5	Release of Real Property from Radiologically Controlled Area (Residency)	Urban resident	0.1, 0.004	
F4-6	Release of Real Property from Radiologically Controlled area (Residency)	Suburban resident	0.1, 0.004	
F4-7	Release of Real Property from Radiologically Controlled Area (Residency)	Rural resident	0.1, 0.004	
F4-8	Release of Real Property from Radiologically Controlled Area (Commercial Buildings)	Large warehouse indoor worker	0.1, 0.004	
F4-9	Release of Real Property from Radiologically Controlled Area (Commercial Buildings)	Small store/office indoor worker	0.1, 0.004	

TABLE 2.5 (Cont.)

[a] The applicable PAG for Group B for decision making on evacuation or sheltering in the early phase is set to 1 rem or 5 rem. The early phase is defined as the first four days following the RDD incident.

[b] There are no designated PAGs for Group F operational guidelines. The PAGs are to be determined using the optimization process. The 0.1 and 0.004 rem values were used to develop illustrative operational guidelines that would fall within (but not necessarily bound) the range of most anticipated optimization-based decisions. These dose criteria were applied in the derivation of operational guidelines for Group F, for consideration as a starting point within the optimization process.

TABLE 2.6 Exposure Pathways Considered in Operational Guideline Derivation

	External						Inhalation		Radon	Air Submersion		Dust Ingestion	
Scenarios/ Pathways	Street, Outdoor	Street, Indoor	Exterior Walls, Indoor	Roof, Indoor	Interior Walls, Indoor	Interior Floor, Indoor	Outdoor	Indoor	Indoor	Outdoor	Indoor	Outdoor	Indoor
B1-1		x						x			x		
B1-2	x	x					x	x		x	x	x	
B1-3	x							x		x		x	
B2-1		x	x	x				x			x		
B2-2	x	x	x	x			x	x		x	x	x	
B2-3	x						x			x		x	
C1-1	x	x	x	x	x	x	x	x	x	x	x	x	x
C1-2	x	x	x	x	x	x	x	x	x	x	x	x	x
C1-3	x	x	x	x	x	x	x	x	x	x	x	x	x
C1-4	x	x	x	x	x	x	x	x	x	x	x	x	x
C2-1		x	x	x	x	x		x	x		x		x
C2-2	x						x			x		x	
C3-1		x	x	x	x	x		x	x		x		x
C3-2	x						x			x		x	
C4-1	x						x			x		x	
C4-2		x	x	x	x	x		x	x		x		x
C4-3		x	x	x	x	x		x	x		x		x
C5-1		x	x	x	x	x		x	x		x		x
C5-2	x						x			x		x	
C5-3		x	x	x	x	x		x	x		x		x
C5-4	x	x	x	x	x	x	x	x	x	x	x	x	x
C6-1	x						x			x		x	
C6-2		x	x	x	x	x		x	x		x		x
C6-3		x	x	x	x	x		x	x		x		x
C6-4	x						x			x		x	
C7-1	x						x			x		x	
C7-2		x	x	x	x	x		x	x		x		x
C7-3		x	x	x	x	x		x	x		x		x
C7-4	x						x			x		x	
D1-1	x						x			x		x	
D1-2		x	x	x	x	x		x	x		x		x
D2-1	x						x			x		x	
D2-2		x	x	x	x	x		x	x		x		x

TABLE 2.6 (Cont.)

	External						Inhalation		Radon	Air Submersion		Dust Ingestion	
Scenarios/ Pathways	Street, Outdoor	Street, Indoor	Exterior Walls, Indoor	Roof, Indoor	Interior Walls, Indoor	Interior Floor, Indoor	Outdoor	Indoor	Indoor	Outdoor	Indoor	Outdoor	Indoor
E1-1	x						x			x			
E1-2	x						x			x			
E2-1	x						x			x			
E2-2	x						x			x			
E3-1	x						x			x		x	
E3-2	x						x			x		x	
E3-3	x						x			x		x	

TABLE 2.7 Common Most Sensitive Parameters and Receptor Descriptions Used in Operational Guideline Derivation

Group-Receptor No.	Multiplication Factor for Outdoor Resuspension	Exposure Frequency (d/yr)	Dust Ingestion Rate (m^2/h)	Indoor Exposure Duration (h/d)	Outdoor Exposure Duration (h/d)	Indoor Inhalation Rate (m^3/h)	Outdoor Inhalation Rate (m^3/h)	Geometry No. for External Exposure to Buildings	Building/Source Description	Initial Outdoor Source
B1-1	1	4	1.25E-5	24	0	0.92	0.92	3	Urban house	Streets
B1-2	1	4	1.25E-5	16.4	7.6	0.92	0.92	3	Urban house	Streets
B1-3	1	4	1.25E-5	0	24	0.92	0.92	3	Urban house	Streets
B2-1	10	4	1.25E-5	24	0	0.9	1.2	3	Urban house	Streets
B2-2	10	4	1.25E-5	16.4	7.6	0.9	1.2	3	Urban house	Streets
B2-3	10	4	1.25E-5	0	24	0.9	1.2	3	Urban house	Streets
C1-1	10	365	1.25E-5	24	0	0.9	1.2	3	Urban house	Streets
C1-2	10	365	1.25E-5	16.4	7.6	0.9	1.2	3	Urban house	Streets
C1-3	1	365	1.25E-5	24	0	0.9	1.2	1	Rural house	Soils
C1-4	1	365	1.25E-5	16.4	7.6	0.9	1.2	1	Rural house	Soils
C2-1	10	250	1.25E-5	8	0	1.2	1.2	5	Warehouse	Streets
C2-2	10	250	1.25E-5	0	8	1.2	1.6	5	Warehouse	Streets
C3-1	10	250	1.25E-5	8	0	1.2	1.2	6	Monument	Soils
C3-2	10	250	1.25E-5	0	8	1.2	1.6	6	Monument	Soils
C4-1	10	125	1.25E-5	0	8	1.2	1.6	5	Warehouse	Streets
C4-2	10	125	1.25E-5	8	0	1.2	1.2	5	Warehouse	Streets
C4-3	10	14	1.25E-5	24	0	0.5	1.5	5	Warehouse	Streets
C5-1	10	250	1.25E-5	8	0	1.2	1.2	7	Subway station	Streets
C5-2	10	250	1.25E-5	0	8	1.2	1.6	7	Subway station	Streets
C5-3	10	250	1.25E-5	1.25	0	1	1.5	8	Rail car	Streets
C5-4	10	250	1.25E-5	1	0.25	1	1.5	8	Rail car	Streets
C6-1	10	250	1.25E-5	0	8	1.2	1.6	5	Warehouse	Streets
C6-2	10	250	1.25E-5	8	0	1.2	1.2	5	Warehouse	Streets
C6-3	10	250	1.25E-5	2	0	1.2	1.2	5	Warehouse	Streets
C6-4	10	250	1.25E-5	0	2	1.2	1.6	5	Warehouse	Streets
C7-1	10	250	1.25E-5	0	8	1.2	1.6	5	Warehouse	Streets
C7-2	10	250	1.25E-5	8	0	1.2	1.2	5	Warehouse	Streets
C7-3	10	250	1.25E-5	2	0	1.2	1.2	5	Warehouse	Streets
C7-4	10	250	1.25E-5	0	2	1.2	1.6	5	Warehouse	Streets

TABLE 2.7 (Cont.)

Group-Receptor No.	Multiplication Factor for Outdoor Resuspension	Exposure Frequency (d/yr)	Dust Ingestion Rate (m^2/h)	Indoor Exposure Duration (h/d)	Outdoor Exposure Duration (h/d)	Indoor Inhalation Rate (m^3/h)	Outdoor Inhalation Rate (m^3/h)	Geometry No. for External Exposure to Buildings	Building/Source Description	Initial Outdoor Source
D1-1	1	NA[a]	1.25E-5	NA	NA	1.2	1.6	5	Warehouse	Streets
D1-2	1	NA	1.25E-5	NA	NA	1.2	1.2	5	Warehouse	Streets
D2-1	1	NA	1.25E-5	NA	NA	1.2	1.2	3	Urban house	Streets
D2-2	1	NA	1.25E-5	NA	NA	1.2	1.2	3	Urban house	Streets
E1-1	10	250	0	0	1	1.2	1.2	NA	Vehicle passing bridges	Streets
E1-2	100	250	0	0	0.02	1.2	1.2	NA	Vehicle passing bridges	Streets
E2-1	10	250	0	0	1	1.2	1.2	NA	Vehicle passing streets	Streets
E2-2	100	250	0	0	0.02	1.2	1.2	NA	Vehicle passing streets	Streets
E3-1	10	250	1.25E-5	0	1	1.2	1.2	NA	Streets	Streets
E3-2	100	250	1.25E-5	0	1	1.2	1.2	NA	Streets	Streets
E3-3	10	250	1.25E-5	0	8	1.2	1.2	NA	Streets	Streets

[a] NA = not applicable.

The inhalation rates listed in Table 2.7 were developed by considering different activities that may be taken by the receptors while staying indoors and outdoors. Corresponding inhalation rates for the different activities were taken from the ICRP 66 (ICRP 1994) report, which was also used by FRMAC for developing its default inhalation rate. Table 2.8 provides the assumptions used for developing the inhalation rates listed in Table 2.7.

TABLE 2.8 Inhalation Rates Used for Different Scenarios

Scenario	Indoor (m^3/hr)	Outdoor (m^3/hr)	Basis for Inhalation Rate
B1-1	0.92	0.92	Average breathing rate for sedentary worker
B1-2	0.92	0.92	Same as B1-1
B1-3	0.92	0.92	Same as B1-1
B2-1	0.9	1.2	Scale the average indoor breathing rate for sedentary worker with exposure duration for indoor and scale the average outdoor breathing rate for sedentary worker with exposure duration for outdoor
B2-2	0.9	1.2	Same as B2-1
B2-3	0.9	1.2	Same as B2-1
C1-1	0.9	1.2	Same as B2-1
C1-2	0.9	1.2	Same as B2-1
C1-3	0.9	1.2	Same as B2-1
C1-4	0.9	1.2	Same as B2-1
C2-1	1.2	1.2	Use the sedentary worker indoor hourly rate, excluding sleeping for indoor, and scale the average outdoor breathing rate for sedentary worker with exposure duration for outdoor
C2-2	1.2	1.6	Use the outdoor worker indoor hourly rate, excluding sleeping for indoor, and use the average outdoor breathing rate for outdoor worker for outdoor
C3-1	1.2	1.2	Same as C2-1
C3-2	1.2	1.6	Same as C2-2
C4-1	1.2	1.6	Same as C2-2
C4-2	1.2	1.2	Same as C2-1
C4-3	0.5	1.5	Use the average for sleeping, sitting, and awake for indoor; use the average for light activity for outdoor
C5-1	1.2	1.2	Same as C2-1
C5-2	1.2	1.6	Same as C2-2

TABLE 2.8 (Cont.)

Scenario	Indoor (m^3/hr)	Outdoor (m^3/hr)	Basis for Inhalation Rate
C5-3	1.0	1.5	Use the average for sitting, awake, and light activity for indoor and the average for light activity for outdoor
C5-4	1.0	1.5	Same as C5-3
C6-1	1.2	1.6	Same as C2-2
C6-2	1.2	1.2	Same as C2-1
C6-3	1.2	1.2	Same as C2-1
C6-4	1.2	1.6	Same as C2-2
C7-1	1.2	1.6	Same as C2-2
C7-2	1.2	1.2	Same as C2-1
C7-3	1.2	1.2	Same as C2-1
C7-4	1.2	1.6	Same as C2-2
D1-1	1.2	1.6	Same as C2-2
D1-2	1.2	1.2	Same as C2-1
D2-1	1.2	1.2	Same as C2-1
D2-2	1.2	1.2	Same as C2-1
E1-1	–[a]	1.2	Use the breathing rate for miscellaneous activities indoors
E1-2	–	1.2	Same as E1-1
E2-1	–	1.2	Same as E1-1
E2-2	–	1.2	Same as E1-1
E3-1	–	1.2	Use the average outdoor breathing rate for sedentary worker for outdoor
E3-2	–	1.2	Same as E3-1
E3-3	–	1.2	Same as E3-1

[a] Note that "–" means the parameter is not needed in the calculations.

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3 GROUP A: ACCESS CONTROL DURING EMERGENCY RESPONSE OPERATIONS

The release of radionuclides in an RDD event could occur inside or outside a building and could result from different dispersion mechanisms, such as the explosion of a conventional bomb, spray from an aircraft, or spray from an injection into an air-handling system. Due to the potential risks that could result from radiation exposures incurred by the first responders who arrive at the scene, stay times at the event location would need to be limited in order to protect human health and save lives. Since little information would be known on the type and extent of radiation contamination shortly after the event, the following objectives were considered when developing stay times for use in the early response phase (Group A): (1) the stay times are to be applicable immediately after an RDD event, (2) they are independent of the location and type of release, and (3) they are simple to implement.

The stay time tables for Group A were developed for controlling access to the RDD event location during emergency response operations. They can be applied to provide life and property saving measures (Group A1) and to set emergency worker demarcation (Group A2).

In many cases, the first responders may use respirators, which would reduce the dose from inhalation of airborne particulates. Therefore, stay-time tables were developed for three different cases: (1) without a respirator, (2) with a full-face air-purifying respirator, and (3) with a full-face continuous-flow atmosphere-supplying respirator. The assigned protection factor of 100 and 1,000, respectively, for a full-face air-purifying respirator operating under negative pressure and a full-face continuous flow atmosphere-supplying respirator are based on the values provided in Appendix A to 10 CFR Part 20.

To use the stay-time tables, the first responders would need to know either the air concentration or the ground surface concentration and have obtained data from one of the following: (1) gross alpha measurements, (2) gross β-γ measurements, (3) γ exposure rate measurements, or (4) radionuclide-specific measurements.

3.1 SCENARIO DESCRIPTION

It was assumed that a large area (either inside or outside a building) was contaminated during an RDD event. Even though the distribution of contamination would most likely be uneven, in order to develop the stay-time tables, it was assumed that the contamination was uniformly distributed. It was further assumed that receptors were exposed to contaminated air as well as contaminated material deposited on the ground surface.

The first responders were assumed to stay in the event location continuously searching for evidence and conducting investigations. The potential radiation dose would result from (1) inhalation of airborne radioactive particulates, (2) external exposure due to air submersion, and (3) external exposure to materials deposited on the ground surface. For the responders that do not wear respirators (case 1), the radiation dose would also result from direct ingestion of contaminated dust particles.

3.2 PARAMETER ASSUMPTIONS

The airborne radionuclides could be due to the remnant of the dispersion triggered by the RDD event as well as the resuspension of deposited radionuclides disturbed by the first responders. In the stay-time development, it was assumed that the air concentration and ground deposition were linearly related by a surrogate resuspension factor, with a value reflecting the above two mechanisms for air contamination.

The following five key parameters were used in the calculations: (1) the resuspension factor was 1×10^{-6} m^{-1}, which is used in NCRP 129 (NCRP 1999; Loosmore 2003), to simulate exposures of first responders in emergency scenarios; (2) the inhalation rate was 1.4 m^3/h, which was the most likely value for outdoor activities, from Section A.3 of Biwer et al. (2002); (3) the inhalation and ingestion dose conversion factors were taken from ICRP 72 (ICRP 1996) and are based on the ICRP 60 methodology (ICRP 1991); (4) the dose coefficients for air submersion and exposure to contaminated ground surface were based on the effective dose calculated by DCAL software (Eckerman et al. 2006); and (5) the dust ingestion rate of 3×10^{-4} m^2/day for the emergency workers without respirators was taken from the FRMAC manual (Rhodes 2003). Table 3.1 provides dose conversion factors for the contaminants considered in developing stay time tables. The dose conversion factors include the contribution from short-lived (half-life <30 days) progenies along with the parent radionuclides. For example, Sr-90 dose conversion factors in Table 3.1 include the contribution from short-lived progeny Y-90.

TABLE 3.1 Dose Coefficients for Exposure to Contaminated Ground Surface, Air Submersion, and Inhalation

Radionuclide	Ground Surface (mrem/yr per pCi/cm^2)	Submersion (mrem/yr per pCi/m^3)	Inhalation (mrem/pCi)	Ingestion (mrem/pCi)
Am-241	2.72E-02	7.91E-05	3.55E-01	7.40E-04
Cf-252	4.98E-01	2.70E-03	7.40E-02	3.33E-04
Cm-244	7.51E-04	3.97E-07	2.11E-01	4.44E-04
Co-60	2.69E+00	1.39E-02	1.15E-04	1.26E-05
Cs-137	6.42E-01	2.98E-03	1.44E-04	4.81E-05
Ir-192	9.06E-01	4.23E-03	2.44E-05	5.18E-06
Po-210	9.43E-06	4.54E-08	1.59E-02	4.44E-03
Pu-238	7.31E-04	4.10E-07	4.07E-01	8.51E-04
Pu-239	3.32E-04	4.08E-07	4.44E-01	9.25E-04
Ra-226	1.97E+00	9.79E-03	3.53E-02	1.04E-03
Sr-90	1.30E-01	1.04E-04	5.98E-04	1.14E-04

TABLE 3.2 Pathway-Specific and Total Dose-to-Source Ratio (mrem/h per pCi/m^3) from Unit Air Concentration[a]

Radionuclide	Deposited Surface Concentration (pCi/m^2)	Inhalation (mrem/h)	Ingestion (mrem/h)	Submersion (mrem/h)	Groundshine (mrem/h)	Total (mrem/h)
Am-241	1,000,000	4.97E-01	9.25E-03	9.03E-09	3.11E-04	5.07E-01
Cf-252	1,000,000	1.04E-01	4.16E-03	3.08E-07	5.68E-03	1.13E-01
Cm-244	1,000,000	2.95E-01	5.55E-03	4.53E-11	8.57E-06	3.01E-01
Co-60	1,000,000	1.61E-04	1.57E-04	1.59E-06	3.07E-02	3.10E-02
Cs-137	1,000,000	2.02E-04	6.01E-04	3.40E-07	7.33E-03	8.13E-03
Ir-192	1,000,000	3.42E-05	6.48E-05	4.83E-07	1.03E-02	1.04E-02
Po-210	1,000,000	2.23E-02	5.55E-02	5.18E-12	1.08E-07	7.78E-02
Pu-238	1,000,000	5.70E-01	1.06E-02	4.68E-11	8.34E-06	5.80E-01
Pu-239	1,000,000	6.22E-01	1.16E-02	4.66E-11	3.79E-06	6.33E-01
Ra-226	1,000,000	4.94E-02	1.30E-02	1.12E-06	2.25E-02	8.48E-02
Sr-90	1,000,000	8.37E-04	1.42E-03	1.19E-08	1.48E-03	3.74E-03

[a] Air concentration = 1 pCi/m^3 in all cases.

Table 3.2 provides the DSRs for different exposure pathways based on unit air concentrations. (The surface deposition concentration was calculated from the air concentration by using a resuspension factor of 1×10^{-6} m^{-1}.) The instantaneous doses were calculated (i.e., no decay and ingrowth were included). It was assumed that the ground contamination was infinite in extent.

Although the calculation of the external dose from an infinitely large ground surface is more representative for an outdoor situation, the dose results are either more conservative than or comparable with those from contaminated building surfaces representative of an indoor situation. To compare the groundshine dose with the dose from contaminated building surfaces, the total external dose was calculated for buildings with different geometries. It was assumed that all the interior surfaces of buildings were uniformly contaminated with Co-60 (a high-energy gamma emitter). The external doses from all six contaminated surfaces (floor, ceiling, and four walls) were added to get the total external dose. Table 3.3 shows the external dose to a receptor located at the center of the contaminated floor. (This receptor would receive the maximum dose.) The building area was varied from 36 m^2 (representative of a small store) to 2,500 m^2 (representative of a large warehouse), and the building height was varied from 2.5 to 6 m. In Table 3.2, groundshine dose for Co-60 is 3.07E-2 mrem/h for a deposition concentration of 10^6 pCi/m^2 on an infinitely large ground surface; when this dose is converted to mrem/yr per pCi/m^2, it results in a groundshine dose of 3.07E-2 × 1E-6 × 365.25 × 24 = 2.69E-4 mrem/yr per pCi/m^2. As shown in Table 3.3, for most of the building geometries considered, the external dose is significantly lower than this value. Even for the building geometries with very large areas and small heights (area = 900 m^2 and height = 2.5 m; area = 2,500 m^2 and height = 2.5 m; and area = 2,500 m^2 and height = 4 m), the total external doses are not significantly different from this value. In any case, it is very unlikely that a receptor would be exposed to a large building without any shielding from the contaminated walls. On the basis of the above comparison, it is concluded that the groundshine dose from an infinitely large contaminated surface (listed in Table 3.2) can be used to develop stay times that are protective for both indoor and outdoor situations.

The following sections provide stay time tables for the three different cases: without a respirator, with a full-face respirator, and with a full-face continuous-flow atmosphere-supplying respirator. If multiple radionuclides are present, and the measured activity concentrations (gross alpha, beta and gamma, or exposure rates) are the sum from all radionuclides, the stay time based on the most restrictive radionuclide should be used. If radionuclides are identified and the relative concentration ratios among radionuclides are known, the sum of fractions rule should be used in determining the stay times.

TABLE 3.3 External Exposure Pathway Dose (mrem/yr per pCi/m²) to a Receptor in Buildings with Co-60 Contamination and Different Geometries[a]

Area (m^2)	Height = 2.5 m	Height = 4.0 m	Height = 6.0 m
36	1.52E-04	1.44E-04	1.45E-04
100	1.84E-04	1.67E-04	1.62E-04
900	2.74E-04	2.46E-04	2.28E-04
2,500	3.21E-04	2.89E-04	2.69E-04

[a] Receptor is at the center of the building, 1 m above the contaminated floor.

3.3 STAY TIME TABLES WITHOUT A RESPIRATOR

Table 3.4 provides the stay times without a respirator for given doses when the surface concentration is known. Since Pu-239 has the maximum DSR (see Table 3.2), it was used as a reference radionuclide for calculating stay times. This table should be used only when the surface concentration (in terms of gross alpha concentration) is known but the radionuclides are not identified. If the contaminants are β-γ emitters (rather than alpha emitters), the stay times for β-γ surface concentration (listed in Table 3.5) should be used. (Note that values in Table 3.4 are more restrictive than values in Table 3.5.) To determine the stay times for β-γ emitters, Co-60 was used as a reference radionuclide because it has the maximum DSR among the β-γ emitters (see Table 3.2). One important note is that Table 3.5 stay times should be used only when it is clear that β-γ emitters are the dominant hazard. It is for this reason that a determination regarding whether β-γ emitters or alpha emitters are present should be made as soon as possible and that respirators should be employed at least until that is determined. Refer to Section 3.4 for stay time operational guidelines with respirators. Table 3.6 provides stay times for given doses when the air concentration is known. Since Pu-239 has the maximum DSR (see Table 3.2), it was used as a reference radionuclide for calculating stay times. Table 3.7 presents stay time tables for β-γ emitters when exposure rates are known. It is assumed that an exposure rate of 1 R would result in a dose of 0.7 rem (effective dose). Since the fractional dose contribution from submersion and groundshine to the total dose is the least for Po-210 (see Table 3.2), it was used as a reference radionuclide for calculating stay times based on the exposure rate measurement.

Stay times listed in Tables 3.4–3.7 are for use when radionuclides are not identified. If radionuclides are identified, the radionuclide correction factors listed in Table 3.8 can be used to

TABLE 3.4 Stay Times[a] without a Respirator Based on Gross Alpha Surface Measurement

Activity per Unit Area			Stay Time[a] for Given Dose, h							
pCi/cm^2	Bq/cm^2	dpm/100 cm^2	0.1 rem	0.5 rem	1 rem	2 rem	5 rem	10 rem	25 rem	100 rem
10	0.37	2,220	1.6E+03	-	-	-	-	-	-	-
100	3.7	22,200	1.6E+02	7.9E+02	1.6E+03	-	-	-	-	-
1,000	37	222,000	1.6E+01	7.9E+01	1.6E+02	3.2E+02	7.9E+02	1.6E+03	-	-
10,000	370	2.22×10^6	1.6E+00	7.9E+00	1.6E+01	3.2E+01	7.9E+01	1.6E+02	3.9E+02	1.6E+03
100,000	3,700	2.22×10^7	1.6E-01	7.9E-01	1.6E+00	3.2E+00	7.9E+00	1.6E+01	3.9E+01	1.6E+02
1×10^6	37,000	2.22×10^8	1.6E-02	7.9E-02	1.6E-01	3.2E-01	7.9E-01	1.6E+00	3.9E+00	1.6E+01

[a] For stay time calculations, Pu-239 was used as a reference radionuclide. If the contaminant is known and is other than Pu-239, stay times can be adjusted with multiplication by the correction factors. The correction factors were calculated as the ratio of the DSR of a reference radionuclide to the DSR of the radionuclide of concern. The correction factors for different radionuclides are as follows: Am-241 = 1; Cf-252 = 6; Cm-244 = 2; Po-210 = 8; Pu-238 = 1; Pu-239 = 1; and Ra-226 = 7. For example, if the contaminant is Cf-252 and the measured surface concentration is 100 pCi/cm^2, the first responder who does not use a respirator can spend up to 160 × 6 = 960 hours at the RDD event location without receiving a dose greater than 0.1 rem.

TABLE 3.5 Stay Times[a,b] without a Respirator Based on β-γ Surface Measurement

Activity per Unit Area			Stay Time[a] for Given Dose, h							
pCi/cm^2	Bq/cm^2	dpm/100 cm^2	0.1 rem	0.5 rem	1 rem	2 rem	5 rem	10 rem	25 rem	100 rem
1,000	37	222,200	3.2E+02	1.6E+03	–	–	–	–	–	–
10,000	370	2.22×10^6	3.2E+01	1.6E+02	3.2E+02	6.4E+02	1.6E+03	–	–	–
100,000	3,700	2.22×10^7	3.2E+00	1.6E+01	3.2E+01	6.4E+01	1.6E+02	3.2E+02	8.1E+02	–
1×10^6	37,000	2.22×10^8	3.2E-01	1.6E+00	3.2E+00	6.4E+00	1.6E+01	3.2E+01	8.1E+01	3.2E+02
1×10^7	370,000	2.22×10^9	3.2E-02	1.6E-01	3.2E-01	6.4E-01	1.6E+00	3.2E+00	8.1E+00	3.2E+01

[a] For stay time calculations, Co-60 was used as a reference radionuclide. If the contaminant is known and is other than Co-60, stay times can be adjusted with multiplication by the correction factors. The correction factors were calculated as the ratio of the DSR of a reference radionuclide to the DSR of the radionuclide of concern. The correction factors for different radionuclides are as follows: Am-241 = 0.06; Co-60 = 1; Cs-137 = 4; Ir-192 = 3; Ra-226 = 0.4; and Sr-90 = 8. For example, if the contaminant is Cs-137 and the measured surface concentration is 1,000 pCi cm^{-2}, the first responder who does not use a respirator can spend up to 320 × 4 = 1,280 hours at the RDD event location without receiving a dose greater than 0.1 rem.

[b] Stay times in this table should be used only after the exclusion of potential alpha emitters.

TABLE 3.6 Stay Times[a] without a Respirator Based on Air Concentration Measurement

Air Concentration			Stay Time[a] for Given Dose, h							
pCi/m³	Bq/m³	dpm/m³	0.1 rem	0.5 rem	1 rem	2 rem	5 rem	10 rem	25 rem	100 rem
0.1	0.0037	0.222	1.6E+03	–	–	–	–	–	–	–
1	0.037	2.22	1.6E+02	7.9E+02	1.6E+03	–	–	–	–	–
10	0.37	22.2	1.6E+01	7.9E+01	1.6E+02	3.2E+02	7.9E+02	1.6E+03	–	–
100	3.7	222	1.6E+00	7.9E+00	1.6E+01	3.2E+01	7.9E+01	1.6E+02	3.9E+02	1.6E+03
1,000	37	2,220	1.6E-01	7.9E-01	1.6E+00	3.2E+00	7.9E+00	1.6E+01	3.9E+01	1.6E+02
10,000	370	22,200	1.6E-02	7.9E-02	1.6E-01	3.2E-01	7.9E-01	1.6E+00	3.9E+00	1.6E+01
100,000	3,700	222,000	1.6E-03	7.9E-03	1.6E-02	3.2E-02	7.9E-02	1.6E-01	3.9E-01	1.6E+00

[a] For stay time calculations, Pu-239 was used as a reference radionuclide. If the contaminant is known and is other than Pu-239, stay times can be adjusted with multiplication by the correction factors. The correction factors were calculated as the ratio of the DSR of a reference radionuclide to the DSR of the radionuclide of concern. The correction factors for different radionuclides are as follows: Am-241 = 1; Cf-252 = 6; Cm-244 = 2; Co-60 = 20; Cs-137 = 80; Ir-192 = 60; Po-210 = 8; Pu-238 = 1; Pu-239 = 1; Ra-226 = 7; and Sr-90 = 170. For example, if the contaminant is Cf-252 and the measured air concentration is 1 pCi m^{-3}, the first responder who does not use a respirator can spend up to 160 × 6 = 960 hours at the RDD event location without receiving a dose greater than 0.1 rem.

TABLE 3.7 Stay Times[a] without a Respirator Based on Gamma Exposure Rate Measurement

Exposure Rate		Stay Time[a] for Given Dose, h							
μR/h	mR/h	0.1 rem	0.5 rem	1 rem	2 rem	5 rem	10 rem	25 rem	100 rem
10	0.01	2.0E-02	9.9E-02	2.0E-01	4.0E-01	9.9E-01	2.0E+00	4.9E+00	2.0E+01
100	0.1	2.0E-03	9.9E-03	2.0E-02	4.0E-02	9.9E-02	2.0E-01	4.9E-01	2.0E+00
1,000	1	2.0E-04	9.9E-04	2.0E-03	4.0E-03	9.9E-03	2.0E-02	4.9E-02	2.0E-01
10,000	10	2.0E-05	9.9E-05	2.0E-04	4.0E-04	9.9E-04	2.0E-03	4.9E-03	2.0E-02
100,000	100	2.0E-06	9.9E-06	2.0E-05	4.0E-05	9.9E-05	2.0E-04	4.9E-04	2.0E-03
1×10^6	1,000	2.0E-07	9.9E-07	2.0E-06	4.0E-06	9.9E-06	2.0E-05	4.9E-05	2.0E-04
1×10^7	10,000	2.0E-08	9.9E-08	2.0E-07	4.0E-07	9.9E-07	2.0E-06	4.9E-06	2.0E-05

[a] For stay time calculations, Po-210 was used as a reference radionuclide. If the contaminant is known and is other than Po-210, stay times can be adjusted with multiplication by the correction factors. The correction factors were calculated as the ratio of the fractional dose contribution from submersion and groundshine to the total for the radionuclide of concern to the fractional dose contribution from submersion and groundshine to the total for Po-210. The correction factors for different radionuclides are as follows: Am-241 = 440; Cf-252 = 36,000; Cm-244 = 21; Co-60 = 720,000; Cs-137 = 650,000; Ir-192 = 720,000; Po-210 = 1; Pu-238 = 10; Pu-239 = 4; Ra-226 = 190,000; and Sr-90 = 290,000. For example, if the contaminant is Cs-137 and the measured exposure rate is 10 mR/h, the first responder who does not use a respirator can spend up to 2.0E-5 × 650,000 = 13 hours at the RDD event location without receiving a dose greater than 0.1 rem.

TABLE 3.8 Radionuclide Correction Factors without a Respirator

	Correction Factor for Stay Times Based on Surface Concentration Measurement			
Radionuclide	Air Concentration Measurement[a]	Alpha Emitters[b]	β-γ Emitters[c]	Exposure Rate Measurement[d]
Am-241	1	1	0.06	440
Cf-252	6	6	–	36,000
Cm-244	2	2	–	21
Co-60	20	–	1	720,000
Cs-137	80	–	4	650,000
Ir-192	60	–	3	720,000
Po-210	8	8	–	1
Pu-238	1	1	–	10
Pu-239	1	1	–	4
Ra-226	7	7	0.4	190,000
Sr-90	170	–	8	290,000

[a] For stay times based on the air concentration measurement, Pu-239 is used as the reference radionuclide.

[b] For stay times based on the surface concentration measurement, Pu-239 is used as the reference radionuclide for alpha emitters.

[c] For stay times based on the surface concentration measurement, Co-60 is used as the reference radionuclide for β-γ emitters.

[d] For stay times based on the exposure rate measurement, Po-210 is used as the reference radionuclide.

adjust the stay times. For stay times developed based on air concentration or surface concentration measurements, the correction factors were calculated as the ratio of the DSR of the reference radionuclide to the DSR of the radionuclide of concern. For stay times developed based on exposure rate measurements, the correction factors were calculated as the ratio of the fractional dose contribution from submersion and groundshine to the total for the radionuclide of concern to the fractional dose contribution from submersion and groundshine to the total for the reference radionuclide.

3.4 STAY TIME TABLES WITH A FULL-FACE AIR-PURIFYING RESPIRATOR

The stay time tables for this case apply to emergency workers who wear full-face air-purifying respirators operating at a negative pressure. The assigned protection factor for this type of respirator was 100 (Appendix A to 10 CFR Part 20). The ground surface concentration was calculated from the air concentration by using a resuspension factor of 1×10^{-6} m^{-1}. The instantaneous dose was calculated (i.e., no decay and ingrowth were included). It was assumed that ground surface contamination was infinite in extent. Table 3.9 provides the DSRs for different exposure pathways based on unit air concentrations to which workers would be exposed.

Table 3.10 provides the stay times for given doses when the gross alpha surface concentration is known. Since Ra-226 has the maximum DSR among alpha emitters (see Table 3.9), it was used as a reference radionuclide for calculating stay times. This table should be used when the surface concentration (in terms of gross alpha) is known but the radionuclides are not identified. If there is the possibility of β-γ emitters, the stay times for β-γ surface concentrations (listed in Table 3.11) should be used. (Note that values in Table 3.11 are more restrictive than values in Table 3.10.) Table 3.11 can also be used when the contaminant type (alpha or β-γ) is not known. To get the stay times for β-γ emitters, Co-60 was used as a reference radionuclide because it has the maximum DSR. Table 3.12 provides stay times for given doses when the air concentration is known. Since Co-60 has the maximum DSR (see Table 3.9), it was used as a reference radionuclide for calculating stay times. Table 3.13 presents stay times for β-γ emitters when exposure rates are known. It is assumed that an exposure rate of 1 R would result in a dose of 0.7 rem (effective dose). Since the fractional dose contribution from air submersion and groundshine to the total dose is the least for Po-210 (see Table 3.9), it was used as a reference radionuclide for calculating the stay times based on the exposure rate measurement.

Stay times listed in Tables 3.10–3.13 are for use when radionuclides are not identified. If radionuclides are identified, the radionuclide correction factors listed in Table 3.14 can be used to adjust the stay times. For stay times developed based on air concentration or surface concentration measurements, the correction factors were calculated as the ratio of the DSR of the reference radionuclide to the DSR of the radionuclide of concern. For stay times developed based on exposure rate measurements, the correction factors were calculated as the ratio of the fractional dose contribution from submersion and groundshine to the total for the radionuclide of concern to the fractional dose contribution from submersion and groundshine to the total for the reference radionuclide.

TABLE 3.9 Pathway-Specific and Total Dose-to-Source Ratio (mrem/h per pCi/m^3) with a Full-Face Air-Purifying Respirator from Unit Air Concentration[a]

Radionuclide	Deposited Surface Concentration (pCi/m^2)	Inhalation (mrem/h)	Submersion (mrem/h)	Groundshine (mrem/h)	Total (mrem/h)
Am-241	1,000,000	4.97E-03	9.03E-09	3.11E-04	5.28E-03
Cf-252	1,000,000	1.04E-03	3.08E-07	5.68E-03	6.72E-03
Cm-244	1,000,000	2.95E-03	4.53E-11	8.57E-06	2.96E-03
Co-60	1,000,000	1.61E-06	1.59E-06	3.07E-02	3.07E-02
Cs-137	1,000,000	2.02E-06	3.40E-07	7.33E-03	7.33E-03
Ir-192	1,000,000	3.42E-07	4.83E-07	1.03E-02	1.03E-02
Po-210	1,000,000	2.23E-04	5.18E-12	1.08E-07	2.23E-04
Pu-238	1,000,000	5.70E-03	4.68E-11	8.34E-06	5.71E-03
Pu-239	1,000,000	6.22E-03	4.66E-11	3.79E-06	6.22E-03
Ra-226	1,000,000	4.94E-04	1.12E-06	2.25E-02	2.30E-02
Sr-90	1,000,000	8.37E-06	1.19E-08	1.48E-03	1.49E-03

[a] Air concentration = 1 pCi/m^3 in all cases.

TABLE 3.10 Stay Times[a] with Full-Face Air-Purifying Respirators Based on Gross Alpha Surface Measurement

Activity per Unit Area			Stay Time[a] for Given Dose, h							
pCi/cm^2	Bq/cm^2	dpm/100 cm^2	0.1 rem	0.5 rem	1 rem	2 rem	5 rem	10 rem	25 rem	100 rem
1,000	37	222,200	4.4E+02	–	–	–	–	–	–	–
10,000	370	2.22×10^6	4.4E+01	2.2E+02	4.4E+02	8.7E+02	–	–	–	–
100,000	3,700	2.22×10^7	4.4E+00	2.2E+01	4.4E+01	8.7E+01	2.2E+02	4.4E+02	1.1E+03	–
1×10^6	37,000	2.22×10^8	4.4E-01	2.2E+00	4.4E+00	8.7E+00	2.2E+01	4.4E+01	1.1E+02	4.4E+02
1×10^7	370,000	2.22×10^9	4.4E-02	2.2E-01	4.4E-01	8.7E-01	2.2E+00	4.4E+00	1.1E+01	4.4E+01

[a] For stay time calculations, Ra-226 was used as a reference radionuclide. If the contaminant is known and is other than Ra-226, stay times can be adjusted with multiplication by the correction factors. The correction factors were calculated as the ratio of the DSR of the reference radionuclide to the DSR of the radionuclide of concern. The correction factors for different radionuclides are as follows: Am-241 = 4; Cf-252 = 3; Cm-244 = 8; Po-210 = 100; Pu-238 = 4; Pu-239 = 4; and Ra-226 = 1. For example, if the contaminant is Cf-252 and the measured surface concentration is 1,000 pCi/cm^2, the first responder with a full-face air-purifying respirator can spend up to 440 × 3 = 1,320 hours at the RDD event location without receiving a radiation dose greater than 0.1 rem.

TABLE 3.11 Stay Times[a] with Full-Face Air-Purifying Respirators Based on β-γ Surface Measurement

Activity per Unit Area			Stay Time[a] for Given Dose, h							
pCi/cm^2	Bq/cm^2	dpm/100 cm^2	0.1 rem	0.5 rem	1 rem	2 rem	5 rem	10 rem	25 rem	100 rem
1,000	37	222,200	3.3E+02	1.6E+03	–	–	–	–	–	–
10,000	370	2.22×10^6	3.3E+01	1.6E+02	3.3E+02	6.5E+02	1.6E+03	–	–	–
100,000	3,700	2.22×10^7	3.3E+00	1.6E+01	3.3E+01	6.5E+01	1.6E+02	3.3E+02	8.1E+02	–
1×10^6	37,000	2.22×10^8	3.3E-01	1.6E+00	3.3E+00	6.5E+00	1.6E+01	3.3E+01	8.1E+01	3.3E+02
1×10^7	370,000	2.22×10^9	3.3E-02	1.6E-01	3.3E-01	6.5E-01	1.6E+00	3.3E+00	8.1E+00	3.3E+01

[a] For stay time calculations, Co-60 was used as a reference radionuclide. If the contaminant is known and is other than Co-60, stay times can be adjusted with multiplication by the correction factors. The correction factors were calculated as the ratio of the DSR of the reference radionuclide to the DSR of the radionuclide of concern. The correction factors for different radionuclides are as follows: Am-241 = 6; Co-60 = 1; Cs-137 = 4; Ir-192 = 3; Ra-226 = 1; and Sr-90 = 20. For example, if the contaminant is Cs-137 and the measured surface concentration is 1,000 pCi/cm^2, the first responder with a full-face air-purifying respirator can spend up to 330 × 4 = 1,320 hours at the RDD event location without receiving a radiation dose greater than 0.1 rem.

TABLE 3.12 Stay Times[a] with Full-Face Air-Purifying Respirators Based on Air Concentration Measurement

Air Concentration			Stay Time[a] for Given Dose, h							
pCi/m^3	Bq/m^3	Dpm/m^3	0.1 rem	0.5 rem	1 rem	2 rem	5 rem	10 rem	25 rem	100 rem
10	0.37	22.2	3.3E+02	1.6E+03	–	–	–	–	–	–
100	3.7	222	3.3E+01	1.6E+02	3.3E+02	6.5E+02	1.6E+03	–	–	–
1,000	37	2,220	3.3E+00	1.6E+01	3.3E+01	6.5E+01	1.6E+02	3.3E+02	8.1E+02	–
10,000	370	22,200	3.3E-01	1.6E+00	3.3E+00	6.5E+00	1.6E+01	3.3E+01	8.1E+01	3.3E+02
100,000	3,700	222,000	3.3E-02	1.6E-01	3.3E-01	6.5E-01	1.6E+00	3.3E+00	8.1E+00	3.3E+01

[a] For stay time calculations, Co-60 is used as a reference radionuclide. If the contaminant is known and is other than Co-60, stay times can be adjusted with multiplication by the correction factors. The correction factors were calculated as the ratio of the DSR of the reference radionuclide to the DSR of the radionuclide of concern. The correction factors for different radionuclides are as follows: Am-241 = 6; Cf-252 = 5; Cm-244 = 10; Co-60 = 1; Cs-137 = 4; Ir-192 = 3; Po-210 = 140; Pu-238 = 5; Pu-239 = 5; Ra-226 = 1; and Sr-90 = 20. For example, if the contaminant is Cf-252 and the measured air concentration is 100 pCi/m^3, the first responder who uses a full-face air-purifying respirator can spend up to 33 × 5 = 165 hours at the RDD event location without receiving a radiation dose greater than 0.1 rem.

TABLE 3.13 Stay Times[a] with Full-Face Air-Purifying Respirators Based on Gamma Exposure Rate Measurement

Exposure Rate		Stay Time[a] for Given Dose, h							
μR/h	mR/h	0.1 rem	0.5 rem	1 rem	2 rem	5 rem	10 rem	25 rem	100 rem
10	0.01	6.9E+00	3.5E+01	6.9E+01	1.4E+02	3.5E+02	6.9E+02	1.7E+03	–
100	0.1	6.9E-01	3.5E+00	6.9E+00	1.4E+01	3.5E+01	6.9E+01	1.7E+02	6.9E+02
1,000	1	6.9E-02	3.5E-01	6.9E-01	1.4E+00	3.5E+00	6.9E+00	1.7E+01	6.9E+01
10,000	10	6.9E-03	3.5E-02	6.9E-02	1.4E-01	3.5E-01	6.9E-01	1.7E+00	6.9E+00
100,000	100	6.9E-04	3.5E-03	6.9E-03	1.4E-02	3.5E-02	6.9E-02	1.7E-01	6.9E-01
1×10^6	1,000	6.9E-05	3.5E-04	6.9E-04	1.4E-03	3.5E-03	6.9E-03	1.7E-02	6.9E-02
1×10^7	10,000	6.9E-06	3.5E-05	6.9E-05	1.4E-04	3.5E-04	6.9E-04	1.7E-03	6.9E-03

[a] For stay time calculations, Po-210 was used as a reference radionuclide. If the contaminant is known and is other than Po-210, stay times can be adjusted with multiplication by the correction factors. The correction factors were calculated as the ratio of the fractional dose contribution from submersion and groundshine to the total for the radionuclide of concern to the fractional dose contribution from submersion and groundshine to the total for Po-210. The correction factors for different radionuclides are as follows: Am-241 = 120; Cf-252 = 1,800; Cm-244 = 6; Co-60 = 2,100; Cs-137 = 2,100; Ir-192 = 2,100; Po-210 = 1; Pu-238 = 3; Pu-239 = 1; Ra-226 = 2,000; and Sr-90 = 2,100. For example, if the contaminant is Cm-244 and the measured exposure rate is 10 mR/h, the first responder who wears a full-face air-purifying respirator can spend up to 6.9E-3 × 6 = 0.041 hours (2.5 minutes) at the RDD event location without receiving a radiation dose greater than 0.1 rem.

3.5 STAY TIME TABLES WITH FULL-FACE CONTINUOUS-FLOW ATMOSPHERE-SUPPLYING RESPIRATORS

The stay time tables for this case apply to emergency workers who wear full-face continuous-flow atmosphere-supplying respirators. The assigned protection factor for this type of respirator was 1,000 (Appendix A to 10 CFR Part 20). The ground surface concentration was calculated from the air concentration by using a resuspension factor of 1×10^{-6} m^{-1}. The instantaneous dose was calculated (i.e., no decay and ingrowth were included). It was assumed that ground contamination was infinite in extent. Table 3.15 provides the DSRs for different exposure pathways based on the air concentration to which workers would be exposed.

Table 3.16 provides the stay times for given doses when the surface concentration is known. Since Ra-226 has the maximum DSR among the alpha emitters (see Table 3.15), it was used as a reference radionuclide for calculating stay times. This table should be used only when the total surface concentration (in terms of gross alpha concentration) is known but radionuclides

TABLE 3.14 Radionuclide Correction Factor with Full-Face Air-Purifying Respirators

		Correction Factor for Stay Times Based on Surface Concentration Measurement		
Radionuclide	Air Concentration Measurement[a]	Alpha Emitters[b]	β-γ Emitters[c]	Exposure Rate Measurement[d]
Am-241	6	4	6	120
Cf-252	5	3	–	1,800
Cm-244	10	8	–	6
Co-60	1	–	1	2,100
Cs-137	4	–	4	2,100
Ir-192	3	–	3	2,100
Po-210	140	100	–	1
Pu-238	5	4	–	3
Pu-239	5	4	–	1
Ra-226	1	1	1	2,000
Sr-90	20	–	20	2,100

[a] For stay times based on the air concentration measurement, Co-60 was used as the reference radionuclide.

[b] For stay times based on the surface concentration measurements, Ra-226 was used as the reference radionuclide for alpha emitters.

[c] For stay times based on the surface concentration measurements, Co-60 was used as the reference radionuclide for β-γ emitters.

[d] For stay times based on the exposure rate measurement, Po-210 was used as the reference radionuclide.

are not identified. If the contaminants are β-γ emitters (rather than alpha emitters), the stay times for β-γ surface concentration (listed in Table 3.17) should be used. (Note that values in Table 3.17 are more restrictive than values in Table 3.16.) Table 3.17 can also be used when the contaminant type (alpha or β-γ) is not known. To get the stay times for β-γ emitters, Co-60 was used as a reference radionuclide because it has the maximum DSR. Table 3.18 provides stay times for given doses when the air concentration is known. Since Co-60 has the maximum DSR (see Table 3.15), it was used as a reference radionuclide for calculating stay times. Table 3.19 presents stay times for β-γ emitters when exposure rates are known. It is assumed that an exposure rate of 1 R would result in a dose of 0.7 rem (effective dose). Since the fractional contribution of submersion and groundshine to the total dose is the least for Po-210, it was used as a reference radionuclide for calculating stay times based on the exposure rate measurement.

TABLE 3.15 Pathway-Specific and Total Dose-to-Source Ratio (mrem/h per pCi/m^3) with Full-Face Continuous-Flow Atmosphere-Supplying Respirator from Unit Air Concentration[a]

Radionuclide	Deposited Surface Concentration (pCi/m^2)	Inhalation (mrem/h)	Submersion (mrem/h)	Groundshine (mrem/h)	Total (mrem/h)
Am-241	1,000,000	4.97E-04	9.03E-09	3.11E-04	8.08E-04
Cf-252	1,000,000	1.04E-04	3.08E-07	5.68E-03	5.79E-03
Cm-244	1,000,000	2.95E-04	4.53E-11	8.57E-06	3.04E-04
Co-60	1,000,000	1.61E-07	1.59E-06	3.07E-02	3.07E-02
Cs-137	1,000,000	2.02E-07	3.40E-07	7.33E-03	7.33E-03
Ir-192	1,000,000	3.42E-08	4.83E-07	1.03E-02	1.03E-02
Po-210	1,000,000	2.23E-05	5.18E-12	1.08E-07	2.24E-05
Pu-238	1,000,000	5.70E-04	4.68E-11	8.34E-06	5.78E-04
Pu-239	1,000,000	6.22E-04	4.66E-11	3.79E-06	6.25E-04
Ra-226	1,000,000	4.94E-05	1.12E-06	2.25E-02	2.25E-02
Sr-90	1,000,000	8.37E-07	1.19E-08	1.48E-03	1.48E-03

[a] Air concentration = 1 pCi/m^3 in all cases.

TABLE 3.16 Stay Times[a] with Full-Face Continuous-Flow Atmosphere-Supplying Respirators Based on Gross Alpha Surface Measurement

Activity per Unit Area			Stay Time[a] for Given Dose, h							
pCi/cm^2	Bq/cm^2	dpm/100 cm^2	0.1 rem	0.5 rem	1 rem	2 rem	5 rem	10 rem	25 rem	100 rem
1,000	37	222,200	4.4E+02	–	–	–	–	–	–	–
10,000	370	2.22×10^6	4.4E+01	2.2E+02	4.4E+02	8.9E+02	–	–	–	–
100,000	3,700	2.22×10^7	4.4E+00	2.2E+01	4.4E+01	8.9E+01	2.2E+02	4.4E+02	1.1E+03	–
1×10^6	37,000	2.22×10^8	4.4E-01	2.2E+00	4.4E+00	8.9E+00	2.2E+01	4.4E+01	1.1E+02	4.4E+02
1×10^7	370,000	2.22×10^9	4.4E-02	2.2E-01	4.4E-01	8.9E-01	2.2E+00	4.4E+00	1.1E+01	4.4E+01

[a] For stay time calculations, Ra-226 was used as a reference radionuclide. If the contaminant is known and is other than Ra-226, stay times can be adjusted with multiplication by the correction factors. The correction factors were calculated as the ratio of the DSR of a reference radionuclide to the DSR of the radionuclide of concern. The correction factors for different radionuclides are as follows: Am-241 = 30; Cf-252 = 4; Cm-244 = 70; Po-210 = 1,000; Pu-238 = 40; Pu-239 = 40; and Ra-226 = 1. For example, if the contaminant is Cf-252 and the measured surface concentration is 100,000 pCi/cm^2, the first responder with a full-face continuous-flow atmosphere-supplying respirator can spend up to $4.4 \times 4 = 17.6$ hours at the RDD event location without receiving a radiation dose greater than 0.1 rem.

TABLE 3.17 Stay Times[a] with Full-Face Continuous-Flow Atmosphere-Supplying Respirators Based on β-γ Surface Measurement

Activity per Unit Area			Stay Time[a] for Given Dose, h							
pCi cm^{-2}	Bq cm^{-2}	dpm/100 cm^2	0.1 rem	0.5 rem	1 rem	2 rem	5 rem	10 rem	25 rem	100 rem
1,000	37	222,200	3.3E+02	1.6E+03	–	–	–	–	–	–
10,000	370	2.22×10^6	3.3E+01	1.6E+02	3.3E+02	6.5E+02	1.6E+03	–	–	–
100,000	3,700	2.22×10^7	3.3E+00	1.6E+01	3.3E+01	6.5E+01	1.6E+02	3.3E+02	8.1E+02	–
1×10^6	37,000	2.22×10^8	3.3E-01	1.6E+00	3.3E+00	6.5E+00	1.6E+01	3.3E+01	8.1E+01	3.3E+02
1×10^7	370,000	2.22×10^9	3.3E-02	1.6E-01	3.3E-01	6.5E-01	1.6E+00	3.3E+00	8.1E+00	3.3E+01

[a] For stay time calculations, Co-60 was used as a reference radionuclide. If the contaminant is known and is other than Co-60, stay times can be adjusted with multiplication by the correction factors. The correction factors were calculated as the ratio of the DSR of a reference radionuclide to the DSR of the radionuclide of concern. The correction factors for different radionuclides are as follows: Am-241 = 40; Co-60 = 1; Cs-137 = 4; Ir-192 = 3; Ra-226 = 1; and Sr-90 = 20. For example, if the contaminant is Cs-137 and the measured surface concentration is 1,000 pCi/cm^2, the first responder with a full-face continuous-flow atmosphere-supplying respirator can spend up to 330 × 4 = 1,320 hours at the RDD event location without receiving a radiation dose greater than 0.1 rem.

TABLE 3.18 Stay Times[a] with Full-Face Continuous-Flow Atmosphere-Supplying Respirators Based on Air Concentration Measurement

Air Concentration			Stay Time[a] for Given Dose, h							
pCi/m^3	Bq/m^3	Dpm/m^3	0.1 rem	0.5 rem	1 rem	2 rem	5 rem	10 rem	25 rem	100 rem
10	0.37	22.2	3.3E+02	1.6E+03	–	–	–	–	–	–
100	3.7	222	3.3E+01	1.6E+02	3.3E+02	6.5E+02	1.6E+03	–	–	–
1,000	37	2,220	3.3E+00	1.6E+01	3.3E+01	6.5E+01	1.6E+02	3.3E+02	8.1E+02	–
10,000	370	22,200	3.3E-01	1.6E+00	3.3E+00	6.5E+00	1.6E+01	3.3E+01	8.1E+01	3.3E+02
100,000	3,700	222,000	3.3E-02	1.6E-01	3.3E-01	6.5E-01	1.6E+00	3.3E+00	8.1E+00	3.3E+01

[a] For stay time calculations, Co-60 was used as a reference radionuclide. If the contaminant is known and is other than Co-60, stay times can be adjusted with multiplication by the correction factors. The correction factors were calculated as the ratio of the DSR of a reference radionuclide to the DSR of the radionuclide of concern. The correction factors for different radionuclides are as follows: Am-241 = 40; Cf-252 = 5; Cm-244 = 100; Co-60 = 1; Cs-137 = 4; Ir-192 = 3; Po-210 = 1,400; Pu-238 = 50; Pu-239 = 50; Ra-226 = 1; and Sr-90 = 20. For example, if the contaminant is Cf-252 and the measured air concentration is 100 pCi/m^3, the first responder who uses a full-face continuous-flow atmosphere-supplying respirator can spend up to 33 × 5 = 165 hours at the RDD event location without receiving a radiation dose greater than 0.1 rem.

TABLE 3.19 Stay Times[a] with Full-Face Continuous-Flow Atmosphere-Supplying Respirators Based on Gamma Exposure Rate Measurement

Exposure Rate		Stay Time[a] for Given Dose, h							
μR/h	mR/h	0.1 rem	0.5 rem	1 rem	2 rem	5 rem	10 rem	25 rem	100 rem
10	0.01	6.9E+01	3.4E+02	6.9E+02	1.4E+03	–	–	–	–
100	0.1	6.9E+00	3.4E+01	6.9E+01	1.4E+02	3.4E+02	6.9E+02	1.7E+03	–
1,000	1	6.9E-01	3.4E+00	6.9E+00	1.4E+01	3.4E+01	6.9E+01	1.7E+02	6.9E+02
10,000	10	6.9E-02	3.4E-01	6.9E-01	1.4E+00	3.4E+00	6.9E+00	1.7E+01	6.9E+01
100,000	100	6.9E-03	3.4E-02	6.9E-02	1.4E-01	3.4E-01	6.9E-01	1.7E+00	6.9E+00
1×10^6	1,000	6.9E-04	3.4E-03	6.9E-03	1.4E-02	3.4E-02	6.9E-02	1.7E-01	6.9E-01
1×10^7	10,000	6.9E-05	3.4E-04	6.9E-04	1.4E-03	3.4E-03	6.9E-03	1.7E-02	6.9E-02

[a] For stay time calculations, Po-210 was used as a reference radionuclide. If the contaminant is known and is other than Po-210, stay times can be adjusted with multiplication by the correction factors. The correction factors were calculated as the ratio of the fractional dose contribution from submersion and groundshine to the total for the radionuclide of concern to the fractional dose contribution from submersion and groundshine to the total for Pu-239. The correction factors for different radionuclides are as follows: Am-241 =80; Cf-252 = 200; Cm-244 = 6; Co-60 = 210; Cs-137 = 210; Ir-192 = 210; Po-210 = 1; Pu-238 = 3; Pu-239 = 1; Ra-226 = 210; and Sr-90 = 210. For example, if the contaminant is Cm-244 and the measured exposure rate is 10 mR/h, the first responder who wears a full-face continuous-flow atmosphere-supplying respirator can spend up to 6.9E-2 × 6 = 0.41 hours = 25 minutes at the RDD event location without receiving a radiation dose greater than 0.1 rem.

Stay times listed in Tables 3.16–3.19 are for use when radionuclides are not identified. If radionuclides are identified, the radionuclide correction factors listed in Table 3.20 can be used to adjust the stay times. For stay times developed based on air concentration or surface concentration measurements, the correction factors were calculated as the ratio of the DSR of the reference radionuclide to the DSR of the radionuclide of concern. For stay times developed based on exposure rate measurements, the correction factors were calculated as the ratio of the fractional dose contribution from submersion and groundshine to the total for the radionuclide of concern to the fractional dose contribution from submersion and groundshine to the total for the reference radionuclide.

TABLE 3.20 Radionuclide Correction Factor with Full-Face Continuous-Flow Atmosphere-Supplying Respirators

Radionuclide	Air Concentration Measurement[a]	Correction Factor for Stay Times Based on Surface Concentration Measurement: Alpha Emitters[b]	Correction Factor for Stay Times Based on Surface Concentration Measurement: β-γ Emitters[c]	Exposure Rate Measurement[d]
Am-241	40	30	40	80
Cf-252	5	4	–	200
Cm-244	100	70	–	6
Co-60	1	–	1	210
Cs-137	4	–	4	210
Ir-192	3	–	3	210
Po-210	1,400	1,000	–	1
Pu-238	50	40	–	3
Pu-239	50	40	–	1
Ra-226	1	1	1	210
Sr-90	20	–	20	210

[a] For stay times based on the air concentration measurement, Co-60 was used as the reference radionuclide.

[b] For stay times based on the surface concentration measurements, Ra-226 was used as the reference radionuclide for alpha emitters.

[c] For stay times based on the surface concentration measurements, Co-60 was used as the reference radionuclide for β-γ emitters.

[d] For stay times based on the exposure rate measurement, Po-210 was used as the reference radionuclide.

3.6 REFERENCES

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4 GROUP B: EARLY-PHASE PROTECTIVE ACTION (EVACUATION OR SHELTERING)

The operational guidelines for early phase protective action were developed for use in deciding whether to evacuate or shelter the general public after an RDD event. "Early phase" is defined as the first 4 days following an RDD event. The 4-day integrated dose was calculated, and the operational guidelines were derived on the basis of a total effective dose of 1 rem or 5 rem. The operational guidelines are expressed as limiting concentrations in the ground surface (soil/street). If the measured ground surface concentration is higher than the values in the operational guidelines, the protective actions would be justified in the early phase of an RDD event.

Three potential exposure scenarios were considered for deriving the Group B operational guidelines. The scenarios take into account the different time fractions spent in an indoor and outdoor environment by different receptors. The scenarios assume that the receptor would spend 100% of the time (either indoors or outdoors) in the contaminated area. The concentration was corrected for radioactive decay. The operational guidelines were derived by using two methodologies.[5] One methodology is used by FRMAC. The other methodology is used by OGT. The FRMAC methodology is an emulation of FRMAC's published methods and is designed specifically for this group and should be used in an emergency situation for evacuation and sheltering-in-place decisions. The OGT methodology presented in this group is for comparison and demonstrating the use of the consistent method that was used for other groups. The differences between these two methodologies are discussed in the following sections.

4.1 FRMAC METHODOLOGY

When the FRMAC methodology was used to derive the operational guidelines for the early phase, it was assumed that only the outdoor ground surface was contaminated, which has an infinitely large area. A receptor was assumed to incur radiation doses through (1) exposure to

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[5] The FRMAC methodology described here is an emulation of the computational process used by FRMAC, but is not quite identical. The OGT emulation includes additional dose pathways (dirt ingestion and external exposure to resuspended contamination), which are omitted in FRMAC's published methods. The FRMAC method is designed primarily for early- and intermediate-phase applications for any single radionuclide or combination of radionuclides, whereas the OGT method can be used for all (early, intermediate, and late) phases involving one or more of the 11 selected radionuclides. The FRMAC method is currently being updated to match the new EPA PAG guidance. It is expected that both methods will produce similar (if not identical) operational guidelines.

external radiation from the contaminated ground surface, (2) inhalation of contaminated air, (3) exposure to external radiation from submersion in contaminated air, and (4) ingestion of contamination deposited on the surface. The submersion dose (Pathway 3, above) and ingestion dose (Pathway 4, above) are added to be consistent with the OGT methodology. The FRMAC method is being updated to include the ingestion dose (see Footnote 3 on Page 4-1). As indicated in the results to be discussed later, these pathways may be significant for some of the RDD radionuclides such as Po-210. The external doses were corrected for ground surface roughness. The outdoor air concentration was corrected only for resuspension. When the receptor was indoors, the indoor air concentration was corrected by the indoor dust filtration factor (dose reduction due to sheltering); the external dose was also corrected for shielding provided by the building.

4.2 OGT METHODOLOGY

In the OGT methodology, for the early phase, it was assumed that a ground surface measuring 10,000 m^2, as well as the exterior of a building (four walls and the roof), were contaminated after an RDD event. It was assumed that the RDD event occurred in an urban environment. It was further assumed that the indoor surfaces were not contaminated during the first four days (early phase). The contamination level on the roof was assumed to be the same as that on the ground surface, and the contamination level on the other exterior walls was assumed to be half of the contamination level on the ground surface. This is a conservative assumption because the concentration levels on exterior walls could actually be much lower than half of the soil/street contamination level (Andersson et al. 2003). If the actual contamination data are available for roof and exterior walls, then those values can be used in deriving site-specific operational guidelines.

To be consistent with the overall OGT methodology, the weathering correction was applied for the 4-day period, even though it would not be significant for the first 4-day period for the 11 selected radionuclides. A receptor was assumed to incur radiation doses through (1) exposure to external radiation from the multiple contaminated surfaces, (2) inhalation of contaminated air, (3) exposure to external radiation from submersion in contaminated air, and (4) ingestion of contamination deposited on the surfaces. As mentioned earlier, FRMAC's published methods omit the last two pathways (external exposure to resuspended contamination and soil/dust ingestion). The external doses from the ground surface were corrected for surface roughness. The roughness for building surfaces would depend on the type of material used.

Rochedo et al. (1996) provided initial shielding factors (roughness correction factors) for different urban building surfaces. The surface roughness correction factors for the roof and exterior walls were 1 and 0.95, respectively. For derivation of operational guidelines, it was conservatively assumed that both the roof and exterior walls have smooth surfaces, so a roughness correction factor of unity was applied.

The average resuspension factor accounting for weathering, radionuclide decay, and vehicular traffic was used to calculate the outdoor air concentration. A multiplication factor of 10 was used to account for vehicular traffic in an urban environment (Walsh 2002). The indoor air concentration had two components: one from resuspension of interior surface contamination and the other from air exchange with outdoor air contamination. The outdoor air concentration was corrected by the indoor dust filtration factor to get the second component for the indoor air concentration. The indoor resuspension factor was assumed to be constant at 10^{-6} m^{-1} (IAEA 2002; NRC 2001; EPA 1991). However, for the 4-day period, since the contamination was only outdoors, the first component for the indoor air concentration would be zero. The external dose for the inside receptor from outside contamination was also corrected for shielding provided by the building.

4.3 KEY PARAMETERS USED

An average resuspension factor for the 4-day exposure period was used in calculating the outdoor air concentration for the early phase protective action (evacuation/sheltering) operational guidelines. The resuspension factors used to calculate the average values were 10^{-6} m^{-1} for the first day, which decreased at $10^{-6}/t$ (t = time in days) for times from 1 day to 1,000 days and was constant at 10^{-9} m^{-1} for times greater than 1,000 days. For the OGT method, an average resuspension factor was also multiplied by a factor of 10 to account for the higher resuspension due to vehicular traffic in an urban environment (Walsh 2002).

The indoor dust infiltration factor of 0.55 was used, which is the mean value of the uniform distribution reported in NUREG/CR-6697 (Yu et al. 2000). Although the FRMAC default scenario deals with outdoor receptors only, the FRMAC manual suggests using a 50% reduction in the inhalation dose if the structure is closed up (Rhodes et al. 2003a). This value (50%) is close to the value (0.55) used in this analysis for calculating the Group B operational guidelines by using both the FRMAC and OGT methodologies.

A roughness correction factor of 0.82 for the ground surface, based on the default value from FRMAC, was used in both methodologies. The FRMAC provides shielding factors for different structures for external radiation incurred by a receptor inside a building from outdoor ground surface deposition (Rhodes et al. 2003b). The values vary from 0.4 (one- and two-story wood frame house) to 0.005 (in the basement of a multistory structure). Since the RDD event was assumed to occur in an urban environment, a shielding factor of 0.2 was used in the dose calculations, which is the value suggested by the FRMAC methodology for one- and two-story block and brick houses. The ingestion rate of 1.25×10^{-5} m^2/h was used for direct ingestion of the contamination on the ground surface. This ingestion rate was used on the basis of comments received from FRMAC, and it is half of the ingestion rate of 6×10^{-4} m^2/d reported in the FRMAC manual for the public (Rhodes et al. 2003a).

The inhalation rate used for the resident in the FRMAC methodology was 0.92 m^3/h (22.08 m^3/d). This value corresponds to the average breathing rate for a sedentary worker (ICRP 1994) and is adopted by the Interagency Assessment Working Group (AWG) for Emergency Response for use in FRMAC. It is also close to the mode of distribution for the inhalation rates of residents in NUREG/CR-6697 (Yu et al. 2000). In the OGT methodology when the resident was indoors, the average indoor breathing rates of 0.9 m^3/h for a sedentary worker was used, and when the resident was outdoors, the average outdoor breathing rate of 1.2 m^3/h for a sedentary worker was used.

The urban building modeled with the OGT methodology was the urban apartment (geometry number 3) listed in Table 2.4 in Chapter 2. It has a floor area of 100 m^2, a ceiling height of 2.4 m, and a shielding thickness of 10 cm of concrete for walls and roof.

4.4 SCENARIO DESCRIPTION

Scenario B-1 (resident spending time indoors) assumes that the outside ground surface is contaminated and that the resident spends 100% of the time indoors. Under this scenario, the resident would incur radiation doses through (1) exposure to external radiation from the contaminated surfaces while indoors, (2) inhalation of contaminated air while indoors, and (3) exposure to external radiation from submersion in contaminated air while indoors. Since the resident would not be in direct contact with contaminated surfaces, there would not be any direct ingestion dose. The external dose was corrected for ground surface roughness and the shielding provided by the building. The air concentration inside the building was corrected by the dust filtration factor.

Scenario B-2 (resident spending time both indoors and outdoors) assumes that the resident spends 16.4 h/d indoors and 7.6 h/d outdoors. The value chosen for the time spent indoors is based on the recommendation in the *Exposure Factor Handbook* (EPA 1997). Under this scenario, it is assumed that the resident would incur radiation doses through (1) exposure to external radiation from the contaminated surfaces while indoors, (2) exposure to external radiation from the contaminated ground surface while outdoors, (3) inhalation of contaminated air while indoors, (4) inhalation of contaminated air while outdoors, (5) exposure to external radiation from submersion in contaminated air while indoors, (6) exposure to external radiation from submersion in contaminated air while outdoors, and (7) ingestion of contamination deposited on the ground surface while outdoors. The external ground surface dose was corrected for surface roughness. While the receptor was indoors, the external dose from the ground surface was also corrected for the shielding provided by the building. The air concentration inside the building was considered to result from resuspension from the outside ground surface contamination, corrected by the dust filtration factor.

Scenario B-3 (worker spending time outdoors) assumes that the worker spends 100% of the time outdoors. Under this scenario, it is assumed that the worker would incur radiation doses through (1) exposure to external radiation from the contaminated ground surface, (2) inhalation of contaminated air, (3) exposure to external radiation from submersion in contaminated air, and (4) ingestion of contamination deposited on the ground surface. The external dose from ground surface contamination was corrected for ground surface roughness.

4.5 DOSE CALCULATION BASED ON FRMAC METHODOLOGY

Tables 4.1–4.3 provide the time-integrated dose for the 4-day period calculated by using the FRMAC methodology. Table 4.1 shows the DSRs for the B-1 scenario (resident spending 100% of the time indoors) from individual pathways. The doses from individual pathways were added to get the total DSRs. Since the receptor spends all the time indoors, the doses from external radiation from the contaminated ground surface while outdoors, inhalation of contaminated air while outdoors, external radiation from submersion in contaminated air while outdoors, and ingestion of contamination deposited on the ground surface while outdoors were all zero.

TABLE 4.1 DSRs (mrem per pCi/m²) for 4-Day Exposure Calculated with the FRMAC Methodology for a Resident Spending 100% of the Time Indoors

Radionuclide	DSR from Individual Exposure Pathway							
	External, Outside	External, Inside	Inhalation, Outside	Inhalation, Inside	Submersion, Outside	Submersion, Inside	Dust Ingestion, Outside	Total
Am-241	0.0E+00	4.9E-09	0.0E+00	1.0E-05	0.0E+00	2.8E-13	0.0E+00	1.0E-05
Cf-252	0.0E+00	8.9E-08	0.0E+00	2.1E-06	0.0E+00	9.7E-12	0.0E+00	2.2E-06
Cm-244	0.0E+00	1.3E-10	0.0E+00	6.1E-06	0.0E+00	1.4E-15	0.0E+00	6.1E-06
Co-60	0.0E+00	4.8E-07	0.0E+00	3.3E-09	0.0E+00	5.0E-11	0.0E+00	4.9E-07
Cs-137	0.0E+00	1.2E-07	0.0E+00	4.2E-09	0.0E+00	1.1E-11	0.0E+00	1.2E-07
Ir-192	0.0E+00	1.6E-07	0.0E+00	7.0E-10	0.0E+00	1.5E-11	0.0E+00	1.6E-07
Po-210	0.0E+00	1.7E-12	0.0E+00	4.6E-07	0.0E+00	1.6E-16	0.0E+00	4.6E-07
Pu-238	0.0E+00	1.3E-10	0.0E+00	1.2E-05	0.0E+00	1.5E-15	0.0E+00	1.2E-05
Pu-239	0.0E+00	6.0E-11	0.0E+00	1.3E-05	0.0E+00	1.5E-15	0.0E+00	1.3E-05
Ra-226	0.0E+00	3.5E-07	0.0E+00	1.0E-06	0.0E+00	3.5E-11	0.0E+00	1.4E-06
Sr-90	0.0E+00	2.3E-08	0.0E+00	1.7E-08	0.0E+00	3.7E-13	0.0E+00	4.1E-08

TABLE 4.2 DSRs (mrem per pCi/m²) for 4-Day Exposure Calculated with the FRMAC Methodology for a Resident Spending 16.4 h/d Indoors and 7.6 h/d Working Outdoors

Radionuclide	DSR from Individual Exposure Pathway							
	External, Outside	External, Inside	Inhalation, Outside	Inhalation, Inside	Submersion, Outside	Submersion, Inside	Dust Ingestion, Outside	Total
Am-241	7.7E-09	3.3E-09	5.9E-06	7.0E-06	1.6E-13	1.9E-13	2.8E-07	1.3E-05
Cf-252	1.4E-07	6.1E-08	1.2E-06	1.5E-06	5.6E-12	6.6E-12	1.3E-07	3.0E-06
Cm-244	2.1E-10	9.2E-11	3.5E-06	4.2E-06	8.2E-16	9.8E-16	1.7E-07	7.9E-06
Co-60	7.6E-07	3.3E-07	1.9E-09	2.3E-09	2.9E-11	3.4E-11	4.8E-09	1.1E-06
Cs-137	1.8E-07	7.9E-08	2.4E-09	2.9E-09	6.2E-12	7.3E-12	1.8E-08	2.9E-07
Ir-192	2.5E-07	1.1E-07	4.0E-10	4.8E-10	8.6E-12	1.0E-11	1.9E-09	3.7E-07
Po-210	2.7E-12	1.1E-12	2.6E-07	3.1E-07	9.3E-17	1.1E-16	1.7E-06	2.2E-06
Pu-238	2.1E-10	9.0E-11	6.8E-06	8.1E-06	8.5E-16	1.0E-15	3.2E-07	1.5E-05
Pu-239	9.4E-11	4.1E-11	7.4E-06	8.8E-06	8.4E-16	1.0E-15	3.5E-07	1.7E-05
Ra-226	5.6E-07	2.4E-07	5.9E-07	7.0E-07	2.0E-11	2.4E-11	3.9E-07	2.5E-06
Sr-90	3.7E-08	1.6E-08	1.0E-08	1.2E-08	2.2E-13	2.6E-13	4.3E-08	1.2E-07

TABLE 4.3 DSRs (mrem per pCi/m^2) for 4-Day Exposure Calculated with the FRMAC Methodology for a Worker Spending 100% of the Time Outdoors

	DSR from Individual Exposure Pathway							
Radionuclide	External, Outside	External, Inside	Inhalation, Outside	Inhalation, Inside	Submersion, Outside	Submersion, Inside	Dust Ingestion, Outside	Total
Am-241	2.4E-08	0.0E+00	1.9E-05	0.0E+00	5.2E-13	0.0E+00	8.9E-07	2.0E-05
Cf-252	4.5E-07	0.0E+00	3.9E-06	0.0E+00	1.8E-11	0.0E+00	4.0E-07	4.7E-06
Cm-244	6.7E-10	0.0E+00	1.1E-05	0.0E+00	2.6E-15	0.0E+00	5.3E-07	1.2E-05
Co-60	2.4E-06	0.0E+00	6.0E-09	0.0E+00	9.1E-11	0.0E+00	1.5E-08	2.4E-06
Cs-137	5.8E-07	0.0E+00	7.6E-09	0.0E+00	1.9E-11	0.0E+00	5.8E-08	6.4E-07
Ir-192	8.0E-07	0.0E+00	1.3E-09	0.0E+00	2.7E-11	0.0E+00	6.1E-09	8.1E-07
Po-210	8.4E-12	0.0E+00	8.3E-07	0.0E+00	2.9E-16	0.0E+00	5.3E-06	6.1E-06
Pu-238	6.6E-10	0.0E+00	2.1E-05	0.0E+00	2.7E-15	0.0E+00	1.0E-06	2.2E-05
Pu-239	3.0E-10	0.0E+00	2.3E-05	0.0E+00	2.7E-15	0.0E+00	1.1E-06	2.5E-05
Ra-226	1.8E-06	0.0E+00	1.9E-06	0.0E+00	6.4E-11	0.0E+00	1.2E-06	4.9E-06
Sr-90	1.2E-07	0.0E+00	3.1E-08	0.0E+00	6.8E-13	0.0E+00	1.4E-07	2.8E-07

Table 4.2 shows DSRs for the B-2 scenario (resident spending 16.4 h/d indoors and 7.6 h/d outdoors) from individual pathways. Doses from individual pathways were added to get the total DSRs. Since the receptor spends time indoors as well as outdoors, all the pathways were active.

Table 4.3 shows DSRs for the B-3 scenario (worker spending 100% of the time outdoors) from individual pathways. Doses from individual pathways were added to get the total DSRs. Since the receptor spends all the time outdoors, doses from external radiation from the contaminated ground surface while indoors, inhalation of contaminated air while indoors, and external radiation from submersion in contaminated air while indoors were all zero.

4.6 DOSE CALCULATION BASED ON OGT METHODOLOGY

Tables 4.4–4.6 provide dose results by using the OGT methodology. Table 4.4 shows DSRs for the B-1 scenario (resident spending 100% of the time indoors) from individual pathways. Doses from individual pathways were added to get the total DSRs. Since the receptor spends all the time indoors, doses from external radiation from the contaminated ground surface while outdoors, inhalation of contaminated air while outdoors, external radiation from submersion in contaminated air while outdoors, and ingestion of contamination deposited on the

TABLE 4.4 DSRs (mrem per pCi/m^2) for 4-Day Exposure Calculated with the OGT Methodology for a Resident Spending 100% of the Time Indoors

	DSR from Individual Exposure Pathway									
Radionuclide	External, Street, Outside	External, Street, Inside	External, Exterior Walls, Inside	External, Roof, Inside	Inhalation, Outside	Inhalation, Inside	Submersion, Outside	Submersion, Inside	Dust Ingestion, Outside	Total
Am-241	0.0E+00	4.8E-09	2.1E-12	1.8E-12	0.0E+00	1.0E-04	0.0E+00	2.8E-12	0.0E+00	1.0E-04
Cf-252	0.0E+00	8.8E-08	0.0E+00	0.0E+00	0.0E+00	2.1E-05	0.0E+00	9.6E-11	0.0E+00	2.1E-05
Cm-244	0.0E+00	1.3E-10	0.0E+00	0.0E+00	0.0E+00	5.9E-05	0.0E+00	1.4E-14	0.0E+00	5.9E-05
Co-60	0.0E+00	3.6E-07	6.9E-08	1.9E-07	0.0E+00	3.2E-08	0.0E+00	5.0E-10	0.0E+00	6.4E-07
Cs-137	0.0E+00	8.6E-08	1.4E-08	3.1E-08	0.0E+00	4.1E-08	0.0E+00	1.1E-10	0.0E+00	1.7E-07
Ir-192	0.0E+00	9.6E-08	1.9E-08	5.1E-08	0.0E+00	6.8E-09	0.0E+00	1.5E-10	0.0E+00	1.7E-07
Po-210	0.0E+00	1.2E-12	2.2E-13	5.2E-13	0.0E+00	4.4E-06	0.0E+00	1.6E-15	0.0E+00	4.4E-06
Pu-238	0.0E+00	1.3E-10	2.7E-14	2.1E-14	0.0E+00	1.1E-04	0.0E+00	1.5E-14	0.0E+00	1.1E-04
Pu-239	0.0E+00	5.9E-11	7.0E-13	1.1E-12	0.0E+00	1.2E-04	0.0E+00	1.5E-14	0.0E+00	1.2E-04
Ra-226	0.0E+00	2.6E-07	4.8E-08	1.2E-07	0.0E+00	9.9E-06	0.0E+00	3.5E-10	0.0E+00	1.0E-05
Sr-90	0.0E+00	1.7E-08	5.8E-12	1.5E-11	0.0E+00	1.7E-07	0.0E+00	3.7E-12	0.0E+00	1.9E-07

TABLE 4.5 DSRs (mrem per pCi/m^2) for 4-Day Exposure Calculated with the OGT Methodology for a Resident Spending 16.4 h/d Indoors and 7.6 h/d Working Outdoors

	DSR from Individual Exposure Pathway									
Radionuclide	External, Street, Outside	External, Street, Inside	External, Exterior Walls, Inside	External, Roof, Inside	Inhalation, Outside	Inhalation, Inside	Submersion, Outside	Submersion, Inside	Dust Ingestion, Outside	Total
Am-241	7.7E-09	3.3E-09	1.4E-12	1.2E-12	7.7E-05	6.8E-05	1.6E-12	1.9E-12	2.8E-07	1.5E-04
Cf-252	1.4E-07	6.0E-08	0.0E+00	0.0E+00	1.6E-05	1.4E-05	5.5E-11	6.6E-11	1.3E-07	3.1E-05
Cm-244	2.1E-10	9.1E-11	0.0E+00	0.0E+00	4.6E-05	4.1E-05	8.2E-15	9.7E-15	1.7E-07	8.6E-05
Co-60	5.6E-07	2.4E-07	4.7E-08	1.3E-07	2.5E-08	2.2E-08	2.9E-10	3.4E-10	4.7E-09	1.0E-06
Cs-137	1.4E-07	5.9E-08	9.4E-09	2.1E-08	3.1E-08	2.8E-08	6.1E-11	7.3E-11	1.8E-08	3.0E-07
Ir-192	1.5E-07	6.5E-08	1.3E-08	3.5E-08	5.2E-09	4.6E-09	8.6E-11	1.0E-10	1.9E-09	2.8E-07
Po-210	1.9E-12	8.4E-13	1.5E-13	3.5E-13	3.4E-06	3.0E-06	9.3E-16	1.1E-15	1.7E-06	8.1E-06
Pu-238	2.1E-10	8.9E-11	1.8E-14	1.4E-14	8.8E-05	7.8E-05	8.4E-15	1.0E-14	3.2E-07	1.7E-04
Pu-239	9.4E-11	4.0E-11	4.8E-13	7.5E-13	9.6E-05	8.5E-05	8.4E-15	9.9E-15	3.5E-07	1.8E-04
Ra-226	4.2E-07	1.8E-07	3.3E-08	8.4E-08	7.6E-06	6.8E-06	2.0E-10	2.4E-10	3.9E-07	1.6E-05
Sr-90	2.7E-08	1.2E-08	4.0E-12	9.9E-12	1.3E-07	1.1E-07	2.1E-12	2.5E-12	4.3E-08	3.3E-07

TABLE 4.6 DSRs (mrem per pCi/m^2) for 4-Day Exposure Calculated with the OGT Methodology for a Resident Spending 100% of the Time Outdoors

	DSR from Individual Exposure Pathway									
Radionuclide	External, Street, Outside	External, Street, Inside	External, Exterior Walls, Inside	External, Roof, Inside	Inhalation, Outside	Inhalation, Inside	Submersion, Outside	Submersion, Inside	Dust Ingestion, Outside	Total
Am-241	2.4E-08	0.0E+00	0.0E+00	0.0E+00	2.4E-04	0.0E+00	5.1E-12	0.0E+00	8.8E-07	2.4E-04
Cf-252	4.4E-07	0.0E+00	0.0E+00	0.0E+00	5.0E-05	0.0E+00	1.7E-10	0.0E+00	3.9E-07	5.1E-05
Cm-244	6.7E-10	0.0E+00	0.0E+00	0.0E+00	1.4E-04	0.0E+00	2.6E-14	0.0E+00	5.3E-07	1.4E-04
Co-60	1.8E-06	0.0E+00	0.0E+00	0.0E+00	7.8E-08	0.0E+00	9.0E-10	0.0E+00	1.5E-08	1.9E-06
Cs-137	4.3E-07	0.0E+00	0.0E+00	0.0E+00	9.8E-08	0.0E+00	1.9E-10	0.0E+00	5.7E-08	5.9E-07
Ir-192	4.8E-07	0.0E+00	0.0E+00	0.0E+00	1.6E-08	0.0E+00	2.7E-10	0.0E+00	6.0E-09	5.0E-07
Po-210	6.1E-12	0.0E+00	0.0E+00	0.0E+00	1.1E-05	0.0E+00	2.9E-15	0.0E+00	5.2E-06	1.6E-05
Pu-238	6.5E-10	0.0E+00	0.0E+00	0.0E+00	2.8E-04	0.0E+00	2.7E-14	0.0E+00	1.0E-06	2.8E-04
Pu-239	3.0E-10	0.0E+00	0.0E+00	0.0E+00	3.0E-04	0.0E+00	2.6E-14	0.0E+00	1.1E-06	3.0E-04
Ra-226	1.3E-06	0.0E+00	0.0E+00	0.0E+00	2.4E-05	0.0E+00	6.4E-10	0.0E+00	1.2E-06	2.7E-05
Sr-90	8.5E-08	0.0E+00	0.0E+00	0.0E+00	4.1E-07	0.0E+00	6.7E-12	0.0E+00	1.3E-07	6.3E-07

ground surface were all zero. Table 4.5 shows DSRs for the B-2 scenario (resident spending 16.4 h/d indoors and 7.6 h/d outdoors) from individual pathways. Since the receptor spends time indoors as well as outdoors, all the pathways were active. Table 4.6 shows DSRs for the B-3 scenario (worker spending 100% of the time outdoors) from individual pathways. Since the receptor spends all the time outdoors, doses from external radiation from the contaminated ground surface while indoors, inhalation of contaminated air while indoors, and external radiation from submersion in contaminated air while indoors were all zero.

4.7 OPERATIONAL GUIDELINE DERIVATION BASED ON FRMAC METHODOLOGY

Table 4.7 provides the operational guidelines (for deciding which protective action to implement after an RDD event for a contaminated area) that are based on the FRMAC methodology. Operational guidelines listed in Table 4.7 were obtained by using the total DSRs (listed in Tables 4.1–4.3) with dose criteria of 1 and 5 rem. They were obtained for a resident spending 100% of the time indoors, a resident spending 16.4 h/d indoors and 7.6 h/d outdoors in the contaminated area, and a worker spending 100% of the time outdoors. The most restrictive operational guidelines were for a worker spending 100% of the time outdoors, because the radiation doses that the outdoor workers received would be greater than those received by indoor

TABLE 4.7 Operational Guidelines (pCi/m^2) for Early Phase Calculated with the FRMAC Methodology[a]

	Resident Spending 100% of the Time Indoors		Resident Spending 16.4 h/d Indoors and 7.6 h/d Outdoors		Worker Spending 100% of the Time Outdoors	
Radionuclide	PAG = 1 rem	PAG = 5 rem	PAG = 1 rem	PAG = 5 rem	PAG = 1 rem	PAG = 5 rem
Am-241	9.7E+07	4.9E+08	7.5E+07	3.8E+08	5.1E+07	2.5E+08
Cf-252	4.5E+08	2.2E+09	3.3E+08	1.7E+09	2.1E+08	1.1E+09
Cm-244	1.6E+08	8.2E+08	1.3E+08	6.4E+08	8.6E+07	4.3E+08
Co-60	2.1E+09	1.0E+10	9.1E+08	4.5E+09	4.1E+08	2.1E+09
Cs-137	8.4E+09	4.2E+10	3.5E+09	1.8E+10	1.6E+09	7.8E+09
Ir-192	6.2E+09	3.1E+10	2.7E+09	1.4E+10	1.2E+09	6.2E+09
Po-210	2.2E+09	1.1E+10	4.5E+08	2.2E+09	1.6E+08	8.2E+08
Pu-238	8.5E+07	4.2E+08	6.6E+07	3.3E+08	4.5E+07	2.2E+08
Pu-239	7.8E+07	3.9E+08	6.0E+07	3.0E+08	4.1E+07	2.0E+08
Ra-226	7.3E+08	3.6E+09	4.0E+08	2.0E+09	2.1E+08	1.0E+09
Sr-90	2.5E+10	1.2E+11	8.5E+09	4.2E+10	3.5E+09	1.8E+10

[a] PAG = protective action guide.

residents (spending 100% of the time indoors or spending some time indoors and some time outdoors), if the workers and the residents spent the same amount of time in the contaminated area. Depending on the contamination levels, these different operational guidelines can be used to choose the protective action (evacuation or sheltering) after an RDD event.

4.8 OPERATIONAL GUIDELINE DERIVATION BASED ON OGT METHODOLOGY

Table 4.8 provides the operational guidelines (for deciding which protective action to implement after an RDD event for a contaminated area) that are based on the OGT methodology. Operational guidelines listed in Table 4.8 were obtained by using the total DSR ratios (listed in Tables 4.4–4.6) with dose criteria of 1 and 5 rem. They were obtained for a resident spending 100% of the time indoors, a resident spending 16.4 h/d indoors and 7.6 h/d outdoors in the contaminated area, and a worker spending 100% of the time outdoors. The most restrictive operational guidelines were for a worker spending 100% of the time outdoors, because the radiation doses that outdoor workers would receive would be greater than those received by indoor residents (spending 100% of the time indoors or spending some time indoors and some time outdoors), if the workers and residents spent the same amount of time in the contaminated area.

TABLE 4.8 Operational Guidelines (pCi/m^2) for Early Phase Calculated with the OGT Methodology[a]

	Resident Spending 100% of the Time Indoors		Resident Spending 16.4 h/d Indoors and 7.6 h/d Outdoors		Worker Spending 100% of the Time Outdoors	
Radionuclide	PAG = 1 rem	PAG = 5 rem	PAG = 1 rem	PAG = 5 rem	PAG = 1 rem	PAG = 5 rem
Am-241	1.0E+07	5.0E+07	6.9E+06	3.4E+07	4.1E+06	2.1E+07
Cf-252	4.8E+07	2.4E+08	3.3E+07	1.6E+08	2.0E+07	9.8E+07
Cm-244	1.7E+07	8.4E+07	1.2E+07	5.8E+07	6.9E+06	3.5E+07
Co-60	1.6E+09	7.8E+09	9.7E+08	4.8E+09	5.3E+08	2.7E+09
Cs-137	5.8E+09	2.9E+10	3.3E+09	1.7E+10	1.7E+09	8.5E+09
Ir-192	5.8E+09	2.9E+10	3.6E+09	1.8E+10	2.0E+09	1.0E+10
Po-210	2.3E+08	1.1E+09	1.2E+08	6.2E+08	6.3E+07	3.1E+08
Pu-238	8.7E+06	4.4E+07	6.0E+06	3.0E+07	3.6E+06	1.8E+07
Pu-239	8.0E+06	4.0E+07	5.5E+06	2.8E+07	3.3E+06	1.6E+07
Ra-226	9.7E+07	4.8E+08	6.5E+07	3.2E+08	3.8E+07	1.9E+08
Sr-90	5.4E+09	2.7E+10	3.1E+09	1.5E+10	1.6E+09	8.0E+09

[a] PAG = protective action guide.

4.9 DISCUSSION

The FRMAC methodology is designed specifically for developing the derived response levels (DRLs) in the early phase of response after a nuclear or radiological incident. Therefore, in an emergency, the operational guidelines developed with the FRMAC methodology (presented in Table 4.7) should be used in making protective action decisions.

The OGT methodology has more provisions that can be modified to reflect site-specific conditions. Therefore, when sufficient measurement data are available to characterize the distribution of radioactivity on different surfaces, the OGT methodology can be applied to develop site-specific operational guidelines.

For all three scenarios considered for Group B, in most cases, the operational guidelines obtained by using the OGT methodology were more restrictive. The OGT methodology calculated a higher concentration in the air in an urban environment as a result of vehicular traffic. The OGT methodology also considered multiple contamination sources including the building surfaces, which also resulted in a higher exposure to external radiation for the indoor receptor. However, for a few strong gamma emitters (Co-60, Cs-137, Ir-192), when the receptor was outdoors for 100% of the time, the FRMAC methodology provided somewhat more restrictive guidelines. This was due to the different initial size assumption for ground surface contamination in the methodologies. The FRMAC methodology assumed that an infinitely large ground surface was contaminated after an RDD event, whereas the OGT methodology assumed that a finite area of 10,000 m^2 was contaminated after an RDD event.

4.10 REFERENCES

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5 GROUP C: RELOCATION, PART 1 — RELOCATION FROM RESIDENTIAL, COMMERCIAL/INDUSTRIAL, AND OTHER AREAS

The operational guidelines for Group C (Part 1) were developed to delineate areas that could result in radiological doses exceeding the relocation PAGs (i.e., 2 rem in the first year and 0.5 rem per year thereafter). Operational guidelines in this group address residential areas (Group C1), commercial/industrial areas (Group C2), and other areas (Group C3) as separate subgroups. The other areas could be monuments, parks, cemeteries, or other special areas. If such areas exceed the above dose criteria, access to those areas should be limited. These relocation operational guidelines provide reasonable assurance that workers or members of the public, as appropriate, would not incur radiation exposure exceeding the dose criteria. A total of eight receptors (see Table 2.5 in Chapter 2) were considered for the derivation of operational guidelines for these three subgroups.

5.1 RELOCATION FROM RESIDENTIAL AREAS (GROUP C1)

Calculations for relocation from residential areas assume both urban and rural settings. Four potential exposure scenarios were considered for the derivation of operational guidelines. Potential radiation doses resulting from 13 exposure pathways were considered. The applicability of these exposure pathways to the four scenarios evaluated is summarized in Table 2.6 in Chapter 2.

Two scenarios were considered in an urban environment, and two scenarios were considered in a rural environment. The building dimensions considered for external exposure were based on an average urban house or a rural house. For the urban environment, initial outdoor contamination was assumed on streets; for the rural environment, initial outdoor contamination was assumed on soil. The base outdoor resuspension factor was multiplied by 10 to account for traffic under urban conditions (see Table 2.3 in Chapter 2).

Both the urban and rural residential scenarios considered for the derivation of relocation operational guidelines do not include the food ingestion pathway, because potential radiation exposure from food ingestion would be covered by a separate PAG, which is discussed in Chapter 10 on Group G. In addition to food ingestion, ingestion of contaminated water was also not considered prior to the implementation of the late-phase PAGs for unrestricted release of properties (see Chapter 9 on Group F).

To account for the differences in the time fractions spent indoors and outdoors by different people, two receptors, one that would spend 100% of the time indoors and the other that would spend some time working outdoors, were considered for each environmental setting. The time fractions spent indoors and outdoors by the working residents were based on the guidance provided in the EPA *Exposure Factor Handbook* (EPA 1997). The other exposure parameters used in the different exposure scenarios are listed in Table 2.7 in Chapter 2.

5.1.1 Scenario Description for Relocation from Residential Areas

Scenario C1-1 (relocation from a residential area in an urban setting) assumes continued use of the contaminated area in an urban environment. Under this scenario, a resident was assumed to spend all the time indoors in the contaminated area, which is consistent with the Group B1 scenario. The building dimensions considered for external exposure were based on an average urban house, as shown in Table 2.4 in Chapter 2.

Scenario C1-2 (relocation from a residential area in an urban setting) also assumes continued use of the contaminated area in an urban environment. Under this scenario, an adult worker was assumed to spend all the time in the contaminated area, sometimes indoors and sometimes outdoors (an average of 16.4 h/d indoors and 7.6 h/d outdoors). The building dimensions considered for external exposure were based on an average urban house.

Scenario C1-3 (relocation from a residential area in a rural setting) assumes continued use of the contaminated area in a rural environment. Under this scenario, a resident was assumed to spend all the time indoors in the contaminated area. The building dimensions considered for external exposure were based on an average rural house, as shown in Table 2.4 in Chapter 2.

Scenario C1-4 (relocation from a residential area in a rural setting) assumes continued use of the contaminated area in a rural environment. Under this scenario, an adult worker was assumed to spend all the time in the contaminated area, sometimes indoors and sometimes outdoors (an average of 16.4 h/d indoors and 7.6 h/d outdoors). The building dimensions considered for external exposure were based on an average rural house.

5.1.2 Dose Calculation for Relocation from Residential Areas

In Appendix 5.A, Tables 5.A.1 through 5.A.4 provide the DSRs from individual exposure pathways for Group C1 (relocation from a residential area) for the first year, and Tables 5.A.5 through 5.A.8 provide the DSRs from individual exposure pathways for the same group for the second year. Table 5.1 lists the total DSRs for all four scenarios (C1-1 through C1-4) for the first and second years.

5.1.3 Operational Guideline Derivation for Relocation from Residential Areas

Table 5.2 provides the operational guidelines for relocating from residential areas. The PAGs used in deriving guidelines for different scenarios are provided in Table 2.5 in Chapter 2. These operational guidelines apply to residential areas and are not applicable for locations such as parks, cemeteries, monuments, or industrial/commercial properties. The PAGs used were 2 rem for the first year and 0.5 rem per year after that.

Four different receptors/scenarios were considered in deriving generic operational guideline values. Scenarios C1-1 and C1-2 are for relocating from residential areas in an urban setting. For all radionuclides, Scenario C1-2 (an adult working outdoors) would result in the more restrictive operational guideline for the first year. For the subsequent years, Scenario C1-2 would result in the more restrictive operational guideline for Co-60, Cs-137, Ir-192, Po-210, Ra-226, and Sr-90. Scenarios C1-3 and C1-4 are for relocating from residential areas in a rural setting. For Cf-252, Co-60, Cs-137, Ir-192, Po-210, Ra-226, and Sr-90, Scenario C1-4 (an adult working outdoors) would result in the more restrictive operational guideline for the first year. After the first year following an RDD event, Scenario C1-4 would result in the more restrictive operational guideline for Co-60, Cs-137, Ir-192, Po-210, Ra-226, and Sr-90. Table 5.3 lists the most restrictive operational guidelines for Group C1 scenarios in urban and rural settings for the first year and after the first year following an RDD event.

5.2 RELOCATION FROM COMMERCIAL/INDUSTRIAL AREAS (GROUP C2)

Two potential exposure scenarios were considered for the derivation of operational guidelines for relocating from commercial/industrial areas (Group C2). The commercial/industrial area was assumed to be located in an urban environment. Potential radiation doses resulting from 13 exposure pathways were considered, as shown in Table 2.6 in Chapter 2.

TABLE 5.1 Generic Dose-to-Source Ratios (DSRs) for Relocation from Residential Areas (Group C1) Scenarios

	DSR (mrem/yr per pCi/m^2) Based on Initial Street/Soil Contamination for the First Year following an RDD Event, by Scenario			
Radionuclide	C1-1[a]	C1-2[b]	C1-3[c]	C1-4[d]
Am-241	4.08E-04	4.83E-04	2.90E-04	2.44E-04
Cf-252	8.81E-05	1.11E-04	7.22E-05	7.32E-05
Cm-244	2.40E-04	2.84E-04	1.69E-04	1.42E-04
Co-60	4.37E-05	5.78E-05	1.10E-04	1.20E-04
Cs-137	1.01E-05	1.49E-05	2.90E-05	3.25E-05
Ir-192	4.18E-06	5.79E-06	9.49E-06	1.04E-05
Po-210	2.78E-05	7.22E-05	2.72E-05	8.51E-05
Pu-238	4.67E-04	5.52E-04	3.30E-04	2.77E-04
Pu-239	5.10E-04	6.03E-04	3.61E-04	3.03E-04
Ra-226	7.97E-05	1.15E-04	1.23E-04	1.54E-04
Sr-90	2.53E-06	5.62E-06	4.74E-06	9.02E-06
	DSR (mrem/yr per pCi/m^2) Based on Initial Street/Soil Contamination after First Year following an RDD Event, by Scenario			
Radionuclide	C1-1[a]	C1-2[b]	C1-3[c]	C1-4[d]
Am-241	1.18E-04	9.56E-05	2.22E-04	1.73E-04
Cf-252	2.00E-05	1.97E-05	4.33E-05	4.25E-05
Cm-244	6.63E-05	5.36E-05	1.24E-04	9.70E-05
Co-60	2.75E-05	3.19E-05	8.40E-05	9.02E-05
Cs-137	6.73E-06	8.77E-06	2.47E-05	2.73E-05
Ir-192	8.95E-08	1.06E-07	2.67E-07	2.88E-07
Po-210	1.54E-06	4.71E-06	3.51E-06	1.12E-05
Pu-238	1.34E-04	1.08E-04	2.51E-04	1.96E-04
Pu-239	1.48E-04	1.19E-04	2.77E-04	2.16E-04
Ra-226	3.87E-05	4.96E-05	1.04E-04	1.28E-04
Sr-90	1.18E-06	2.70E-06	3.87E-06	7.36E-06

[a] C1-1: relocation from residential areas (urban setting); residents spending 100% of the time indoors.

[b] C1-2: relocation from residential areas (urban setting); adults working outdoors.

[c] C1-3: relocation from residential areas (rural); residents spending 100% of the time indoors.

[d] C1-4: relocation from residential areas (rural); adults working outdoors.

TABLE 5.2 Generic Operational Guidelines for Relocation from Residential Areas (Group C1) Scenarios

Radionuclide	Operational Guideline (pCi/m^2) Based on Initial Street/Soil Contamination for the First Year following an RDD Event, by Scenario			
	C1-1[a]	C1-2[b]	C1-3[c]	C1-4[d]
Am-241	4.90E+06	4.14E+06	6.90E+06	8.21E+06
Cf-252	2.27E+07	1.80E+07	2.77E+07	2.73E+07
Cm-244	8.32E+06	7.03E+06	1.19E+07	1.41E+07
Co-60	4.58E+07	3.46E+07	1.82E+07	1.67E+07
Cs-137	1.99E+08	1.34E+08	6.91E+07	6.15E+07
Ir-192	4.78E+08	3.46E+08	2.11E+08	1.93E+08
Po-210	7.19E+07	2.77E+07	7.36E+07	2.35E+07
Pu-238	4.29E+06	3.63E+06	6.06E+06	7.22E+06
Pu-239	3.92E+06	3.32E+06	5.54E+06	6.60E+06
Ra-226	2.51E+07	1.74E+07	1.62E+07	1.30E+07
Sr-90	7.91E+08	3.56E+08	4.22E+08	2.22E+08
	Operational Guideline (pCi/m^2) Based on Initial Street/Soil Contamination after First Year following an RDD Event, by Scenario			
Radionuclide	C1-1[a]	C1-2[b]	C1-3[c]	C1-4[d]
Am-241	4.24E+06	5.23E+06	2.25E+06	2.88E+06
Cf-252	2.51E+07	2.54E+07	1.15E+07	1.18E+07
Cm-244	7.55E+06	9.33E+06	4.02E+06	5.15E+06
Co-60	1.82E+07	1.57E+07	5.95E+06	5.54E+06
Cs-137	7.43E+07	5.70E+07	2.02E+07	1.83E+07
Ir-192	5.59E+09	4.74E+09	1.87E+09	1.74E+09
Po-210	3.26E+08	1.06E+08	1.42E+08	4.46E+07
Pu-238	3.74E+06	4.62E+06	1.99E+06	2.56E+06
Pu-239	3.39E+06	4.19E+06	1.81E+06	2.32E+06
Ra-226	1.29E+07	1.01E+07	4.79E+06	3.91E+06
Sr-90	4.23E+08	1.85E+08	1.29E+08	6.79E+07

[a] C1-1: relocation from residential areas (urban setting); residents spending 100% of the time indoors.

[b] C1-2: relocation from residential areas (urban setting); adults working outdoors.

[c] C1-3: relocation from residential areas (rural); residents spending 100% of the time indoors.

[d] C1-4: relocation from residential areas (rural); adults working outdoors.

TABLE 5.3 Most Restrictive Operational Guidelines for Relocation from Residential Areas (Group C1)

	Street/Soil Contamination (pCi/m^2)			
	Urban		Rural	
Radionuclide	2 rem in First Year	0.5 rem after First Year	2 rem in First Year	0.5 rem after First Year
Am-241	4.14E+06	4.24E+06	6.90E+06	2.25E+06
Cf-252	1.80E+07	2.51E+07	2.73E+07	1.15E+07
Cm-244	7.03E+06	7.55E+06	1.19E+07	4.02E+06
Co-60	3.46E+07	1.57E+07	1.67E+07	5.54E+06
Cs-137	1.34E+08	5.70E+07	6.15E+07	1.83E+07
Ir-192	3.46E+08	4.74E+09	1.93E+08	1.74E+09
Po-210	2.77E+07	1.06E+08	2.35E+07	4.46E+07
Pu-238	3.63E+06	3.74E+06	6.06E+06	1.99E+06
Pu-239	3.32E+06	3.39E+06	5.54E+06	1.81E+06
Ra-226	1.74E+07	1.01E+07	1.30E+07	3.91E+06
Sr-90	3.56E+08	1.85E+08	2.22E+08	6.79E+07

To account for the differences in the time fractions spent indoors and outdoors by different people, two receptors — one who would spend all the time indoors and the other who would spend all the time outdoors — were considered. The exposure parameters used in different exposure scenarios are listed in Table 2.7 in Chapter 2. The building dimensions considered for external exposure were based on a warehouse with dimensions shown in Table 2.4 in Chapter 2, and the initial outdoor contamination was assumed on streets. The outdoor resuspension factor was multiplied by 10 to account for traffic in urban conditions (see Table 2.7 in Chapter 2).

5.2.1 Scenario Description for Relocation from Commercial/Industrial Areas

Scenario C2-1 (relocation from commercial/industrial area, indoor office worker) assumes continued use of the contaminated area in an urban environment. Under this scenario, an indoor office worker was assumed to spend all the time (an average of 8 h/d for 250 days in 1 year) indoors in the contaminated building.

Scenario C2-2 (relocation from commercial/industrial area, outdoor worker) also assumes continued use of the contaminated area in an urban environment. Under this scenario, an outdoor worker was assumed to spend all the time (an average of 8 h/d for 250 days in 1 year) outdoors in the contaminated area.

5.2.2 Dose Calculation for Relocation from Commercial/Industrial Areas

In Appendix 5.A, Tables 5.A.9 and 5.A.10 provide the DSRs from individual exposure pathways for Group C2 (relocation from commercial/industrial area) for the first year, and Tables 5.A.11 and 5.A.12 provide the DSRs from individual exposure pathways for the second year for this group. Table 5.4 provides the total DSRs for both scenarios for the first and second years.

TABLE 5.4 Generic Dose-to-Source Ratios (DSRs) for Relocation from Commercial/Industrial Areas (Group C2) Scenarios

	DSR (mrem/yr per pCi/m^2) Based on Initial Street Contamination following an RDD Event			
	First Year		After First Year	
Radionuclide	C2-1[a]	C2-2[b]	C2-1[a]	C2-2[b]
Am-241	1.24E-04	1.92E-04	3.57E-05	1.24E-05
Cf-252	2.62E-05	4.58E-05	5.78E-06	4.61E-06
Cm-244	7.29E-05	1.14E-04	2.01E-05	6.95E-06
Co-60	1.00E-05	2.02E-05	6.10E-06	9.45E-06
Cs-137	2.34E-06	5.78E-06	1.50E-06	3.01E-06
Ir-192	9.71E-07	2.11E-06	2.00E-08	3.20E-08
Po-210	7.37E-06	4.01E-05	3.80E-07	2.64E-06
Pu-238	1.42E-04	2.20E-04	4.05E-05	1.40E-05
Pu-239	1.55E-04	2.40E-04	4.47E-05	1.54E-05
Ra-226	2.12E-05	4.81E-05	9.46E-06	1.69E-05
Sr-90	6.55E-07	2.88E-06	2.96E-07	1.37E-06

[a] C2-1: relocation from commercial/industrial areas, indoor office worker.

[b] C2-2: relocation from commercial/industrial areas, outdoor worker.

5.2.3 Operational Guideline Derivation for Relocation from Commercial/Industrial Areas

Table 5.5 lists the operational guidelines for relocating from commercial/industrial areas. The PAGs used in deriving guidelines for different scenarios are provided in Table 2.5 in Chapter 2. These operational guidelines apply to commercial/industrial areas that are not used as residences, nor are they used as parks, cemeteries, or monuments. The PAGs used were 2 rem for the first year and 0.5 rem per year after that.

TABLE 5.5 Generic Operational Guidelines for Relocation from Commercial/Industrial Areas (Group C2) Scenarios

	Operational Guidelines (pCi/m^2) Based on Initial Street Contamination following an RDD Event, by Scenario			
	First Year		After First Year	
Radionuclide	C2-1[a]	C2-2[b]	C2-1[a]	C2-2[b]
Am-241	1.61E+07	1.04E+07	1.40E+07	4.02E+07
Cf-252	7.65E+07	4.36E+07	8.66E+07	1.08E+08
Cm-244	2.74E+07	1.76E+07	2.49E+07	7.20E+07
Co-60	2.00E+08	9.91E+07	8.19E+07	5.29E+07
Cs-137	8.56E+08	3.46E+08	3.33E+08	1.66E+08
Ir-192	2.06E+09	9.46E+08	2.50E+10	1.56E+10
Po-210	2.71E+08	4.98E+07	1.32E+09	1.89E+08
Pu-238	1.41E+07	9.10E+06	1.23E+07	3.58E+07
Pu-239	1.29E+07	8.34E+06	1.12E+07	3.25E+07
Ra-226	9.45E+07	4.15E+07	5.29E+07	2.96E+07
Sr-90	3.05E+09	6.94E+08	1.69E+09	3.66E+08

[a] C2-1: relocation from commercial/industrial areas, indoor office worker.

[b] C2-2: relocation from commercial/industrial areas, outdoor worker.

Two scenarios, C2-1 and C2-2, were considered in deriving generic operational guidelines for relocating from commercial/industrial areas in an urban setting. For all radionuclides, Scenario C2-2, an outdoor worker, resulted in more restrictive operational guidelines for the first year following an RDD event. For the year following the first year, Scenario C2-2 resulted in the more restrictive operational guideline for Co-60, Cs-137, Ir-192, Po-210, Ra-226, and Sr-90. Table 5.6 provides the most restrictive operational guidelines for Group C2 scenarios for the first year and after the first year following an RDD event.

TABLE 5.6 Most Restrictive Operational Guidelines for Relocation from Commercial/ Industrial Areas (Group C2)

	Street Contamination (pCi/m^2)	
Radionuclide	2 rem in First Year	0.5 rem after First Year
Am-241	1.04E+07	1.40E+07
Cf-252	4.36E+07	8.66E+07
Cm-244	1.76E+07	2.49E+07
Co-60	9.91E+07	5.29E+07
Cs-137	3.46E+08	1.66E+08
Ir-192	9.46E+08	1.56E+10
Po-210	4.98E+07	1.89E+08
Pu-238	9.10E+06	1.23E+07
Pu-239	8.34E+06	1.12E+07
Ra-226	4.15E+07	2.96E+07
Sr-90	6.94E+08	3.66E+08

5.3 RELOCATION FROM OTHER AREAS (GROUP C3)

Two potential exposure scenarios were considered for the derivation of operational guidelines for relocating from other areas. The “other area” was assumed to be a special building or open area located in an urban environment. It could be a monument, a cemetery, or a park. Potential radiation doses resulting from 13 exposure pathways were considered, as summarized in Table 2.6 in Chapter 2. To account for the differences in the time fractions spent indoors and outdoors by different people, two receptors — one spending all the time indoors and the other spending all of the time outdoors — were considered. The most common parameters used in the different exposure scenarios are listed in Table 2.7 in Chapter 2. The building dimensions considered for external exposure were based on a monument with dimensions specified in Table 2.4 in Chapter 2. The initial outdoor contamination was assumed to be on the soil. The base outdoor resuspension factor was multiplied by 10 to account for light pedestrian activity under urban conditions (see Table 2.3 in Chapter 2).

5.3.1 Scenario Description for Relocation from Other Areas

Scenario C3-1 (relocation from other areas, indoor worker at a monument) assumes continued use of the contaminated area in an urban environment. Under this scenario, an indoor worker at a monument was assumed to spend all the time (an average of 8 h/d for 250 days in 1 year) inside the contaminated building.

Under Scenario C3-2 (relocation from other areas, outdoor worker at a monument or a park), an outdoor worker outside a monument or in a park was assumed to spend all the time (an average of 8 h/d for 250 days in one year) outdoors in the contaminated area in an urban environment.

5.3.2 Dose Calculation for Relocation from Other Areas

In Appendix 5.A, Tables 5.A.13 and 5.A.14 provide the DSRs from individual exposure pathways for Group C3 (relocation from other areas) for the first year, and Tables 5.A.15 and 5.A.16 provide the DSRs for the second year. Table 5.7 provides the total DSRs for both scenarios for the first and second years.

5.3.3 Operational Guideline Derivation for Relocation from Other Areas

Table 5.8 lists the operational guidelines for relocating from other areas. The PAGs used in deriving guidelines for the two different scenarios are provided in Table 2.5 in Chapter 2. These operational guidelines apply to areas other than residential and industrial/commercial areas (normal work places). Such areas include parks, cemeteries, and monuments.

Two scenarios, C3-1 and C3-2, were considered in deriving generic operational guidelines for relocating from other areas. For all radionuclides, Scenario C3-2, an outdoor worker at a monument or park, resulted in the most restrictive operational guidelines for the first year. After the first year, Scenario C3-1 resulted in the most restrictive operational guideline for

Am-241, Cf-252, Cm-244, Pu-238, and Pu-239; and Scenario C3-2 resulted in the most restrictive operational guideline for Co-60, Cs-137, Ir-192, Po-210, Ra-226, and Sr-90. Table 5.9 lists the most restrictive operational guidelines for Group C3 scenarios for the first year and after the first year following an RDD event.

TABLE 5.7 Generic Dose-to-Source Ratios (DSRs) for Relocation from Other Areas (Group C3) Scenarios

	DSR (mrem/yr per pCi/m^2) Based on Initial Soil Contamination following an RDD Event, by Scenario			
	First Year		After First Year	
Radionuclide	C3-1[a]	C3-2[b]	C3-1[a]	C3-2[b]
Am-241	1.65E-04	2.26E-04	7.31E-05	3.10E-05
Cf-252	3.46E-05	5.61E-05	1.21E-05	1.15E-05
Cm-244	9.68E-05	1.33E-04	4.10E-05	1.73E-05
Co-60	1.36E-05	3.22E-05	1.03E-05	2.37E-05
Cs-137	3.36E-06	9.25E-06	2.80E-06	7.54E-06
Ir-192	1.18E-06	2.80E-06	3.29E-08	7.60E-08
Po-210	9.57E-06	5.52E-05	8.80E-07	6.42E-06
Pu-238	1.88E-04	2.58E-04	8.28E-05	3.48E-05
Pu-239	2.06E-04	2.82E-04	9.14E-05	3.83E-05
Ra-226	2.89E-05	6.92E-05	1.81E-05	4.24E-05
Sr-90	9.99E-07	4.49E-06	7.14E-07	3.43E-06

[a] C3-1: relocation from other areas, indoor worker at a monument or park.

[b] C3-2: relocation from other areas, outdoor worker at a monument or park.

5.4 SUMMARY OF OPERATIONAL GUIDELINES FOR RELOCATION FROM DIFFERENT AREAS

Table 5.10 compares the final operational guidelines for relocation from the three different areas considered in Subgroups C1–C3. They are the most conservative values between the first year and the subsequent years after an RDD event. From the comparison, it is shown that for all radionuclides, the operational guidelines for relocation from a residential area are the most restrictive, and those for relocation from an industrial/commercial area are the least restrictive;

however, the differences are within an order of magnitude. Considering the level of uncertainties involved in developing the operational guidelines, a final set of guideline values, selected to be the most restrictive ones and listed in the last column, were proposed for use as the generic guidelines for relocation regardless of the characteristics of the impacted area.

TABLE 5.8 Generic Operational Guidelines for Relocation from Other Areas (Group C3) Scenarios

	Operational Guidelines (pCi/m^2) Based on Initial Soil Contamination following an RDD Event, by Scenario			
	First Year		After First Year	
Radionuclide	C3-1[a]	C3-2[b]	C3-1[a]	C3-2[b]
Am-241	1.21E+07	8.86E+06	6.84E+06	1.61E+07
Cf-252	5.78E+07	3.56E+07	4.12E+07	4.35E+07
Cm-244	2.07E+07	1.50E+07	1.22E+07	2.89E+07
Co-60	1.47E+08	6.22E+07	4.85E+07	2.11E+07
Cs-137	5.95E+08	2.16E+08	1.79E+08	6.63E+07
Ir-192	1.69E+09	7.14E+08	1.52E+10	6.58E+09
Po-210	2.09E+08	3.63E+07	5.68E+08	7.79E+07
Pu-238	1.06E+07	7.75E+06	6.04E+06	1.44E+07
Pu-239	9.70E+06	7.10E+06	5.47E+06	1.31E+07
Ra-226	6.91E+07	2.89E+07	2.77E+07	1.18E+07
Sr-90	2.00E+09	4.46E+08	7.01E+08	1.46E+08

[a] C3-1: relocation from other areas, indoor worker at a monument or park.

[b] C3-2: relocation from other areas, outdoor worker at a monument or park.

TABLE 5.9 Most Restrictive Operational Guidelines for Relocation from Other Areas (Group C3)

	Soil Contamination (pCi/m^2)	
Radionuclide	2 rem in First Year	0.5 rem after First Year
Am-241	8.86E+06	6.84E+06
Cf-252	3.56E+07	4.12E+07
Cm-244	1.50E+07	1.22E+07
Co-60	6.22E+07	2.11E+07
Cs-137	2.16E+08	6.63E+07
Ir-192	7.14E+08	6.58E+09
Po-210	3.63E+07	7.79E+07
Pu-238	7.75E+06	6.04E+06
Pu-239	7.10E+06	5.47E+06
Ra-226	2.89E+07	1.18E+07
Sr-90	4.46E+08	1.46E+08

TABLE 5.10 Summary of Operational Guidelines for Relocations from Different Areas[a]

Radionuclide	Residential Area	Industrial/ Commercial Area	Other Areas	Most Restrictive Guideline
Am-241	2.25E+06	1.04E+07	6.84E+06	2.25E+06
Cf-252	1.15E+07	4.36E+07	3.56E+07	1.15E+07
Cm-244	4.02E+06	1.76E+07	1.22E+07	4.02E+06
Co-60	5.54E+06	5.29E+07	2.11E+07	5.54E+06
Cs-137	1.83E+07	1.66E+08	6.63E+07	1.83E+07
Ir-192	1.93E+08	9.46E+08	7.14E+08	1.93E+08
Po-210	2.35E+07	4.98E+07	3.63E+07	2.35E+07
Pu-238	1.99E+06	9.10E+06	6.04E+06	1.99E+06
Pu-239	1.81E+06	8.34E+06	5.47E+06	1.81E+06
Ra-226	3.91E+06	2.96E+07	1.18E+07	3.91E+06
Sr-90	6.79E+07	3.66E+08	1.46E+08	6.79E+07

[a] All guidelines are in pCi/m^2, and the values for relocation from the residential area are the most restrictive.

5.5 REFERENCE

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 5.A:

DOSE-TO-SOURCE RATIOS (DSRs)
FOR GROUP C1–C3 SCENARIOS

- Group C1: Tables 5.A.1 through 5.A.8
- Group C2: Tables 5.A.9 through 5.A.12
- Group C3: Tables 5.A.13 through 5.A.16

APPENDIX 5.A:

DOSE-TO-SOURCE RATIOS (DSRs) FOR GROUP C1–C3 SCENARIOS

This appendix includes DSRs from individual exposure pathways for Group C1-C3 scenarios. Tables 5.A.1 through 5.A.8 include DSRs for relocation from a residential area scenarios: Scenario C1-1 (indoor resident in urban setting), Scenario C1-2 (adult working outdoor in urban setting), Scenario C1-3 (indoor resident in rural setting), and Scenario C1-4 (adult working outdoor in rural setting). Tables 5.A.1 through 5.A.4 provide the DSRs from individual exposure pathways for Group C1 for the first year, and Tables 5.A.5 through 5.A.8 provide the DSRs from individual exposure pathways for the same group for the second year.

Tables 5.A.9 through 5.A.12 include DSRs for relocation from commercial/industrial area scenarios: Scenario C2-1 (indoor office worker) and Scenario C2-2 (outdoor worker). Tables 5.A.9 and 5.A.10 provide the DSRs from individual exposure pathways for Group C2 for the first year, and Tables 5.A.11 and 5.A.12 provide the DSRs from individual exposure pathways for the second year for this group.

Tables 5.A.13 through 5.A.16 include DSRs for relocation from other area scenarios: Scenario C3-1 (indoor worker at a monument) and Scenario C3-2 (outdoor worker at a monument). Tables 5.A.13 and 5.A.14 provide the DSRs from individual exposure pathways for Group C3 for the first year, and Tables 5.A.15 and 5.A.16 provide the DSRs from individual exposure pathways for the second year for this group.

TABLE 5.A.1 Individual Pathway DSRs for Scenario C1-1: Resident Spending 100% of the Time Indoors in Urban Setting, First Year

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	0.00E+00	2.51E-07	1.60E-10	1.53E-10	1.66E-08	7.50E-08	0.00E+00	4.03E-04	0.00E+00	0.00E+00	1.14E-11	0.00E+00	4.55E-06	4.08E-04
Cf-252	0.00E+00	4.13E-06	0.00E+00	0.00E+00	3.87E-07	2.22E-06	0.00E+00	7.95E-05	0.00E+00	0.00E+00	3.68E-10	0.00E+00	1.84E-06	8.81E-05
Cm-244	0.00E+00	6.82E-09	0.00E+00	0.00E+00	5.99E-10	3.61E-09	0.00E+00	2.38E-04	0.00E+00	0.00E+00	5.67E-14	0.00E+00	2.69E-06	2.40E-04
Co-60	0.00E+00	1.75E-05	5.03E-06	1.52E-05	1.05E-06	4.70E-06	0.00E+00	1.27E-07	0.00E+00	0.00E+00	1.95E-09	0.00E+00	7.34E-08	4.37E-05
Cs-137	0.00E+00	4.41E-06	1.05E-06	2.71E-06	2.66E-07	1.18E-06	0.00E+00	1.63E-07	0.00E+00	0.00E+00	4.27E-10	0.00E+00	2.93E-07	1.01E-05
Ir-192	0.00E+00	1.82E-06	4.45E-07	1.31E-06	9.25E-08	4.89E-07	0.00E+00	1.75E-08	0.00E+00	0.00E+00	3.85E-10	0.00E+00	1.15E-08	4.18E-06
Po-210	0.00E+00	3.40E-11	8.15E-12	2.12E-11	1.84E-12	9.06E-12	0.00E+00	1.33E-05	0.00E+00	0.00E+00	4.83E-15	0.00E+00	1.45E-05	2.78E-05
Pu-238	0.00E+00	6.72E-09	2.07E-12	1.78E-12	5.64E-10	3.52E-09	0.00E+00	4.61E-04	0.00E+00	0.00E+00	5.90E-14	0.00E+00	5.22E-06	4.67E-04
Pu-239	0.00E+00	3.06E-09	5.40E-11	9.55E-11	1.34E-10	1.81E-09	0.00E+00	5.04E-04	0.00E+00	0.00E+00	5.88E-14	0.00E+00	5.70E-06	5.10E-04
Ra-226	0.00E+00	1.36E-05	3.70E-06	1.08E-05	8.21E-07	3.62E-06	0.00E+00	4.00E-05	7.89E-07	0.00E+00	1.41E-09	0.00E+00	6.38E-06	7.97E-05
Sr-90	0.00E+00	8.72E-07	4.44E-10	1.25E-09	5.27E-08	2.33E-07	0.00E+00	6.75E-07	0.00E+00	0.00E+00	1.49E-11	0.00E+00	6.93E-07	2.53E-06

TABLE 5.A.2 Individual Pathway DSRs for Scenario C1-2: Adults Working Outside in Urban Setting, First Year

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	3.97E-07	1.71E-07	1.10E-10	1.04E-10	1.13E-08	5.13E-08	1.89E-04	2.76E-04	0.00E+00	4.00E-12	7.78E-12	1.44E-05	3.11E-06	4.83E-04
Cf-252	6.53E-06	2.82E-06	0.00E+00	0.00E+00	2.65E-07	1.52E-06	3.84E-05	5.43E-05	0.00E+00	1.33E-10	2.51E-10	5.83E-06	1.26E-06	1.11E-04
Cm-244	1.08E-08	4.66E-09	0.00E+00	0.00E+00	4.10E-10	2.46E-09	1.12E-04	1.62E-04	0.00E+00	2.00E-14	3.88E-14	8.52E-06	1.84E-06	2.84E-04
Co-60	2.77E-05	1.20E-05	3.44E-06	1.04E-05	7.20E-07	3.21E-06	6.02E-08	8.65E-08	0.00E+00	6.94E-10	1.33E-09	2.32E-07	5.01E-08	5.78E-05
Cs-137	6.99E-06	3.02E-06	7.18E-07	1.85E-06	1.82E-07	8.03E-07	7.65E-08	1.11E-07	0.00E+00	1.50E-10	2.92E-10	9.29E-07	2.00E-07	1.49E-05
Ir-192	2.88E-06	1.24E-06	3.04E-07	8.93E-07	6.32E-08	3.34E-07	1.05E-08	1.20E-08	0.00E+00	1.72E-10	2.63E-10	3.63E-08	7.84E-09	5.79E-06
Po-210	5.38E-11	2.32E-11	5.57E-12	1.45E-11	1.26E-12	6.19E-12	7.38E-06	9.12E-06	0.00E+00	2.00E-15	3.30E-15	4.58E-05	9.89E-06	7.22E-05
Pu-238	1.06E-08	4.59E-09	1.41E-12	1.22E-12	3.85E-10	2.41E-09	2.16E-04	3.15E-04	0.00E+00	2.07E-14	4.03E-14	1.65E-05	3.57E-06	5.52E-04
Pu-239	4.85E-09	2.09E-09	3.69E-11	6.53E-11	9.17E-11	1.24E-09	2.36E-04	3.45E-04	0.00E+00	2.06E-14	4.02E-14	1.80E-05	3.89E-06	6.03E-04
Ra-226	2.16E-05	9.30E-06	2.53E-06	7.35E-06	5.61E-07	2.47E-06	1.87E-05	2.74E-05	5.39E-07	4.95E-10	9.64E-10	2.02E-05	4.36E-06	1.15E-04
Sr-90	1.38E-06	5.96E-07	3.03E-10	8.52E-10	3.60E-08	1.59E-07	3.17E-07	4.61E-07	0.00E+00	5.25E-12	1.02E-11	2.19E-06	4.73E-07	5.62E-06

TABLE 5.A.3 Individual Pathway DSRs for Scenario C1-3: Resident Spending 100% of the Time Indoors in Rural Setting, First Year

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		Total
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	
Am-241	0.00E+00	8.06E-07	1.01E-07	1.91E-07	2.63E-08	8.84E-08	0.00E+00	2.81E-04	0.00E+00	0.00E+00	7.95E-12	0.00E+00	7.32E-06	2.90E-04
Cf-252	0.00E+00	1.31E-05	2.39E-07	1.71E-07	7.42E-07	2.74E-06	0.00E+00	5.23E-05	0.00E+00	0.00E+00	2.42E-10	0.00E+00	2.91E-06	7.22E-05
Cm-244	0.00E+00	2.19E-08	3.31E-13	2.45E-13	1.21E-09	4.59E-09	0.00E+00	1.64E-04	0.00E+00	0.00E+00	3.92E-14	0.00E+00	4.32E-06	1.69E-04
Co-60	0.00E+00	5.58E-05	1.31E-05	3.37E-05	1.64E-06	5.42E-06	0.00E+00	8.58E-08	0.00E+00	0.00E+00	1.32E-09	0.00E+00	1.17E-07	1.10E-04
Cs-137	0.00E+00	1.42E-05	3.47E-06	8.95E-06	4.13E-07	1.37E-06	0.00E+00	1.13E-07	0.00E+00	0.00E+00	2.97E-10	0.00E+00	4.71E-07	2.90E-05
Ir-192	0.00E+00	4.83E-06	1.16E-06	2.87E-06	1.44E-07	4.68E-07	0.00E+00	6.62E-09	0.00E+00	0.00E+00	1.46E-10	0.00E+00	1.52E-08	9.49E-06
Po-210	0.00E+00	9.75E-11	2.45E-11	6.16E-11	2.87E-12	9.42E-12	0.00E+00	6.41E-06	0.00E+00	0.00E+00	2.32E-15	0.00E+00	2.08E-05	2.72E-05
Pu-238	0.00E+00	2.16E-08	1.23E-10	2.11E-10	1.17E-09	4.53E-09	0.00E+00	3.22E-04	0.00E+00	0.00E+00	4.11E-14	0.00E+00	8.40E-06	3.30E-04
Pu-239	0.00E+00	9.85E-09	3.76E-10	9.21E-10	4.42E-10	2.62E-09	0.00E+00	3.52E-04	0.00E+00	0.00E+00	4.10E-14	0.00E+00	9.16E-06	3.61E-04
Ra-226	0.00E+00	4.38E-05	9.95E-06	2.55E-05	1.27E-06	4.20E-06	0.00E+00	2.80E-05	5.15E-07	0.00E+00	9.84E-10	0.00E+00	1.03E-05	1.23E-04
Sr-90	0.00E+00	2.80E-06	2.89E-09	7.43E-09	8.19E-08	2.70E-07	0.00E+00	4.69E-07	0.00E+00	0.00E+00	1.03E-11	0.00E+00	1.11E-06	4.74E-06

TABLE 5.A.4 Individual Pathway DSRs for Scenario C1-4: Adults Working Outside in Rural Setting, First Year

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		Total
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	
Am-241	6.38E-07	5.51E-07	6.89E-08	1.30E-07	1.80E-08	6.04E-08	2.17E-05	1.92E-04	0.00E+00	4.60E-13	5.43E-12	2.32E-05	5.01E-06	2.44E-04
Cf-252	1.03E-05	8.92E-06	1.63E-07	1.17E-07	5.07E-07	1.87E-06	4.37E-06	3.57E-05	0.00E+00	1.52E-11	1.65E-10	9.23E-06	1.99E-06	7.32E-05
Cm-244	1.73E-08	1.49E-08	2.26E-13	1.67E-13	8.27E-10	3.14E-09	1.28E-05	1.12E-04	0.00E+00	2.30E-15	2.68E-14	1.37E-05	2.95E-06	1.42E-04
Co-60	4.42E-05	3.81E-05	8.98E-06	2.30E-05	1.12E-06	3.70E-06	6.89E-09	5.86E-08	0.00E+00	7.94E-11	9.01E-10	3.71E-07	8.00E-08	1.20E-04
Cs-137	1.12E-05	9.69E-06	2.37E-06	6.12E-06	2.82E-07	9.35E-07	8.79E-09	7.74E-08	0.00E+00	1.73E-11	2.03E-10	1.49E-06	3.22E-07	3.25E-05
Ir-192	3.82E-06	3.30E-06	7.93E-07	1.96E-06	9.82E-08	3.19E-07	1.12E-09	4.53E-09	0.00E+00	1.85E-11	9.94E-11	4.82E-08	1.04E-08	1.04E-05
Po-210	7.72E-11	6.66E-11	1.67E-11	4.21E-11	1.96E-12	6.44E-12	8.08E-07	4.38E-06	0.00E+00	2.19E-16	1.58E-15	6.57E-05	1.42E-05	8.51E-05
Pu-238	1.71E-08	1.48E-08	8.44E-11	1.44E-10	7.98E-10	3.09E-09	2.49E-05	2.20E-04	0.00E+00	2.38E-15	2.81E-14	2.66E-05	5.74E-06	2.77E-04
Pu-239	7.80E-09	6.73E-09	2.57E-10	6.29E-10	3.02E-10	1.79E-09	2.71E-05	2.41E-04	0.00E+00	2.37E-15	2.80E-14	2.90E-05	6.26E-06	3.03E-04
Ra-226	3.47E-05	2.99E-05	6.80E-06	1.74E-05	8.70E-07	2.87E-06	2.16E-06	1.91E-05	3.52E-07	5.69E-11	6.73E-10	3.25E-05	7.02E-06	1.54E-04
Sr-90	2.22E-06	1.91E-06	1.97E-09	5.08E-09	5.59E-08	1.84E-07	3.64E-08	3.20E-07	0.00E+00	6.03E-13	7.07E-12	3.52E-06	7.60E-07	9.02E-06

TABLE 5.A.5 Individual Pathway DSRs for Scenario C1-1: Resident Spending 100% of the Time Indoors in Urban Setting, Second Year

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		Total
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	
Am-241	0.00E+00	1.35E-07	1.45E-10	1.40E-10	1.50E-08	4.04E-08	0.00E+00	1.15E-04	0.00E+00	0.00E+00	3.26E-12	0.00E+00	2.45E-06	1.18E-04
Cf-252	0.00E+00	1.69E-06	0.00E+00	0.00E+00	2.68E-07	9.09E-07	0.00E+00	1.63E-05	0.00E+00	0.00E+00	7.56E-11	0.00E+00	7.54E-07	2.00E-05
Cm-244	0.00E+00	3.53E-09	0.00E+00	0.00E+00	5.21E-10	1.87E-09	0.00E+00	6.49E-05	0.00E+00	0.00E+00	1.55E-14	0.00E+00	1.39E-06	6.63E-05
Co-60	0.00E+00	8.21E-06	3.98E-06	1.22E-05	8.34E-07	2.20E-06	0.00E+00	3.07E-08	0.00E+00	0.00E+00	4.72E-10	0.00E+00	3.45E-08	2.75E-05
Cs-137	0.00E+00	2.32E-06	9.27E-07	2.43E-06	2.35E-07	6.19E-07	0.00E+00	4.54E-08	0.00E+00	0.00E+00	1.19E-10	0.00E+00	1.54E-07	6.73E-06
Ir-192	0.00E+00	2.77E-08	1.25E-08	3.91E-08	2.60E-09	7.44E-09	0.00E+00	7.59E-11	0.00E+00	0.00E+00	1.67E-12	0.00E+00	1.74E-10	8.95E-08
Po-210	0.00E+00	2.69E-12	1.15E-12	3.11E-12	2.59E-13	7.18E-13	0.00E+00	3.88E-07	0.00E+00	0.00E+00	1.41E-16	0.00E+00	1.15E-06	1.54E-06
Pu-238	0.00E+00	3.59E-09	1.86E-12	1.62E-12	5.06E-10	1.88E-09	0.00E+00	1.31E-04	0.00E+00	0.00E+00	1.67E-14	0.00E+00	2.79E-06	1.34E-04
Pu-239	0.00E+00	1.65E-09	4.88E-11	8.75E-11	1.21E-10	9.76E-10	0.00E+00	1.45E-04	0.00E+00	0.00E+00	1.68E-14	0.00E+00	3.07E-06	1.48E-04
Ra-226	0.00E+00	7.34E-06	3.34E-06	9.86E-06	7.42E-07	1.95E-06	0.00E+00	1.15E-05	5.45E-07	0.00E+00	4.04E-10	0.00E+00	3.44E-06	3.87E-05
Sr-90	0.00E+00	4.59E-07	3.92E-10	1.12E-09	4.65E-08	1.22E-07	0.00E+00	1.88E-07	0.00E+00	0.00E+00	4.15E-12	0.00E+00	3.64E-07	1.18E-06

TABLE 5.A.6 Individual Pathway DSRs for Scenario C1-2: Adults Working Outside in Urban Setting, Second Year

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		Total
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	
Am-241	2.14E-07	9.22E-08	9.88E-11	9.54E-11	1.02E-08	2.76E-08	6.94E-06	7.88E-05	0.00E+00	1.47E-13	2.23E-12	7.76E-06	1.67E-06	9.56E-05
Cf-252	2.67E-06	1.15E-06	0.00E+00	0.00E+00	1.83E-07	6.21E-07	1.00E-06	1.12E-05	0.00E+00	3.48E-12	5.17E-11	2.39E-06	5.15E-07	1.97E-05
Cm-244	5.59E-09	2.41E-09	0.00E+00	0.00E+00	3.56E-10	1.28E-09	3.91E-06	4.43E-05	0.00E+00	7.01E-16	1.06E-14	4.41E-06	9.52E-07	5.36E-05
Co-60	1.30E-05	5.61E-06	2.72E-06	8.36E-06	5.70E-07	1.51E-06	1.87E-09	2.10E-08	0.00E+00	2.15E-11	3.23E-10	1.09E-07	2.35E-08	3.19E-05
Cs-137	3.68E-06	1.59E-06	6.34E-07	1.66E-06	1.60E-07	4.23E-07	2.74E-09	3.10E-08	0.00E+00	5.38E-12	8.13E-11	4.89E-07	1.05E-07	8.77E-06
Ir-192	4.38E-08	1.89E-08	8.54E-09	2.67E-08	1.78E-09	5.08E-09	5.67E-12	5.18E-11	0.00E+00	9.34E-14	1.14E-12	5.52E-10	1.19E-10	1.06E-07
Po-210	4.26E-12	1.84E-12	7.85E-13	2.13E-12	1.77E-13	4.91E-13	2.67E-08	2.65E-07	0.00E+00	7.24E-18	9.61E-17	3.63E-06	7.84E-07	4.71E-06
Pu-238	5.69E-09	2.45E-09	1.27E-12	1.11E-12	3.45E-10	1.29E-09	7.89E-06	8.95E-05	0.00E+00	7.56E-16	1.14E-14	8.84E-06	1.91E-06	1.08E-04
Pu-239	2.61E-09	1.13E-09	3.33E-11	5.98E-11	8.29E-11	6.67E-10	8.70E-06	9.88E-05	0.00E+00	7.60E-16	1.15E-14	9.72E-06	2.10E-06	1.19E-04
Ra-226	1.16E-05	5.01E-06	2.28E-06	6.74E-06	5.07E-07	1.33E-06	6.90E-07	7.84E-06	3.73E-07	1.82E-11	2.76E-10	1.09E-05	2.35E-06	4.96E-05
Sr-90	7.26E-07	3.13E-07	2.68E-10	7.62E-10	3.18E-08	8.37E-08	1.13E-08	1.28E-07	0.00E+00	1.87E-13	2.83E-12	1.15E-06	2.49E-07	2.70E-06

TABLE 5.A.7 Individual Pathway DSRs for Scenario C1-3: Resident Spending 100% of the Time Indoors in Rural Setting, Second Year

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		Total
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	
Am-241	0.00E+00	6.77E-07	9.10E-08	1.75E-07	2.38E-08	7.42E-08	0.00E+00	2.15E-04	0.00E+00	0.00E+00	6.07E-12	0.00E+00	6.15E-06	2.22E-04
Cf-252	0.00E+00	8.43E-06	1.66E-07	1.21E-07	5.14E-07	1.77E-06	0.00E+00	3.04E-05	0.00E+00	0.00E+00	1.41E-10	0.00E+00	1.88E-06	4.33E-05
Cm-244	0.00E+00	1.77E-08	2.88E-13	2.16E-13	1.05E-09	3.71E-09	0.00E+00	1.21E-04	0.00E+00	0.00E+00	2.88E-14	0.00E+00	3.50E-06	1.24E-04
Co-60	0.00E+00	4.11E-05	1.04E-05	2.71E-05	1.29E-06	3.99E-06	0.00E+00	5.72E-08	0.00E+00	0.00E+00	8.80E-10	0.00E+00	8.63E-08	8.40E-05
Cs-137	0.00E+00	1.17E-05	3.06E-06	8.02E-06	3.64E-07	1.12E-06	0.00E+00	8.45E-08	0.00E+00	0.00E+00	2.21E-10	0.00E+00	3.87E-07	2.47E-05
Ir-192	0.00E+00	1.31E-07	3.26E-08	8.58E-08	4.04E-09	1.27E-08	0.00E+00	1.42E-10	0.00E+00	0.00E+00	3.13E-12	0.00E+00	4.14E-10	2.67E-07
Po-210	0.00E+00	1.31E-11	3.45E-12	9.05E-12	4.04E-13	1.26E-12	0.00E+00	7.27E-07	0.00E+00	0.00E+00	2.63E-16	0.00E+00	2.78E-06	3.51E-06
Pu-238	0.00E+00	1.80E-08	1.11E-10	1.92E-10	1.05E-09	3.78E-09	0.00E+00	2.44E-04	0.00E+00	0.00E+00	3.12E-14	0.00E+00	7.01E-06	2.51E-04
Pu-239	0.00E+00	8.29E-09	3.40E-10	8.44E-10	3.99E-10	2.21E-09	0.00E+00	2.69E-04	0.00E+00	0.00E+00	3.14E-14	0.00E+00	7.71E-06	2.77E-04
Ra-226	0.00E+00	3.68E-05	8.99E-06	2.34E-05	1.15E-06	3.53E-06	0.00E+00	2.14E-05	4.47E-07	0.00E+00	7.52E-10	0.00E+00	8.64E-06	1.04E-04
Sr-90	0.00E+00	2.30E-06	2.55E-09	6.65E-09	7.22E-08	2.22E-07	0.00E+00	3.50E-07	0.00E+00	0.00E+00	7.72E-12	0.00E+00	9.14E-07	3.87E-06

TABLE 5.A.8 Individual Pathway DSRs for Scenario C1-4: Adults Working Outside in Rural Setting, Second Year

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		Total
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	
Am-241	5.36E-07	4.63E-07	6.22E-08	1.19E-07	1.62E-08	5.07E-08	1.72E-06	1.47E-04	0.00E+00	3.64E-14	4.15E-12	1.95E-05	4.20E-06	1.73E-04
Cf-252	6.68E-06	5.76E-06	1.13E-07	8.23E-08	3.51E-07	1.21E-06	2.47E-07	2.08E-05	0.00E+00	8.58E-13	9.63E-11	5.96E-06	1.29E-06	4.25E-05
Cm-244	1.40E-08	1.21E-08	1.97E-13	1.47E-13	7.19E-10	2.54E-09	9.69E-07	8.25E-05	0.00E+00	1.73E-16	1.97E-14	1.11E-05	2.39E-06	9.70E-05
Co-60	3.26E-05	2.81E-05	7.10E-06	1.85E-05	8.84E-07	2.73E-06	4.61E-10	3.91E-08	0.00E+00	5.32E-12	6.01E-10	2.73E-07	5.89E-08	9.02E-05
Cs-137	9.22E-06	7.96E-06	2.09E-06	5.48E-06	2.49E-07	7.68E-07	6.77E-10	5.78E-08	0.00E+00	1.33E-12	1.51E-10	1.23E-06	2.65E-07	2.73E-05
Ir-192	1.04E-07	8.98E-08	2.23E-08	5.87E-08	2.76E-09	8.69E-09	1.34E-12	9.72E-11	0.00E+00	2.20E-14	2.14E-12	1.31E-09	2.83E-10	2.88E-07
Po-210	1.03E-11	8.93E-12	2.35E-12	6.18E-12	2.76E-13	8.63E-13	6.40E-09	4.97E-07	0.00E+00	1.74E-18	1.80E-16	8.82E-06	1.90E-06	1.12E-05
Pu-238	1.43E-08	1.23E-08	7.57E-11	1.31E-10	7.15E-10	2.58E-09	1.95E-06	1.67E-04	0.00E+00	1.87E-16	2.13E-14	2.22E-05	4.79E-06	1.96E-04
Pu-239	6.56E-09	5.66E-09	2.32E-10	5.77E-10	2.73E-10	1.51E-09	2.15E-06	1.84E-04	0.00E+00	1.88E-16	2.14E-14	2.44E-05	5.27E-06	2.16E-04
Ra-226	2.92E-05	2.52E-05	6.14E-06	1.60E-05	7.86E-07	2.41E-06	1.71E-07	1.46E-05	3.05E-07	4.52E-12	5.14E-10	2.73E-05	5.90E-06	1.28E-04
Sr-90	1.82E-06	1.57E-06	1.74E-09	4.54E-09	4.94E-08	1.51E-07	2.80E-09	2.39E-07	0.00E+00	4.64E-14	5.27E-12	2.89E-06	6.24E-07	7.36E-06

TABLE 5.A.9 Individual Pathway DSRs for Scenario C2-1: Indoor Worker at Industrial/Commercial Area, First Year

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		Total
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	
Am-241	0.00E+00	5.72E-08	1.96E-11	3.37E-11	2.13E-09	2.73E-08	0.00E+00	1.23E-04	0.00E+00	0.00E+00	2.60E-12	0.00E+00	1.04E-06	1.24E-04
Cf-252	0.00E+00	9.42E-07	0.00E+00	0.00E+00	1.48E-08	5.75E-07	0.00E+00	2.42E-05	0.00E+00	0.00E+00	8.40E-11	0.00E+00	4.21E-07	2.62E-05
Cm-244	0.00E+00	1.56E-09	0.00E+00	0.00E+00	1.79E-11	9.49E-10	0.00E+00	7.23E-05	0.00E+00	0.00E+00	1.29E-14	0.00E+00	6.14E-07	7.29E-05
Co-60	0.00E+00	3.99E-06	6.34E-07	3.48E-06	1.31E-07	1.73E-06	0.00E+00	3.85E-08	0.00E+00	0.00E+00	4.44E-10	0.00E+00	1.68E-08	1.00E-05
Cs-137	0.00E+00	1.01E-06	1.32E-07	6.13E-07	3.32E-08	4.34E-07	0.00E+00	4.96E-08	0.00E+00	0.00E+00	9.75E-11	0.00E+00	6.70E-08	2.34E-06
Ir-192	0.00E+00	4.16E-07	5.62E-08	2.99E-07	1.15E-08	1.80E-07	0.00E+00	5.34E-09	0.00E+00	0.00E+00	8.79E-11	0.00E+00	2.62E-09	9.71E-07
Po-210	0.00E+00	7.75E-12	1.02E-12	4.79E-12	2.29E-13	3.34E-12	0.00E+00	4.06E-06	0.00E+00	0.00E+00	1.10E-15	0.00E+00	3.30E-06	7.37E-06
Pu-238	0.00E+00	1.53E-09	2.58E-13	3.94E-13	1.61E-11	9.35E-10	0.00E+00	1.40E-04	0.00E+00	0.00E+00	1.35E-14	0.00E+00	1.19E-06	1.42E-04
Pu-239	0.00E+00	6.99E-10	6.66E-12	2.14E-11	3.10E-12	4.26E-10	0.00E+00	1.54E-04	0.00E+00	0.00E+00	1.34E-14	0.00E+00	1.30E-06	1.55E-04
Ra-226	0.00E+00	3.11E-06	4.66E-07	2.46E-06	1.03E-07	1.34E-06	0.00E+00	1.22E-05	3.58E-08	0.00E+00	3.22E-10	0.00E+00	1.46E-06	2.12E-05
Sr-90	0.00E+00	1.99E-07	5.58E-11	2.82E-10	6.59E-09	8.58E-08	0.00E+00	2.06E-07	0.00E+00	0.00E+00	3.40E-12	0.00E+00	1.58E-07	6.55E-07

TABLE 5.A.10 Individual Pathway DSRs for Scenario C2-2: Outdoor Worker at Industrial/Commercial Area, First Year

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		Total
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	
Am-241	2.86E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.82E-04	0.00E+00	0.00E+00	2.88E-12	0.00E+00	1.04E-05	0.00E+00	1.92E-04
Cf-252	4.71E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.69E-05	0.00E+00	0.00E+00	9.61E-11	0.00E+00	4.21E-06	0.00E+00	4.58E-05
Cm-244	7.78E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.07E-04	0.00E+00	0.00E+00	1.44E-14	0.00E+00	6.14E-06	0.00E+00	1.14E-04
Co-60	2.00E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.79E-08	0.00E+00	0.00E+00	5.01E-10	0.00E+00	1.68E-07	0.00E+00	2.02E-05
Cs-137	5.04E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.36E-08	0.00E+00	0.00E+00	1.08E-10	0.00E+00	6.70E-07	0.00E+00	5.78E-06
Ir-192	2.08E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.01E-08	0.00E+00	0.00E+00	1.24E-10	0.00E+00	2.62E-08	0.00E+00	2.11E-06
Po-210	3.88E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.09E-06	0.00E+00	0.00E+00	1.44E-15	0.00E+00	3.30E-05	0.00E+00	4.01E-05
Pu-238	7.67E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.08E-04	0.00E+00	0.00E+00	1.49E-14	0.00E+00	1.19E-05	0.00E+00	2.20E-04
Pu-239	3.50E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.27E-04	0.00E+00	0.00E+00	1.49E-14	0.00E+00	1.30E-05	0.00E+00	2.40E-04
Ra-226	1.55E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-05	0.00E+00	0.00E+00	3.57E-10	0.00E+00	1.46E-05	0.00E+00	4.81E-05
Sr-90	9.95E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.05E-07	0.00E+00	0.00E+00	3.78E-12	0.00E+00	1.58E-06	0.00E+00	2.88E-06

TABLE 5.A.11 Individual Pathway DSRs for Scenario C2-1: Indoor Worker at Industrial/Commercial Area, Second Year

	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
Radionuclide	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	0.00E+00	3.08E-08	1.77E-11	3.09E-11	1.93E-09	1.47E-08	0.00E+00	3.51E-05	0.00E+00	0.00E+00	7.44E-13	0.00E+00	5.60E-07	3.57E-05
Cf-252	0.00E+00	3.85E-07	0.00E+00	0.00E+00	1.03E-08	2.35E-07	0.00E+00	4.97E-06	0.00E+00	0.00E+00	1.73E-11	0.00E+00	1.72E-07	5.78E-06
Cm-244	0.00E+00	8.06E-10	0.00E+00	0.00E+00	1.55E-11	4.91E-10	0.00E+00	1.97E-05	0.00E+00	0.00E+00	3.54E-15	0.00E+00	3.18E-07	2.01E-05
Co-60	0.00E+00	1.87E-06	5.02E-07	2.79E-06	1.04E-07	8.13E-07	0.00E+00	9.35E-09	0.00E+00	0.00E+00	1.08E-10	0.00E+00	7.87E-09	6.10E-06
Cs-137	0.00E+00	5.30E-07	1.17E-07	5.49E-07	2.93E-08	2.28E-07	0.00E+00	1.38E-08	0.00E+00	0.00E+00	2.71E-11	0.00E+00	3.52E-08	1.50E-06
Ir-192	0.00E+00	6.32E-09	1.58E-09	8.96E-09	3.22E-10	2.74E-09	0.00E+00	2.31E-11	0.00E+00	0.00E+00	3.81E-13	0.00E+00	3.98E-11	2.00E-08
Po-210	0.00E+00	6.14E-13	1.44E-13	7.04E-13	3.23E-14	2.65E-13	0.00E+00	1.18E-07	0.00E+00	0.00E+00	3.21E-17	0.00E+00	2.62E-07	3.80E-07
Pu-238	0.00E+00	8.20E-10	2.31E-13	3.58E-13	1.45E-11	5.00E-10	0.00E+00	3.99E-05	0.00E+00	0.00E+00	3.82E-15	0.00E+00	6.38E-07	4.05E-05
Pu-239	0.00E+00	3.77E-10	6.02E-12	1.96E-11	2.80E-12	2.30E-10	0.00E+00	4.40E-05	0.00E+00	0.00E+00	3.85E-15	0.00E+00	7.01E-07	4.47E-05
Ra-226	0.00E+00	1.67E-06	4.21E-07	2.25E-06	9.27E-08	7.20E-07	0.00E+00	3.49E-06	2.28E-08	0.00E+00	9.23E-11	0.00E+00	7.85E-07	9.46E-06
Sr-90	0.00E+00	1.05E-07	4.93E-11	2.53E-10	5.81E-09	4.51E-08	0.00E+00	5.72E-08	0.00E+00	0.00E+00	9.46E-13	0.00E+00	8.31E-08	2.96E-07

TABLE 5.A.12 Individual Pathway DSRs for Scenario C2-2: Outdoor Worker at Industrial/Commercial Area, Second Year

	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
Radionuclide	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	1.54E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.67E-06	0.00E+00	0.00E+00	1.06E-13	0.00E+00	5.60E-06	0.00E+00	1.24E-05
Cf-252	1.93E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.65E-07	0.00E+00	0.00E+00	2.51E-12	0.00E+00	1.72E-06	0.00E+00	4.61E-06
Cm-244	4.03E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.76E-06	0.00E+00	0.00E+00	5.05E-16	0.00E+00	3.18E-06	0.00E+00	6.95E-06
Co-60	9.37E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-09	0.00E+00	0.00E+00	1.55E-11	0.00E+00	7.87E-08	0.00E+00	9.45E-06
Cs-137	2.65E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.63E-09	0.00E+00	0.00E+00	3.88E-12	0.00E+00	3.52E-07	0.00E+00	3.01E-06
Ir-192	3.16E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.45E-12	0.00E+00	0.00E+00	6.73E-14	0.00E+00	3.98E-10	0.00E+00	3.20E-08
Po-210	3.07E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.56E-08	0.00E+00	0.00E+00	5.22E-18	0.00E+00	2.62E-06	0.00E+00	2.64E-06
Pu-238	4.10E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.58E-06	0.00E+00	0.00E+00	5.45E-16	0.00E+00	6.38E-06	0.00E+00	1.40E-05
Pu-239	1.88E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.36E-06	0.00E+00	0.00E+00	5.48E-16	0.00E+00	7.01E-06	0.00E+00	1.54E-05
Ra-226	8.37E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.64E-07	0.00E+00	0.00E+00	1.31E-11	0.00E+00	7.85E-06	0.00E+00	1.69E-05
Sr-90	5.23E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.09E-08	0.00E+00	0.00E+00	1.35E-13	0.00E+00	8.31E-07	0.00E+00	1.37E-06

TABLE 5.A.13 Individual Pathway DSRs for Scenario C3-1: Indoor Worker at Monument/Park Area, First Year

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		Total
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	
Am-241	0.00E+00	9.21E-08	3.04E-11	2.97E-11	4.64E-09	4.39E-08	0.00E+00	1.63E-04	0.00E+00	0.00E+00	3.46E-12	0.00E+00	1.67E-06	1.65E-04
Cf-252	0.00E+00	1.49E-06	0.00E+00	0.00E+00	2.87E-08	9.08E-07	0.00E+00	3.15E-05	0.00E+00	0.00E+00	1.09E-10	0.00E+00	6.65E-07	3.46E-05
Cm-244	0.00E+00	2.50E-09	0.00E+00	0.00E+00	3.38E-11	1.52E-09	0.00E+00	9.58E-05	0.00E+00	0.00E+00	1.72E-14	0.00E+00	9.86E-07	9.68E-05
Co-60	0.00E+00	6.37E-06	1.31E-06	2.85E-06	2.82E-07	2.76E-06	0.00E+00	5.07E-08	0.00E+00	0.00E+00	5.85E-10	0.00E+00	2.67E-08	1.36E-05
Cs-137	0.00E+00	1.62E-06	2.67E-07	5.34E-07	7.17E-08	6.97E-07	0.00E+00	6.59E-08	0.00E+00	0.00E+00	1.29E-10	0.00E+00	1.08E-07	3.36E-06
Ir-192	0.00E+00	5.51E-07	1.16E-07	2.44E-07	2.48E-08	2.39E-07	0.00E+00	6.02E-09	0.00E+00	0.00E+00	9.91E-11	0.00E+00	3.47E-09	1.18E-06
Po-210	0.00E+00	1.11E-11	2.07E-12	4.14E-12	4.96E-13	4.80E-12	0.00E+00	4.83E-06	0.00E+00	0.00E+00	1.31E-15	0.00E+00	4.74E-06	9.57E-06
Pu-238	0.00E+00	2.47E-09	3.78E-13	3.43E-13	3.10E-11	1.50E-09	0.00E+00	1.87E-04	0.00E+00	0.00E+00	1.79E-14	0.00E+00	1.92E-06	1.88E-04
Pu-239	0.00E+00	1.12E-09	1.26E-11	1.97E-11	6.21E-12	6.86E-10	0.00E+00	2.04E-04	0.00E+00	0.00E+00	1.78E-14	0.00E+00	2.09E-06	2.06E-04
Ra-226	0.00E+00	5.00E-06	9.50E-07	2.03E-06	2.22E-07	2.15E-06	0.00E+00	1.62E-05	4.30E-08	0.00E+00	4.28E-10	0.00E+00	2.34E-06	2.89E-05
Sr-90	0.00E+00	3.20E-07	1.14E-10	2.39E-10	1.42E-08	1.38E-07	0.00E+00	2.73E-07	0.00E+00	0.00E+00	4.51E-12	0.00E+00	2.54E-07	9.99E-07

TABLE 5.A.14 Individual Pathway DSRs for Scenario C3-2: Outdoor Worker at Monument/Park Area, First Year

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		Total
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	
Am-241	4.60E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.09E-04	0.00E+00	0.00E+00	3.32E-12	0.00E+00	1.67E-05	0.00E+00	2.26E-04
Cf-252	7.45E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.20E-05	0.00E+00	0.00E+00	1.09E-10	0.00E+00	6.65E-06	0.00E+00	5.61E-05
Cm-244	1.25E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.23E-04	0.00E+00	0.00E+00	1.66E-14	0.00E+00	9.86E-06	0.00E+00	1.33E-04
Co-60	3.18E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.62E-08	0.00E+00	0.00E+00	5.73E-10	0.00E+00	2.67E-07	0.00E+00	3.22E-05
Cs-137	8.09E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.45E-08	0.00E+00	0.00E+00	1.25E-10	0.00E+00	1.08E-06	0.00E+00	9.25E-06
Ir-192	2.76E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.08E-08	0.00E+00	0.00E+00	1.33E-10	0.00E+00	3.47E-08	0.00E+00	2.80E-06
Po-210	5.56E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.76E-06	0.00E+00	0.00E+00	1.58E-15	0.00E+00	4.74E-05	0.00E+00	5.52E-05
Pu-238	1.23E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.39E-04	0.00E+00	0.00E+00	1.72E-14	0.00E+00	1.92E-05	0.00E+00	2.58E-04
Pu-239	5.62E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.61E-04	0.00E+00	0.00E+00	1.71E-14	0.00E+00	2.09E-05	0.00E+00	2.82E-04
Ra-226	2.50E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.07E-05	0.00E+00	0.00E+00	4.10E-10	0.00E+00	2.34E-05	0.00E+00	6.92E-05
Sr-90	1.60E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.50E-07	0.00E+00	0.00E+00	4.35E-12	0.00E+00	2.54E-06	0.00E+00	4.49E-06

TABLE 5.A.15 Individual Pathway DSRs for Scenario C3-1: Indoor Worker at Monument/Park Area, Second Year

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	0.00E+00	7.73E-08	2.74E-11	2.71E-11	4.19E-09	3.68E-08	0.00E+00	7.15E-05	0.00E+00	0.00E+00	1.52E-12	0.00E+00	1.40E-06	7.31E-05
Cf-252	0.00E+00	9.63E-07	0.00E+00	0.00E+00	1.99E-08	5.87E-07	0.00E+00	1.01E-05	0.00E+00	0.00E+00	3.52E-11	0.00E+00	4.30E-07	1.21E-05
Cm-244	0.00E+00	2.02E-09	0.00E+00	0.00E+00	2.94E-11	1.23E-09	0.00E+00	4.02E-05	0.00E+00	0.00E+00	7.20E-15	0.00E+00	7.98E-07	4.10E-05
Co-60	0.00E+00	4.69E-06	1.03E-06	2.29E-06	2.23E-07	2.03E-06	0.00E+00	1.91E-08	0.00E+00	0.00E+00	2.20E-10	0.00E+00	1.97E-08	1.03E-05
Cs-137	0.00E+00	1.33E-06	2.36E-07	4.78E-07	6.33E-08	5.73E-07	0.00E+00	2.81E-08	0.00E+00	0.00E+00	5.53E-11	0.00E+00	8.84E-08	2.80E-06
Ir-192	0.00E+00	1.50E-08	3.25E-09	7.31E-09	6.96E-10	6.50E-09	0.00E+00	4.81E-11	0.00E+00	0.00E+00	7.92E-13	0.00E+00	9.45E-11	3.29E-08
Po-210	0.00E+00	1.49E-12	2.91E-13	6.08E-13	6.99E-14	6.43E-13	0.00E+00	2.44E-07	0.00E+00	0.00E+00	6.63E-17	0.00E+00	6.36E-07	8.80E-07
Pu-238	0.00E+00	2.06E-09	3.39E-13	3.12E-13	2.78E-11	1.26E-09	0.00E+00	8.12E-05	0.00E+00	0.00E+00	7.78E-15	0.00E+00	1.60E-06	8.28E-05
Pu-239	0.00E+00	9.46E-10	1.14E-11	1.80E-11	5.61E-12	5.77E-10	0.00E+00	8.96E-05	0.00E+00	0.00E+00	7.83E-15	0.00E+00	1.76E-06	9.14E-05
Ra-226	0.00E+00	4.20E-06	8.58E-07	1.86E-06	2.00E-07	1.81E-06	0.00E+00	7.11E-06	3.72E-08	0.00E+00	1.88E-10	0.00E+00	1.97E-06	1.81E-05
Sr-90	0.00E+00	2.63E-07	1.01E-10	2.14E-10	1.25E-08	1.13E-07	0.00E+00	1.16E-07	0.00E+00	0.00E+00	1.93E-12	0.00E+00	2.09E-07	7.14E-07

TABLE 5.A.16 Individual Pathway DSRs for Scenario C3-2: Outdoor Worker at Monument/Park Area, Second Year

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	3.87E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.65E-05	0.00E+00	0.00E+00	2.63E-13	0.00E+00	1.40E-05	0.00E+00	3.10E-05
Cf-252	4.81E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.38E-06	0.00E+00	0.00E+00	6.19E-12	0.00E+00	4.30E-06	0.00E+00	1.15E-05
Cm-244	1.01E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.31E-06	0.00E+00	0.00E+00	1.25E-15	0.00E+00	7.98E-06	0.00E+00	1.73E-05
Co-60	2.35E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.44E-09	0.00E+00	0.00E+00	3.84E-11	0.00E+00	1.97E-07	0.00E+00	2.37E-05
Cs-137	6.65E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.51E-09	0.00E+00	0.00E+00	9.59E-12	0.00E+00	8.84E-07	0.00E+00	7.54E-06
Ir-192	7.50E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.28E-11	0.00E+00	0.00E+00	1.59E-13	0.00E+00	9.45E-10	0.00E+00	7.60E-08
Po-210	7.46E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.16E-08	0.00E+00	0.00E+00	1.25E-17	0.00E+00	6.36E-06	0.00E+00	6.42E-06
Pu-238	1.03E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.88E-05	0.00E+00	0.00E+00	1.35E-15	0.00E+00	1.60E-05	0.00E+00	3.48E-05
Pu-239	4.73E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.07E-05	0.00E+00	0.00E+00	1.36E-15	0.00E+00	1.76E-05	0.00E+00	3.83E-05
Ra-226	2.10E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.64E-06	0.00E+00	0.00E+00	3.26E-11	0.00E+00	1.97E-05	0.00E+00	4.24E-05
Sr-90	1.31E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.69E-08	0.00E+00	0.00E+00	3.35E-13	0.00E+00	2.09E-06	0.00E+00	3.43E-06

6 GROUP C: RELOCATION, PART 2 — CRITICAL INFRASTRUCTURE UTILIZATION IN RELOCATION AREAS

The operational guidelines for Group C (Part 2) are intended as screening values so that facilities critical to the public welfare can continue to operate if needed after an RDD event. The operational guidelines in this group apply only to facilities in areas that exceed relocation PAGs and might, as a result, be closed for general use and access, except for the fact that their operation is critical to the public welfare. The operational guidelines are generally applicable during the intermediate phase. It was assumed that the continued use of such facilities would be temporary (less than 6 months for hospitals and other health care facilities). After this time, it would be possible to either provide the services through alternate means or implement interim control, restoration, or decontamination measures in order to reduce contamination levels below relocation operational guidelines. It is expected that after their restoration or decontamination, the facilities would be treated as any commercial/industrial facility. The critical infrastructures considered include hospitals and other health care facilities, critical transport facilities, water and sewer facilities, and power and fuel facilities. To derive operational guidelines for use of critical infrastructure facilities, doses were estimated for different critical receptors (see Table 2.5 in Chapter 2) that would work in these contaminated areas.

6.1 HOSPITALS AND OTHER HEALTH CARE FACILITIES (GROUP C4)

The operational guidelines for this group allow for the continued use of health care facilities and services that are in areas that exceed relocation criteria. The 5-rem occupational exposure PAG was applied to health care facility employees. Three potential exposure scenarios were considered for the derivation of operational guidelines. Potential radiation doses resulting from 13 exposure pathways were considered. The applicability of these exposure pathways to the three scenarios evaluated is summarized in Table 2.6 in Chapter 2. All scenarios considered were in an urban environment, and the building dimensions considered for external exposure were based on a warehouse geometry shown in Table 2.4 in Chapter 2. The initial outdoor contamination was assumed to be on streets. The average correction factors for outdoor air presented in the last 2 columns of Table 2.2 in Chapter 2 were multiplied by 10 to account for traffic in an urban environment (see Table 2.3 in Chapter 2).

To account for the differences in the time fractions spent inside and outside by different people, two receptors — one that would spend all the time indoors and the other that would spend all the time outdoors — were considered. A third receptor was assumed to be a patient that would spend the initial 2 weeks after an RDD event inside the hospital. The parameters used in different exposure scenarios are listed in Table 2.7 in Chapter 2.

6.1.1 Scenario Description for Hospitals and Other Health Care Facilities

Scenario C4-1 (hospital outdoor worker) assumed continued use of the contaminated area in an urban environment. Under this scenario, an outdoor worker was assumed to spend all the time outdoors in the contaminated area (an average of 8 h/d for 125 days [6 months]). For the hospital outdoor worker, the 6-month average weathering correction factors listed in Table 2.2 in Chapter 2 were applied. It was assumed that the facility would be cleaned within 6 months or alternate arrangements would be made. The outdoor worker was exposed to radiation through exposure to outside contamination, inhaling contaminated outdoor air, and directly ingesting dust from contaminated outdoor areas.

Scenario C4-2 (hospital indoor worker) assumed continued use of the contaminated area in an urban environment. Under this scenario, an indoor worker was assumed to spend all the time indoors in the contaminated area (an average of 8 h/d indoors for 125 days [6 months]). For the hospital indoor worker, the 6-month average weathering correction factors listed in Table 2.2 in Chapter 2 were applied. It was assumed that the facility would be cleaned within 6 months or alternate arrangements would be made. The building dimensions considered for external exposure were based on a warehouse geometry shown in Table 2.4 in Chapter 2. All applicable exposure pathways are shown in Table 2.6 in Chapter 2.

Scenario C4-3 (patient staying in hospital) assumed continued use of the contaminated area in an urban environment. Under this scenario, a patient was assumed to spend all the time indoors in the contaminated area (an average of 24 h/d for first 2 weeks). For the patient, the 14-day average weathering correction factors listed in Table 2.2 in Chapter 2 were applied. It was assumed that the patient would be released within 2 weeks or alternate arrangements would be made. The building dimensions considered for external exposure were based on a warehouse geometry shown in Table 2.4 in Chapter 2. All applicable exposure pathways are shown in Table 2.6 in Chapter 2.

6.1.2 Dose Calculation for Hospitals and Other Health Care Facilities

In Appendix 6.A, Tables 6.A.1 through 6.A.3 provide the DSRs from individual exposure pathways for Group C4 (hospitals and other health care facilities for the short duration [6 months for C4-1 and C4-2, and 2 weeks for C4-3]). Table 6.1 lists the total DSRs for all three scenarios (C4-1, C4-2, and C4-3) for the short duration.

TABLE 6.1 Generic Dose-to-Source Ratios (DSRs) for Hospitals and Other Health Care Facilities (Group C4) Scenarios

	DSR (mrem/yr per pCi/m^2) Based on Initial Street Contamination for the Short Duration[a]		
Radionuclide	C4-1[b]	C4-2[c]	C4-3[d]
Am-241	1.79E-04	1.02E-04	8.98E-05
Cf-252	4.12E-05	2.17E-05	1.92E-05
Cm-244	1.06E-04	6.00E-05	5.33E-05
Co-60	1.29E-05	5.93E-06	2.58E-06
Cs-137	3.62E-06	1.38E-06	6.17E-07
Ir-192	1.92E-06	8.62E-07	6.68E-07
Po-210	3.37E-05	6.47E-06	5.67E-06
Pu-238	2.05E-04	1.16E-04	1.03E-04
Pu-239	2.24E-04	1.27E-04	1.12E-04
Ra-226	3.58E-05	1.53E-05	1.11E-05
Sr-90	1.89E-06	4.49E-07	2.81E-07

[a] For Scenarios C4-1 and C4-2, the DSRs were based on an initial 6 months of exposure. For Scenario C4-3, the DSRs were based on an initial 2 weeks of exposure.

[b] C4-1: hospital and other health care facilities, hospital outdoor worker.

[c] C4-2: hospital and other health care facilities, hospital indoor worker.

[d] C4-3: hospital and other health care facilities, patient staying in hospital.

6.1.3 Operational Guideline Derivation for Hospitals and Other Health Care Facilities

Table 6.2 provides the operational guidelines for hospitals and other health care facilities. To derive guidelines for the short duration, the occupational PAG (5 rem) was used for the C4-1 and C4-2 scenarios, and the public PAG (2 rem) was used for the C4-3 scenario.

Different scenarios were considered in deriving generic operational guidelines for use of hospitals for a short duration. The scenarios considered included occupational use by the hospital staff for 6 months and use by a patient staying for 2 weeks immediately after an RDD event. In fact, hospital buildings would most likely be cleaned before 6 months, and patients would stay in the hospital for less than 2 weeks. Table 6.3 provides the most restrictive operational guideline values for occupational exposure and public exposure for the short duration. For occupational exposure, the hospital outdoor worker scenario resulted in more restrictive operational guidelines than the hospital indoor worker scenario. However, overall, for Am-241, Cf-252, Cm-244, Pu-238, and Pu-239, Scenario C4-3 (a patient brought in immediately after an RDD event) gives the most restrictive operational guidelines, and for Co-60, Cs-137, Ir-192, Po-210, Ra-226, and Sr-90, Scenario C4-2 (hospital outdoor worker) gives the most restrictive operational guidelines.

To continue using the hospitals and health care facilities beyond 6 months, the relocation operational guidelines for commercial/industrial areas should be applied to these facilities after necessary decontamination activities for the first year and after the first year. It should be noted that occupational exposure should never exceed 5 rem in a year, and public exposure should never exceed 2 rem for the first year; therefore, even if the buildings were cleaned after 6 months, the workers who have already received a dose of 5 rem should not be allowed to work in these buildings for the rest of the year. Those who have received a dose of less than 5 rem during the first 6 months could continue working in these buildings until the total dose meets the 5 rem/yr criterion.

6.2 CRITICAL TRANSPORT FACILITIES (GROUP C5)

The operational guidelines for this group would allow continued use of critical transport facilities located in areas that exceed relocation criteria. The 5-rem occupational exposure PAG was applied to the facility employees. Four potential exposure scenarios were considered for the

TABLE 6.2 Generic Operational Guidelines for Hospitals and Other Health Care Facilities (Group C4) Scenarios

	Operational Guideline (pCi/m²) Based on Initial Street Contamination[a]		
	Occupational		Patient
Radionuclide	C4-1[b]	C4-2[c]	C4-3[d]
Am-241	2.79E+07	4.92E+07	2.23E+07
Cf-252	1.21E+08	2.30E+08	1.04E+08
Cm-244	4.71E+07	8.33E+07	3.75E+07
Co-60	3.89E+08	8.43E+08	7.75E+08
Cs-137	1.38E+09	3.61E+09	3.24E+09
Ir-192	2.61E+09	5.80E+09	2.99E+09
Po-210	1.48E+08	7.73E+08	3.53E+08
Pu-238	2.44E+07	4.30E+07	1.94E+07
Pu-239	2.23E+07	3.94E+07	1.78E+07
Ra-226	1.40E+08	3.28E+08	1.80E+08
Sr-90	2.64E+09	1.11E+10	7.12E+09

[a] For Scenarios C4-1 and C4-2, operational guidelines were based on an initial 6 months of exposure and an occupational PAG of 5 rem. For Scenario C4-3, operational guidelines were based on an initial 2 weeks of exposure and a public PAG of 2 rem for the first year.

[b] C4-1: hospital and other health care facilities, hospital outdoor worker.

[c] C4-2: hospital and other health care facilities, hospital indoor worker.

[d] C4-3: hospital and other health care facilities, patient staying in hospital.

derivation of operational guidelines. Potential exposure pathways for the four scenarios evaluated are summarized in Table 2.6 in Chapter 2. All scenarios were considered in an urban environment, and the building dimensions considered for external exposure for facility employees and the general public were based on a subway station geometry and railcar geometry, respectively, as shown in Table 2.4 in Chapter 2. The initial outdoor contamination was assumed to be on streets. The average correction factors for outdoor air presented in the last two columns of Table 2.2 in Chapter 2 were multiplied by 10 to account for pedestrian activity and traffic in an urban environment (see Table 2.3 in Chapter 2).

TABLE 6.3 Most Restrictive Operational Guidelines for Hospitals and Other Health Care Facilities (Group C4)

	Street Contamination (pCi/m^2)	
Radionuclide	5 rem for Occupational Worker	2 rem for General Public (Patient)
Am-241	2.79E+07	2.23E+07
Cf-252	1.21E+08	1.04E+08
Cm-244	4.71E+07	3.75E+07
Co-60	3.89E+08	7.75E+08
Cs-137	1.38E+09	3.24E+09
Ir-192	2.61E+09	2.99E+09
Po-210	1.48E+08	3.53E+08
Pu-238	2.44E+07	1.94E+07
Pu-239	2.23E+07	1.78E+07
Ra-226	1.40E+08	1.80E+08
Sr-90	2.64E+09	7.12E+09

To account for differences in the time fractions spent inside and outside of a transport facility by different people, two receptors accounting for occupational workers and two receptors accounting for the general public were considered. For the occupational receptors, it was assumed that one receptor would spend all the time outdoors and the other one would spend all the time indoors. For the general public receptors, the time fractions spent indoors and outdoors were based on the guidance provided in the EPA *Exposure Factor Handbook* (EPA 1997). The parameters used for different receptors are listed in Table 2.7 in Chapter 2.

6.2.1 Scenario Description for Critical Transport Facilities

Scenario C5-1 (critical transport facilities, ticket clerk staying inside) assumed continued use of a contaminated facility in an urban environment. Under this scenario, an indoor ticket clerk was assumed to spend all the time (an average of 8 h/d for 250 days in 1 year) indoors in the contaminated subway station.

Scenario C5-2 (critical transport facilities, baggage handler staying outside) assumed continued use of a contaminated facility in an urban environment. Under this scenario, a baggage handler was assumed to spend all the time (an average of 8 h/d for 250 days in 1 year) outdoors in the contaminated subway station.

Scenario C5-3 (critical transport facilities, passenger staying inside) assumed continued use of a contaminated facility in an urban environment. Under this scenario, a passenger was assumed to spend all the time (an average of 1.25 h/d for 250 days in 1 year) indoors in a contaminated railcar.

Scenario C5-4 (critical transport facilities, passenger staying both outside and inside) assumed continued use of a contaminated facility in an urban environment. Under this scenario, a passenger was assumed to spend some time (an average of 1 h/d for 250 days in 1 year) inside a contaminated railcar and some time (an average of 0.25 h/d for 250 days in one year) outside in the subway station.

6.2.2 Dose Calculation for Critical Transport Facilities

In Appendix 6.A, Tables 6.A.4 through 6.A.7 provide the DSRs from individual exposure pathways for Group C5 (critical transport facilities for the first year). Table 6.4 provides the total DSRs for all scenarios for the first year.

6.2.3 Operational Guideline Derivation for Critical Transport Facilities

Table 6.5 provides the generic operational guidelines for critical transport facilities. The PAGs used in deriving guidelines for different scenarios were 5 rem for facility workers (occupational) and 2 rem for others (general public), as detailed in Table 2.5 in Chapter 2.

Different scenarios were considered in deriving generic operation guidelines for continued use of critical transport facilities. The scenarios considered included occupational use by facility workers and public use by passengers after an RDD event. For occupational use, for all radionuclides, Scenario C5-2 (baggage handler staying outside) resulted in more restrictive operational guideline values. For public use, for all radionuclides except Co-60 and Ir-192, Scenario C5-4 (passenger staying both outside and inside) resulted in more restrictive operational guideline values. For Co-60 and Ir-192, Scenario C5-3 (passenger staying inside) resulted in more restrictive operational guideline values. The occupational worker operational guideline

TABLE 6.4 Generic Dose-to-Source Ratios (DSRs) for Critical Transport Facilities (Group C5) Scenarios

	DSR (mrem/yr per pCi/m^2) Based on Initial Street Contamination following an RDD Event			
Radionuclide	C5-1[a]	C5-2[b]	C5-3[c]	C5-4[d]
Am-241	1.24E-04	1.92E-04	1.62E-05	1.86E-05
Cf-252	2.62E-05	4.58E-05	3.61E-06	4.25E-06
Cm-244	7.29E-05	1.14E-04	9.51E-06	1.09E-05
Co-60	1.28E-05	2.02E-05	3.57E-06	3.48E-06
Cs-137	3.20E-06	5.78E-06	9.11E-07	9.09E-07
Ir-192	1.20E-06	2.11E-06	3.34E-07	3.33E-07
Po-210	7.37E-06	4.01E-05	1.05E-06	2.08E-06
Pu-238	1.42E-04	2.20E-04	1.85E-05	2.12E-05
Pu-239	1.55E-04	2.40E-04	2.02E-05	2.32E-05
Ra-226	2.33E-05	4.81E-05	4.55E-06	5.11E-06
Sr-90	6.40E-07	2.88E-06	1.25E-07	1.89E-07

[a] C5-1: critical transport facilities, ticket clerk staying inside.

[b] C5-2: critical transport facilities, baggage handler staying outside.

[c] C5-3: critical transport facilities, passenger staying inside.

[d] C5-4: critical transport facilities, passenger staying both outside and inside.

values are more restrictive than the general public operational guideline values. Table 6.6 provides the most restrictive operational guideline values for both occupational and public use of the facilities following an RDD event. For extended use of the transport facilities beyond one year, the relocation operational guidelines for commercial/ industrial areas should be applied to evaluate the facilities after necessary decontamination activities.

6.3 WATER AND SEWER FACILITIES (GROUP C6)

The operational guidelines for this group allow continued use of water and sewer facilities located in areas that exceed relocation criteria. The 5-rem occupational PAG exposure was applied to the facility employees. Four potential exposure scenarios were considered for the derivation of operational guidelines. Potential exposure pathways for the four scenarios

TABLE 6.5 Generic Operational Guidelines for Critical Transport Facilities (Group C5) Scenarios

	Operational Guideline (pCi/m^2) Based on Initial Street Contamination following an RDD Event			
	Occupational		General Public	
Radionuclide	C5-1[a]	C5-2[b]	C5-3[c]	C5-4[d]
Am-241	4.04E+07	2.60E+07	1.24E+08	1.08E+08
Cf-252	1.91E+08	1.09E+08	5.54E+08	4.71E+08
Cm-244	6.86E+07	4.40E+07	2.10E+08	1.83E+08
Co-60	3.90E+08	2.48E+08	5.61E+08	5.74E+08
Cs-137	1.56E+09	8.65E+08	2.20E+09	2.20E+09
Ir-192	4.17E+09	2.36E+09	5.98E+09	6.00E+09
Po-210	6.79E+08	1.25E+08	1.91E+09	9.63E+08
Pu-238	3.53E+07	2.27E+07	1.08E+08	9.41E+07
Pu-239	3.23E+07	2.08E+07	9.90E+07	8.62E+07
Ra-226	2.14E+08	1.04E+08	4.39E+08	3.91E+08
Sr-90	7.81E+09	1.74E+09	1.60E+10	1.06E+10

[a] C5-1: critical transport facilities, ticket clerk staying inside.

[b] C5-2: critical transport facilities, baggage handler staying outside.

[c] C5-3: critical transport facilities, passenger staying inside.

[d] C5-4: critical transport facilities, passenger staying both outside and inside.

TABLE 6.6 Most Restrictive Operational Guidelines for Critical Transport Facilities (Group C5)

	Street Contamination (pCi/m^2)	
Radionuclide	5 rem for Occupational Worker	2 rem for General Public
Am-241	2.60E+07	1.08E+08
Cf-252	1.09E+08	4.71E+08
Cm-244	4.40E+07	1.83E+08
Co-60	2.48E+08	5.61E+08
Cs-137	8.65E+08	2.20E+09
Ir-192	2.36E+09	5.98E+09
Po-210	1.25E+08	9.63E+08
Pu-238	2.27E+07	9.41E+07
Pu-239	2.08E+07	8.62E+07
Ra-226	1.04E+08	3.91E+08
Sr-90	1.74E+09	1.06E+10

evaluated are summarized in Table 2.6 in Chapter 2. All scenarios considered were in an urban environment, and the building dimensions considered for external exposure for facility employees and the general public were based on the warehouse geometry shown in Table 2.4 in Chapter 2. The initial outdoor contamination was assumed to be on the streets. The average correction factors for outdoor air presented in the last 2 columns of Table 2.2 in Chapter 2 were multiplied by 10 to account for pedestrian activity and traffic in an urban environment (see Table 2.3 in Chapter 2).

To account for differences in the time fractions spent inside and outside water and sewer facilities by different people, two receptors accounting for regular occupational work at the facilities and two receptors accounting for the general public who happen to perform contract work at the facilities were considered. For the occupational receptors, it was assumed that one receptor would spend all the time outdoors, and the other one would spend all the time indoors. For the general public receptors, it was assumed that one receptor would spend an average of 2 h/d for 250 days indoors, and the other would spend the same amount of time outdoors. The most common parameters used for different receptors are listed in Table 2.7 in Chapter 2.

6.3.1 Scenario Description for Water and Sewer Facilities

Scenario C6-1 (water and sewer facilities, facility outdoor worker) assumed continued use of the contaminated facility in an urban environment. Under this scenario, an outdoor facility worker was assumed to spend all the time (an average of 8 h/d for 250 days in 1 year) outdoors in the contaminated facility.

Scenario C6-2 (water and sewer facilities, facility indoor worker) assumed continued use of the contaminated facility in an urban environment. Under this scenario, a facility indoor worker was assumed to spend all the time (an average of 8 h/d for 250 days in 1 year) indoors in the contaminated facility.

Scenario C6-3 (water and sewer facilities, contractor works inside) assumed continued use of the contaminated facility in an urban environment. Under this scenario, a contract worker was assumed to spend all the time (an average of 2 h/d for 250 days in 1 year) indoors in the contaminated facility.

Scenario C6-4 (water and sewer facilities, contractor works outside) assumed continued use of the contaminated facility in an urban environment. Under this scenario, a contract worker was assumed to spend all the time (an average of 2 h/d for 250 days in 1 year) outdoors in the contaminated facility.

6.3.2 Dose Calculation for Water and Sewer Facilities

In Appendix 6.A, Tables 6.A.8 through 6.A.11 provide the DSRs from individual exposure pathways for Group C6 (water and sewer facilities for the first year). Table 6.7 provides the total DSRs for all scenarios for the first year.

6.3.3 Operational Guideline Derivation for Water and Sewer Facilities

Table 6.8 provides the generic operational guidelines for water and sewer facilities. The PAGs used in deriving guidelines for different scenarios were 5 rem for facility workers (occupational) and 2 rem for others (general public), as discussed in Table 2.5 in Chapter 2. Different scenarios were considered in deriving generic operation guideline values for use of water and sewer facilities. The scenarios considered included occupational use by facility workers and public use by contract workers after an RDD event. For all radionuclides, Scenario C6-1 (facility outdoor worker) resulted in the most restrictive operational guideline values. For public use, for all radionuclides, Scenario C6-4 (contract worker working outside) resulted in more restrictive operational guideline values. Table 6.9 provides the most restrictive operational guideline values for both occupational and public use following an RDD event. For extended use of the water and sewer facilities beyond one year, the relocation operational guidelines for commercial/industrial areas should be applied to evaluate the facilities after necessary decontamination activities.

6.4 POWER AND FUEL FACILITIES (GROUP C7)

The operational guidelines for this group allow continued use of power and fuel facilities located in areas that exceed relocation criteria. The 5-rem occupational exposure PAG was applied to the facility employees. Four potential exposure scenarios were considered for the

TABLE 6.7 Generic Dose-to-Source Ratios (DSRs) for Water and Sewer Facilities (Group C6) and for Power and Fuel Facilities (Group C7) Scenarios

	DSR (mrem/yr per pCi/m^2) Based on Initial Street Contamination following an RDD Event[a]			
Radionuclide	C6-1[b]	C6-2[c]	C6-3[d]	C6-4[e]
Am-241	1.92E-04	1.24E-04	3.10E-05	4.80E-05
Cf-252	4.58E-05	2.62E-05	6.54E-06	1.15E-05
Cm-244	1.14E-04	7.29E-05	1.82E-05	2.84E-05
Co-60	2.02E-05	1.00E-05	2.51E-06	5.05E-06
Cs-137	5.78E-06	2.34E-06	5.84E-07	1.45E-06
Ir-192	2.11E-06	9.71E-07	2.43E-07	5.29E-07
Po-210	4.01E-05	7.37E-06	1.84E-06	1.00E-05
Pu-238	2.20E-04	1.42E-04	3.54E-05	5.49E-05
Pu-239	2.40E-04	1.55E-04	3.87E-05	6.00E-05
Ra-226	4.81E-05	2.12E-05	5.29E-06	1.20E-05
Sr-90	2.88E-06	6.55E-07	1.64E-07	7.20E-07

[a] C7 scenarios are the same as C6 scenarios but are for power and fuel facilities.

[b] C6-1: water and sewer facilities, facility outdoor worker.

[c] C6-2: water and sewer facilities, facility indoor worker.

[d] C6-3: water and sewer facilities, contractor works inside.

[e] C6-4: water and sewer facilities, contractor works outside.

derivation of operational guidelines. Potential exposure pathways for the four scenarios evaluated are summarized in Table 2.6 in Chapter 2. All scenarios considered were in an urban environment, and the building dimensions considered for external exposure for facility employees and the general public were based on the warehouse geometry shown in Table 2.4 in Chapter 2. The initial outdoor contamination was assumed to be on streets. The average correction factors for outdoor air presented in the last 2 columns of Table 2.2 in Chapter 2 were multiplied by 10 to account for pedestrian activity and traffic in an urban environment (see Table 2.3 in Chapter 2).

To account for differences in the time fractions spent inside and outside of power/fuel facilities by different people, two receptors accounting for regular occupational work at the facilities and two receptors accounting for the general public who happen to perform contract work at the facilities were considered. For the occupational receptors, it was assumed that one

TABLE 6.8 Generic Operational Guidelines for Water and Sewer Facilities (Group C6) and for Power and Fuel Facilities (Group C7) Scenarios

	Operational Guideline (pCi/m^2) Based on Initial Street/Soil Contamination following an RDD Event[a]			
	Occupational		General Public	
Radionuclide	C6-1[b]	C6-2[c]	C6-3[d]	C6-4[e]
Am-241	2.60E+07	4.04E+07	6.46E+07	4.16E+07
Cf-252	1.09E+08	1.91E+08	3.06E+08	1.75E+08
Cm-244	4.40E+07	6.86E+07	1.10E+08	7.05E+07
Co-60	2.48E+08	4.99E+08	7.98E+08	3.96E+08
Cs-137	8.65E+08	2.14E+09	3.42E+09	1.38E+09
Ir-192	2.36E+09	5.15E+09	8.24E+09	3.78E+09
Po-210	1.25E+08	6.79E+08	1.09E+09	1.99E+08
Pu-238	2.27E+07	3.53E+07	5.65E+07	3.64E+07
Pu-239	2.08E+07	3.23E+07	5.17E+07	3.33E+07
Ra-226	1.04E+08	2.36E+08	3.78E+08	1.66E+08
Sr-90	1.74E+09	7.63E+09	1.22E+10	2.78E+09

[a] C7 scenarios are the same as C6 scenarios but are for power and fuel facilities.

[b] C6-1: water and sewer facilities, facility outdoor worker.

[c] C6-2: water and sewer facilities, facility indoor worker.

[d] C6-3: water and sewer facilities, contractor works inside.

[e] C6-4: water and sewer facilities, contractor works outside.

receptor would spend all the time outdoors, and the other one would spend all the time indoors. For the general public receptors, it was assumed that one receptor would spend an average of 2 h/d for 250 days indoors, and the other would spend the same amount of time outdoors. The parameters used for different receptors are listed in Table 2.7 in Chapter 2.

6.4.1 Scenario Description for Power and Fuel Facilities

Scenario C7-1 (power and fuel facilities, facility outdoor worker) assumed continued use of the contaminated facility in an urban environment. Under this scenario, an outdoor facility

TABLE 6.9 Most Restrictive Operational Guidelines for Water and Sewer Facilities (Group C6) and for Power and Fuel Facilities (Group C7) Scenarios

	Street/Soil Contamination (pCi/m^2)	
Radionuclide	5 rem for Occupational Worker	2 rem for General Public
Am-241	2.60E+07	4.16E+07
Cf-252	1.09E+08	1.75E+08
Cm-244	4.40E+07	7.05E+07
Co-60	2.48E+08	3.96E+08
Cs-137	8.65E+08	1.38E+09
Ir-192	2.36E+09	3.78E+09
Po-210	1.25E+08	1.99E+08
Pu-238	2.27E+07	3.64E+07
Pu-239	2.08E+07	3.33E+07
Ra-226	1.04E+08	1.66E+08
Sr-90	1.74E+09	2.78E+09

worker was assumed to spend all the time (an average of 8 h/d for 250 days in 1 year) outdoors in the contaminated facility.

Scenario C7-2 (power and fuel facilities, facility indoor worker) assumed continued use of the contaminated facility in an urban environment. Under this scenario, a facility indoor worker was assumed to spend all the time (an average of 8 h/d for 250 days in 1 year) indoors in the contaminated facility.

Scenario C7-3 (power and fuel facilities, contractor works inside) assumed continued use of the contaminated facility in an urban environment. Under this scenario, a contract worker was assumed to spend all the time (an average of 2 h/d for 250 days in 1 year) indoors in the contaminated facility.

Scenario C7-4 (power and fuel facilities, contractor works outside) assumed continued use of the contaminated facility in an urban environment. Under this scenario, a contract worker was assumed to spend all the time (an average of 2 h/d for 250 days in 1 year) outdoors in the contaminated facility.

6.4.2 Dose Calculation for Power and Fuel Facilities

The DSRs for different scenarios considered for power and fuel facilities would be the same as the DSRs for water and sewer facilities. Table 6.7 provides the total DSRs for all scenarios.

6.4.3 Operational Guideline Derivation for Power and Fuel Facilities

The generic operational guidelines (Table 6.8) and the most restrictive operational guidelines (Table 6.9) for water and sewer facilities are also applicable to power and fuel facilities.

6.5 SUMMARY OF OPERATIONAL GUIDELINES

6.5.1 Summary of Operational Guidelines for Critical Infrastructure Utilization

Table 6.10 compares the final operational guidelines for continued utilization of different critical infrastructures. They are the most conservative values derived considering potential exposures of both occupational workers and the general public at each facility. From the comparison, it is shown that for Am-241, Cf-252, Cm-244, Pu-238, and Pu-239, hospital and other health care facilities have more restrictive guidelines than other facilities (transport, water and sewage/power and fuel); for Co-60, Cs-137, Ir-192, Po-210, Ra-226, and Sr-90, the other facilities (transport, water and sewage/power and fuel) have more restrictive guidelines than hospital and other health care facilities. However, the differences are within a factor of two for all radionuclides. Considering the level of uncertainties involved in developing the operational guidelines, a final set of values, selected to be the more restrictive ones and listed in the last column, was proposed for use as the generic guidelines for continued utilization of a critical facility, regardless of functionality and the facility type.

6.5.2 Summary of Operational Guidelines for Group C

The operational guidelines for Group C, Part 1, were developed to delineate areas that could result in radiological doses that exceed relocation PAGs (i.e., 2 rem in the first year and

TABLE 6.10 Comparison of Operational Guidelines for Continued Utilization of Different Critical Infrastructures[a]

Radionuclide	Hospitals and Other Health Care Facilities	Critical Transport Facility	Water and Sewage/ Power and Fuel Facilities	Most Restrictive Guideline
Am-241	2.23E+07	2.60E+07	2.60E+07	2.23E+07
Cf-252	1.04E+08	1.09E+08	1.09E+08	1.04E+08
Cm-244	3.75E+07	4.40E+07	4.40E+07	3.75E+07
Co-60	3.89E+08	2.48E+08	2.48E+08	2.48E+08
Cs-137	1.38E+09	8.65E+08	8.65E+08	8.65E+08
Ir-192	2.61E+09	2.36E+09	2.36E+09	2.36E+09
Po-210	1.48E+08	1.25E+08	1.25E+08	1.25E+08
Pu-238	1.94E+07	2.27E+07	2.27E+07	1.94E+07
Pu-239	1.78E+07	2.08E+07	2.08E+07	1.78E+07
Ra-226	1.40E+08	1.04E+08	1.04E+08	1.04E+08
Sr-90	2.64E+09	1.74E+09	1.74E+09	1.74E+09

[a] All guidelines are in pCi/m^2. Utilization of hospitals and other health care facilities resulted in the most restrictive guideline values for all radionuclides, except Co-60, Cs-137, Ir-192, Po-210, Ra-226, and Sr-90. For those, utilization of other facilities resulted in the most restrictive guideline values.

0.5 rem per year thereafter). Operational guidelines in this group address residential areas (Group C1), commercial/industrial areas (Group C2), and other areas (Group C3) as separate subgroups. The other areas could be monuments, parks, cemeteries, or other special areas.

The operational guidelines for Group C, Part 2, are intended as screening values so facilities critical to the public welfare can continue to operate as needed after an RDD event. The operational guidelines in this group apply only to facilities in areas that exceed relocation PAGs. Such facilities might otherwise be closed for general use and access, except for the fact that their operation is critical to the public welfare. The critical infrastructures considered include hospitals and other health care facilities (Group C4), critical transport facilities (Group C5), water and sewer facilities (Group C6), and power and fuel facilities (Group C7). For deriving operational guidelines for Group C, Part 2, an occupational PAG of 5 rem was used for workers, and 2 rem was used for the general public.

Table 6.11 summarizes the operational guidelines for Group C.

TABLE 6.11 Summary Operational Guidelines for Relocations from Different Areas[a]

Radionuclide	Residential	Industrial/ Commercial	Other Areas	Hospital and Other Health Care Facilities	Critical Transport Facility	Water and Sewage/ Power and Fuel Facilities	Most Restrictive Guideline
Am-241	2.25E+06	1.04E+07	6.84E+06	2.23E+07	2.60E+07	2.60E+07	2.25E+06
Cf-252	1.15E+07	4.36E+07	3.56E+07	1.04E+08	1.09E+08	1.09E+08	1.15E+07
Cm-244	4.02E+06	1.76E+07	1.22E+07	3.75E+07	4.40E+07	4.40E+07	4.02E+06
Co-60	5.54E+06	5.29E+07	2.11E+07	3.89E+08	2.48E+08	2.48E+08	5.54E+06
Cs-137	1.83E+07	1.66E+08	6.63E+07	1.38E+09	8.65E+08	8.65E+08	1.83E+07
Ir-192	1.93E+08	9.46E+08	7.14E+08	2.61E+09	2.36E+09	2.36E+09	1.93E+08
Po-210	2.35E+07	4.98E+07	3.63E+07	1.48E+08	1.25E+08	1.25E+08	2.35E+07
Pu-238	1.99E+06	9.10E+06	6.04E+06	1.94E+07	2.27E+07	2.27E+07	1.99E+06
Pu-239	1.81E+06	8.34E+06	5.47E+06	1.78E+07	2.08E+07	2.08E+07	1.81E+06
Ra-226	3.91E+06	2.96E+07	1.18E+07	1.40E+08	1.04E+08	1.04E+08	3.91E+06
Sr-90	6.79E+07	3.66E+08	1.46E+08	2.64E+09	1.74E+09	1.74E+09	6.79E+07

a All guidelines are in pCi/m^2, and the relocation from the residential area resulted in the most restrictive guidelines.

6.6 REFERENCE

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 6.A:

DOSE-TO-SOURCE RATIOS (DSRs) FOR GROUP C4–C7 SCENARIOS

- Group C4: Tables 6.A.1 through 6.A.3
- Group C5: Tables 6.A.4 through 6.A.7
- Groups C6 and C7: Tables 6.A.8 through 6.A.11

APPENDIX 6.A:

DOSE-TO-SOURCE RATIOS (DSRs) FOR GROUP C4–C7 SCENARIOS

This appendix includes DSRs from individual exposure pathways for Group C4-C7 scenarios. Tables 6.A.1 through 6.A.3 include DSRs for hospital and other health care facilities for a short duration: 6 months for Scenario C4-1 (hospital outdoor worker) and C4-2 (hospital indoor worker), and 2 weeks for Scenario C4-3 (patient staying in hospital).

Tables 6.A.4 through 6.A.7 include DSRs for critical transport facility scenarios: Scenario C5-1 (ticket clerk staying inside), Scenario C5-2 (baggage handler staying outside), Scenario C5-3 (passenger staying inside), and Scenario C5-4 (passenger staying both outside and inside).

Tables 6.A.8 through 6.A.11 include DSRs for both water and sewer facility scenarios and for power and fuel facility scenarios: Scenarios C6-1 and C7-1 (facility outdoor worker), Scenarios C6-2 and C7-2 (facility indoor worker), Scenarios C6-3 and C7-3 (contractor works inside), and Scenarios C6-4 and C7-4 (contractor works outside).

Results for Group C4: Hospitals and Other Health Care Facilities

TABLE 6.A.1 Receptor C4-1: Hospital Outdoor Worker (First 6 Months)

	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
Radionuclide	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	1.77E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.73E-04	0.00E+00	0.00E+00	2.74E-12	0.00E+00	6.45E-06	0.00E+00	1.79E-04
Cf-252	3.07E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.54E-05	0.00E+00	0.00E+00	9.21E-11	0.00E+00	2.74E-06	0.00E+00	4.12E-05
Cm-244	4.86E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E-04	0.00E+00	0.00E+00	1.37E-14	0.00E+00	3.84E-06	0.00E+00	1.06E-04
Co-60	1.27E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.53E-08	0.00E+00	0.00E+00	4.78E-10	0.00E+00	1.06E-07	0.00E+00	1.29E-05
Cs-137	3.14E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.00E-08	0.00E+00	0.00E+00	1.03E-10	0.00E+00	4.17E-07	0.00E+00	3.62E-06
Ir-192	1.88E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.00E-08	0.00E+00	0.00E+00	1.24E-10	0.00E+00	2.37E-08	0.00E+00	1.92E-06
Po-210	3.13E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.99E-06	0.00E+00	0.00E+00	1.42E-15	0.00E+00	2.67E-05	0.00E+00	3.37E-05
Pu-238	4.76E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.98E-04	0.00E+00	0.00E+00	1.42E-14	0.00E+00	7.40E-06	0.00E+00	2.05E-04
Pu-239	2.17E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.16E-04	0.00E+00	0.00E+00	1.41E-14	0.00E+00	8.06E-06	0.00E+00	2.24E-04
Ra-226	9.63E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.71E-05	0.00E+00	0.00E+00	3.39E-10	0.00E+00	9.04E-06	0.00E+00	3.58E-05
Sr-90	6.20E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.90E-07	0.00E+00	0.00E+00	3.60E-12	0.00E+00	9.85E-07	0.00E+00	1.89E-06

TABLE 6.A.2 Receptor C4-2: Hospital Indoor Worker (First 6 Months)

	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
Radionuclide	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	0.00E+00	3.55E-08	1.03E-11	1.73E-11	1.13E-09	1.69E-08	0.00E+00	1.01E-04	0.00E+00	0.00E+00	2.14E-12	0.00E+00	6.45E-07	1.02E-04
Cf-252	0.00E+00	6.14E-07	0.00E+00	0.00E+00	8.31E-09	3.74E-07	0.00E+00	2.04E-05	0.00E+00	0.00E+00	7.09E-11	0.00E+00	2.74E-07	2.17E-05
Cm-244	0.00E+00	9.72E-10	0.00E+00	0.00E+00	9.51E-12	5.93E-10	0.00E+00	5.97E-05	0.00E+00	0.00E+00	1.07E-14	0.00E+00	3.84E-07	6.00E-05
Co-60	0.00E+00	2.54E-06	3.45E-07	1.83E-06	7.12E-08	1.10E-06	0.00E+00	3.21E-08	0.00E+00	0.00E+00	3.70E-10	0.00E+00	1.06E-08	5.93E-06
Cs-137	0.00E+00	6.27E-07	7.02E-08	3.15E-07	1.76E-08	2.70E-07	0.00E+00	4.09E-08	0.00E+00	0.00E+00	8.03E-11	0.00E+00	4.17E-08	1.38E-06
Ir-192	0.00E+00	3.77E-07	4.86E-08	2.56E-07	9.92E-09	1.63E-07	0.00E+00	5.21E-09	0.00E+00	0.00E+00	8.58E-11	0.00E+00	2.37E-09	8.62E-07
Po-210	0.00E+00	6.27E-12	7.56E-13	3.47E-12	1.69E-13	2.70E-12	0.00E+00	3.80E-06	0.00E+00	0.00E+00	1.03E-15	0.00E+00	2.67E-06	6.47E-06
Pu-238	0.00E+00	9.52E-10	1.36E-13	2.02E-13	8.53E-12	5.81E-10	0.00E+00	1.16E-04	0.00E+00	0.00E+00	1.11E-14	0.00E+00	7.40E-07	1.16E-04
Pu-239	0.00E+00	4.33E-10	3.51E-12	1.09E-11	1.63E-12	2.64E-10	0.00E+00	1.26E-04	0.00E+00	0.00E+00	1.10E-14	0.00E+00	8.06E-07	1.27E-04
Ra-226	0.00E+00	1.93E-06	2.46E-07	1.26E-06	5.41E-08	8.28E-07	0.00E+00	1.00E-05	2.13E-08	0.00E+00	2.65E-10	0.00E+00	9.04E-07	1.53E-05
Sr-90	0.00E+00	1.24E-07	2.96E-11	1.45E-10	3.50E-09	5.34E-08	0.00E+00	1.69E-07	0.00E+00	0.00E+00	2.80E-12	0.00E+00	9.85E-08	4.49E-07

Results for Group C4: Hospitals and Other Health Care Facilities (Cont.)

TABLE 6.A.3 Receptor C4-3: Patient Staying in Hospital (First 2 Weeks)

	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
Radionuclide	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	0.00E+00	1.65E-08	3.86E-12	5.92E-12	4.20E-10	7.87E-09	0.00E+00	8.95E-05	0.00E+00	0.00E+00	4.55E-12	0.00E+00	3.00E-07	8.98E-05
Cf-252	0.00E+00	3.01E-07	0.00E+00	0.00E+00	3.29E-09	1.83E-07	0.00E+00	1.86E-05	0.00E+00	0.00E+00	1.55E-10	0.00E+00	1.34E-07	1.92E-05
Cm-244	0.00E+00	4.55E-10	0.00E+00	0.00E+00	3.58E-12	2.78E-10	0.00E+00	5.31E-05	0.00E+00	0.00E+00	2.28E-14	0.00E+00	1.80E-07	5.33E-05
Co-60	0.00E+00	1.21E-06	1.33E-07	6.49E-07	2.74E-08	5.25E-07	0.00E+00	2.89E-08	0.00E+00	0.00E+00	7.98E-10	0.00E+00	5.09E-09	2.58E-06
Cs-137	0.00E+00	2.93E-07	2.63E-08	1.09E-07	6.61E-09	1.26E-07	0.00E+00	3.63E-08	0.00E+00	0.00E+00	1.71E-10	0.00E+00	1.95E-08	6.17E-07
Ir-192	0.00E+00	3.12E-07	3.45E-08	1.70E-07	7.04E-09	1.35E-07	0.00E+00	5.94E-09	0.00E+00	0.00E+00	2.35E-10	0.00E+00	1.97E-09	6.68E-07
Po-210	0.00E+00	4.08E-12	4.09E-13	1.75E-12	9.17E-14	1.76E-12	0.00E+00	3.93E-06	0.00E+00	0.00E+00	2.56E-15	0.00E+00	1.74E-06	5.67E-06
Pu-238	0.00E+00	4.44E-10	5.09E-14	6.93E-14	3.19E-12	2.70E-10	0.00E+00	1.03E-04	0.00E+00	0.00E+00	2.36E-14	0.00E+00	3.45E-07	1.03E-04
Pu-239	0.00E+00	2.02E-10	1.31E-12	3.76E-12	6.10E-13	1.23E-10	0.00E+00	1.12E-04	0.00E+00	0.00E+00	2.35E-14	0.00E+00	3.75E-07	1.12E-04
Ra-226	0.00E+00	8.96E-07	9.17E-08	4.31E-07	2.02E-08	3.85E-07	0.00E+00	8.88E-06	9.43E-09	0.00E+00	5.63E-10	0.00E+00	4.20E-07	1.11E-05
Sr-90	0.00E+00	5.79E-08	1.11E-11	5.01E-11	1.31E-09	2.50E-08	0.00E+00	1.50E-07	0.00E+00	0.00E+00	5.98E-12	0.00E+00	4.60E-08	2.81E-07

Results for Group C5: Critical Transport Facilities

TABLE 6.A.4 Receptor C5-1: Ticket Clerk Staying Inside (First Year)

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	0.00E+00	5.72E-08	1.60E-09	1.70E-09	1.11E-08	1.34E-08	0.00E+00	1.23E-04	0.00E+00	0.00E+00	2.60E-12	0.00E+00	1.04E-06	1.24E-04
Cf-252	0.00E+00	9.42E-07	0.00E+00	0.00E+00	2.74E-07	3.85E-07	0.00E+00	2.42E-05	0.00E+00	0.00E+00	8.40E-11	0.00E+00	4.21E-07	2.62E-05
Cm-244	0.00E+00	1.56E-09	0.00E+00	0.00E+00	4.48E-10	6.30E-10	0.00E+00	7.23E-05	0.00E+00	0.00E+00	1.29E-14	0.00E+00	6.14E-07	7.29E-05
Co-60	0.00E+00	3.99E-06	3.82E-06	3.44E-06	6.96E-07	8.33E-07	0.00E+00	3.85E-08	0.00E+00	0.00E+00	4.44E-10	0.00E+00	1.68E-08	1.28E-05
Cs-137	0.00E+00	1.01E-06	8.87E-07	8.09E-07	1.76E-07	2.09E-07	0.00E+00	4.96E-08	0.00E+00	0.00E+00	9.75E-11	0.00E+00	6.70E-08	3.20E-06
Ir-192	0.00E+00	4.16E-07	3.36E-07	2.92E-07	6.11E-08	8.65E-08	0.00E+00	5.34E-09	0.00E+00	0.00E+00	8.79E-11	0.00E+00	2.62E-09	1.20E-06
Po-210	0.00E+00	7.75E-12	6.51E-12	5.80E-12	1.21E-12	1.61E-12	0.00E+00	4.06E-06	0.00E+00	0.00E+00	1.10E-15	0.00E+00	3.30E-06	7.37E-06
Pu-238	0.00E+00	1.53E-09	4.75E-12	5.18E-12	4.33E-10	6.18E-10	0.00E+00	1.40E-04	0.00E+00	0.00E+00	1.35E-14	0.00E+00	1.19E-06	1.42E-04
Pu-239	0.00E+00	6.99E-10	6.09E-11	5.76E-11	1.73E-10	3.49E-10	0.00E+00	1.54E-04	0.00E+00	0.00E+00	1.34E-14	0.00E+00	1.30E-06	1.55E-04
Ra-226	0.00E+00	3.11E-06	2.82E-06	2.56E-06	5.40E-07	6.41E-07	0.00E+00	1.22E-05	2.11E-08	0.00E+00	3.22E-10	0.00E+00	1.46E-06	2.33E-05
Sr-90	0.00E+00	1.99E-07	5.73E-10	5.21E-10	3.49E-08	4.13E-08	0.00E+00	2.06E-07	0.00E+00	0.00E+00	3.40E-12	0.00E+00	1.58E-07	6.40E-07

TABLE 6.A.5 Receptor C5-2: Baggage Handler Staying Outside (First Year)

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	2.86E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.82E-04	0.00E+00	0.00E+00	2.88E-12	0.00E+00	1.04E-05	0.00E+00	1.92E-04
Cf-252	4.71E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.69E-05	0.00E+00	0.00E+00	9.61E-11	0.00E+00	4.21E-06	0.00E+00	4.58E-05
Cm-244	7.78E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.07E-04	0.00E+00	0.00E+00	1.44E-14	0.00E+00	6.14E-06	0.00E+00	1.14E-04
Co-60	2.00E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.79E-08	0.00E+00	0.00E+00	5.01E-10	0.00E+00	1.68E-07	0.00E+00	2.02E-05
Cs-137	5.04E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.36E-08	0.00E+00	0.00E+00	1.08E-10	0.00E+00	6.70E-07	0.00E+00	5.78E-06
Ir-192	2.08E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.01E-08	0.00E+00	0.00E+00	1.24E-10	0.00E+00	2.62E-08	0.00E+00	2.11E-06
Po-210	3.88E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.09E-06	0.00E+00	0.00E+00	1.44E-15	0.00E+00	3.30E-05	0.00E+00	4.01E-05
Pu-238	7.67E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.08E-04	0.00E+00	0.00E+00	1.49E-14	0.00E+00	1.19E-05	0.00E+00	2.20E-04
Pu-239	3.50E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.27E-04	0.00E+00	0.00E+00	1.49E-14	0.00E+00	1.30E-05	0.00E+00	2.40E-04
Ra-226	1.55E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-05	0.00E+00	0.00E+00	3.57E-10	0.00E+00	1.46E-05	0.00E+00	4.81E-05
Sr-90	9.95E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.05E-07	0.00E+00	0.00E+00	3.78E-12	0.00E+00	1.58E-06	0.00E+00	2.88E-06

Results for Group C5: Critical Transport Facilities (Cont.)

TABLE 6.A.6 Receptor C5-3: Passenger Staying Inside (First Year)

	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
Radionuclide	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	0.00E+00	1.79E-08	2.10E-09	2.66E-09	1.56E-09	1.59E-09	0.00E+00	1.60E-05	0.00E+00	0.00E+00	4.06E-13	0.00E+00	1.62E-07	1.62E-05
Cf-252	0.00E+00	2.94E-07	3.42E-19	3.87E-19	4.64E-08	4.93E-08	0.00E+00	3.15E-06	0.00E+00	0.00E+00	1.31E-11	0.00E+00	6.57E-08	3.61E-06
Cm-244	0.00E+00	4.86E-10	1.70E-26	1.93E-26	7.63E-11	8.10E-11	0.00E+00	9.42E-06	0.00E+00	0.00E+00	2.02E-15	0.00E+00	9.60E-08	9.51E-06
Co-60	0.00E+00	1.25E-06	9.24E-07	1.19E-06	9.67E-08	9.86E-08	0.00E+00	5.02E-09	0.00E+00	0.00E+00	6.94E-11	0.00E+00	2.62E-09	3.57E-06
Cs-137	0.00E+00	3.15E-07	2.31E-07	2.99E-07	2.43E-08	2.46E-08	0.00E+00	6.46E-09	0.00E+00	0.00E+00	1.52E-11	0.00E+00	1.05E-08	9.11E-07
Ir-192	0.00E+00	1.30E-07	8.22E-08	1.02E-07	8.46E-09	1.02E-08	0.00E+00	6.95E-10	0.00E+00	0.00E+00	1.37E-11	0.00E+00	4.09E-10	3.34E-07
Po-210	0.00E+00	2.42E-12	1.64E-12	2.09E-12	1.70E-13	1.90E-13	0.00E+00	5.29E-07	0.00E+00	0.00E+00	1.72E-16	0.00E+00	5.16E-07	1.05E-06
Pu-238	0.00E+00	4.79E-10	9.20E-13	1.15E-12	7.50E-11	7.98E-11	0.00E+00	1.83E-05	0.00E+00	0.00E+00	2.10E-15	0.00E+00	1.86E-07	1.85E-05
Pu-239	0.00E+00	2.18E-10	1.34E-11	1.73E-11	3.97E-11	4.76E-11	0.00E+00	2.00E-05	0.00E+00	0.00E+00	2.10E-15	0.00E+00	2.03E-07	2.02E-05
Ra-226	0.00E+00	9.71E-07	7.02E-07	9.10E-07	7.51E-08	7.59E-08	0.00E+00	1.59E-06	3.95E-09	0.00E+00	5.03E-11	0.00E+00	2.28E-07	4.55E-06
Sr-90	0.00E+00	6.22E-08	5.94E-10	7.69E-10	4.82E-09	4.90E-09	0.00E+00	2.68E-08	0.00E+00	0.00E+00	5.32E-13	0.00E+00	2.47E-08	1.25E-07

TABLE 6.A.7 Receptor C5-4: Passenger Staying Both Inside and Outside (First Year)

	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
Radionuclide	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	8.94E-09	1.43E-08	1.68E-09	2.12E-09	1.25E-09	1.27E-09	5.32E-06	1.28E-05	0.00E+00	9.01E-14	3.25E-13	3.25E-07	1.30E-07	1.86E-05
Cf-252	1.47E-07	2.36E-07	2.74E-19	3.09E-19	3.71E-08	3.95E-08	1.08E-06	2.52E-06	0.00E+00	3.00E-12	1.05E-11	1.31E-07	5.26E-08	4.25E-06
Cm-244	2.43E-10	3.89E-10	1.36E-26	1.54E-26	6.10E-11	6.48E-11	3.15E-06	7.53E-06	0.00E+00	4.51E-16	1.62E-15	1.92E-07	7.68E-08	1.09E-05
Co-60	6.24E-07	9.98E-07	7.39E-07	9.54E-07	7.73E-08	7.89E-08	1.70E-09	4.02E-09	0.00E+00	1.56E-11	5.55E-11	5.23E-09	2.09E-09	3.48E-06
Cs-137	1.57E-07	2.52E-07	1.85E-07	2.39E-07	1.95E-08	1.97E-08	2.16E-09	5.17E-09	0.00E+00	3.39E-12	1.22E-11	2.09E-08	8.37E-09	9.09E-07
Ir-192	6.49E-08	1.04E-07	6.57E-08	8.19E-08	6.77E-09	8.19E-09	2.95E-10	5.56E-10	0.00E+00	3.89E-12	1.10E-11	8.18E-10	3.27E-10	3.33E-07
Po-210	1.21E-12	1.94E-12	1.31E-12	1.67E-12	1.36E-13	1.52E-13	2.08E-07	4.23E-07	0.00E+00	4.51E-17	1.38E-16	1.03E-06	4.13E-07	2.08E-06
Pu-238	2.40E-10	3.84E-10	7.36E-13	9.21E-13	6.00E-11	6.39E-11	6.09E-06	1.46E-05	0.00E+00	4.67E-16	1.68E-15	3.73E-07	1.49E-07	2.12E-05
Pu-239	1.09E-10	1.75E-10	1.07E-11	1.39E-11	3.17E-11	3.81E-11	6.65E-06	1.60E-05	0.00E+00	4.65E-16	1.68E-15	4.06E-07	1.63E-07	2.32E-05
Ra-226	4.86E-07	7.77E-07	5.62E-07	7.28E-07	6.00E-08	6.07E-08	5.28E-07	1.27E-06	3.16E-09	1.12E-11	4.02E-11	4.55E-07	1.82E-07	5.11E-06
Sr-90	3.11E-08	4.98E-08	4.75E-10	6.15E-10	3.85E-09	3.92E-09	8.93E-09	2.14E-08	0.00E+00	1.18E-13	4.25E-13	4.94E-08	1.98E-08	1.89E-07

Results for Groups C6 and C7: Water and Sewer Facilities and Power and Fuel Facilities

TABLE 6.A.8 Receptors C6-1 and C7-1: Facility Outdoor Worker (First Year)

	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
Radionuclide	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	2.86E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.82E-04	0.00E+00	0.00E+00	2.88E-12	0.00E+00	1.04E-05	0.00E+00	1.92E-04
Cf-252	4.71E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.69E-05	0.00E+00	0.00E+00	9.61E-11	0.00E+00	4.21E-06	0.00E+00	4.58E-05
Cm-244	7.78E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.07E-04	0.00E+00	0.00E+00	1.44E-14	0.00E+00	6.14E-06	0.00E+00	1.14E-04
Co-60	2.00E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.79E-08	0.00E+00	0.00E+00	5.01E-10	0.00E+00	1.68E-07	0.00E+00	2.02E-05
Cs-137	5.04E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.36E-08	0.00E+00	0.00E+00	1.08E-10	0.00E+00	6.70E-07	0.00E+00	5.78E-06
Ir-192	2.08E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.01E-08	0.00E+00	0.00E+00	1.24E-10	0.00E+00	2.62E-08	0.00E+00	2.11E-06
Po-210	3.88E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.09E-06	0.00E+00	0.00E+00	1.44E-15	0.00E+00	3.30E-05	0.00E+00	4.01E-05
Pu-238	7.67E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.08E-04	0.00E+00	0.00E+00	1.49E-14	0.00E+00	1.19E-05	0.00E+00	2.20E-04
Pu-239	3.50E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.27E-04	0.00E+00	0.00E+00	1.49E-14	0.00E+00	1.30E-05	0.00E+00	2.40E-04
Ra-226	1.55E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-05	0.00E+00	0.00E+00	3.57E-10	0.00E+00	1.46E-05	0.00E+00	4.81E-05
Sr-90	9.95E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.05E-07	0.00E+00	0.00E+00	3.78E-12	0.00E+00	1.58E-06	0.00E+00	2.88E-06

TABLE 6.A.9 Receptors C6-2 and C7-2: Facility Indoor Worker (First Year)

	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
Radionuclide	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	0.00E+00	5.72E-08	1.96E-11	3.37E-11	2.13E-09	2.73E-08	0.00E+00	1.23E-04	0.00E+00	0.00E+00	2.60E-12	0.00E+00	1.04E-06	1.24E-04
Cf-252	0.00E+00	9.42E-07	0.00E+00	0.00E+00	1.48E-08	5.75E-07	0.00E+00	2.42E-05	0.00E+00	0.00E+00	8.40E-11	0.00E+00	4.21E-07	2.62E-05
Cm-244	0.00E+00	1.56E-09	0.00E+00	0.00E+00	1.79E-11	9.49E-10	0.00E+00	7.23E-05	0.00E+00	0.00E+00	1.29E-14	0.00E+00	6.14E-07	7.29E-05
Co-60	0.00E+00	3.99E-06	6.34E-07	3.48E-06	1.31E-07	1.73E-06	0.00E+00	3.85E-08	0.00E+00	0.00E+00	4.44E-10	0.00E+00	1.68E-08	1.00E-05
Cs-137	0.00E+00	1.01E-06	1.32E-07	6.13E-07	3.32E-08	4.34E-07	0.00E+00	4.96E-08	0.00E+00	0.00E+00	9.75E-11	0.00E+00	6.70E-08	2.34E-06
Ir-192	0.00E+00	4.16E-07	5.62E-08	2.99E-07	1.15E-08	1.80E-07	0.00E+00	5.34E-09	0.00E+00	0.00E+00	8.79E-11	0.00E+00	2.62E-09	9.71E-07
Po-210	0.00E+00	7.75E-12	1.02E-12	4.79E-12	2.29E-13	3.34E-12	0.00E+00	4.06E-06	0.00E+00	0.00E+00	1.10E-15	0.00E+00	3.30E-06	7.37E-06
Pu-238	0.00E+00	1.53E-09	2.58E-13	3.94E-13	1.61E-11	9.35E-10	0.00E+00	1.40E-04	0.00E+00	0.00E+00	1.35E-14	0.00E+00	1.19E-06	1.42E-04
Pu-239	0.00E+00	6.99E-10	6.66E-12	2.14E-11	3.10E-12	4.26E-10	0.00E+00	1.54E-04	0.00E+00	0.00E+00	1.34E-14	0.00E+00	1.30E-06	1.55E-04
Ra-226	0.00E+00	3.11E-06	4.66E-07	2.46E-06	1.03E-07	1.34E-06	0.00E+00	1.22E-05	3.58E-08	0.00E+00	3.22E-10	0.00E+00	1.46E-06	2.12E-05
Sr-90	0.00E+00	1.99E-07	5.58E-11	2.82E-10	6.59E-09	8.58E-08	0.00E+00	2.06E-07	0.00E+00	0.00E+00	3.40E-12	0.00E+00	1.58E-07	6.55E-07

Results for Groups C6 and C7: Water and Sewer Facilities and Power and Fuel Facilities (Cont.)

TABLE 6.A.10 Receptors C6-3 and C7-3: Contractor Works Inside (First Year)

	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
Radionuclide	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	0.00E+00	1.43E-08	4.90E-12	8.43E-12	5.33E-10	6.82E-09	0.00E+00	3.07E-05	0.00E+00	0.00E+00	6.50E-13	0.00E+00	2.60E-07	3.10E-05
Cf-252	0.00E+00	2.36E-07	0.00E+00	0.00E+00	3.71E-09	1.44E-07	0.00E+00	6.05E-06	0.00E+00	0.00E+00	2.10E-11	0.00E+00	1.05E-07	6.54E-06
Cm-244	0.00E+00	3.89E-10	0.00E+00	0.00E+00	4.47E-12	2.37E-10	0.00E+00	1.81E-05	0.00E+00	0.00E+00	3.24E-15	0.00E+00	1.54E-07	1.82E-05
Co-60	0.00E+00	9.98E-07	1.59E-07	8.69E-07	3.27E-08	4.33E-07	0.00E+00	9.64E-09	0.00E+00	0.00E+00	1.11E-10	0.00E+00	4.19E-09	2.51E-06
Cs-137	0.00E+00	2.52E-07	3.31E-08	1.53E-07	8.30E-09	1.09E-07	0.00E+00	1.24E-08	0.00E+00	0.00E+00	2.44E-11	0.00E+00	1.67E-08	5.84E-07
Ir-192	0.00E+00	1.04E-07	1.40E-08	7.48E-08	2.87E-09	4.51E-08	0.00E+00	1.33E-09	0.00E+00	0.00E+00	2.20E-11	0.00E+00	6.55E-10	2.43E-07
Po-210	0.00E+00	1.94E-12	2.56E-13	1.20E-12	5.73E-14	8.36E-13	0.00E+00	1.02E-06	0.00E+00	0.00E+00	2.76E-16	0.00E+00	8.26E-07	1.84E-06
Pu-238	0.00E+00	3.84E-10	6.44E-14	9.84E-14	4.04E-12	2.34E-10	0.00E+00	3.51E-05	0.00E+00	0.00E+00	3.37E-15	0.00E+00	2.98E-07	3.54E-05
Pu-239	0.00E+00	1.75E-10	1.66E-12	5.35E-12	7.75E-13	1.07E-10	0.00E+00	3.84E-05	0.00E+00	0.00E+00	3.36E-15	0.00E+00	3.25E-07	3.87E-05
Ra-226	0.00E+00	7.77E-07	1.16E-07	6.14E-07	2.57E-08	3.34E-07	0.00E+00	3.05E-06	8.94E-09	0.00E+00	8.05E-11	0.00E+00	3.64E-07	5.29E-06
Sr-90	0.00E+00	4.98E-08	1.40E-11	7.06E-11	1.65E-09	2.15E-08	0.00E+00	5.14E-08	0.00E+00	0.00E+00	8.51E-13	0.00E+00	3.95E-08	1.64E-07

TABLE 6.A.11 Receptors C6-4 and C7-4: Contractor Works Outside (First Year)

	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
Radionuclide	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	7.15E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.54E-05	0.00E+00	0.00E+00	7.21E-13	0.00E+00	2.60E-06	0.00E+00	4.80E-05
Cf-252	1.18E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.23E-06	0.00E+00	0.00E+00	2.40E-11	0.00E+00	1.05E-06	0.00E+00	1.15E-05
Cm-244	1.95E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.68E-05	0.00E+00	0.00E+00	3.61E-15	0.00E+00	1.54E-06	0.00E+00	2.84E-05
Co-60	4.99E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.45E-08	0.00E+00	0.00E+00	1.25E-10	0.00E+00	4.19E-08	0.00E+00	5.05E-06
Cs-137	1.26E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.84E-08	0.00E+00	0.00E+00	2.71E-11	0.00E+00	1.67E-07	0.00E+00	1.45E-06
Ir-192	5.19E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.52E-09	0.00E+00	0.00E+00	3.11E-11	0.00E+00	6.55E-09	0.00E+00	5.29E-07
Po-210	9.69E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.77E-06	0.00E+00	0.00E+00	3.61E-16	0.00E+00	8.26E-06	0.00E+00	1.00E-05
Pu-238	1.92E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.20E-05	0.00E+00	0.00E+00	3.73E-15	0.00E+00	2.98E-06	0.00E+00	5.49E-05
Pu-239	8.74E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.67E-05	0.00E+00	0.00E+00	3.72E-15	0.00E+00	3.25E-06	0.00E+00	6.00E-05
Ra-226	3.89E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.50E-06	0.00E+00	0.00E+00	8.92E-11	0.00E+00	3.64E-06	0.00E+00	1.20E-05
Sr-90	2.49E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.62E-08	0.00E+00	0.00E+00	9.46E-13	0.00E+00	3.95E-07	0.00E+00	7.20E-07

7 GROUP D: TEMPORARY ACCESS TO RELOCATION AREAS FOR ESSENTIAL ACTIVITIES

The operational guidelines for this group are meant to define protective actions or restrictions necessary to allow for temporary access to relocation areas. The public or employees of businesses may need temporary access to residences or commercial, agricultural, or industrial facilities in order to retrieve essential records or equipment, conduct maintenance to protect the facilities, prevent environmental damage, attend to animals, or retrieve pets. The operational guidelines are levels at which these actions could be taken without exceeding the relocation PAGs. They are expressed in terms of stay times, which are total time periods in a year during which the public or employees may access the contaminated areas and be within the PAGs employed as criteria for derivation of the operational guidelines. The total time may be spread over various periods (e.g., weekly or monthly increments) within a year-long period.

Worker access to businesses for essential actions and the public's access to residences for retrieval purposes were considered in deriving the operational guidelines. The 0.5 rem per year relocation PAGs were applied in their development. In deriving stay times, doses were estimated for different critical receptors (see Table 2.5 in Chapter 2) that would be allowed temporary access in these contaminated areas. Alternative dose criterion could be employed and the stay times ratioed accordingly.

7.1 WORKER ACCESS TO BUSINESSES FOR ESSENTIAL ACTIONS (GROUP D1)

The operational guidelines in this group are to aid in the implementation of protective actions that would allow workers access to industrial, commercial, or other workplaces for limited periods to retrieve essential materials or perform essential functions (e.g., facility maintenance, animal care, and security checks). The 0.5 rem per year relocation PAGs were applied to workers to perform the essential functions. Two potential exposure scenarios with 13 exposure pathways were considered in deriving the operational guidelines. The exposure pathways are summarized in Table 2.6 in Chapter 2. All scenarios were considered to occur in an urban environment, and the building dimensions considered for external exposure were based on the warehouse geometry shown in Table 2.4 in Chapter 2. The initial outdoor contamination was assumed to occur on the streets. Because of the low traffic expected under the limited access conditions, the average correction factors for outdoor air presented in the last two columns of Table 2.2 in Chapter 2 were used directly, without multiplication by a factor of 10.

To account for differences in the time fractions spent inside and outside of the contaminated buildings by different people, two receptors were considered — one that would spend all the time indoors and another that would spend all the time outdoors. The parameters used in different exposure scenarios are listed in Table 2.7 in Chapter 2.

7.1.1 Scenario Description for Worker Access to Businesses for Essential Actions

Scenario D1-1 (outdoor worker accessing an essential business location) assumed assess to the contaminated area in an urban environment. Under this scenario, a worker was assumed to spend all the time outdoors in the contaminated area. The outdoor worker received radiation doses from external exposure to outside contamination, inhalation of contaminated outdoor air, and direct ingestion of dust from contaminated outdoor areas.

Scenario D1-2 (indoor worker performing essential business inside the building) assumed access to the contaminated area in an urban environment. Under this scenario, an indoor worker was assumed to spend all the time indoors in the contaminated building. The building dimensions considered for external exposure were based on the warehouse geometry shown in Table 2.4 in Chapter 2. The indoor worker was exposed only to applicable pathways in the indoor environment. All applicable exposure pathways are shown in Table 2.6 in Chapter 2.

7.1.2 Operational Guideline Derivation for Worker Access to Businesses for Essential Actions

The operational guidelines are presented in the form of stay times that could be used as a restriction to the total time periods during which a person could remain on the site to conduct necessary activities.

Hourly DSRs were calculated as a function of time on the basis of an initial street concentration. Media concentrations thereafter were obtained by using the modeling approach described in Chapter 2. The cumulative radiation dose as a function of time was obtained by integrating the hourly DSRs over time. The stay times for different contamination levels were then derived by using the cumulative radiation doses. They are the durations of continuous exposures starting immediately after an RDD event that would result in a radiation dose of 0.5 rem. Tables 7.1 and 7.2 provide continuous exposure times (stay times) to get a radiation dose equal to 0.5 rem. The stay times are provided for different initial concentration levels. It should be noted that the stay times normally may not be inversely linearly proportional to concentrations because the dose rate curves as function of time are nonlinear, although the dose rate at any time is proportional to source concentrations. However, the dose rate curve within the first day is nearly linear because the weathering effect for the first day is negligible and the resuspension factor for the first day is assumed to be constant for that 24 hour period.

Tables 7.3 and 7.4 list surface street concentration levels for Scenarios D1-1 and D1-2, respectively, that would result in a dose equal to 0.5 rem for specified time periods. The specified time periods are 4 workdays, 12 workdays, 4 workweeks, and 12 workweeks. The time starts immediately after an RDD event, and it was assumed that workers would work 8 hours per day and 7 days a week.

Figures 7.1–7.11 provide limiting concentrations of individual radionuclides for access to businesses for essential actions, assuming an exposure of 8 hours per day. For example, an outdoor worker could access a business area contaminated with Am-241 at a level of 1.1×10^8 pCi/m^2 for 1 day (8-hour workday) and would not receive a dose greater than 0.5 rem (see Figure 7.1). Similarly, if access is required for 12 days, the contamination level for outdoor access should be less than 3.0×10^7 pCi/m^2. In all cases for a short period of time (<30 days), the stay times for outdoor exposure (Scenario D1-1) were more restrictive than for indoor exposure (Scenario D1-2).

7.2 PUBLIC ACCESS TO RESIDENCES FOR RETRIEVAL (GROUP D2)

The operational guidelines for this group are to aid in the implementation of protective actions that would allow public access to residential areas for limited periods to retrieve essential properties such as records, pets, or resources, or to conduct important maintenance activities. The 0.5 rem per year relocation PAG was applied to residents to perform such retrieval or maintenance. Two potential exposure scenarios were considered for the derivation of operational guidelines. Potential radiation doses resulting from 13 exposure pathways were considered. The exposure pathways of the two evaluated scenarios are summarized in Table 2.6 in Chapter 2. All scenarios were considered to occur in an urban environment, and the building dimensions considered for external exposure were based on the urban house geometry shown in Table 2.4 in Chapter 2. The initial outdoor contamination was assumed to occur on the streets. Because of the low traffic expected under the limited access conditions, the average correction factors for

TABLE 7.1 Stay Times for Group D1-1 Scenario: Worker Access to Business (Outdoor Exposure)

Radionuclide Concentration				Stay Time (continuous exposure time in hours) to Receive 0.5 rem (500 mrem)[a]										
pCi/cm^2	pCi/m^2	Bq/cm^2	dpm/100 cm^2	Am-241	Cf-252	Cm-244	Co-60	Cs-137	Ir-192	Po-210	Pu-238	Pu-239	Ra-226	Sr-90
1.00E+01	1.00E+05	3.70E-01	2.22E+03	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760
1.00E+02	1.00E+06	3.70E+00	2.22E+04	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760
1.00E+03	1.00E+07	3.70E+01	2.22E+05	3.00E+02	6.92E+03	1.99E+03	3.74E+03	> 8760	> 8760	1.05E+03	1.98E+02	1.55E+02	1.94E+03	> 8760
1.00E+04	1.00E+08	3.70E+02	2.22E+06	8.68E+00	4.57E+01	1.46E+01	2.72E+02	1.09E+03	1.42E+03	6.89E+01	7.57E+00	6.94E+00	7.82E+01	2.71E+03
1.00E+05	1.00E+09	3.70E+03	2.22E+07	8.68E-01	3.94E+00	1.46E+00	2.63E+01	9.60E+01	9.86E+01	6.21E+00	7.57E-01	6.94E-01	6.03E+00	1.90E+02
1.00E+06	1.00E+10	3.70E+04	2.22E+08	8.68E-02	3.94E-01	1.46E-01	2.63E+00	9.36E+00	9.61E+00	6.21E-01	7.57E-02	6.94E-02	6.03E-01	1.53E+01
1.00E+07	1.00E+11	3.70E+05	2.22E+09	8.68E-03	3.94E-02	1.46E-02	2.63E-01	9.36E-01	9.61E-01	6.21E-02	7.57E-03	6.94E-03	6.03E-02	1.53E+00

[a] A stay time >8,760 hours indicates that the dose criterion (in this case 0.5 rem in a year) used for the derivation of stay times at the specific concentrations will not be exceeded under continuous 24 hours/day, 365 days per year exposures (i.e., no protective actions are necessary to avert doses at or above the criterion). For concentrations and radionuclide combinations that exceed 8,760 hours, the figures presented in this section (Figures 7.1-7.11) can be used to determine the new stay times.

TABLE 7.2 Stay Times for Group D1-2 Scenario: Worker Access to Business (Indoor Exposure)

Radionuclide Concentration				Stay Time (continuous exposure time in hours) to Receive 0.5 rem (500 mrem)[a]										
pCi/cm^2	pCi/m^2	Bq/cm^2	dpm/100 cm^2	Am-241	Cf-252	Cm-244	Co-60	Cs-137	Ir-192	Po-210	Pu-238	Pu-239	Ra-226	Sr-90
1.00E+02	1.00E+06	3.70E+00	2.22E+04	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760
1.00E+03	1.00E+07	3.70E+01	2.22E+05	6.51E+02	7.39E+03	1.52E+03	> 8760	> 8760	> 8760	> 8760	5.17E+02	4.44E+02	6.23E+03	> 8760
1.00E+04	1.00E+08	3.70E+02	2.22E+06	1.80E+01	1.57E+02	3.26E+01	6.74E+02	3.53E+03	> 8760	6.06E+02	1.57E+01	1.44E+01	2.85E+02	> 8760
1.00E+05	1.00E+09	3.70E+03	2.22E+07	1.80E+00	8.41E+00	3.04E+00	6.38E+01	2.81E+02	2.47E+02	2.89E+01	1.57E+00	1.44E+00	1.46E+01	1.08E+03
1.00E+06	1.00E+10	3.70E+04	2.22E+08	1.80E-01	8.41E-01	3.04E-01	6.34E+00	2.65E+01	2.31E+01	2.80E+00	1.57E-01	1.44E-01	1.46E+00	6.63E+01
1.00E+07	1.00E+11	3.70E+05	2.22E+09	1.80E-02	8.41E-02	3.04E-02	6.34E-01	2.65E+00	2.31E+00	2.80E-01	1.57E-02	1.44E-02	1.46E-01	5.77E+00

[a] A stay time >8,760 hours indicates that the dose criterion (in this case 0.5 rem in a year) used for the derivation of stay times at the specific concentrations will not be exceeded under continuous 24 hours/day, 365 days per year exposures (i.e., no protective actions are necessary to avert doses at or above the criterion). For concentrations and radionuclide combinations that exceed 8,760 hours, the figures presented in this section (Figures 7.1-7.11) can be used to determine the new stay times.

TABLE 7.3 Scenario D1-1 Operational Guidelines for PAG of 0.5 rem: Outdoor Worker Accessing Business Location for Essential Actions

	Surface Street Concentration (pCi/m^2)			
Radionuclide	4 Workdays	12 Workdays	4 Workweeks	12 Workweeks
Am-241	4.52E+07	3.04E+07	2.37E+07	1.77E+07
Cf-252	1.98E+08	1.23E+08	8.65E+07	5.26E+07
Cm-244	7.61E+07	5.12E+07	4.01E+07	2.99E+07
Co-60	8.31E+08	2.84E+08	1.27E+08	4.84E+07
Cs-137	3.00E+09	1.03E+09	4.64E+08	1.76E+08
Ir-192	3.08E+09	1.09E+09	5.21E+08	2.44E+08
Po-210	2.25E+08	8.77E+07	4.29E+07	1.89E+07
Pu-238	3.95E+07	2.65E+07	2.08E+07	1.55E+07
Pu-239	3.62E+07	2.43E+07	1.90E+07	1.42E+07
Ra-226	2.61E+08	1.24E+08	6.68E+07	2.92E+07
Sr-90	5.47E+09	2.07E+09	9.71E+08	3.79E+08

TABLE 7.4 Scenario D1-2 Operational Guidelines for PAG of 0.5 rem: Indoor Worker Performing Essential Business inside the Building

	Surface Street Concentration (pCi/m^2)			
Radionuclide	4 Workdays	12 Workdays	4 Workweeks	12 Workweeks
Am-241	8.59E+07	4.77E+07	2.94E+07	1.48E+07
Cf-252	3.95E+08	2.14E+08	1.29E+08	6.42E+07
Cm-244	1.45E+08	8.04E+07	4.97E+07	2.51E+07
Co-60	2.00E+09	6.80E+08	3.01E+08	1.10E+08
Cs-137	8.50E+09	2.93E+09	1.30E+09	4.81E+08
Ir-192	7.40E+09	2.60E+09	1.23E+09	5.61E+08
Po-210	1.16E+09	5.22E+08	2.78E+08	1.31E+08
Pu-238	7.50E+07	4.16E+07	2.57E+07	1.30E+07
Pu-239	6.87E+07	3.82E+07	2.36E+07	1.19E+07
Ra-226	6.30E+08	2.98E+08	1.60E+08	6.87E+07
Sr-90	2.22E+10	9.11E+09	4.46E+09	1.80E+09

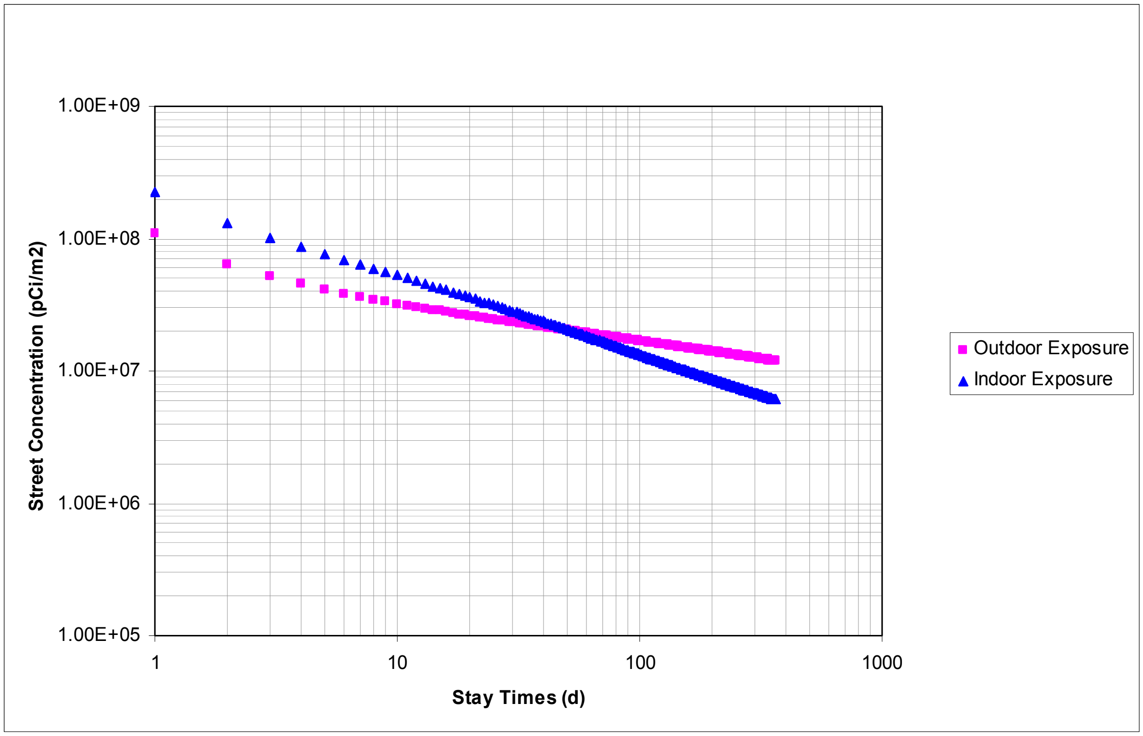

FIGURE 7.1 Limiting Concentrations of Am-241 for Access to Business

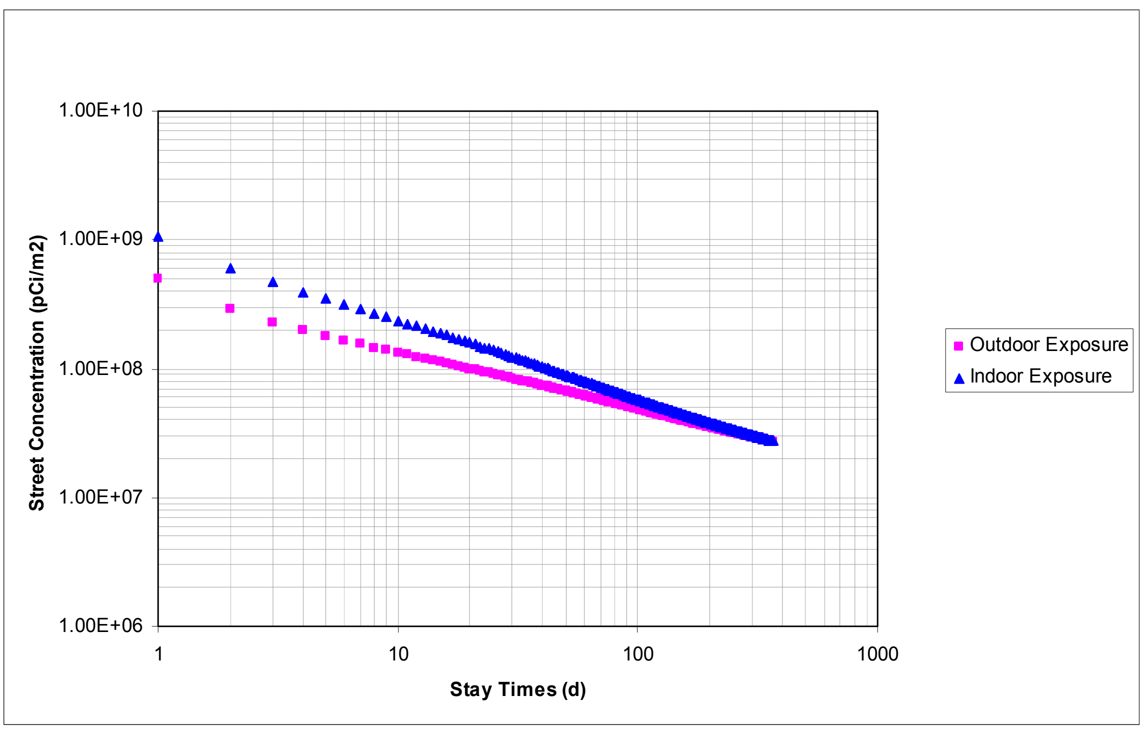

FIGURE 7.2 Limiting Concentrations of Cf-252 for Access to Business

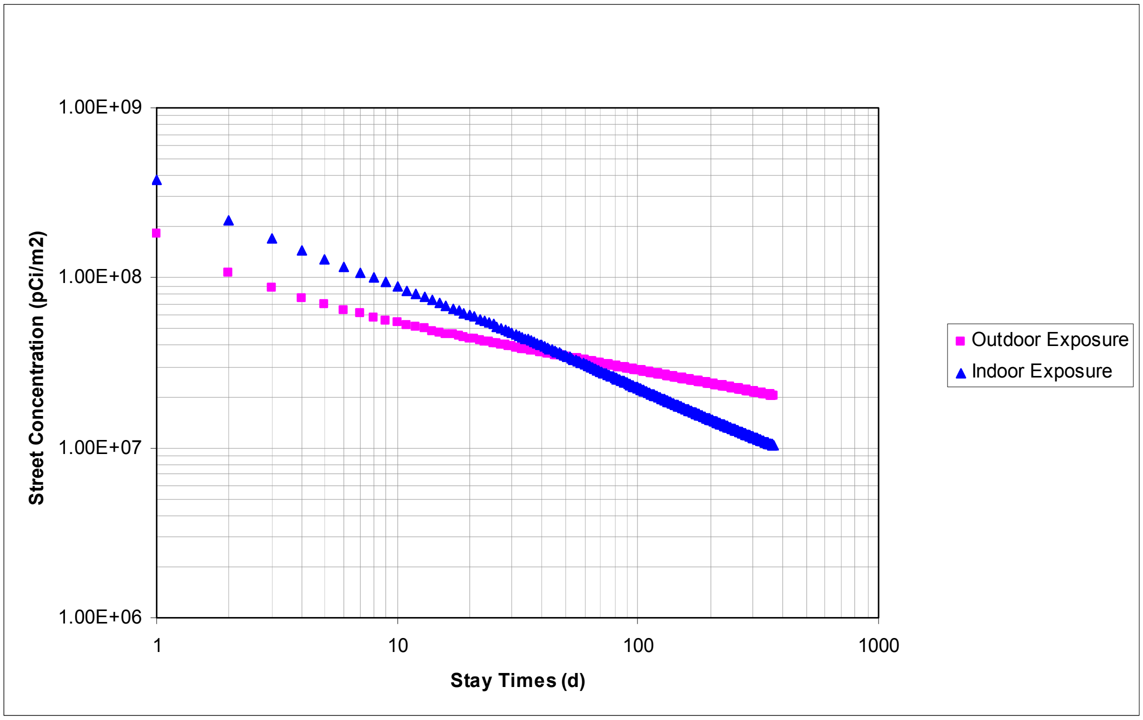

FIGURE 7.3 Limiting Concentrations of Cm-244 for Access to Business

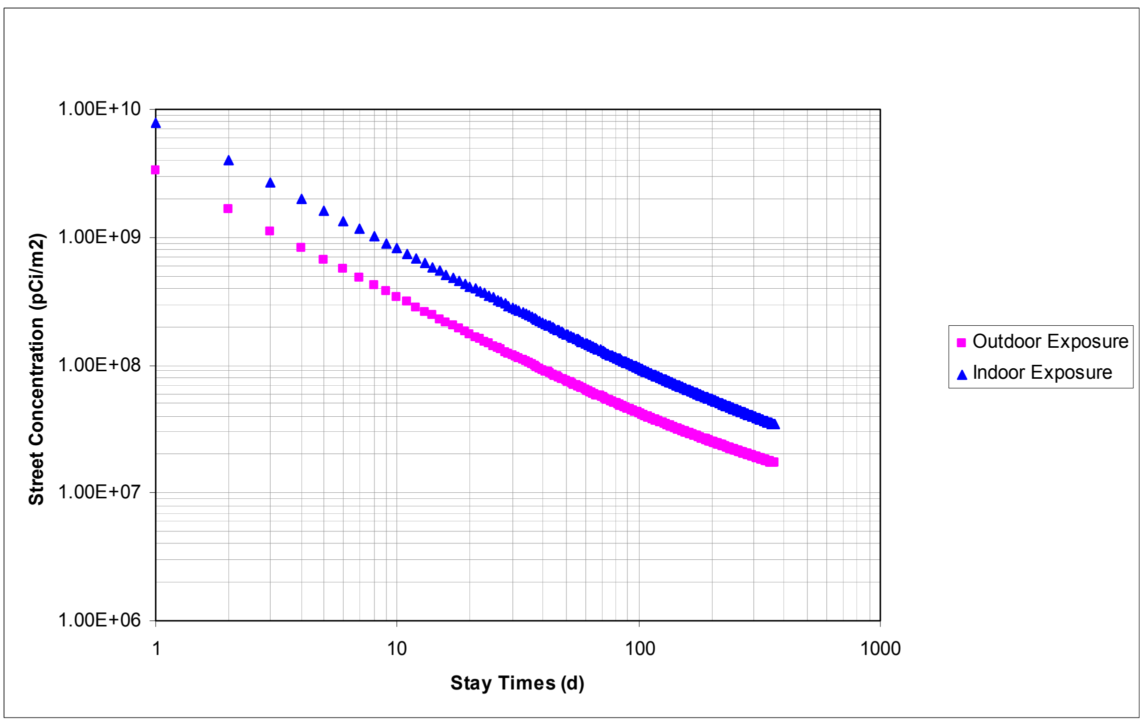

FIGURE 7.4 Limiting Concentrations of Co-60 for Access to Business

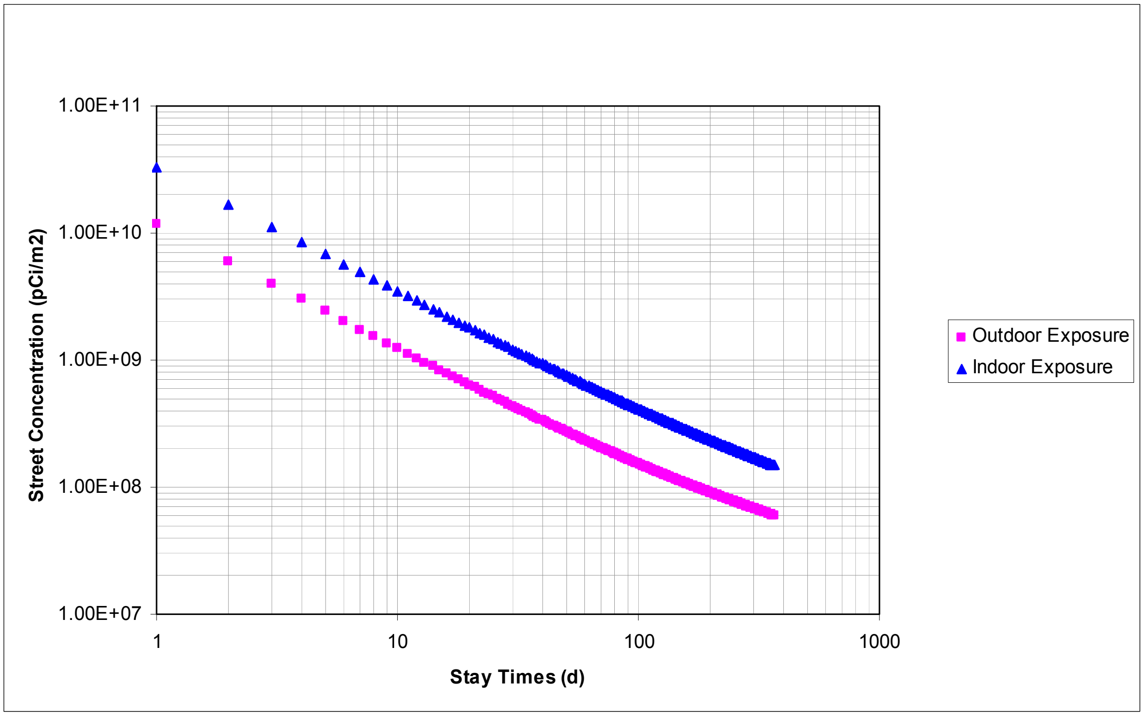

FIGURE 7.5 Limiting Concentrations of Cs-137 for Access to Business

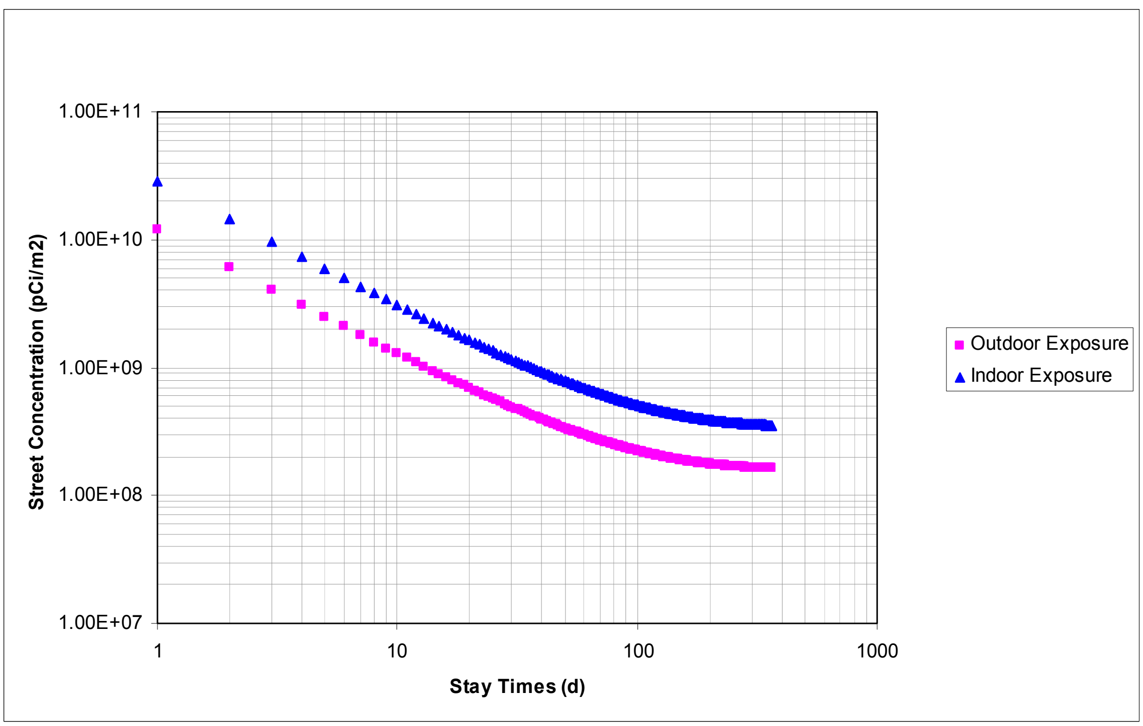

FIGURE 7.6 Limiting Concentrations of Ir-192 for Access to Business

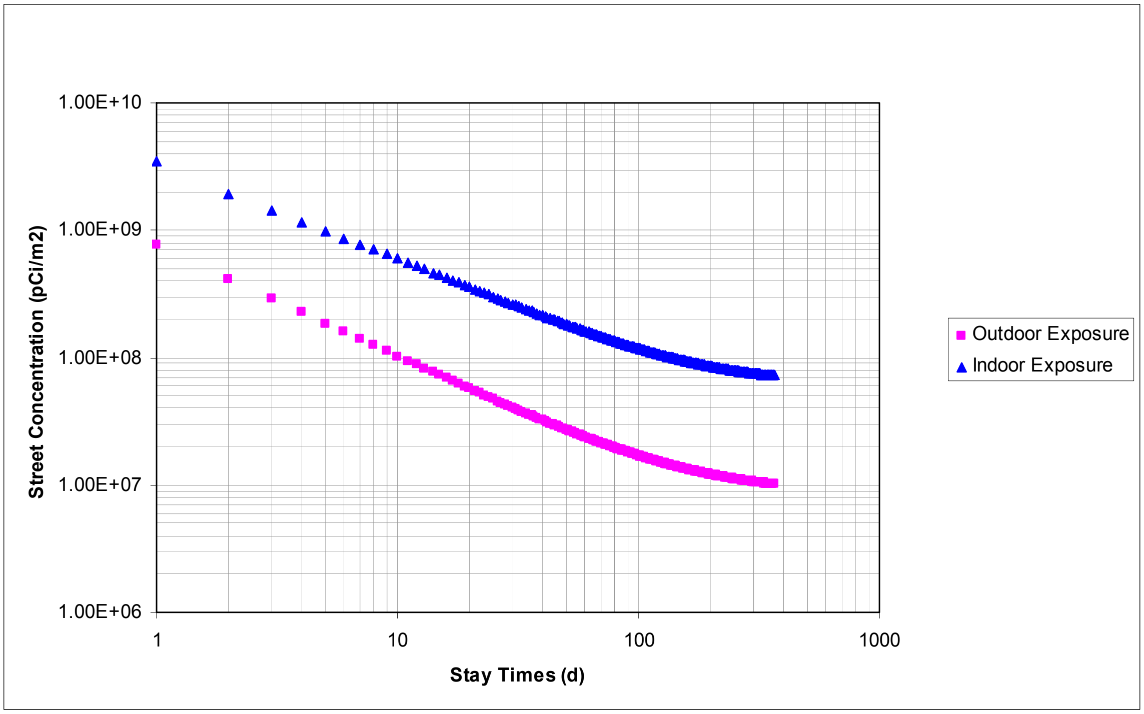

FIGURE 7.7 Limiting Concentrations of Po-210 for Access to Business

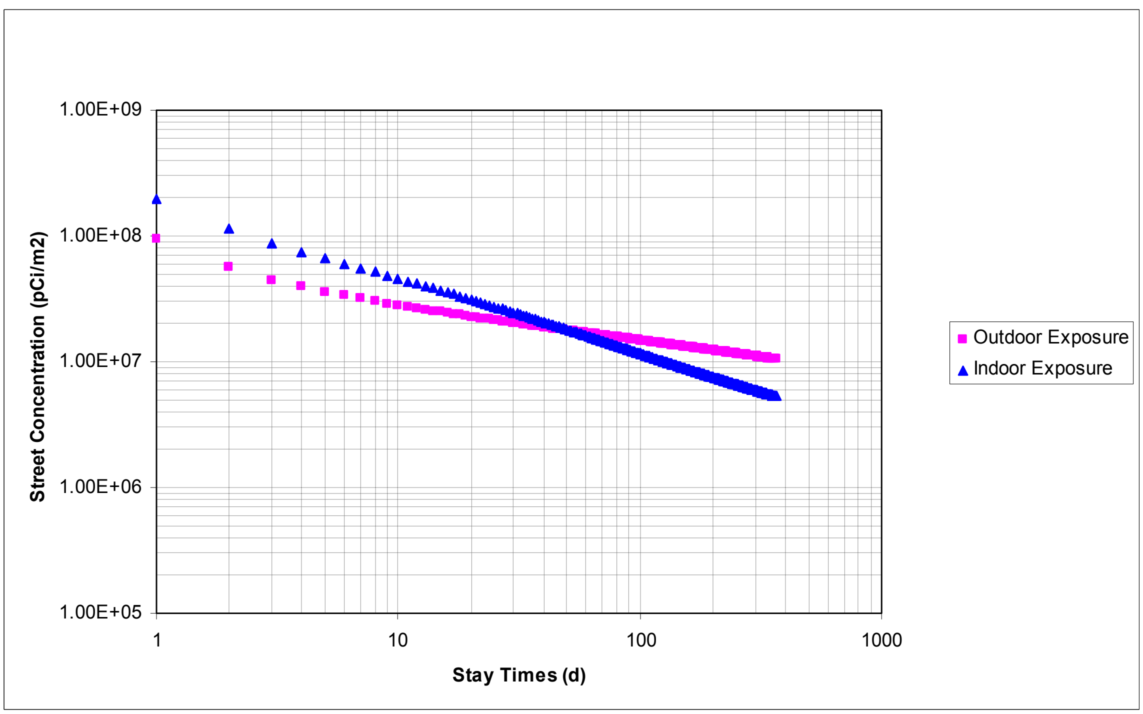

FIGURE 7.8 Limiting Concentrations of Pu-238 for Access to Business

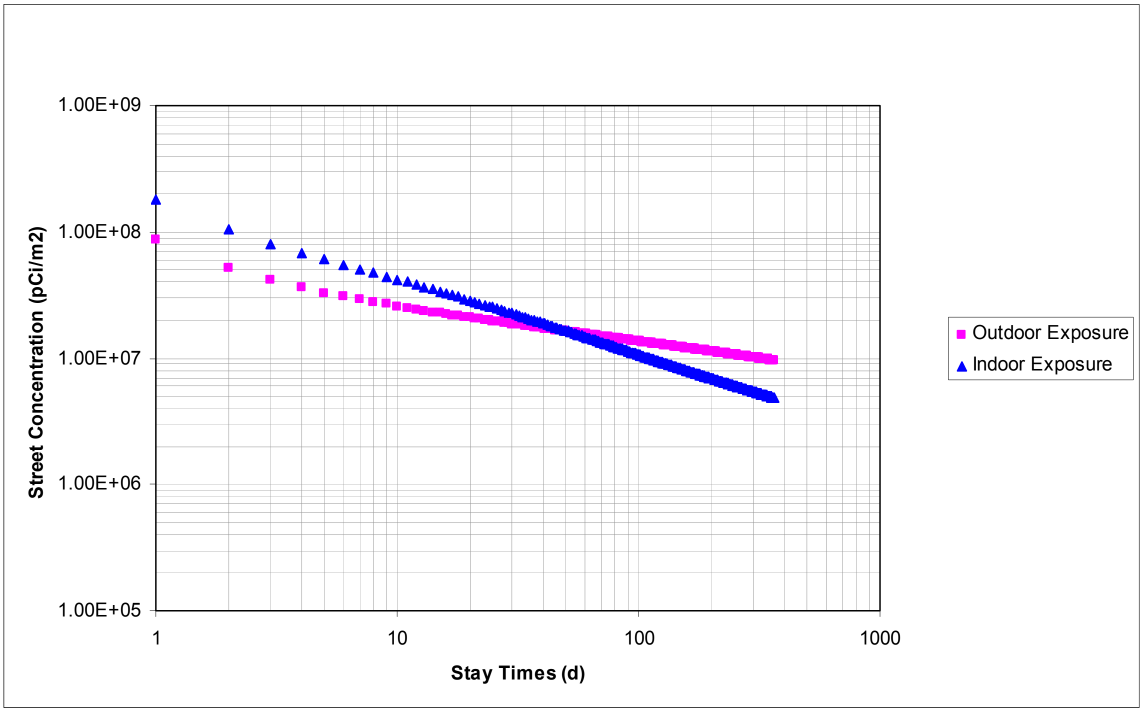

FIGURE 7.9 Limiting Concentrations of Pu-239 for Access to Business

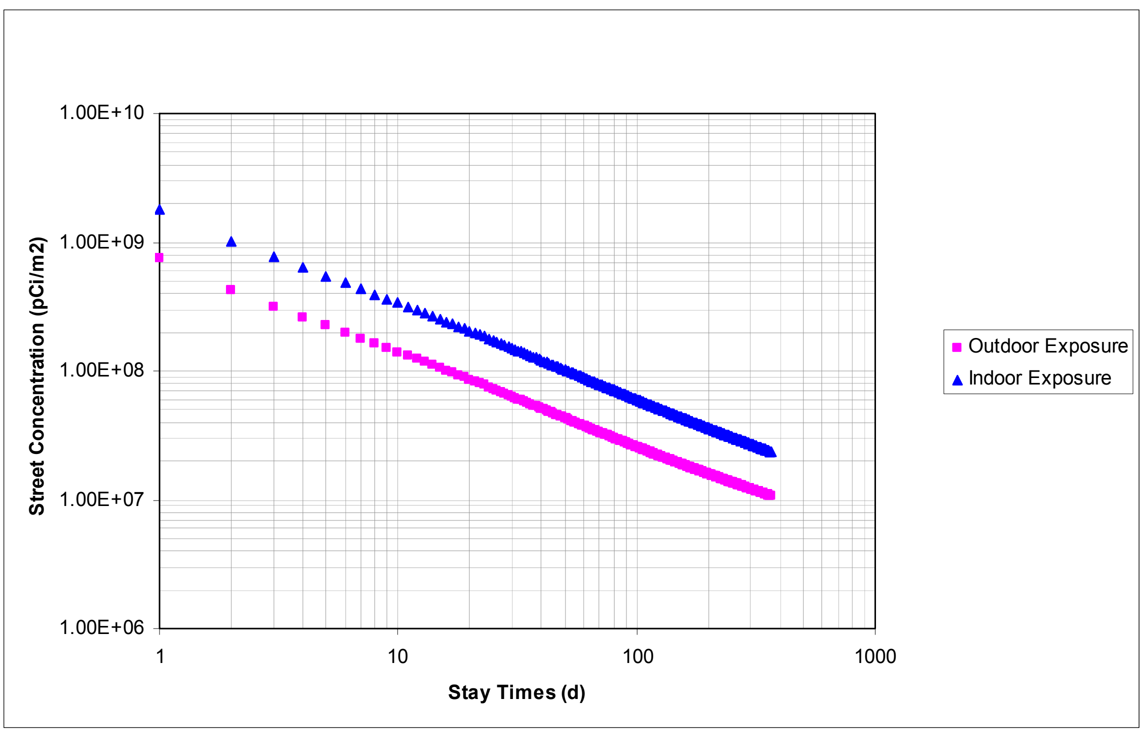

FIGURE 7.10 Limiting Concentrations of Ra-226 for Access to Business

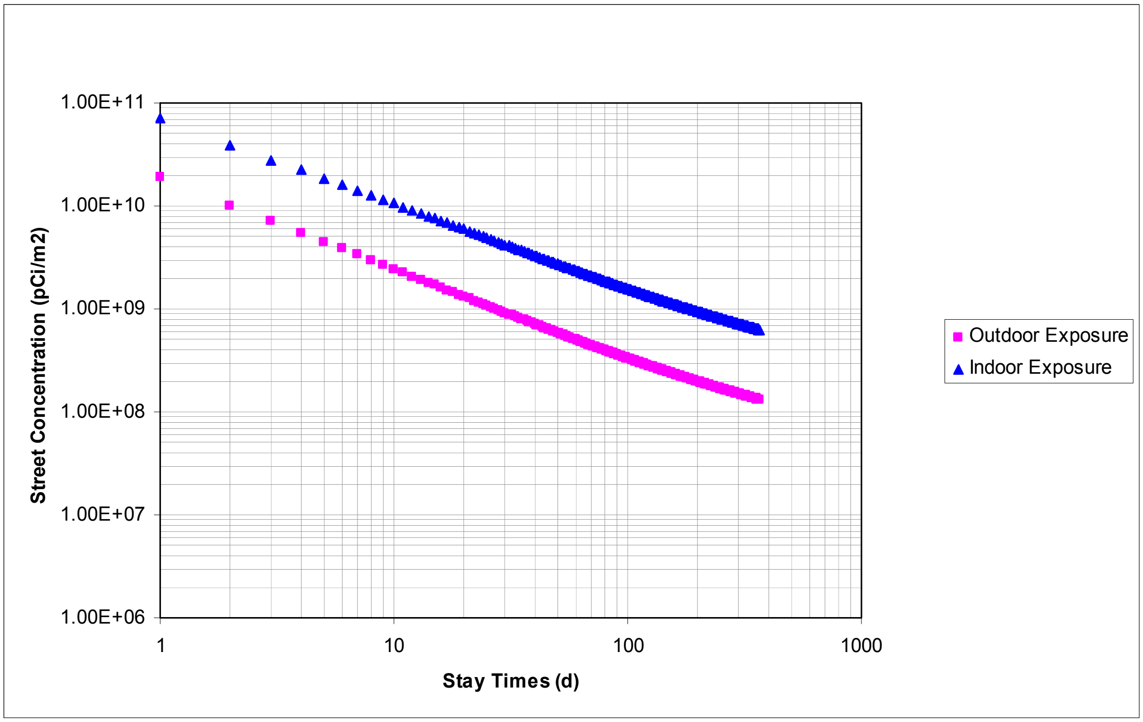

FIGURE 7.11 Limiting Concentrations of Sr-90 for Access to Business

outdoor air presented in the last two columns of Table 2.2 in Chapter 2 were used directly, without multiplication by a factor of 10.

To account for differences in the time fractions spent inside and outside of residences by different people, two receptors were considered — one that would spend all the time indoors and the other that would spend all the time outdoors. The parameters used in the different exposure scenarios are listed in Table 2.7 in Chapter 2.

The weathering correction for a rural environment is different from that for an urban environment. However, the differences would be insignificant for short periods of time. Therefore, only the urban environment was considered for dose calculation.

7.2.1 Scenario Description for Public Access to Residences for Retrieval

Scenario D2-1 (public accessing a residential area and staying outside) assumed access to a contaminated residential area in an urban environment. Under this scenario, a resident was assumed to spend all the time outdoors in the contaminated area. The resident received radiation doses from external exposure to outside contamination, inhalation of contaminated outdoor air, and direct dust ingestion from contaminated outdoor areas.

Scenario D2-2 (public accessing residential area and staying inside) assumed access to a contaminated residential area in an urban environment. Under this scenario, a resident was assumed to spend all the time indoors in the contaminated area. The building dimensions considered for external exposure were based on the urban house geometry shown in Table 2.4 in Chapter 2. Exposure pathways applicable for this scenario are shown in Table 2.6 in Chapter 2.

7.2.2 Operational Guideline Derivation for Public Access to Residences for Retrieval

The operational guidelines are presented in the form of stay time tables that could be used to provide recommendations for total time periods during which a resident could remain in the contaminated area to conduct necessary activities.

Hourly DSRs as a function of time were calculated on the basis of an initial street concentration. The media concentrations were obtained by using the modeling approach described in Chapter 2. The cumulative radiation dose as a function of time was obtained by integrating the hourly DSRs over time. The stay times for different contamination levels were then derived by using the cumulative radiation doses. They are the durations of continuous exposures immediately after an RDD event that would result in a radiation dose equal to 0.5 rem. Tables 7.5 and 7.6 provide continuous exposure times (stay times) to get a dose of 0.5 rem. The stay times are provided for different initial concentration levels.

Tables 7.7 and 7.8 list surface street concentration levels for Scenarios D2-1 and D2-2, respectively, that would result in doses equivalent to 0.5 rem for specified time periods. The specified time periods are 1 day, 4 days, and 12 days. The time starts immediately after an RDD event, and it was assumed that a resident would spend 24 hours per day in the contaminated area.

Stay times for a specific exposure pattern can be derived by using Tables 7.5–7.8, depending on the time fractions spent indoors and outdoors by a receptor. For example, in an environment contaminated with Am-241 at a level of 4.79×10^7 pCi/m^2, a receptor could stay for 1 day (24 hours) outdoors to incur a 0.5 rem dose (Table 7.7). Another receptor spending

TABLE 7.5 Stay Times for Group D2-1 Scenario: Residents Access to Houses (Outdoor Exposure)

Radionuclide Concentration				Stay Time (continuous exposure time in hours) to Receive 0.5 rem (500 mrem)[a]										
pCi/cm^2	pCi/m^2	Bq/cm^2	dpm/100 cm^2	Am-241	Cf-252	Cm-244	Co-60	Cs-137	Ir-192	Po-210	Pu-238	Pu-239	Ra-226	Sr-90
1.00E+00	1.00E+04	3.70E-02	2.22E+02	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760
1.00E+01	1.00E+05	3.70E-01	2.22E+03	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760
1.00E+02	1.00E+06	3.70E+00	2.22E+04	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760
1.00E+03	1.00E+07	3.70E+01	2.22E+05	7.25E+02	8.31E+03	4.29E+03	3.74E+03	> 8760	> 8760	1.07E+03	4.63E+02	3.49E+02	2.03E+03	> 8760
1.00E+04	1.00E+08	3.70E+02	2.22E+06	1.15E+01	7.04E+01	1.94E+01	2.72E+02	1.09E+03	1.42E+03	7.39E+01	1.00E+01	9.21E+00	9.74E+01	2.73E+03
1.00E+05	1.00E+09	3.70E+03	2.22E+07	1.15E+00	5.14E+00	1.94E+00	2.64E+01	9.67E+01	9.87E+01	6.74E+00	1.00E+00	9.21E-01	7.26E+00	1.97E+02
1.00E+06	1.00E+10	3.70E+04	2.22E+08	1.15E-01	5.14E-01	1.94E-01	2.63E+00	9.46E+00	9.63E+00	6.74E-01	1.00E-01	9.21E-02	7.26E-01	1.65E+01
1.00E+07	1.00E+11	3.70E+05	2.22E+09	1.15E-02	5.14E-02	1.94E-02	2.63E-01	9.46E-01	9.63E-01	6.74E-02	1.00E-02	9.21E-03	7.26E-02	1.65E+00

[a] A stay time >8,760 hours indicates that the dose criterion (in this case 0.5 rem in a year) used for the derivation of stay times at the specific concentrations will not be exceeded under continuous 24 hours/day, 365 days per year exposures (i.e., no protective actions are necessary to avert doses at or above the criterion). For concentrations and radionuclide combinations that exceed 8,760 hours, the figures presented in this section (Figures 7.12-7.22) can be used to determine the new stay times.

TABLE 7.6 Stay Times for Group D2-2 Scenario: Residents Access to Houses (Indoor Exposure)

Radionuclide Concentration				Stay Time (continuous exposure time in hours) to Receive 0.5 rem (500 mrem)[a]										
pCi/cm^2	pCi/m^2	Bq/cm^2	dpm/100 cm^2	Am-241	Cf-252	Cm-244	Co-60	Cs-137	Ir-192	Po-210	Pu-238	Pu-239	Ra-226	Sr-90
1.00E+00	1.00E+04	3.70E-02	2.22E+02	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760
1.00E+01	1.00E+05	3.70E-01	2.22E+03	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760
1.00E+02	1.00E+06	3.70E+00	2.22E+04	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760
1.00E+03	1.00E+07	3.70E+01	2.22E+05	6.51E+02	7.39E+03	1.52E+03	> 8760	> 8760	> 8760	> 8760	5.17E+02	4.44E+02	6.20E+03	> 8760
1.00E+04	1.00E+08	3.70E+02	2.22E+06	1.80E+01	1.58E+02	3.26E+01	6.93E+02	3.64E+03	> 8760	6.06E+02	1.57E+01	1.44E+01	2.87E+02	> 8760
1.00E+05	1.00E+09	3.70E+03	2.22E+07	1.80E+00	8.41E+00	3.04E+00	6.57E+01	2.91E+02	2.55E+02	2.89E+01	1.57E+00	1.44E+00	1.46E+01	1.14E+03
1.00E+06	1.00E+10	3.70E+04	2.22E+08	1.80E-01	8.41E-01	3.04E-01	6.53E+00	2.75E+01	2.38E+01	2.80E+00	1.57E-01	1.44E-01	1.46E+00	6.91E+01
1.00E+07	1.00E+11	3.70E+05	2.22E+09	1.80E-02	8.41E-02	3.04E-02	6.53E-01	2.74E+00	2.38E+00	2.80E-01	1.57E-02	1.44E-02	1.46E-01	5.95E+00

[a] A stay time >8,760 hours indicates that the dose criterion (in this case 0.5 rem in a year) used for the derivation of stay times at the specific concentrations will not be exceeded under continuous 24 hours/day, 365 days per year exposures (i.e., no protective actions are necessary to avert doses at or above the criterion). For concentrations and radionuclide combinations that exceed 8,760 hours, the figures presented in this section (Figures 7.12-7.22) can be used to determine the new stay times.

Table 7.7 Scenario D2-1 Operational Guidelines for 0.5 rem Annual Dose: Residents Access to Houses (Outdoor Exposure)

	Surface Street Concentration (pCi/m^2)		
Radionuclide	1 Day	4 Days	12 Days
Am-241	4.79E+07	1.99E+07	1.33E+07
Cf-252	2.14E+08	8.50E+07	5.13E+07
Cm-244	8.08E+07	3.35E+07	2.24E+07
Co-60	1.10E+09	2.77E+08	9.47E+07
Cs-137	3.94E+09	1.01E+09	3.46E+08
Ir-192	4.01E+09	1.03E+09	3.63E+08
Po-210	2.81E+08	7.94E+07	3.01E+07
Pu-238	4.19E+07	1.74E+07	1.16E+07
Pu-239	3.84E+07	1.59E+07	1.06E+07
Ra-226	3.02E+08	1.01E+08	4.56E+07
Sr-90	6.89E+09	1.92E+09	7.09E+08

Table 7.8 Scenario D2-2 Operational Guidelines for 0.5 rem Annual Dose: Residents Access to Houses (Indoor Exposure)

	Surface Street Concentration (pCi/m^2)		
Radionuclide	1 Day	4 Days	12 Days
Am-241	7.51E+07	2.86E+07	1.59E+07
Cf-252	3.50E+08	1.32E+08	7.13E+07
Cm-244	1.27E+08	4.82E+07	2.68E+07
Co-60	2.72E+09	6.87E+08	2.33E+08
Cs-137	1.14E+10	2.94E+09	1.01E+09
Ir-192	9.93E+09	2.54E+09	8.92E+08
Po-210	1.17E+09	3.86E+08	1.74E+08
Pu-238	6.56E+07	2.50E+07	1.39E+07
Pu-239	6.01E+07	2.29E+07	1.27E+07
Ra-226	6.08E+08	2.10E+08	9.97E+07
Sr-90	2.48E+10	7.70E+09	3.18E+09

6 hours outdoors and 18 hours indoors (total 24 hours) would receive only 0.36 rem ($[0.5] \times [6/24] \times [4.79 \times 10^7/4.79 \times 10^7] + [0.5] \times [18/24] \times [4.79 \times 10^7/7.51 \times 10^7]$), therefore permitting additional time in that environment.

Figures 7.12–7.22 provide limiting concentrations of individual radionuclides for access to residences for essential activities. For example, a resident could access the outdoor area of a house contaminated with Am-241 at a level of 4.8×10^7 pCi/m^2 for one day (24 hours) and would not receive a dose greater than 0.5 rem (see Figure 7.12). Similarly, if access is required for 12 days, the contamination level for outdoor access should be less than 1.3×10^7 pCi/m^2. In all cases for a short period of time (<20 days), the stay times for outdoor exposure (Scenario D2-1) are more restrictive than for indoor exposure (Scenario D2-2).

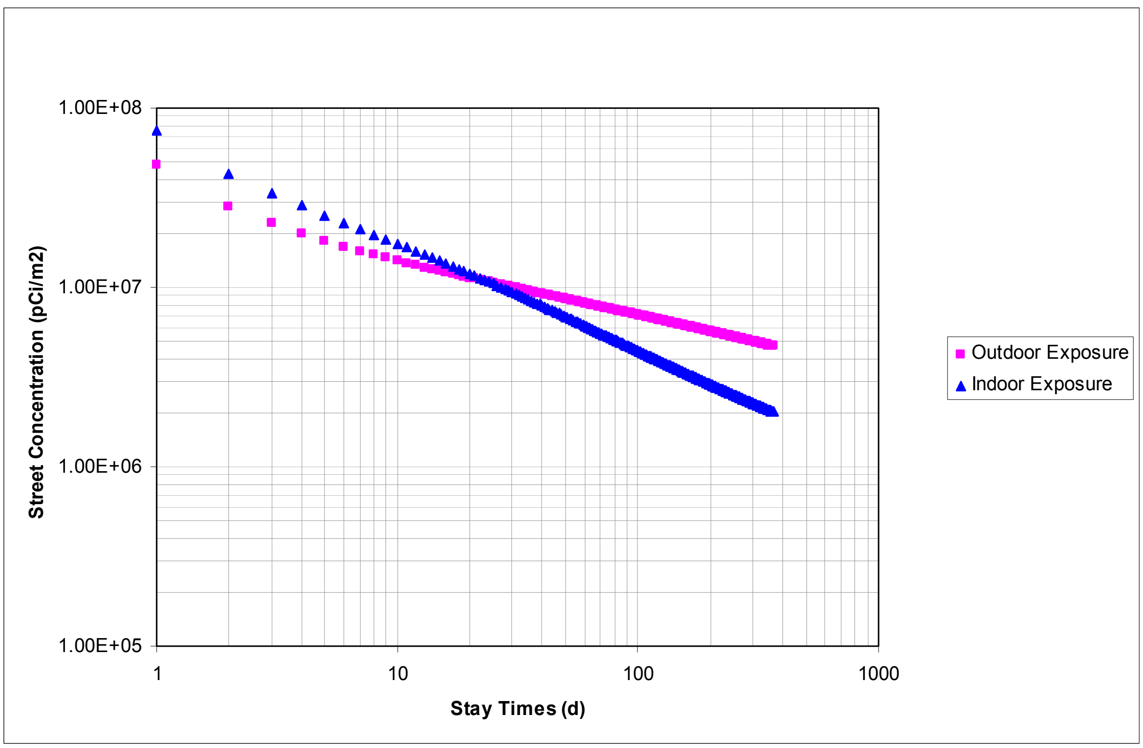

FIGURE 7.12 Limiting Concentrations of Am-241 for Access to Homes

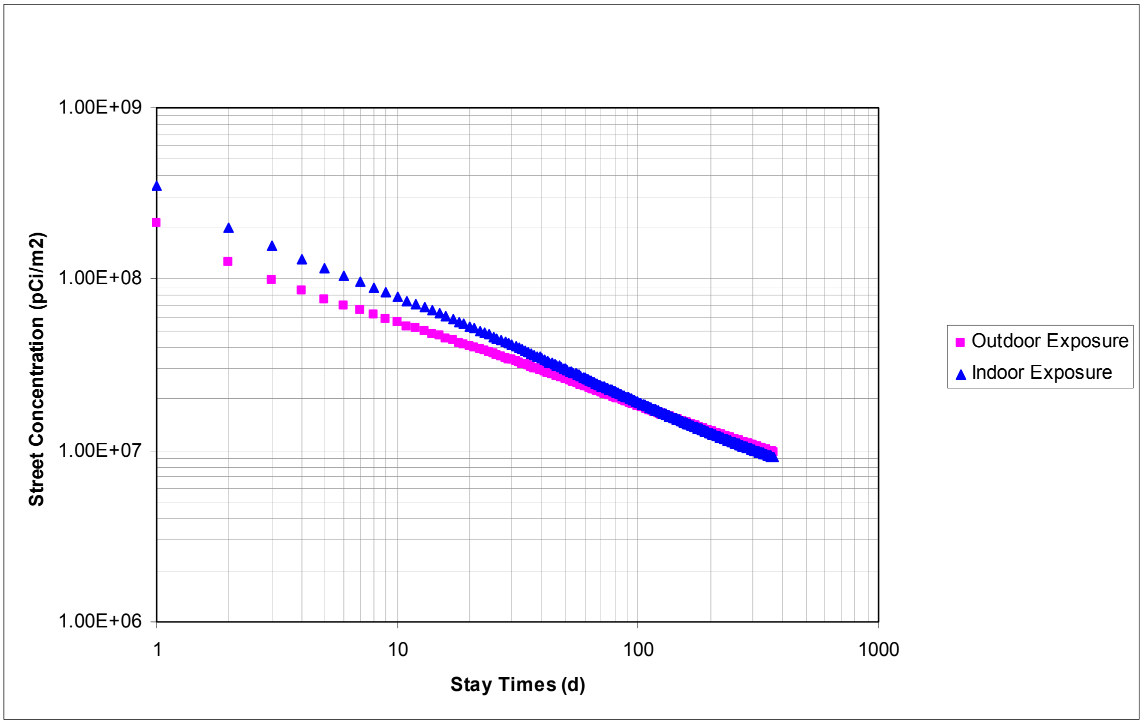

FIGURE 7.13 Limiting Concentrations of Cf-252 for Access to Homes

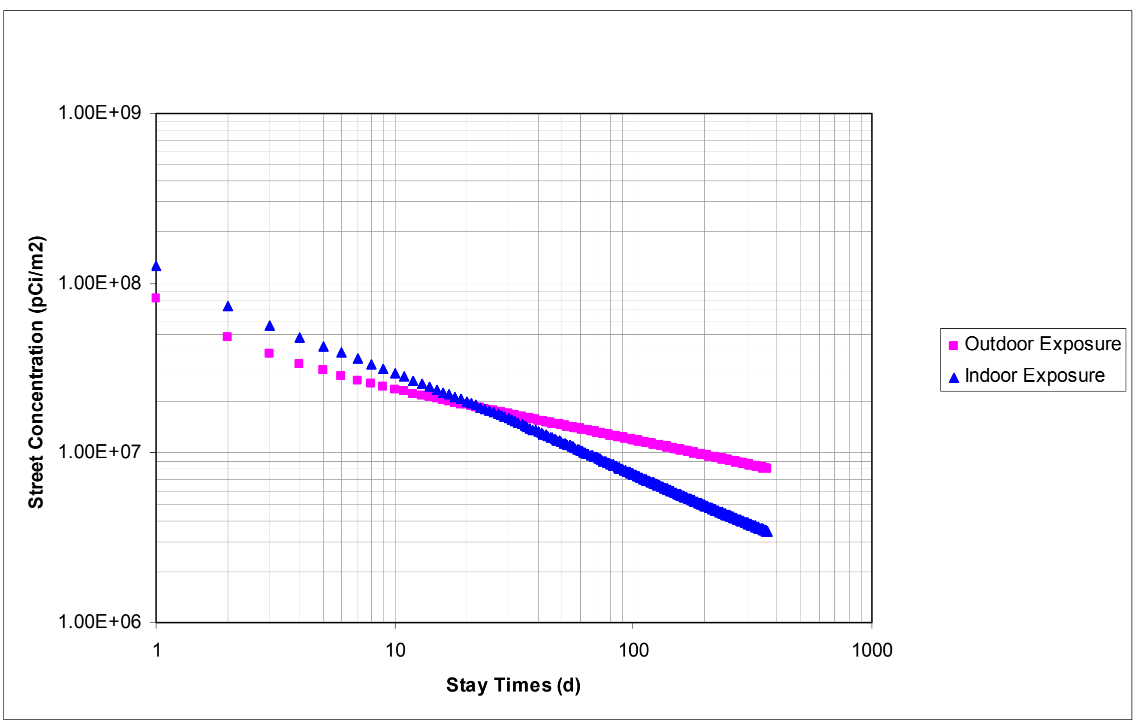

FIGURE 7.14 Limiting Concentrations of Cm-244 for Access to Homes

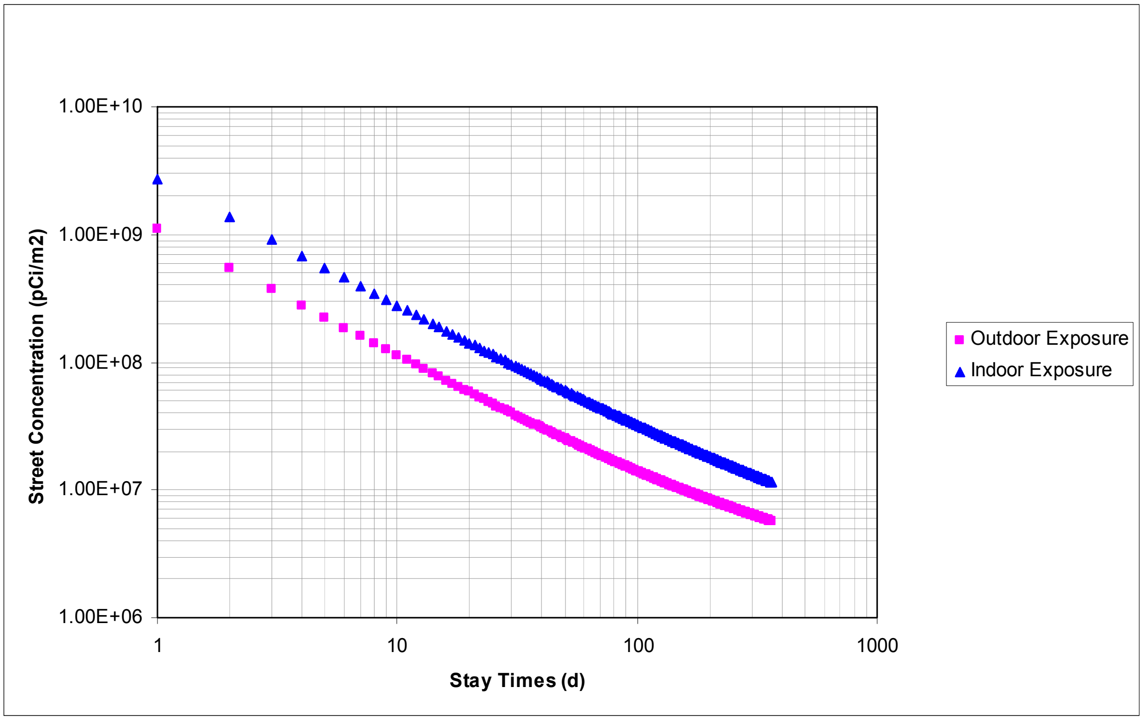

FIGURE 7.15 Limiting Concentrations of Co-60 for Access to Homes

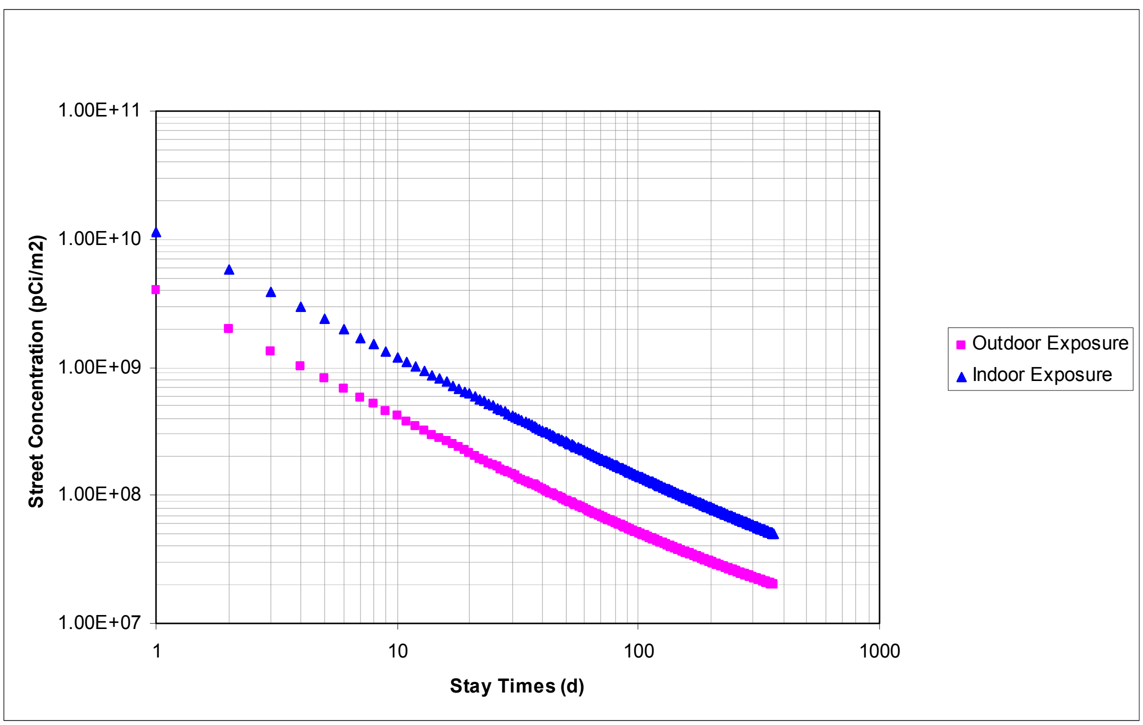

FIGURE 7.16 Limiting Concentrations of Cs-137 for Access to Homes

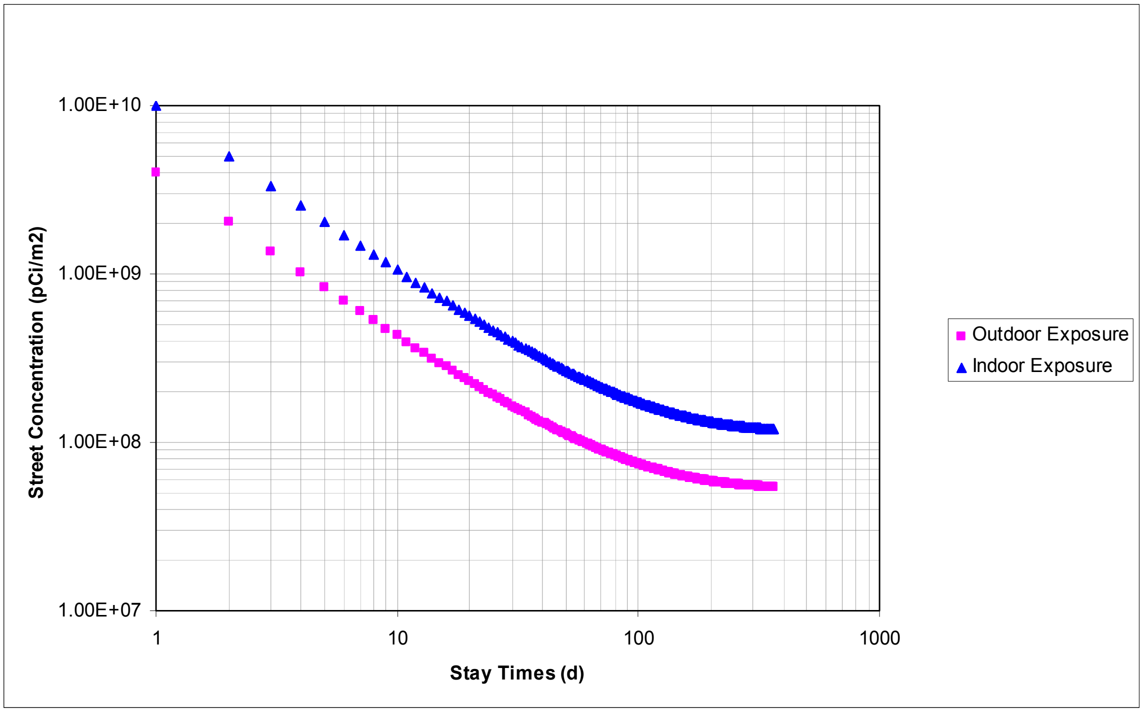

FIGURE 7.17 Limiting Concentrations of Ir-192 for Access to Homes

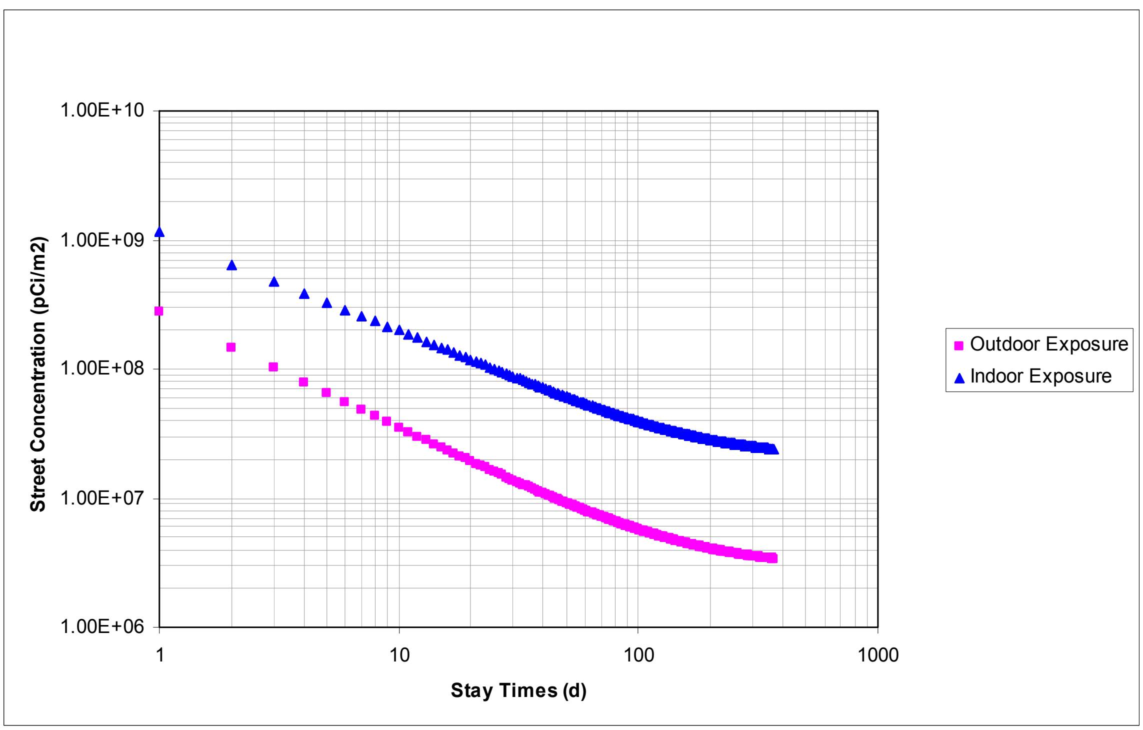

FIGURE 7.18 Limiting Concentrations of Po-210 for Access to Homes

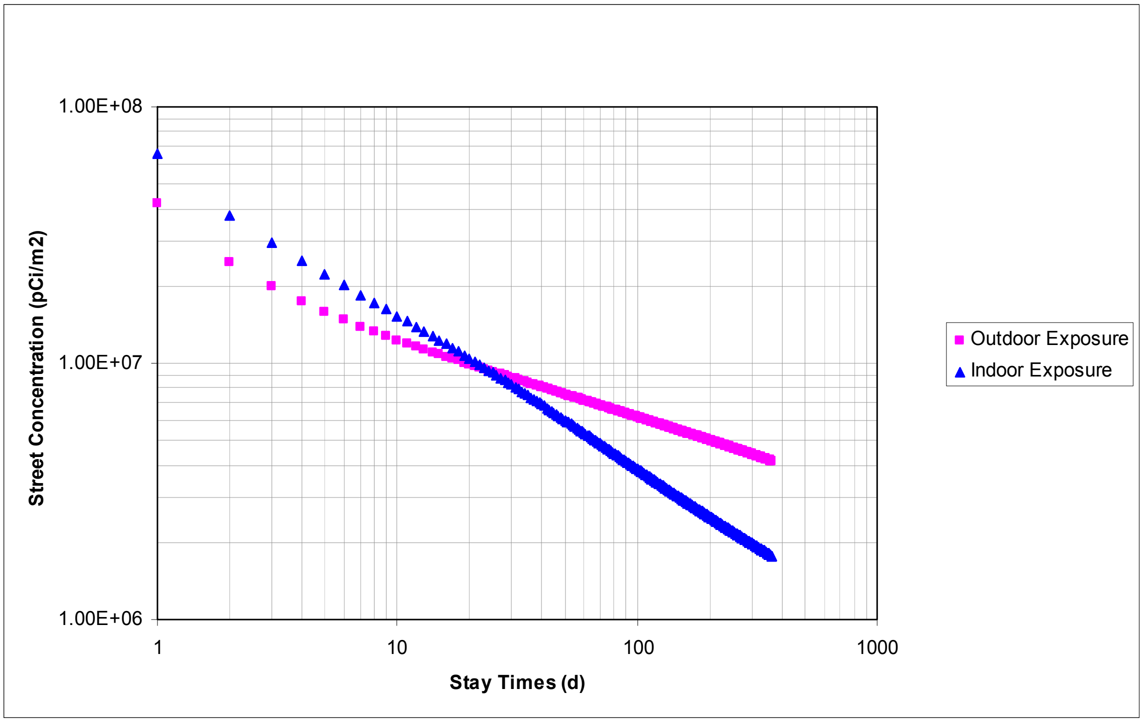

FIGURE 7.19 Limiting Concentrations of Pu-238 for Access to Homes

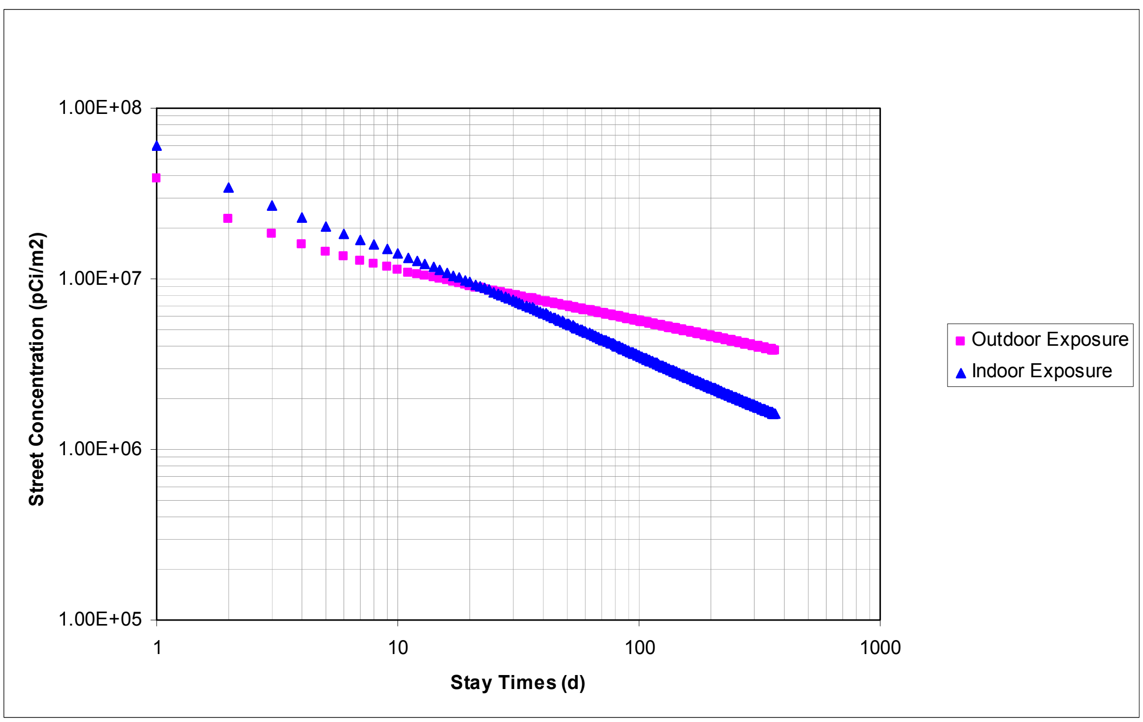

FIGURE 7.20 Limiting Concentrations of Pu-239 for Access to Homes

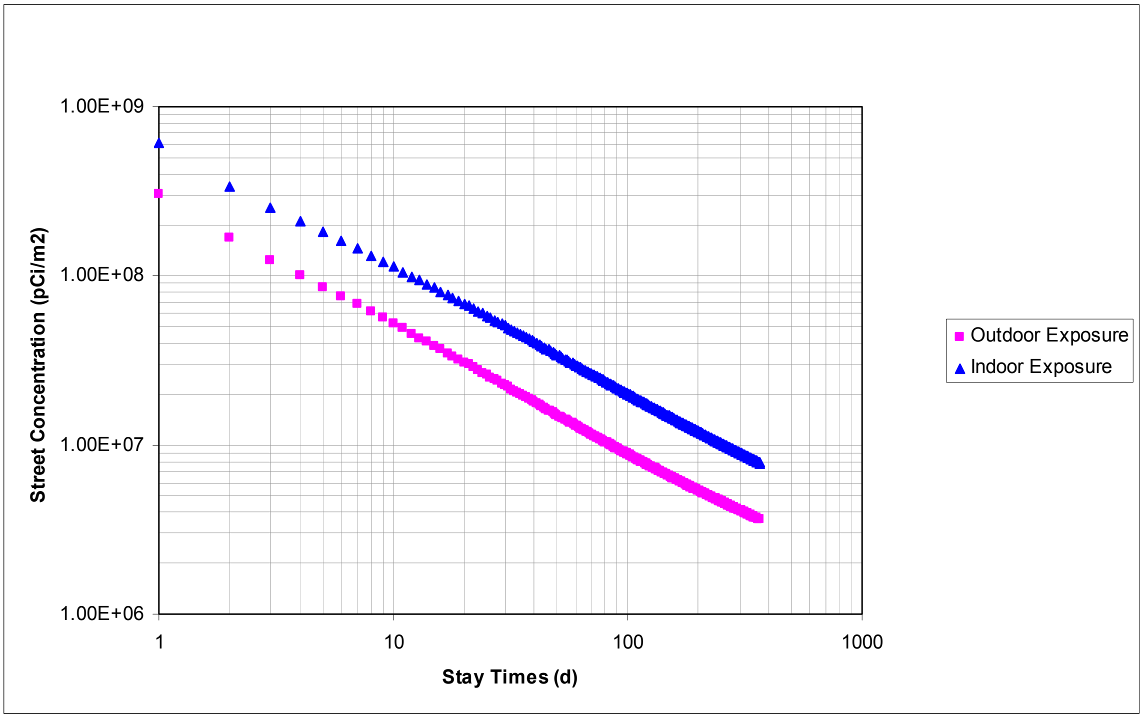

FIGURE 7.21 Limiting Concentrations of Ra-226 for Access to Homes

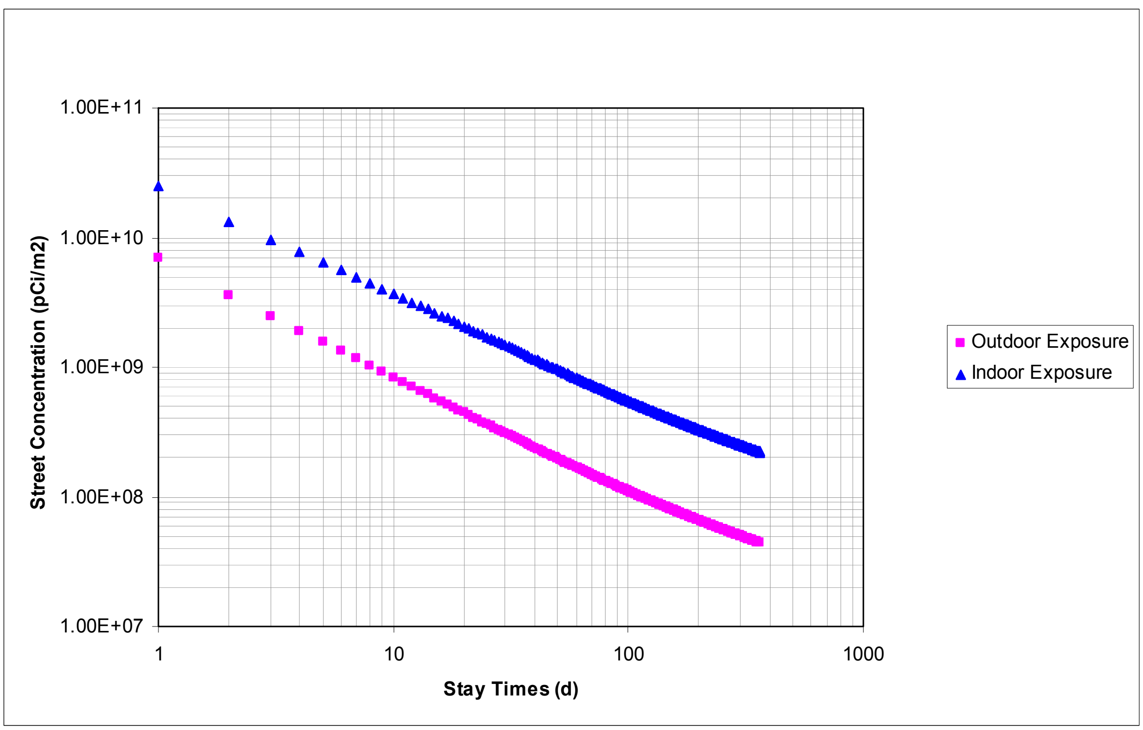

FIGURE 7.22 Limiting Concentrations of Sr-90 for Access to Homes

8 GROUP E: TRANSPORTATION AND ACCESS ROUTES

The operational guidelines for Group E are intended to assist in determining whether contaminated bridges, streets and thoroughfares, or sidewalks and walkways can be open for unrestricted or restricted access. The relocation PAGs (i.e., 2 rem in the first year and 0.5 rem per year thereafter) were used as the basis for deriving operational guidelines for unrestricted access. A PAG of 5 rem was used for deriving operational guidelines for restricted access, because it may be necessary to use the transportation routes in a relocation area to commute between nonrelocation areas or to provide emergency/recovery services to the relocation area.

The operational guidelines assume regular or periodic access to the transportation route. They are applicable during the intermediate response phase after an RDD event. Different scenarios were considered for deriving the operational guidelines. They address continued use of bridges, streets and thoroughfares, and sidewalks and walkways. In considering the use of bridges and streets and thoroughfares, it is assumed that the receptor would be inside a vehicle while driving through these areas and would not come in direct contact with the contamination on the ground. The difference in the continued use of bridges and streets and thoroughfares is in the external exposure: two supplementary surface sources, representing the bridge railings, were added to the contaminated road source in the bridge scenario. A methodology that accounts for the time-integrated concentration inside a vehicle that passes through a contaminated area was used to assess the inhalation dose.

8.1 AIR CONCENTRATION INSIDE THE VEHICLE

The inhalation dose depends on the air concentration inside the vehicle; therefore, it must be evaluated first. By using a mass-balance model, and assuming that no air cleaning devices are used in the vehicle and that the vehicle is clean at time $t = 0$ (i.e., $C_i(0) = 0$), a well-mixed inside air concentration, $C_i(t)$, can be related to a constant outside concentration, C_o, as shown in Equation 8.1 (Engelmann et al. 1992):

$$C_i(t) = \left(\frac{a_c}{b_c}\right) C_o (1 - e^{-b_c t}) , \tag{8.1}$$

where t is the time spent in the contaminated area, and a_c and b_c are vehicle parameters defined in Equations 8.2 and 8.3 (Engelmann et al. 1992):

$$a_c \quad = \quad (f \times Q_1 + f_r \times Q_2) \tag{8.2}$$

$$b_c \quad = \quad Q_1 + Q_2 + V_d \times A + (1 - f_r) \times Q_r \ . \tag{8.3}$$

The definitions account for the natural infiltration exchange rate (Q_1); the fraction that escapes capture during ingress (f); the air exchange rate when the heating, ventilating, and air-conditioning (HVAC) unit is operating (Q_2); recirculation air flow through the HVAC unit (Q_r); the fraction that escapes capture, passing through the HVAC unit (f_r); dry deposition inside the vehicle (V_d); and the area of the interior (A).

After the vehicle has passed through the contaminated area, the inside concentration decays according to the parameters defined in Equation 8.4:

$$C_i(t) \quad = \quad C_{ii} e^{-bt} \ , \tag{8.4}$$

where $C_i(t)$ is the inside air concentration at time, t, after the passage; C_{ii} is the inside air concentration at the end of the passage; and b is the vehicle parameter defined by Equation 8.3 after the passage.

As shown in Equation 8.5, assuming the outside air concentration is constant within the contaminated area and is clean beyond the contaminated area, then the time-integrated concentration inside the vehicle is:

$$\begin{aligned} & C_o \frac{a_c}{b_c} [\int_o^{T_c} (1 - e^{-b_c t}) dt + (1 - e^{-b_c T_c}) \int_o^{T} e^{-bt} dt] \\ = \quad & C_o \frac{a_c T_c}{b_c} \left\{ 1 - \frac{(1 - e^{-b_c T_c})}{b_c T_c} \left[1 - \frac{b_c}{b} (1 - e^{-bT}) \right] \right\} , \end{aligned} \tag{8.5}$$

where T_c is the time the driver/passenger spends inside the vehicle while passing the contaminated area; T is the time the driver/passenger spends inside the vehicle after passing the contaminated area; and a_c, b_c, and b are the vehicular parameters discussed above while passing and after passing the contaminated area, respectively.

When the outside air concentration is zero (after passing the contaminated zone), a parameter study of Equation 8.4 shows that the concentration inside the vehicle decreases rapidly with time. The time to reach 1% of the concentration C_{ii} ranges from a few hundred to a few thousand seconds, depending on the values of the vehicle parameters b, a_c, and b_c. Since parameter b was found to range from 0.001 to 0.02 s^{-1} for a moving vehicle (Engelmann et al. 1992; Johnson 2002), and assuming that the driver/passenger spends more than three to four times the air exchange rate inside the vehicle after crossing the contaminated area, the time-integrated air concentration reduces to the parameters defined in Equation 8.6:

$$C_o \frac{a_c T_c}{b_c} \{1 - \frac{(1 - e^{-b_c T_c})}{b_c T_c} [1 - \frac{b_c}{b}]\} . \qquad (8.6)$$

Since T_c is determined exclusively by the vehicle speed and the length of the contaminated area (36 s for 500 m at 50 km/h), the study of Equations 8.5 and 8.6 shows that, in order to minimize the inside concentration, one should minimize a_c and maximize b. In other words, to get maximum protection, the driver/passenger should turn the HVAC/fan system on and put the system in the recycle mode (with vent closed) while driving through the contaminated zone, and then open the windows for a few minutes after passing the contaminated area to increase air circulation in order to get rid of inside contamination. The actual air concentration inside the vehicle under these circumstances could be much less than the outside air concentration in the contaminated zone.

If the vehicle is driven in the same condition ($b = b_c$) while passing and after passing the contaminated area, Equation 8.5 reduces to:

$$C_o \frac{a_c T_c}{b_c} [1 - \frac{(1 - e^{-b_c T_c})}{b_c T_c} e^{-b_c T}] . \qquad (8.7)$$

The maximum value for Equation 8.7, regardless of the applicable b_c value, is:

$$C_o \frac{a_c T_c}{b_c} . \qquad (8.8)$$

Equation 8.8 can be minimized by reducing the ratio a_c/b_c. As discussed above, this ratio depends on factors such as vehicle make, speed, and natural and forced air exchange rates. For a stationary vehicle, the ratio a_c/b_c in different experimental conditions (i.e., air-conditioning

[AC] on, AC off, fan on, fan off, etc.) was found to vary from 0.013 to 0.705 (Engelmann et al. 1992). From Johnson (2002), which considers moving vehicles, it was found that, for a vehicle speed of 50 km/h, this ratio varies from 0.1 to 0.9.

For a conservative estimate of the time-integrated air concentration inside the vehicle, it was assumed that there was no loss of airborne radionuclides due to deposition and no recirculation of air through the HVAC system (HVAC/fan system is turned off). Under these conditions, the vehicle ratio a_C/b_C is 1, a situation that also corresponds to the limiting case of driving convertible cars with the tops down when passing through the contaminated areas.

Based on the above discussion and considering the various makes of vehicles (with different a_C, b_C, or b values) and different driving habits (with HVAC/fan on or off), it is concluded that for reasonably conservative dose estimates, the receptor inside the vehicle can be assumed to be exposed to the same air concentration as was outside, and the exposure duration can be limited to the time required for the vehicle to pass through the contaminated area.

8.2 BRIDGES (GROUP E1)

The operational guidelines for this group were derived by considering continued (unrestricted) use of bridges by the general public or restricted use by emergency workers. The 5-rem occupational exposure PAG was applied to emergency workers, and the 2-rem first-year and 0.5-rem subsequent-year PAGs were applied to the general public. Potential radiation doses resulting from external radiation (from the contaminated bridge), inhalation, and air submersion exposure were considered. The radiation dose resulting from ingesting contaminated material deposited inside the vehicle was not included. Both the general public and emergency worker scenarios were considered in an urban environment. The external exposure was calculated based on a vehicle passing a bridge with a geometry shown in Table 2.4 in Chapter 2. The initial contamination was assumed to be on the bridge. The average correction factors for outdoor air in the last 2 columns of Table 2.2 in Chapter 2 were multiplied by 10 and 100, respectively, for restricted and public use (more traffic when access is unrestricted), to account for traffic in an urban environment (see Table 2.3 in Chapter 2). The parameters used in both exposure scenarios are listed in Table 2.7 in Chapter 2.

8.2.1 Scenario Description for Bridges

Scenario E1-1 (emergency worker drives over bridges under restricted conditions) assumed use of the contaminated bridges by emergency workers in an urban environment. Under this scenario, an emergency worker was assumed to spend an average of 1 hour per day for 250 days in 1 year passing the contaminated bridges (multiple passages per day in his vehicle).

Scenario E1-2 (a member of the general public drives over bridges under unrestricted conditions) assumed continued (unrestricted) use of the contaminated bridges by the general public in an urban environment. Under this scenario, a member of the general public was assumed to spend an average of 0.02 hour per day for 250 days in 1 year passing the contaminated bridges twice daily in a vehicle. (The bridge is 500 m long; the vehicle speed is 50 km/h; and the time taken to cross the bridge once is 0.01 hour; therefore, the twice daily time/day is 0.02 hour.)

8.2.2 Dose Calculation for Bridges

Tables 8.A.1–8.A.2 in Appendix 8.A provide the DSRs from individual exposure pathways for Scenarios E1-1 and E1-2 for the first year. Table 8.A.3 in Appendix 8.A provides the DSRs for Scenario E1-2 from individual exposure pathways for the second year. Table 8.1 provides the total DSRs for both scenarios for the first year and the DSRs for Scenario E1-2 for the second year.

8.2.3 Operational Guideline Derivation for Bridges

Table 8.2 provides operational guidelines for the use of bridges. The occupational PAG (5 rem for first year) was used for Scenario E1-1, and the public PAGs (2 rem for the first year and 0.5 rem after the first year) were used for Scenario E1-2. Table 8.2 shows that for all radionuclides, Scenario E1-1 would result in more restrictive operational guidelines.

TABLE 8.1 Total Dose-to-Source Ratios (DSRs) for Bridges (Group E1) Scenarios

	DSR (mrem/yr per pCi/m^2) Based on Initial Bridge Contamination following an RDD Event		
	First Year		After First Year
Radionuclide	E1-1[a]	E1-2[b]	E1-2[b]
Am-241	1.70E-05	3.40E-06	1.25E-07
Cf-252	3.46E-06	6.92E-07	1.81E-08
Cm-244	1.01E-05	2.01E-06	7.06E-08
Co-60	2.74E-06	5.58E-08	2.83E-08
Cs-137	6.62E-07	1.45E-08	7.67E-09
Ir-192	2.82E-07	5.80E-09	9.46E-11
Po-210	6.65E-07	1.33E-07	4.81E-10
Pu-238	1.95E-05	3.90E-06	1.42E-07
Pu-239	2.13E-05	4.25E-06	1.57E-07
Ra-226	3.72E-06	3.79E-07	3.67E-08
Sr-90	3.42E-08	5.83E-09	2.70E-10

[a] E1-1: emergency workers driving over bridges under restricted conditions.

[b] E1-2: the public driving over bridges under unrestricted conditions.

8.3 STREETS AND THOROUGHFARES (GROUP E2)

The operational guidelines for this group were derived by considering continued use of streets and thoroughfares by the general public or restricted use by emergency workers. The 5-rem occupational exposure PAG was applied to emergency workers, and the 2-rem PAG was applied to the general public. Potential radiation doses resulting from external radiation (to the contaminated streets), inhalation, and air submersion exposure were considered. The radiation dose resulting from ingesting contaminated material deposited inside the vehicle was not included. Both the general public and emergency worker scenarios were considered in an urban environment, and the external exposure was calculated based on a vehicle passing through a street with a geometry shown in Table 2.4 in Chapter 2. The initial contamination was assumed to be on the street. The average correction factors for outdoor air in the last two columns of

TABLE 8.2 Operational Guidelines for Bridges (Group E1) Scenarios

	Operational Guidelines (pCi/m^2) for Initial Bridge Contamination following an RDD Event		
	E1-1[a]	E1-2[b]	
Radionuclide	5 rem in First Year	2 rem in First Year	0.5 rem after First Year
Am-241	2.94E+08	5.88E+08	3.99E+09
Cf-252	1.44E+09	2.89E+09	2.76E+10
Cm-244	4.97E+08	9.93E+08	7.09E+09
Co-60	1.82E+09	3.58E+10	1.77E+10
Cs-137	7.56E+09	1.38E+11	6.52E+10
Ir-192	1.78E+10	3.45E+11	5.28E+12
Po-210	7.52E+09	1.50E+10	1.04E+12
Pu-238	2.57E+08	5.13E+08	3.52E+09
Pu-239	2.35E+08	4.70E+08	3.19E+09
Ra-226	1.34E+09	5.28E+09	1.36E+10
Sr-90	1.46E+11	3.43E+11	1.85E+12

[a] E1-1: emergency workers driving over bridges under restricted conditions.

[b] E1-2: the public driving over bridges under unrestricted conditions.

Table 2.2 in Chapter 2 were multiplied by 10 and 100, respectively, for restricted and public use (more traffic when the access is unlimited), to account for traffic in urban conditions (see Table 2.3 in Chapter 2). The parameters used in both exposure scenarios are listed in Table 2.7 in Chapter 2.

8.3.1 Scenario Description for Streets and Thoroughfares

Scenario E2-1 (emergency worker drives through streets under restricted conditions) assumed use of the contaminated streets by emergency workers in an urban environment. Under this scenario, an emergency worker was assumed to spend an average 1 hour per day for 250 days in 1 year passing the contaminated streets (multiple times per day in a vehicle).

Scenario E2-2 (member of the general public drives through streets under unrestricted conditions) assumed continued (unrestricted) use of the contaminated streets by the general public in an urban environment. Under this scenario, a member of the general public was assumed to spend an average of 0.02 hour per day for 250 days in 1 year passing the contaminated streets twice daily in a vehicle. (The contaminated street is 500 m long, the vehicle speed is 50 km/h, and the time taken to pass the contaminated street once is 0.01 hour; therefore, the twice daily time/day is 0.02 hour.)

8.3.2 Dose Calculation for Streets and Thoroughfares

Tables 8.A.4 and 8.A.5 in Appendix 8.A provide the DSRs from individual exposure pathways for Scenarios E2-1 and E2-2 for the first year. Table 8.A.6 in Appendix 8.A provides the DSRs from individual exposure pathways for Scenario E2-2 for the second year. Table 8.3 provides the total DSRs for both scenarios for the first year and total DSRs for Scenario E2-2 for the second year.

TABLE 8.3 Total Dose-to-Source Ratios (DSRs) for Streets and Thoroughfares (Group E2) Scenarios

	DSR (mrem/y per pCi/m^2) Based on Initial Street Contamination following an RDD Event		
	First Year		After First Year
Radionuclide	E2-1[a]	E2-2[b]	E2-2[b]
Am-241	1.70E-05	3.40E-06	1.25E-07
Cf-252	3.46E-06	6.92E-07	1.81E-08
Cm-244	1.01E-05	2.01E-06	7.06E-08
Co-60	2.34E-06	4.77E-08	2.19E-08
Cs-137	5.60E-07	1.24E-08	5.87E-09
Ir-192	2.46E-07	5.09E-09	7.45E-11
Po-210	6.65E-07	1.33E-07	4.81E-10
Pu-238	1.95E-05	3.90E-06	1.42E-07
Pu-239	2.13E-05	4.25E-06	1.57E-07
Ra-226	3.41E-06	3.72E-07	3.10E-08
Sr-90	3.34E-08	5.81E-09	2.55E-10

[a] E2-1: emergency workers driving through streets under restricted conditions.

[b] E2-2: the public driving through streets under unrestricted conditions.

8.3.3 Operational Guideline Derivation for Streets and Thoroughfares

Table 8.4 provides the operational guidelines for the use of streets and thoroughfares. The occupational PAG (5 rem for the first year) was used for Scenario E2-1, and the public PAGs (2 rem for the first year and 0.5 rem after the first year) were used for Scenario E2-2. Table 8.4 shows that for all radionuclides, Scenario E2-1 would result in more restrictive operational guidelines.

8.4 SIDEWALKS AND WALKWAYS (GROUP E3)

The operational guidelines for this group were derived by considering continued (unrestricted) use of sidewalks and walkways by the general public or restricted use by essential service workers. The 5-rem occupational exposure PAG was applied to essential service workers,

TABLE 8.4 Operational Guidelines for Streets and Thoroughfares (Group E2) Scenarios

	Operational Guidelines (pCi/m^2) for Initial Street Contamination following an RDD Event		
	E2-1	E2-2	
Radionuclide	5 rem in First Year	2 rem in First Year	0.5 rem after First Year
Am-241	2.94E+08	5.88E+08	3.99E+09
Cf-252	1.44E+09	2.89E+09	2.76E+10
Cm-244	4.97E+08	9.93E+08	7.09E+09
Co-60	2.14E+09	4.19E+10	2.28E+10
Cs-137	8.94E+09	1.61E+11	8.52E+10
Ir-192	2.03E+10	3.93E+11	6.71E+12
Po-210	7.52E+09	1.50E+10	1.04E+12
Pu-238	2.57E+08	5.13E+08	3.52E+09
Pu-239	2.35E+08	4.70E+08	3.19E+09
Ra-226	1.47E+09	5.37E+09	1.61E+10
Sr-90	1.50E+11	3.44E+11	1.96E+12

[a] E2-1: Emergency workers drive through streets under restricted conditions.

[b] E2-2: The public drives through streets under unrestricted conditions.

and the 2-rem first-year and 0.5-rem subsequent-year PAGs were applied to the general public. Three exposure scenarios were considered for the derivation of operational guidelines. Potential radiation doses resulting from external radiation, inhalation, ingestion of dust particles, and air submersion exposure pathways were considered. All scenarios were considered in an urban environment, and the external exposure was calculated based on working on a street with a geometry shown in Table 2.4 in Chapter 2. The initial outdoor contamination was assumed to be on the streets. The average correction factors for outdoor air in the last 2 columns of Table 2.2 in Chapter 2 were multiplied by 10 for restricted use and for public use in situations where sidewalks or walkways were away from streets, and multiplied by 100 for public use in situations where sidewalks or walkways were near the streets, to account for traffic in urban conditions (see Table 2.3 in Chapter 2). The parameters used in all three exposure scenarios are listed in Table 2.7 in Chapter 2.

8.4.1 Scenario Description for Sidewalks and Walkways

Scenario E3-1 (essential service worker uses sidewalks and walkways under restricted conditions) assumed use of the contaminated sidewalks and walkways by essential service workers in an urban environment. Under this scenario, an essential service worker was assumed to spend an average 1 hour per day for 250 days in 1 year on the contaminated sidewalks or walkways near streets.

Scenario E3-2 (volunteer collects donations near streets) assumed continued (unrestricted) use of the contaminated sideways or walkways by people collecting donations in an urban environment. Under this scenario, a member of the general public was assumed to spend an average of 1 hour per day for 250 days in 1 year on the contaminated sideways or walkways near streets.

Scenario E3-3 (vendor sells merchandise away from streets) assumed continued (unrestricted) use of the contaminated sideways or walkways by vendors selling merchandise in an urban environment. Under this scenario, a member of the general public was assumed to spend an average of 8 hours per day for 250 days in 1 year on the contaminated sidewalks or walkways away from streets.

8.4.2 Dose Calculation for Sidewalks and Walkways

Tables 8.A.7–8.A.9 in Appendix 8.A provide the DSRs from individual exposure pathways for Scenarios E3-1 to E3-3 for the first year. Tables 8.A.10 and 8.A.11 in Appendix 8.A provide the DSRs for Scenarios E3-2 and E3-3 for individual exposure pathways for the second year. Table 8.5 provides the total DSRs for all scenarios for the first year and the total DSRs for Scenarios E3-2 and E3-3 for the second year.

8.4.3 Operational Guideline Derivation for Sidewalks and Walkways

Table 8.6 provides the operational guidelines for use of sidewalks and walkways. The occupational PAG (5 rem per year) was used for Scenario E3-1, and the public PAGs (2 rem for the first year and 0.5 rem after the first year) were used for Scenarios E3-2 and E3-3. For the first

TABLE 8.5 Total Dose-to-Source Ratios (DSRs) for Sidewalks and Walkways (Group E3) Scenarios

	DSR (mrem/yr per pCi/m^2) Based on Initial Sidewalks/Walkways Contamination following an RDD Event				
	First Year			After First Year	
Radionuclide	E3-1[a]	E3-2[b]	E3-3[c]	E3-2[b]	E3-3[c]
Am-241	1.84E-05	1.71E-04	1.47E-04	6.98E-06	1.08E-05
Cf-252	4.58E-06	3.57E-05	3.66E-05	1.36E-06	4.37E-06
Cm-244	1.08E-05	1.01E-04	8.67E-05	3.93E-06	6.01E-06
Co-60	2.52E-06	2.57E-06	2.02E-05	1.18E-06	9.45E-06
Cs-137	7.20E-07	7.83E-07	5.76E-06	3.78E-07	3.01E-06
Ir-192	2.64E-07	2.73E-07	2.11E-06	4.00E-09	3.20E-08
Po-210	4.79E-06	1.08E-05	3.84E-05	3.51E-07	2.64E-06
Pu-238	2.10E-05	1.96E-04	1.68E-04	7.90E-06	1.21E-05
Pu-239	2.29E-05	2.14E-04	1.83E-04	8.72E-06	1.33E-05
Ra-226	5.45E-06	2.07E-05	4.36E-05	2.65E-06	1.67E-05
Sr-90	3.51E-07	6.08E-07	2.81E-06	1.80E-07	1.36E-06

[a] E3-1: essential service worker using sidewalks and walkways under restricted conditions.

[b] E3-2: volunteer collecting donations near streets.

[c] E3-3: vendor selling merchandise away from streets.

TABLE 8.6 Operational Guidelines for Sidewalks and Walkways (Group E3) Scenarios

	Operational Guidelines (pCi/m^2) Based on Initial Sidewalk/Walkways Contamination following an RDD Event				
		General Public			
	Essential Service Worker	First Year		After First Year	
Radionuclide	E3-1[a]	E3-2[b]	E3-3[c]	E3-2[b]	E3-3[c]
Am-241	2.72E+08	1.17E+07	1.36E+07	7.17E+07	4.65E+07
Cf-252	1.09E+09	5.60E+07	5.46E+07	3.68E+08	1.14E+08
Cm-244	4.61E+08	1.97E+07	2.31E+07	1.27E+08	8.32E+07
Co-60	1.98E+09	7.78E+08	9.91E+07	4.23E+08	5.29E+07
Cs-137	6.94E+09	2.56E+09	3.47E+08	1.32E+09	1.66E+08
Ir-192	1.89E+10	7.34E+09	9.47E+08	1.25E+11	1.56E+10
Po-210	1.04E+09	1.86E+08	5.21E+07	1.42E+09	1.90E+08
Pu-238	2.38E+08	1.02E+07	1.19E+07	6.33E+07	4.14E+07
Pu-239	2.18E+08	9.33E+06	1.09E+07	5.74E+07	3.76E+07
Ra-226	9.17E+08	9.68E+07	4.58E+07	1.89E+08	2.99E+07
Sr-90	1.43E+10	3.29E+09	7.13E+08	2.78E+09	3.67E+08

[a] E3-1: essential service worker using sidewalks and walkways under restricted conditions.

[b] E3-2: volunteer collecting donations near streets.

[c] E3-3: vendor selling merchandise away from streets.

year Scenario E3-3, a vendor selling merchandise, resulted in the most restrictive operational guidelines for Cf-252, Co-60, Cs-137, Ir-192, Po-210, Ra-226, and Sr-90, and Scenario E3-2, a volunteer collecting donations, resulted in the most restrictive operational guidelines for Am-241, Cm-244, Pu-238, and Pu-239. After the first year Scenario E3-3, a vendor selling merchandise, resulted in the most restrictive operational guidelines for all radionuclides. Table 8.7 provides the most restrictive operational guidelines for essential service worker and general public use. It shows that for all radionuclides, public use would result in the most restrictive operational guidelines.

TABLE 8.7 Most Restrictive Operational Guidelines for Sidewalks and Walkways (Group E3) Scenarios

	Operational Guidelines (pCi/m^2) for Initial Sidewalks/Walkways Contamination following an RDD Event		
	Essential Service Worker	General Public	
Radionuclide	5 rem in First Year	2 rem in First Year	0.5 rem after First Year
Am-241	2.72E+08	1.17E+07	4.65E+07
Cf-252	1.09E+09	5.46E+07	1.14E+08
Cm-244	4.61E+08	1.97E+07	8.32E+07
Co-60	1.98E+09	9.91E+07	5.29E+07
Cs-137	6.94E+09	3.47E+08	1.66E+08
Ir-192	1.89E+10	9.47E+08	1.56E+10
Po-210	1.04E+09	5.21E+07	1.90E+08
Pu-238	2.38E+08	1.02E+07	4.14E+07
Pu-239	2.18E+08	9.33E+06	3.76E+07
Ra-226	9.17E+08	4.58E+07	2.99E+07
Sr-90	1.43E+10	7.13E+08	3.67E+08

8.5 REFERENCES

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APPENDIX 8.A:

DOSE-TO-SOURCE RATIOS (DSRs) FOR GROUP E SCENARIOS

- Group E1: Tables 8.A.1 through 8.A.3
- Group E2: Tables 8.A.4 through 8.A.6
- Group E3: Tables 8.A.7 through 8.A.11

APPENDIX 8.A:

DOSE-TO-SOURCE RATIOS (DSRs) FOR GROUP E SCENARIOS

This appendix includes dose-to-source ratios (DSRs) from individual exposure pathways for Group E (Transportation and Access Routes) scenarios. Tables 8.A.1 and 8.A.2 include DSRs for passing over bridges for the first year. In Scenario E1-1, an emergency worker drives over bridges under restricted conditions. In Scenario E1-2, a member of the general public drives over bridges under unrestricted conditions. Table 8.A.3 provides exposure results for Scenario E1-2 after the first year.

Tables 8.A.4–8.A.5 include DSRs for passing through streets and thoroughfares for the first year. In Scenario E2-1, an emergency worker drives through streets and thoroughfares under restricted conditions. In Scenario E2-2, a member of the general public drives through streets and thoroughfares under unrestricted conditions. Table 8.A.6 provides results for Scenario E2-2 after the first year.

Tables 8.A.7–8.A.9 include DSRs for sidewalks and walkways for the first year. In Scenario E3-1, an essential service worker uses sidewalks and walkways under restricted conditions. In Scenario E3-2, a volunteer collects donations near the streets. In Scenario E3-3, a vendor sells merchandise away from the streets. Tables 8.A.10 and 8.A.11 provide results for Scenarios E3-2 and E3-3 after the first year.

Results for Group E1 — Transportation and Access Routes: Bridges

TABLE 8.A.1 Scenario E1-1: Emergency Worker Drives over Bridges under Restricted Conditions (First Year)

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street/soil contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		Total
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	
Am-241	4.09E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-05	0.00E+00	0.00E+00	3.60E-13	0.00E+00	0.00E+00	0.00E+00	1.70E-05
Cf-252	7.49E-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.46E-06	0.00E+00	0.00E+00	1.20E-11	0.00E+00	0.00E+00	0.00E+00	3.46E-06
Cm-244	5.13E-22	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.01E-05	0.00E+00	0.00E+00	1.80E-15	0.00E+00	0.00E+00	0.00E+00	1.01E-05
Co-60	2.73E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.43E-09	0.00E+00	0.00E+00	6.26E-11	0.00E+00	0.00E+00	0.00E+00	2.74E-06
Cs-137	6.55E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.90E-09	0.00E+00	0.00E+00	1.36E-11	0.00E+00	0.00E+00	0.00E+00	6.62E-07
Ir-192	2.81E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.43E-10	0.00E+00	0.00E+00	1.55E-11	0.00E+00	0.00E+00	0.00E+00	2.82E-07
Po-210	5.13E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.65E-07	0.00E+00	0.00E+00	1.81E-16	0.00E+00	0.00E+00	0.00E+00	6.65E-07
Pu-238	1.99E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.95E-05	0.00E+00	0.00E+00	1.87E-15	0.00E+00	0.00E+00	0.00E+00	1.95E-05
Pu-239	3.39E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.13E-05	0.00E+00	0.00E+00	1.86E-15	0.00E+00	0.00E+00	0.00E+00	2.13E-05
Ra-226	2.03E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.69E-06	0.00E+00	0.00E+00	4.46E-11	0.00E+00	0.00E+00	0.00E+00	3.72E-06
Sr-90	5.67E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.86E-08	0.00E+00	0.00E+00	4.73E-13	0.00E+00	0.00E+00	0.00E+00	3.42E-08

TABLE 8.A.2 Scenario E1-2: Member of the General Public Drives over Bridges under Unrestricted Conditions (First Year)

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of bridge contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		Total
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	
Am-241	8.18E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.40E-06	0.00E+00	0.00E+00	7.21E-14	0.00E+00	0.00E+00	0.00E+00	3.40E-06
Cf-252	1.50E-17	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.92E-07	0.00E+00	0.00E+00	2.40E-12	0.00E+00	0.00E+00	0.00E+00	6.92E-07
Cm-244	1.03E-23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.01E-06	0.00E+00	0.00E+00	3.61E-16	0.00E+00	0.00E+00	0.00E+00	2.01E-06
Co-60	5.47E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.09E-09	0.00E+00	0.00E+00	1.25E-11	0.00E+00	0.00E+00	0.00E+00	5.58E-08
Cs-137	1.31E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.38E-09	0.00E+00	0.00E+00	2.71E-12	0.00E+00	0.00E+00	0.00E+00	1.45E-08
Ir-192	5.61E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.89E-10	0.00E+00	0.00E+00	3.11E-12	0.00E+00	0.00E+00	0.00E+00	5.80E-09
Po-210	1.03E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.33E-07	0.00E+00	0.00E+00	3.61E-17	0.00E+00	0.00E+00	0.00E+00	1.33E-07
Pu-238	3.97E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.90E-06	0.00E+00	0.00E+00	3.73E-16	0.00E+00	0.00E+00	0.00E+00	3.90E-06
Pu-239	6.79E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.25E-06	0.00E+00	0.00E+00	3.72E-16	0.00E+00	0.00E+00	0.00E+00	4.25E-06
Ra-226	4.07E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.38E-07	0.00E+00	0.00E+00	8.92E-12	0.00E+00	0.00E+00	0.00E+00	3.79E-07
Sr-90	1.13E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.71E-09	0.00E+00	0.00E+00	9.46E-14	0.00E+00	0.00E+00	0.00E+00	5.83E-09

Results for Group E1 — Transportation and Access Routes: Bridges (Cont.)

TABLE 8.A.3 Scenario E1-2: Member of the General Public Drives over Bridges under Unrestricted Conditions (Second Year)

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of bridge contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		Total
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	
Am-241	5.42E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.25E-07	0.00E+00	0.00E+00	2.65E-15	0.00E+00	0.00E+00	0.00E+00	1.25E-07
Cf-252	7.06E-18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.81E-08	0.00E+00	0.00E+00	6.28E-14	0.00E+00	0.00E+00	0.00E+00	1.81E-08
Cm-244	5.95E-24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.06E-08	0.00E+00	0.00E+00	1.26E-17	0.00E+00	0.00E+00	0.00E+00	7.06E-08
Co-60	2.83E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.37E-11	0.00E+00	0.00E+00	3.88E-13	0.00E+00	0.00E+00	0.00E+00	2.83E-08
Cs-137	7.62E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.93E-11	0.00E+00	0.00E+00	9.69E-14	0.00E+00	0.00E+00	0.00E+00	7.67E-09
Ir-192	9.45E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E-13	0.00E+00	0.00E+00	1.68E-15	0.00E+00	0.00E+00	0.00E+00	9.46E-11
Po-210	9.02E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.81E-10	0.00E+00	0.00E+00	1.30E-19	0.00E+00	0.00E+00	0.00E+00	4.81E-10
Pu-238	2.67E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.42E-07	0.00E+00	0.00E+00	1.36E-17	0.00E+00	0.00E+00	0.00E+00	1.42E-07
Pu-239	4.22E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.57E-07	0.00E+00	0.00E+00	1.37E-17	0.00E+00	0.00E+00	0.00E+00	1.57E-07
Ra-226	2.42E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.24E-08	0.00E+00	0.00E+00	3.29E-13	0.00E+00	0.00E+00	0.00E+00	3.67E-08
Sr-90	6.58E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.04E-10	0.00E+00	0.00E+00	3.38E-15	0.00E+00	0.00E+00	0.00E+00	2.70E-10

Results for Group E2 — Transportation and Access Routes: Streets and Thoroughfares

TABLE 8.A.4 Scenario E2-1: Emergency Worker Drives through Streets under Restricted Conditions (First Year)

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	2.68E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-05	0.00E+00	0.00E+00	3.60E-13	0.00E+00	0.00E+00	0.00E+00	1.70E-05
Cf-252	5.84E-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.46E-06	0.00E+00	0.00E+00	1.20E-11	0.00E+00	0.00E+00	0.00E+00	3.46E-06
Cm-244	4.22E-22	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.01E-05	0.00E+00	0.00E+00	1.80E-15	0.00E+00	0.00E+00	0.00E+00	1.01E-05
Co-60	2.33E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.43E-09	0.00E+00	0.00E+00	6.26E-11	0.00E+00	0.00E+00	0.00E+00	2.34E-06
Cs-137	5.53E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.90E-09	0.00E+00	0.00E+00	1.36E-11	0.00E+00	0.00E+00	0.00E+00	5.60E-07
Ir-192	2.45E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.43E-10	0.00E+00	0.00E+00	1.55E-11	0.00E+00	0.00E+00	0.00E+00	2.46E-07
Po-210	4.41E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.65E-07	0.00E+00	0.00E+00	1.81E-16	0.00E+00	0.00E+00	0.00E+00	6.65E-07
Pu-238	1.23E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.95E-05	0.00E+00	0.00E+00	1.87E-15	0.00E+00	0.00E+00	0.00E+00	1.95E-05
Pu-239	2.62E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.13E-05	0.00E+00	0.00E+00	1.86E-15	0.00E+00	0.00E+00	0.00E+00	2.13E-05
Ra-226	1.72E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.69E-06	0.00E+00	0.00E+00	4.46E-11	0.00E+00	0.00E+00	0.00E+00	3.41E-06
Sr-90	4.80E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.86E-08	0.00E+00	0.00E+00	4.73E-13	0.00E+00	0.00E+00	0.00E+00	3.34E-08

TABLE 8.A.5 Scenario E2-2: Member of the General Public Drives through Streets under Unrestricted Conditions (First Year)

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	5.37E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.40E-06	0.00E+00	0.00E+00	7.21E-14	0.00E+00	0.00E+00	0.00E+00	3.40E-06
Cf-252	1.17E-17	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.92E-07	0.00E+00	0.00E+00	2.40E-12	0.00E+00	0.00E+00	0.00E+00	6.92E-07
Cm-244	8.45E-24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.01E-06	0.00E+00	0.00E+00	3.61E-16	0.00E+00	0.00E+00	0.00E+00	2.01E-06
Co-60	4.66E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.09E-09	0.00E+00	0.00E+00	1.25E-11	0.00E+00	0.00E+00	0.00E+00	4.77E-08
Cs-137	1.11E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.38E-09	0.00E+00	0.00E+00	2.71E-12	0.00E+00	0.00E+00	0.00E+00	1.24E-08
Ir-192	4.90E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.89E-10	0.00E+00	0.00E+00	3.11E-12	0.00E+00	0.00E+00	0.00E+00	5.09E-09
Po-210	8.81E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.33E-07	0.00E+00	0.00E+00	3.61E-17	0.00E+00	0.00E+00	0.00E+00	1.33E-07
Pu-238	2.47E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.90E-06	0.00E+00	0.00E+00	3.73E-16	0.00E+00	0.00E+00	0.00E+00	3.90E-06
Pu-239	5.24E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.25E-06	0.00E+00	0.00E+00	3.72E-16	0.00E+00	0.00E+00	0.00E+00	4.25E-06
Ra-226	3.44E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.38E-07	0.00E+00	0.00E+00	8.92E-12	0.00E+00	0.00E+00	0.00E+00	3.72E-07
Sr-90	9.60E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.71E-09	0.00E+00	0.00E+00	9.46E-14	0.00E+00	0.00E+00	0.00E+00	5.81E-09

Results for Group E2 — Transportation and Access Routes: Streets and Thoroughfares (Cont.)

TABLE 8.A.6 Scenario E2-2: Member of the General Public Drives through Streets under Unrestricted Conditions (Second Year)

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of street contamination)														Total
	External						Inhalation		Radon	Air Submersion		Dust Ingestion			
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside		
Am-241	2.89E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.25E-07	0.00E+00	0.00E+00	2.65E-15	0.00E+00	0.00E+00	0.00E+00		1.25E-07
Cf-252	4.77E-18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.81E-08	0.00E+00	0.00E+00	6.28E-14	0.00E+00	0.00E+00	0.00E+00		1.81E-08
Cm-244	4.38E-24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.06E-08	0.00E+00	0.00E+00	1.26E-17	0.00E+00	0.00E+00	0.00E+00		7.06E-08
Co-60	2.19E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.37E-11	0.00E+00	0.00E+00	3.88E-13	0.00E+00	0.00E+00	0.00E+00		2.19E-08
Cs-137	5.82E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.93E-11	0.00E+00	0.00E+00	9.69E-14	0.00E+00	0.00E+00	0.00E+00		5.87E-09
Ir-192	7.44E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E-13	0.00E+00	0.00E+00	1.68E-15	0.00E+00	0.00E+00	0.00E+00		7.45E-11
Po-210	6.98E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.81E-10	0.00E+00	0.00E+00	1.30E-19	0.00E+00	0.00E+00	0.00E+00		4.81E-10
Pu-238	1.32E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.42E-07	0.00E+00	0.00E+00	1.36E-17	0.00E+00	0.00E+00	0.00E+00		1.42E-07
Pu-239	2.82E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.57E-07	0.00E+00	0.00E+00	1.37E-17	0.00E+00	0.00E+00	0.00E+00		1.57E-07
Ra-226	1.85E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.24E-08	0.00E+00	0.00E+00	3.29E-13	0.00E+00	0.00E+00	0.00E+00		3.10E-08
Sr-90	5.05E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.04E-10	0.00E+00	0.00E+00	3.38E-15	0.00E+00	0.00E+00	0.00E+00		2.55E-10

Results for Group E3 — Transportation and Access Routes: Sidewalks and Walkways

TABLE 8.A.7 Scenario E3-1: Essential Service Worker Uses Sidewalks and Walkways under Restricted Conditions (First Year)

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of sidewalk/walkway contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		Total
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	
Am-241	3.58E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-05	0.00E+00	0.00E+00	3.60E-13	0.00E+00	1.30E-06	0.00E+00	1.84E-05
Cf-252	5.89E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.46E-06	0.00E+00	0.00E+00	1.20E-11	0.00E+00	5.26E-07	0.00E+00	4.58E-06
Cm-244	9.73E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.01E-05	0.00E+00	0.00E+00	1.80E-15	0.00E+00	7.68E-07	0.00E+00	1.08E-05
Co-60	2.50E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.43E-09	0.00E+00	0.00E+00	6.26E-11	0.00E+00	2.09E-08	0.00E+00	2.52E-06
Cs-137	6.30E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.90E-09	0.00E+00	0.00E+00	1.36E-11	0.00E+00	8.37E-08	0.00E+00	7.20E-07
Ir-192	2.60E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.43E-10	0.00E+00	0.00E+00	1.55E-11	0.00E+00	3.27E-09	0.00E+00	2.64E-07
Po-210	4.85E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.65E-07	0.00E+00	0.00E+00	1.81E-16	0.00E+00	4.13E-06	0.00E+00	4.79E-06
Pu-238	9.59E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.95E-05	0.00E+00	0.00E+00	1.87E-15	0.00E+00	1.49E-06	0.00E+00	2.10E-05
Pu-239	4.37E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.13E-05	0.00E+00	0.00E+00	1.86E-15	0.00E+00	1.63E-06	0.00E+00	2.29E-05
Ra-226	1.94E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.69E-06	0.00E+00	0.00E+00	4.46E-11	0.00E+00	1.82E-06	0.00E+00	5.45E-06
Sr-90	1.24E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.86E-08	0.00E+00	0.00E+00	4.73E-13	0.00E+00	1.98E-07	0.00E+00	3.51E-07

TABLE 8.A.8 Scenario E3-2: Volunteer Collects Donations near Streets (First Year)

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of sidewalk/walkway contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		Total
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	
Am-241	3.58E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-04	0.00E+00	0.00E+00	3.60E-12	0.00E+00	1.30E-06	0.00E+00	1.71E-04
Cf-252	5.89E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.46E-05	0.00E+00	0.00E+00	1.20E-10	0.00E+00	5.26E-07	0.00E+00	3.57E-05
Cm-244	9.73E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.01E-04	0.00E+00	0.00E+00	1.80E-14	0.00E+00	7.68E-07	0.00E+00	1.01E-04
Co-60	2.50E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.43E-08	0.00E+00	0.00E+00	6.26E-10	0.00E+00	2.09E-08	0.00E+00	2.57E-06
Cs-137	6.30E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.90E-08	0.00E+00	0.00E+00	1.36E-10	0.00E+00	8.37E-08	0.00E+00	7.83E-07
Ir-192	2.60E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.43E-09	0.00E+00	0.00E+00	1.55E-10	0.00E+00	3.27E-09	0.00E+00	2.73E-07
Po-210	4.85E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.65E-06	0.00E+00	0.00E+00	1.81E-15	0.00E+00	4.13E-06	0.00E+00	1.08E-05
Pu-238	9.59E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.95E-04	0.00E+00	0.00E+00	1.87E-14	0.00E+00	1.49E-06	0.00E+00	1.96E-04
Pu-239	4.37E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.13E-04	0.00E+00	0.00E+00	1.86E-14	0.00E+00	1.63E-06	0.00E+00	2.14E-04
Ra-226	1.94E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.69E-05	0.00E+00	0.00E+00	4.46E-10	0.00E+00	1.82E-06	0.00E+00	2.07E-05
Sr-90	1.24E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.86E-07	0.00E+00	0.00E+00	4.73E-12	0.00E+00	1.98E-07	0.00E+00	6.08E-07

Results for Group E3 — Transportation and Access Routes: Sidewalks and Walkways (Cont.)

TABLE 8.A.9 Scenario E3-3: Vendor Sells Merchandise Away from Streets (First Year)

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of sidewalk/walkway contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	2.86E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.36E-04	0.00E+00	0.00E+00	2.88E-12	0.00E+00	1.04E-05	0.00E+00	1.47E-04
Cf-252	4.71E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.77E-05	0.00E+00	0.00E+00	9.61E-11	0.00E+00	4.21E-06	0.00E+00	3.66E-05
Cm-244	7.78E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.05E-05	0.00E+00	0.00E+00	1.44E-14	0.00E+00	6.14E-06	0.00E+00	8.67E-05
Co-60	2.00E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.34E-08	0.00E+00	0.00E+00	5.01E-10	0.00E+00	1.68E-07	0.00E+00	2.02E-05
Cs-137	5.04E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.52E-08	0.00E+00	0.00E+00	1.08E-10	0.00E+00	6.70E-07	0.00E+00	5.76E-06
Ir-192	2.08E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.55E-09	0.00E+00	0.00E+00	1.24E-10	0.00E+00	2.62E-08	0.00E+00	2.11E-06
Po-210	3.88E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.32E-06	0.00E+00	0.00E+00	1.44E-15	0.00E+00	3.30E-05	0.00E+00	3.84E-05
Pu-238	7.67E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.56E-04	0.00E+00	0.00E+00	1.49E-14	0.00E+00	1.19E-05	0.00E+00	1.68E-04
Pu-239	3.50E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.70E-04	0.00E+00	0.00E+00	1.49E-14	0.00E+00	1.30E-05	0.00E+00	1.83E-04
Ra-226	1.55E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.35E-05	0.00E+00	0.00E+00	3.57E-10	0.00E+00	1.46E-05	0.00E+00	4.36E-05
Sr-90	9.95E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.29E-07	0.00E+00	0.00E+00	3.78E-12	0.00E+00	1.58E-06	0.00E+00	2.81E-06

TABLE 8.A.10 Scenario E3-2: Volunteer Collects Donations near Streets (Second Year)

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of sidewalk/walkway contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	Total
Am-241	1.93E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.26E-06	0.00E+00	0.00E+00	1.33E-13	0.00E+00	6.99E-07	0.00E+00	6.98E-06
Cf-252	2.41E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.04E-07	0.00E+00	0.00E+00	3.14E-12	0.00E+00	2.15E-07	0.00E+00	1.36E-06
Cm-244	5.04E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.53E-06	0.00E+00	0.00E+00	6.32E-16	0.00E+00	3.98E-07	0.00E+00	3.93E-06
Co-60	1.17E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.68E-09	0.00E+00	0.00E+00	1.94E-11	0.00E+00	9.83E-09	0.00E+00	1.18E-06
Cs-137	3.31E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-09	0.00E+00	0.00E+00	4.84E-12	0.00E+00	4.40E-08	0.00E+00	3.78E-07
Ir-192	3.95E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.11E-12	0.00E+00	0.00E+00	8.41E-14	0.00E+00	4.97E-11	0.00E+00	4.00E-09
Po-210	3.84E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.40E-08	0.00E+00	0.00E+00	6.52E-18	0.00E+00	3.27E-07	0.00E+00	3.51E-07
Pu-238	5.13E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.11E-06	0.00E+00	0.00E+00	6.81E-16	0.00E+00	7.97E-07	0.00E+00	7.90E-06
Pu-239	2.36E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.84E-06	0.00E+00	0.00E+00	6.85E-16	0.00E+00	8.76E-07	0.00E+00	8.72E-06
Ra-226	1.05E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.22E-07	0.00E+00	0.00E+00	1.64E-11	0.00E+00	9.82E-07	0.00E+00	2.65E-06
Sr-90	6.54E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E-08	0.00E+00	0.00E+00	1.69E-13	0.00E+00	1.04E-07	0.00E+00	1.80E-07

TABLE 8.A.11 Scenario E3-3: Vendor Sells Merchandise Away from Streets (Second Year)

Radionuclide	Dose-to-Source Ratio from Individual Exposure Pathways (mrem/yr per pCi/m^2 of sidewalk/walkway contamination)													
	External						Inhalation		Radon	Air Submersion		Dust Ingestion		Total
	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Inside	Outside	Inside	Outside	Inside	
Am-241	1.54E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.01E-06	0.00E+00	0.00E+00	1.06E-13	0.00E+00	5.60E-06	0.00E+00	1.08E-05
Cf-252	1.93E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.23E-07	0.00E+00	0.00E+00	2.51E-12	0.00E+00	1.72E-06	0.00E+00	4.37E-06
Cm-244	4.03E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.82E-06	0.00E+00	0.00E+00	5.05E-16	0.00E+00	3.18E-06	0.00E+00	6.01E-06
Co-60	9.37E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.35E-09	0.00E+00	0.00E+00	1.55E-11	0.00E+00	7.87E-08	0.00E+00	9.45E-06
Cs-137	2.65E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.97E-09	0.00E+00	0.00E+00	3.88E-12	0.00E+00	3.52E-07	0.00E+00	3.01E-06
Ir-192	3.16E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.08E-12	0.00E+00	0.00E+00	6.73E-14	0.00E+00	3.98E-10	0.00E+00	3.20E-08
Po-210	3.07E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.92E-08	0.00E+00	0.00E+00	5.22E-18	0.00E+00	2.62E-06	0.00E+00	2.64E-06
Pu-238	4.10E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.69E-06	0.00E+00	0.00E+00	5.45E-16	0.00E+00	6.38E-06	0.00E+00	1.21E-05
Pu-239	1.88E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.27E-06	0.00E+00	0.00E+00	5.48E-16	0.00E+00	7.01E-06	0.00E+00	1.33E-05
Ra-226	8.37E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.98E-07	0.00E+00	0.00E+00	1.31E-11	0.00E+00	7.85E-06	0.00E+00	1.67E-05
Sr-90	5.23E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.16E-09	0.00E+00	0.00E+00	1.35E-13	0.00E+00	8.31E-07	0.00E+00	1.36E-06

9 GROUP F-4: RELEASE OF REAL PROPERTY FROM RADIOLOGICALLY CONTROLLED AREAS

Group F operational guidelines address the release of property from radiological control. It is noteworthy to highlight that, in particular, operational guidelines for real property (subgroup F-4, buildings and lands) are designed to support implementation of the optimization process as presented in the PAGs for RDD and IND incidents (*Federal Register,* 73 FR 149). Subgroup F-4 guidelines are unique in that there is no one specific predefined numerical criterion (e.g., expressed in terms of dose or risk) on which to base protective action decisions. These guidelines are intended to be applied in the optimization process, which will likely consider the magnitude and extent of the contamination and the radionuclide(s) involved, proposed long-term land and building use in the affected areas, the degree of need for expedited recovery, public welfare issues, cost impacts for each proposed cleanup option, ecological considerations, and other factors.

Group F-4 operational guidelines are provided as reference values (e.g., soil and building-surface concentrations or risks) that can be used as a starting point for evaluating optimization process attributes and impacts relative to a range of dose- or risk-based benchmarks (e.g., 500, 100, 25, or 4 millirem per year; comparative lifetime risk ranges, and others) that could be considered as part of recovery-phase options. Thus, they are not regulatory dose limits or criteria, but serve as concentration values that provide perspective and aid in the optimization analyses. Chapter 11 includes data that may be used to develop operational guidelines for other types of property (e.g., vehicles and equipment).

The operational guidelines for subgroup F-4 were developed for use in releasing real properties — soils and buildings — located within radiologically controlled areas after an RDD event. Because the distribution of radionuclides on different contaminated surfaces would have changed from the original state as a result of any cleanup/remediation activities, the default ratios of radionuclide concentrations among different contaminated surfaces assumed for Groups C–E were not used. The operational guidelines for soil were derived by using the RESRAD code (Yu et al. 2001) and considering only soil contamination. The operational guidelines for buildings were derived by using the RESRAD-BUILD code (Yu et al. 2003) and considering only building contamination existing on the interior floor, on the inside and outside of the surrounding four walls, and on the roof.

The operational guidelines for soil and buildings can be applied separately to release a contaminated land area or building facility for unrestricted use, if the actual contamination exists only in the soil or on the building materials. If both the soil and the building materials are contaminated, then the sum of fractions rule must be applied with the measured concentrations for the soil and building materials to ensure that the PAG will not be exceeded after the properties are released.

Because of the uncertainty pertaining to the location of an RDD event and the affected population, probabilistic analyses were conducted to derive the operational guidelines. In the probabilistic analyses, distribution functions were assigned to the RESRAD and RESRAD-BUILD input parameters that were identified as sensitive in terms of influencing the radiation dose results. Parameters not identified as sensitive were assigned RESRAD or RESRAD-BUILD default values. To derive the operational guidelines, the 50th-percentile peak DSRs and the mean plus two standard deviations of the peak DSRs were used, along with dose criteria of 100 and 4 mrem/yr. These operational guidelines are derived considering the uncertainty of the location of a potential RDD event and the building types involved in an RDD incident. In a real case, the probabilistic methodology described in this chapter can be used to derive incident- and site-specific operational guidelines.

Appendix 9.A provides comparisons of the derived operational guidelines with published screening criteria for release of real properties or contaminated materials. Appendix 9.B presents distribution functions assigned to RESRAD and RESRAD-BUILD input parameters. Appendix 9.C discusses the different building characteristics assumed for deriving the building operational guidelines and their impacts on the DSRs.

9.1 RELEASE OF SOILS

To take into account the uncertainty regarding the environmental setting of an RDD event and the use of the affected area, two resident and two worker scenarios were analyzed to derive the soil release criteria. The two resident scenarios considered reflect two environmental settings, rural and urban. For the rural setting, a subsistence farmer was assumed so that all RESRAD exposure pathways (i.e., external radiation, inhalation of radon and dust, ingestion of soil, plant, meat, milk, fish, and water) could be analyzed. For the urban setting, exposures through ingestion of plant, meat, milk, fish, and water are unlikely in the late phase of response after an RDD event; therefore, only external radiation, inhalation of dust and radon, and ingestion of soil were analyzed. Both residential receptors were assumed to follow the living and food consumption patterns of the general public. To consider different use of the affected area, two worker scenarios were selected to contrast the resident scenarios. The two worker scenarios, one indoor and one outdoor, would bound the potential dose associated with industrial use of the affected area. All dose analyses were accomplished by using a probabilistic approach in which the sensitive physical and behavioral parameters were assigned distribution functions, so that the distribution of potential doses could be analyzed. The sensitive parameters had been identified in previous studies (Yu et al. 2000) and characterized as having a great influence on calculated dose results. Appendix 9.B lists the distribution functions used in the dose analyses. For parameters that were not identified as sensitive, the RESRAD default values were used. The dose analysis spans a time frame of 1,000 years to consider long-term effects resulting from leaching of radionuclides to groundwater.

9.1.1 Scenario Description for Release of Soils

9.1.1.1 Resident Scenarios

In the subsistence farmer scenario, a farmer was assumed to settle on the contaminated area after the release. The farmer built a house, grew plant foods, and raised livestock for consumption. In addition, he drilled a well at the downgradient edge of the contaminated area and pumped out groundwater for use. Occasionally, he fished in a nearby pond and consumed the catch. All RESRAD exposure pathways were selected for dose calculations, including external radiation, inhalation of dust particles and radon, and ingestion of plant foods, meat, milk, soil, and groundwater.

The area of contamination was assumed to be 10,000 m^2. Over time, after an RDD event, the contaminants were assumed to be homogeneously mixed within the top 15 cm of soil for the subsistence farmer scenario assumed as a result of weathering and human activities, including root growth, plowing, shrinking and swelling cycles, rain drop impact, or freezing-thawing of top layer of soils. Note that for some radionuclides, such as Cs-137 and plutonium isotopes, this 15 cm thickness may be a conservative estimate, especially for areas not undergoing agricultural activities such as plowing and cultivating. NCRP Report No. 129 (NCRP 1999) suggested a thickness of 5 cm as an effective depth of deposition contributing to resuspension. If data are available, the actual thickness (and area) can be used in RESRAD to calculate site-specific doses and operational guidelines.

The sensitive physical parameters associated with the local environment and soils were assigned distribution functions representing conditions throughout the country. The distribution functions were obtained from NUREG/CR-6697 (Yu et al. 2000).

On the basis of the area assumption and RESRAD default assumptions, 50% of the plant foods, 50% of the fish, 50% of the meat and milk, and 100% of the drinking water (if radionuclides reach the groundwater table) consumed by the farmer would be contaminated. In dose calculation, the inhalation rate was assigned a triangular distribution, with a minimum of 4,380 m^3/yr (0.5 m^3/h), a maximum of 13,100 m^3/yr (1.5 m^3/h), and a mode of 8,400 m^3/yr (0.96 m^3/h). The soil ingestion rate also assumed a triangular distribution, with a minimum, a maximum, and a mode of 0 g/yr (0 mg/d), 36.5 g/yr (100 mg/d), and 18.3 g/yr (50 mg/d), respectively. The inhalation and ingestion rates were consistent with the recommendation from NUREG/CR-6697 (Yu et al. 2000) for the general public. The indoor time fraction was assigned a continuous distribution function (Yu et al. 2000) on the basis of the EPA's comprehensive review (EPA 1997) of human activity patterns, which contains statistics on the amount of time spent inside a house. According to the distribution, the 50th-percentile value is 0.625, corresponding to 15 h/d. To obtain realistically conservative dose estimates, the RESRAD code was modified so that the outdoor time fraction was calculated and assumed a value to make the sum with the indoor time fraction equal 1. In other words, the receptor was assumed to spend 100% of the time in the contaminated area.

For the urban resident scenario, only the external radiation, inhalation of dust particles and radon, and ingestion of soil pathways were considered. Ingestion of plant, meat, milk, and fish, as well as use of contaminated water, were excluded. All input parameters used for dose calculations were the same as those used for the residential farmer scenario.

9.1.1.2 Worker Scenarios

Aside from residential use, industrial use of the contaminated area that could potentially expose many workers was also considered. For the worker scenarios, exposure pathways considered for dose calculations were external radiation, inhalation of dust particles and radon, and ingestion of soil, which are the same as those for the urban resident scenario. However, the time fraction a worker spent in the contaminated area was less than that spent by a resident. The workers were assumed to be in the area 250 d/yr instead of 365 d/yr. The duration of work per day assumed a continuous distribution, as recommended by NUREG/CR-6697 (Yu et al. 2000) for workers, which was on the basis of the distribution for full-time workers in plants, factories, or warehouses (EPA 1997). The 50th-percentile value is 0.365, corresponding to 8.76 hours per workday. To obtain bounding estimates of potential exposures, it was further assumed that a worker worked either 100% indoors (indoor worker scenario) or 100% outdoors (outdoor worker scenario).

Because of different activity patterns, workers were assigned a higher inhalation rate than residents. The triangular distribution assumed a minimum, a maximum, and a mode of 4,380 m^3/yr (0.5 m^3/h), 16,790 (1.92 m^3/h), and 12,264 m^3/yr (1.4 m^3/h), respectively (Yu et al. 2000). The soil ingestion rate was the same as that for residents, which was the EPA's recommendation for adults (EPA 1997). The other input parameters were assigned values or distribution functions that were the same as those for the residential scenarios.

9.1.2 Dose Calculation for Release of Soils

The Latin hypercube sampling technique was used in sampling input parameter values. A total of 1,500 sets of dose results were obtained (a specification of 500 observations and 3 repetitions). Table 9.1 shows the percentiles, mean, and standard deviation of the peak dose for each individual radionuclide for a soil concentration of 1 pCi/g for the residential farmer scenario. Table 9.2 shows the same information for the urban resident scenario. Tables 9.3 and 9.4 list results for the indoor and outdoor worker scenarios, respectively.

9.1.3 Operational Guideline Derivation for Release of Soils

Tables 9.5 and 9.6 provide the operational guidelines for releasing an area with contaminated soils. Operational guidelines listed in Table 9.5 were obtained by using the 50th-percentile values from the peak DSR distributions (listed in Tables 9.1−9.4) with a dose criteria of 100 and 4 mrem/yr. Table 9.6 lists the operational guidelines obtained by using the mean + 2σ DSR values. The values for the worker scenario are those for outdoor workers, because the radiation doses the outdoor workers receive would be greater than those received by indoor workers if they work the same amount of time in the contaminated area. The default operational guidelines for soils should be based on the residential farmer scenario to ensure the maximum protection for human health. However, the values can be reduced to reflect the actual and likely land use of the contaminated area.

The operational guidelines were derived by considering only exposures from contaminated soils; potential exposures from contaminated buildings were not included. Therefore, when applying the operational guidelines, it is important to make sure that the assumption associated with the guidelines is met by the real contamination situation. For instance, if both the soil and the building are contaminated, then the sum of fractions rule must be used to determine compliance with operational guidelines. See Section 9.3 for a more detailed discussion.

The operational guidelines were derived through a probabilistic analysis to account for the uncertainty in (1) the RDD event location, (2) physical conditions of the contaminated area, and (3) exposure patterns of the receptor. Conservative measures, such as assuming the residents spend 100% of the time in the contaminated area, were incorporated in the guideline derivation. In reality, when site-specific information is available, the level of conservatism can be reduced by conducting a site-specific analysis using the RESRAD code.

TABLE 9.1 Peak Dose-to-Source Ratio Distributions for the Residential Farmer Scenario from Contaminated Soil

	DSR (mrem/yr per pCi/g) for Radionuclides in Contaminated Soil										
Percentile	Am-241	Cf-252	Cm-244	Co-60	Cs-137	Ir-192	Po-210	Pu-238	Pu-239	Ra-226	Sr-90
5	2.15E-02	4.51E-01	4.48E-03	2.50E+00	7.10E-01	2.29E-01	6.77E-02	9.72E-03	1.08E-02	2.21E+01	8.65E-02
10	2.61E-02	6.00E-01	5.73E-03	3.32E+00	8.98E-01	2.98E-01	8.52E-02	1.18E-02	1.30E-02	2.59E+01	1.11E-01
15	2.88E-02	6.99E-01	6.55E-03	3.87E+00	1.02E+00	3.47E-01	9.63E-02	1.32E-02	1.45E-02	2.79E+01	1.38E-01
20	3.09E-02	7.85E-01	7.37E-03	4.34E+00	1.14E+00	3.97E-01	1.09E-01	1.49E-02	1.64E-02	2.97E+01	1.65E-01
25	3.29E-02	8.63E-01	8.11E-03	4.75E+00	1.24E+00	4.36E-01	1.19E-01	1.62E-02	1.78E-02	3.13E+01	1.95E-01
30	3.45E-02	9.45E-01	8.86E-03	5.17E+00	1.34E+00	4.74E-01	1.30E-01	1.76E-02	1.92E-02	3.24E+01	2.23E-01
35	3.60E-02	1.02E+00	9.60E-03	5.57E+00	1.41E+00	5.11E-01	1.46E-01	1.92E-02	2.11E-02	3.35E+01	2.58E-01
40	3.75E-02	1.07E+00	1.04E-02	5.86E+00	1.49E+00	5.35E-01	1.57E-01	2.09E-02	2.29E-02	3.49E+01	3.01E-01
45	3.89E-02	1.12E+00	1.15E-02	6.15E+00	1.55E+00	5.64E-01	1.71E-01	2.23E-02	2.43E-02	3.62E+01	3.41E-01
50	4.02E-02	1.16E+00	1.23E-02	6.45E+00	1.61E+00	5.90E-01	1.82E-01	2.38E-02	2.61E-02	3.75E+01	3.97E-01
55	4.19E-02	1.21E+00	1.33E-02	6.71E+00	1.67E+00	6.10E-01	1.96E-01	2.54E-02	2.78E-02	3.89E+01	4.58E-01
60	4.40E-02	1.26E+00	1.42E-02	6.95E+00	1.73E+00	6.34E-01	2.10E-01	2.69E-02	2.98E-02	4.02E+01	5.24E-01
65	4.59E-02	1.31E+00	1.51E-02	7.25E+00	1.80E+00	6.61E-01	2.27E-01	2.91E-02	3.19E-02	4.17E+01	6.01E-01
70	4.82E-02	1.36E+00	1.61E-02	7.51E+00	1.87E+00	6.89E-01	2.50E-01	3.16E-02	3.46E-02	4.36E+01	6.95E-01
75	5.10E-02	1.41E+00	1.77E-02	7.80E+00	1.93E+00	7.17E-01	2.77E-01	3.48E-02	3.80E-02	4.59E+01	8.68E-01
80	5.45E-02	1.47E+00	1.94E-02	8.11E+00	2.02E+00	7.48E-01	3.10E-01	3.80E-02	4.18E-02	4.82E+01	1.04E+00
85	5.84E-02	1.55E+00	2.19E-02	8.55E+00	2.13E+00	7.87E-01	3.51E-01	4.25E-02	4.63E-02	5.04E+01	1.25E+00
90	6.60E-02	1.65E+00	2.60E-02	9.10E+00	2.28E+00	8.45E-01	3.95E-01	5.05E-02	5.54E-02	5.46E+01	1.73E+00
95	8.18E-02	1.82E+00	3.35E-02	1.01E+01	2.49E+00	9.27E-01	4.90E-01	6.41E-02	7.05E-02	5.88E+01	2.67E+00
Mean	4.53E-02	1.15E+00	1.50E-02	6.33E+00	1.61E+00	5.80E-01	2.22E-01	3.01E-02	3.29E-02	3.87E+01	7.81E-01
σ	2.84E-02	4.00E-01	1.29E-02	2.22E+00	5.48E-01	2.04E-01	1.56E-01	3.01E-02	3.30E-02	1.13E+01	1.34E+00
Mean + 2σ	1.02E-01	1.95E+00	4.09E-02	1.08E+01	2.70E+00	9.88E-01	5.35E-01	9.03E-02	9.90E-02	6.13E+01	3.46E+00

TABLE 9.2 Peak Dose-to-Source Ratio Distributions for the Urban Resident Scenario from Contaminated Soil

	DSR (mrem/yr per pCi/g) for Radionuclides in Contaminated Soil										
Percentile	Am-241	Cf-252	Cm-244	Co-60	Cs-137	Ir-192	Po-210	Pu-238	Pu-239	Ra-226	Sr-90
5	1.58E-02	4.49E-01	2.25E-03	2.48E+00	5.93E-01	2.28E-01	5.97E-03	4.34E-03	4.82E-03	2.18E+01	8.47E-03
10	1.92E-02	5.97E-01	2.89E-03	3.29E+00	7.76E-01	2.98E-01	8.43E-03	5.60E-03	6.15E-03	2.50E+01	1.06E-02
15	2.16E-02	6.93E-01	3.54E-03	3.83E+00	9.22E-01	3.46E-01	1.05E-02	6.86E-03	7.58E-03	2.69E+01	1.25E-02
20	2.37E-02	7.79E-01	3.87E-03	4.29E+00	1.02E+00	3.96E-01	1.23E-02	7.52E-03	8.25E-03	2.89E+01	1.41E-02
25	2.51E-02	8.56E-01	4.33E-03	4.71E+00	1.13E+00	4.35E-01	1.39E-02	8.35E-03	9.21E-03	3.03E+01	1.55E-02
30	2.64E-02	9.34E-01	4.73E-03	5.13E+00	1.23E+00	4.73E-01	1.57E-02	9.14E-03	1.01E-02	3.16E+01	1.69E-02
35	2.78E-02	1.01E+00	5.20E-03	5.52E+00	1.31E+00	5.09E-01	1.69E-02	1.00E-02	1.11E-02	3.27E+01	1.84E-02
40	2.91E-02	1.06E+00	5.64E-03	5.81E+00	1.38E+00	5.34E-01	1.85E-02	1.09E-02	1.20E-02	3.43E+01	1.94E-02
45	3.02E-02	1.11E+00	5.98E-03	6.12E+00	1.44E+00	5.63E-01	2.00E-02	1.16E-02	1.27E-02	3.56E+01	2.03E-02
50	3.15E-02	1.16E+00	6.46E-03	6.41E+00	1.50E+00	5.89E-01	2.20E-02	1.25E-02	1.38E-02	3.68E+01	2.13E-02
55	3.26E-02	1.20E+00	7.03E-03	6.67E+00	1.56E+00	6.09E-01	2.38E-02	1.36E-02	1.50E-02	3.83E+01	2.22E-02
60	3.39E-02	1.25E+00	7.69E-03	6.92E+00	1.62E+00	6.34E-01	2.58E-02	1.49E-02	1.63E-02	3.96E+01	2.30E-02
65	3.53E-02	1.30E+00	8.30E-03	7.21E+00	1.69E+00	6.60E-01	2.83E-02	1.61E-02	1.77E-02	4.10E+01	2.38E-02
70	3.66E-02	1.36E+00	8.95E-03	7.47E+00	1.75E+00	6.88E-01	3.11E-02	1.73E-02	1.90E-02	4.29E+01	2.48E-02
75	3.82E-02	1.41E+00	9.71E-03	7.78E+00	1.82E+00	7.16E-01	3.36E-02	1.88E-02	2.07E-02	4.51E+01	2.59E-02
80	3.97E-02	1.47E+00	1.06E-02	8.08E+00	1.89E+00	7.47E-01	3.65E-02	2.05E-02	2.24E-02	4.73E+01	2.68E-02
85	4.14E-02	1.54E+00	1.14E-02	8.53E+00	1.99E+00	7.84E-01	4.04E-02	2.20E-02	2.40E-02	4.95E+01	2.80E-02
90	4.41E-02	1.65E+00	1.28E-02	9.06E+00	2.13E+00	8.44E-01	4.61E-02	2.50E-02	2.73E-02	5.35E+01	2.99E-02
95	4.82E-02	1.82E+00	1.44E-02	1.01E+01	2.35E+00	9.24E-01	5.32E-02	2.79E-02	3.07E-02	5.80E+01	3.31E-02
Mean	3.17E-02	1.14E+00	7.27E-03	6.29E+00	1.48E+00	5.79E-01	2.48E-02	1.41E-02	1.55E-02	3.79E+01	2.08E-02
σ	9.70E-03	3.99E-01	3.80E-03	2.22E+00	5.09E-01	2.04E-01	1.42E-02	7.38E-03	8.06E-03	1.13E+01	7.33E-03
Mean + 2σ	5.11E-02	1.94E+00	1.49E-02	1.07E+01	2.50E+00	9.87E-01	5.33E-02	2.89E-02	3.16E-02	6.04E+01	3.55E-02

TABLE 9.3 Peak Dose-to-Source Ratio Distributions for the Indoor Worker Scenario from Contaminated Soil

	DSR (mrem/yr per pCi/g) for Radionuclides in Contaminated Soil										
Percentile	Am-241	Cf-252	Cm-244	Co-60	Cs-137	Ir-192	Po-210	Pu-238	Pu-239	Ra-226	Sr-90
5	5.04E-04	1.22E-02	1.42E-04	6.71E-02	1.60E-02	6.27E-03	4.33E-04	2.76E-04	3.02E-04	1.38E+00	2.31E-04
10	1.27E-03	3.18E-02	3.49E-04	1.73E-01	4.13E-02	1.62E-02	9.44E-04	6.70E-04	7.44E-04	3.57E+00	6.46E-04
15	2.11E-03	4.78E-02	5.18E-04	2.54E-01	6.09E-02	2.37E-02	1.46E-03	1.01E-03	1.10E-03	5.97E+00	9.57E-04
20	2.68E-03	6.05E-02	6.50E-04	3.33E-01	7.92E-02	3.00E-02	2.00E-03	1.26E-03	1.38E-03	8.18E+00	1.20E-03
25	3.14E-03	7.18E-02	7.92E-04	3.94E-01	9.34E-02	3.62E-02	2.41E-03	1.54E-03	1.69E-03	9.55E+00	1.43E-03
30	3.55E-03	8.24E-02	8.97E-04	4.55E-01	1.07E-01	4.19E-02	2.91E-03	1.74E-03	1.91E-03	1.05E+01	1.62E-03
35	3.88E-03	9.27E-02	1.02E-03	5.04E-01	1.19E-01	4.64E-02	3.35E-03	1.99E-03	2.17E-03	1.12E+01	1.80E-03
40	4.18E-03	1.02E-01	1.14E-03	5.55E-01	1.32E-01	5.06E-02	3.81E-03	2.21E-03	2.42E-03	1.18E+01	2.00E-03
45	4.59E-03	1.11E-01	1.24E-03	6.10E-01	1.45E-01	5.62E-02	4.21E-03	2.40E-03	2.64E-03	1.23E+01	2.18E-03
50	4.89E-03	1.22E-01	1.36E-03	6.69E-01	1.58E-01	6.19E-02	4.70E-03	2.65E-03	2.90E-03	1.28E+01	2.37E-03
55	5.30E-03	1.34E-01	1.54E-03	7.28E-01	1.76E-01	6.82E-02	5.12E-03	2.98E-03	3.27E-03	1.33E+01	2.59E-03
60	5.78E-03	1.49E-01	1.68E-03	8.21E-01	1.94E-01	7.51E-02	5.76E-03	3.25E-03	3.56E-03	1.39E+01	2.84E-03
65	6.18E-03	1.63E-01	1.89E-03	8.94E-01	2.13E-01	8.25E-02	6.46E-03	3.64E-03	4.00E-03	1.45E+01	3.14E-03
70	6.64E-03	1.79E-01	2.08E-03	9.90E-01	2.31E-01	9.00E-02	7.11E-03	4.03E-03	4.42E-03	1.51E+01	3.43E-03
75	7.11E-03	1.97E-01	2.34E-03	1.09E+00	2.55E-01	9.89E-02	8.02E-03	4.55E-03	5.00E-03	1.57E+01	3.76E-03
80	7.74E-03	2.19E-01	2.56E-03	1.21E+00	2.85E-01	1.08E-01	9.04E-03	4.97E-03	5.43E-03	1.64E+01	4.14E-03
85	8.42E-03	2.56E-01	2.88E-03	1.41E+00	3.25E-01	1.27E-01	1.03E-02	5.61E-03	6.11E-03	1.73E+01	4.69E-03
90	9.40E-03	2.92E-01	3.33E-03	1.62E+00	3.76E-01	1.50E-01	1.17E-02	6.49E-03	7.08E-03	1.86E+01	5.48E-03
95	1.09E-02	3.54E-01	3.95E-03	1.96E+00	4.58E-01	1.83E-01	1.38E-02	7.63E-03	8.41E-03	2.00E+01	6.51E-03
Mean	5.29E-03	1.47E-01	1.66E-03	8.09E-01	1.90E-01	7.42E-02	5.66E-03	3.22E-03	3.53E-03	1.22E+01	2.79E-03
σ	3.14E-03	1.08E-01	1.21E-03	5.94E-01	1.38E-01	5.48E-02	4.25E-03	2.35E-03	2.57E-03	5.40E+00	1.96E-03
Mean + 2σ	1.16E-02	3.62E-01	4.08E-03	2.00E+00	4.67E-01	1.84E-01	1.42E-02	7.92E-03	8.67E-03	2.30E+01	6.71E-03

TABLE 9.4 Peak Dose-to-Source Ratio Distributions for the Outdoor Worker Scenario from Contaminated Soil

	DSR (mrem/yr per pCi/g) for Radionuclides in Contaminated Soil										
Percentile	Am-241	Cf-252	Cm-244	Co-60	Cs-137	Ir-192	Po-210	Pu-238	Pu-239	Ra-226	Sr-90
5	1.15E-03	4.97E-02	1.82E-04	2.81E-01	6.43E-02	2.52E-02	4.25E-04	3.54E-04	3.88E-04	2.08E-01	8.82E-04
10	3.52E-03	1.41E-01	4.70E-04	7.58E-01	1.84E-01	7.13E-02	9.65E-04	9.13E-04	1.00E-03	6.08E-01	2.26E-03
15	5.60E-03	2.34E-01	6.57E-04	1.30E+00	3.06E-01	1.16E-01	1.62E-03	1.27E-03	1.41E-03	9.96E-01	3.83E-03
20	7.78E-03	3.21E-01	8.39E-04	1.74E+00	4.18E-01	1.56E-01	2.12E-03	1.62E-03	1.80E-03	1.43E+00	5.12E-03
25	9.15E-03	3.86E-01	1.01E-03	2.15E+00	5.22E-01	1.95E-01	2.49E-03	1.97E-03	2.16E-03	1.73E+00	6.33E-03
30	9.89E-03	4.37E-01	1.17E-03	2.41E+00	5.75E-01	2.25E-01	2.90E-03	2.25E-03	2.49E-03	1.86E+00	7.38E-03
35	1.05E-02	4.61E-01	1.29E-03	2.55E+00	6.03E-01	2.34E-01	3.26E-03	2.51E-03	2.77E-03	1.94E+00	8.11E-03
40	1.10E-02	4.79E-01	1.44E-03	2.64E+00	6.24E-01	2.43E-01	3.74E-03	2.80E-03	3.08E-03	2.02E+00	8.49E-03
45	1.15E-02	4.96E-01	1.56E-03	2.73E+00	6.47E-01	2.52E-01	4.28E-03	3.01E-03	3.34E-03	2.09E+00	8.81E-03
50	1.19E-02	5.12E-01	1.73E-03	2.81E+00	6.65E-01	2.60E-01	4.72E-03	3.36E-03	3.69E-03	2.14E+00	9.13E-03
55	1.25E-02	5.25E-01	1.97E-03	2.91E+00	6.80E-01	2.68E-01	5.21E-03	3.79E-03	4.18E-03	2.20E+00	9.43E-03
60	1.30E-02	5.40E-01	2.11E-03	2.99E+00	6.98E-01	2.76E-01	5.82E-03	4.10E-03	4.52E-03	2.26E+00	9.77E-03
65	1.34E-02	5.55E-01	2.34E-03	3.08E+00	7.16E-01	2.83E-01	6.44E-03	4.53E-03	4.96E-03	2.32E+00	1.00E-02
70	1.40E-02	5.69E-01	2.58E-03	3.16E+00	7.35E-01	2.89E-01	7.26E-03	5.00E-03	5.48E-03	2.37E+00	1.03E-02
75	1.47E-02	5.89E-01	2.87E-03	3.25E+00	7.57E-01	2.98E-01	8.12E-03	5.55E-03	6.11E-03	2.45E+00	1.06E-02
80	1.54E-02	6.10E-01	3.16E-03	3.38E+00	7.90E-01	3.09E-01	9.03E-03	6.13E-03	6.75E-03	2.55E+00	1.09E-02
85	1.61E-02	6.42E-01	3.53E-03	3.55E+00	8.32E-01	3.28E-01	1.02E-02	6.85E-03	7.53E-03	2.68E+00	1.15E-02
90	1.71E-02	6.80E-01	3.93E-03	3.76E+00	8.76E-01	3.47E-01	1.15E-02	7.62E-03	8.38E-03	2.82E+00	1.22E-02
95	1.87E-02	7.35E-01	4.53E-03	4.07E+00	9.54E-01	3.76E-01	1.38E-02	8.81E-03	9.68E-03	3.07E+00	1.33E-02
Mean	1.14E-02	4.71E-01	2.03E-03	2.60E+00	6.12E-01	2.39E-01	5.67E-03	3.93E-03	4.32E-03	1.98E+00	8.34E-03
σ	5.05E-03	1.96E-01	1.37E-03	1.08E+00	2.51E-01	1.00E-01	4.16E-03	2.67E-03	2.92E-03	8.07E-01	3.62E-03
Mean + 2σ	2.15E-02	8.64E-01	4.78E-03	4.77E+00	1.11E+00	4.39E-01	1.40E-02	9.27E-03	1.02E-02	3.59E+00	1.56E-02

TABLE 9.5 Operational Guidelines (pCi/g) for Contaminated Soils Obtained by Using the 50th-Percentile Values from Peak Dose-to-Source Ratio Distributions

	Residential Farmer		Urban Resident		Worker	
Radionuclides	100 mrem/yr	4 mrem/yr	100 mrem/yr	4 mrem/yr	100 mrem/yr	4 mrem/yr
Am-241	2.49E+03	9.96E+01	3.17E+03	1.27E+02	8.38E+03	3.35E+02
Cf-252	8.61E+01	3.44E+00	8.64E+01	3.46E+00	1.95E+02	7.81E+00
Cm-244	8.14E+03	3.25E+02	1.55E+04	6.19E+02	5.77E+04	2.31E+03
Co-60	1.55E+01	6.20E-01	1.56E+01	6.24E-01	3.55E+01	1.42E+00
Cs-137	6.22E+01	2.49E+00	6.68E+01	2.67E+00	1.50E+02	6.01E+00
Ir-192	1.70E+02	6.78E+00	1.70E+02	6.79E+00	3.85E+02	1.54E+01
Po-210	5.50E+02	2.20E+01	4.54E+03	1.82E+02	2.12E+04	8.48E+02
Pu-238	4.21E+03	1.68E+02	7.97E+03	3.19E+02	2.98E+04	1.19E+03
Pu-239	3.83E+03	1.53E+02	7.26E+03	2.90E+02	2.71E+04	1.08E+03
Ra-226	2.67E+00	1.07E-01	2.72E+00	1.09E-01	4.67E+01	1.87E+00
Sr-90	2.52E+02	1.01E+01	4.69E+03	1.88E+02	1.10E+04	4.38E+02

TABLE 9.6 Operational Guidelines (pCi/g) for Contaminated Soils Obtained by Using the Mean + 2σ Values from Peak Dose-to-Source Ratio Distributions

	Residential Farmer		Urban Resident		Worker	
Radionuclides	100 mrem/yr	4 mrem/yr	100 mrem/yr	4 mrem/yr	100 mrem/yr	4 mrem/yr
Am-241	9.80E+02	3.92E+01	1.96E+03	7.83E+01	4.64E+03	1.86E+02
Cf-252	5.13E+01	2.05E+00	5.15E+01	2.06E+00	1.16E+02	4.63E+00
Cm-244	2.44E+03	9.77E+01	6.73E+03	2.69E+02	2.09E+04	8.38E+02
Co-60	9.28E+00	3.71E-01	9.32E+00	3.73E-01	2.10E+01	8.39E-01
Cs-137	3.70E+01	1.48E+00	4.00E+01	1.60E+00	8.98E+01	3.59E+00
Ir-192	1.01E+02	4.05E+00	1.01E+02	4.05E+00	2.28E+02	9.10E+00
Po-210	1.87E+02	7.48E+00	1.88E+03	7.51E+01	7.15E+03	2.86E+02
Pu-238	1.11E+03	4.43E+01	3.47E+03	1.39E+02	1.08E+04	4.32E+02
Pu-239	1.01E+03	4.04E+01	3.17E+03	1.27E+02	9.84E+03	3.93E+02
Ra-226	1.63E+00	6.53E-02	1.65E+00	6.62E-02	2.78E+01	1.11E+00
Sr-90	2.89E+01	1.16E+00	2.82E+03	1.13E+02	6.42E+03	2.57E+02

9.2 RELEASE OF BUILDINGS

Two types of buildings were considered when deriving the operational guidelines: residential buildings and commercial buildings. To account for the differences in the building characteristics, three residential buildings (urban apartment, suburban house, and small rural house) and two commercial buildings (large warehouse and small store/office) with different building dimensions and shielding thicknesses were analyzed. The characteristics of the buildings are described in Appendix 9.C.

Contamination was assumed to exist on the interior floor, the inside and outside of the four surrounding walls, and the roof. The contamination levels on all surfaces were assumed to be equal, in order to safeguard against the uncertainty associated with cleanup/remediation activities. A receptor staying inside a contaminated building (either a resident or a worker) was assumed to incur radiation doses through (1) external radiation from the floor, interior and exterior walls, and roof; (2) inhalation of contaminated particles suspended from the floor and interior walls; (3) ingestion of deposited dust particles; (4) external radiation from submersion in contaminated air; (5) inhalation of radon released from the floor and interior walls contaminated with radon precursors; and (6) external radiation from deposited dust particles.

To account for uncertainty in the type of receptor and in the receptor's activities, a probabilistic approach was used to quantify the distribution of potential radiation doses. The RESRAD-BUILD parameters that were identified as being sensitive in terms of having great influence on the dose results were assigned distribution functions obtained from NUREG/CR-6697 (Yu et al. 2000). Appendix 9.B lists the distribution functions used in the analyses. The other parameters were assigned the RESRAD-BUILD default values. The most sensitive parameters on the basis of the probabilistic analysis results are also discussed in Appendix 9.B.

9.2.1 Scenario Description for Release of Buildings

9.2.1.1 Resident Scenario

The receptors considered for residential buildings were residents of the buildings. The indoor time fraction they spent in the buildings was assigned a continuous distribution function

(Yu et al. 2000) on the basis of EPA's comprehensive review (EPA 1997) of human activity patterns that contains statistics on the amount of time spent inside a house. According to the distribution, the 50th-percentile value is 0.625, corresponding to 15 h/d. This assumption is consistent with that used for deriving soil operational guidelines. The inhalation rate of the residents was assumed to have a triangular distribution ranging from 12 to 35.9 m^3/d (0.5 to 1.5 m^3/h), with a mode at 23 m^3/d (0.96 m^3/d), which is characteristic for the general public (EPA 1997). The indirect ingestion rate of deposited dust particles was assigned a loguniform distribution with a minimum of 2.8E-5 m^2/d and maximum of 2.9E-4 m^2/d (Yu et al. 2000). According to the distribution, the average ingestion rate of deposited dust particles is 1.1 cm^2/h, which is very close to 1 cm^2/h reported in different studies (Healy 1971; Kennedy et al. 1981; ANSI/HPS 1999). Although the receptors may stay at any location inside the building, for external dose calculations, they were assumed to be at the center of the buildings.

9.2.1.2 Worker Scenario

The receptors considered for commercial buildings were workers working inside the buildings. The time fraction they spent inside a building per workday was assumed to follow a continuous distribution, as recommended in NUREG/CR-6697 (Yu et al. 2000). The 50th-percentile value is 0.365, corresponding to 8.76 hours per day. They were further assumed to work 250 days per year. Their inhalation rate was assumed to be greater than that of residents, with a triangular distribution ranging from 12 to 46 m^3/d (0.5 to 1.92 m^3/h) and a mode at 33.6 m^3/d (1.4 m^3/h). The ingestion rate of dust particles was the same as that for residents, which is considered conservative for use in risk assessments. Like the residents, the workers were assumed to be positioned at the center of the commercial buildings for external dose calculations.

9.2.2 Dose Calculations for Release of Buildings

The Latin hypercube sampling technique was used in sampling input parameter values. The dose calculation was repeated 1,500 times (500 observations and 3 repetitions) for the three different residential buildings and two different commercial buildings, and the dose results were analyzed for statistical distribution. Tables 9.7 and 9.8 show the most restrictive dose results for each individual radionuclide for residential and commercial buildings, respectively. Detailed information on dose-to-source ratios associated with different building characteristics is provided in Appendix 9.C.

9.2.3 Operational Guideline Derivation for Release of Buildings

Tables 9.9 and 9.10 provide the operational guidelines in terms of surface concentrations on building materials for releasing residential and commercial buildings. They were obtained by using the 50th-percentile and mean + 2σ values, respectively, from the distributions of dose-to-source ratios (listed in Tables 9.7 and 9.8) and dose criteria of 100 and 4 mrem/yr. Measured concentrations on building surfaces, no matter whether they are from the floor, interior walls, exterior walls, or roof, should be compared with the guideline values. A building can be released for unrestricted use after confirmation that the contamination levels on all surfaces are less than the guideline values. To reduce the conservatism associated with the release, a site-specific analysis can be conducted with measured concentration data by using the RESRAD-BUILD code to demonstrate that the release dose criterion is not exceeded.

The operational guidelines were derived by considering only exposures from contaminated buildings; potential exposures from contaminated soils outside the buildings were not included. Therefore, when applying the operational guidelines, it is important to make sure that the assumption associated with the guidelines is met by the real contamination situation.

TABLE 9.7 Dose-to-Source Ratio Distributions for the Resident Scenario from Contaminated Buildings

Percentile (%)	DSR (mrem/yr per pCi/m^2) for Radionuclides in Residential Buildings										
	Am-241[a]	Cf-252[b]	Cm-244[a]	Co-60[b]	Cs-137[b]	Ir-192[b]	Po-210[a]	Pu-238[a]	Pu-239[a]	Ra-226[a]	Sr-90[a]
5	3.89E-05	5.87E-05	2.20E-05	7.49E-05	1.84E-05	2.06E-05	1.68E-06	4.29E-05	4.74E-05	6.40E-05	2.38E-06
10	6.26E-05	7.53E-05	3.42E-05	8.44E-05	2.06E-05	2.31E-05	2.71E-06	6.86E-05	7.65E-05	8.07E-05	2.70E-06
15	8.56E-05	9.29E-05	4.70E-05	9.17E-05	2.26E-05	2.52E-05	3.65E-06	9.55E-05	1.07E-04	8.97E-05	2.98E-06
20	1.05E-04	1.07E-04	5.92E-05	9.93E-05	2.44E-05	2.72E-05	4.49E-06	1.16E-04	1.30E-04	9.71E-05	3.29E-06
25	1.33E-04	1.20E-04	7.30E-05	1.07E-04	2.61E-05	2.93E-05	5.53E-06	1.49E-04	1.66E-04	1.04E-04	3.48E-06
30	1.60E-04	1.38E-04	8.86E-05	1.11E-04	2.71E-05	3.05E-05	6.61E-06	1.78E-04	2.00E-04	1.12E-04	3.66E-06
35	1.89E-04	1.56E-04	1.04E-04	1.15E-04	2.83E-05	3.16E-05	7.79E-06	2.12E-04	2.36E-04	1.22E-04	3.83E-06
40	2.20E-04	1.77E-04	1.22E-04	1.20E-04	2.93E-05	3.28E-05	9.08E-06	2.44E-04	2.74E-04	1.32E-04	4.04E-06
45	2.50E-04	2.01E-04	1.38E-04	1.24E-04	3.04E-05	3.40E-05	1.03E-05	2.76E-04	3.13E-04	1.42E-04	4.25E-06
50	2.90E-04	2.24E-04	1.60E-04	1.28E-04	3.15E-05	3.51E-05	1.18E-05	3.23E-04	3.62E-04	1.51E-04	4.46E-06
55	3.39E-04	2.53E-04	1.87E-04	1.36E-04	3.33E-05	3.72E-05	1.33E-05	3.74E-04	4.26E-04	1.63E-04	4.73E-06
60	4.01E-04	2.88E-04	2.24E-04	1.43E-04	3.51E-05	3.93E-05	1.58E-05	4.45E-04	5.02E-04	1.75E-04	4.93E-06
65	4.58E-04	3.31E-04	2.57E-04	1.51E-04	3.70E-05	4.13E-05	1.85E-05	5.11E-04	5.75E-04	1.90E-04	5.17E-06
70	5.36E-04	3.81E-04	2.99E-04	1.58E-04	3.88E-05	4.34E-05	2.13E-05	6.01E-04	6.73E-04	2.04E-04	5.42E-06
75	6.43E-04	4.49E-04	3.57E-04	1.66E-04	4.06E-05	4.55E-05	2.55E-05	7.12E-04	8.09E-04	2.26E-04	5.70E-06
80	8.00E-04	5.41E-04	4.48E-04	1.74E-04	4.28E-05	4.79E-05	3.15E-05	8.87E-04	1.01E-03	2.55E-04	5.98E-06
85	9.96E-04	6.77E-04	5.55E-04	1.83E-04	4.50E-05	5.03E-05	3.93E-05	1.13E-03	1.24E-03	2.97E-04	6.26E-06
90	1.32E-03	8.79E-04	7.34E-04	1.93E-04	4.73E-05	5.28E-05	5.07E-05	1.46E-03	1.69E-03	3.68E-04	7.16E-06
95	1.99E-03	1.30E-03	1.05E-03	2.03E-04	4.95E-05	5.57E-05	7.04E-05	2.27E-03	2.54E-03	4.79E-04	9.28E-06
Mean	5.77E-04	4.15E-04	3.17E-04	1.33E-04	3.27E-05	3.66E-05	2.22E-05	6.39E-04	7.33E-04	2.03E-04	4.87E-06
σ	9.36E-04	6.97E-04	5.11E-04	4.20E-05	1.04E-05	1.15E-05	3.42E-05	1.03E-03	1.21E-03	2.12E-04	3.67E-06
Mean + 2σ	2.45E-03	1.81E-03	1.34E-03	2.17E-04	5.35E-05	5.96E-05	9.06E-05	2.70E-03	3.16E-03	6.28E-04	1.22E-05

[a] The most restrictive DSR is based on a rural residential building (area = 36 m^2, height = 2.4 m, shielding thickness = 3.5 cm, and shielding density = 1 g/cm^3 for concrete).

[b] The most restrictive DSR is based on a suburban residential building (area = 196 m^2, height = 2.4 m, shielding thickness = 3.5 cm, and shielding density = 1 g/cm^3 for concrete).

TABLE 9.8 Dose-to-Source Ratio Distributions for the Worker Scenario from Contaminated Buildings

Percentile (%)	DSR (mrem/yr per pCi/m^2) for Radionuclides in Commercial Buildings										
	Am-241[a]	Cf-252[a]	Cm-244[a]	Co-60[b]	Cs-137[b]	Ir-192[b]	Po-210[a]	Pu-238[a]	Pu-239[a]	Ra-226[a]	Sr-90[c]
5	8.82E-06	4.60E-06	5.10E-06	4.21E-06	9.83E-07	1.16E-06	3.78E-07	9.88E-06	1.08E-05	6.55E-06	1.74E-07
10	2.02E-05	1.19E-05	1.09E-05	1.26E-05	2.99E-06	3.45E-06	8.37E-07	2.26E-05	2.49E-05	1.61E-05	4.44E-07
15	2.98E-05	1.86E-05	1.65E-05	2.11E-05	4.89E-06	5.81E-06	1.24E-06	3.28E-05	3.67E-05	2.65E-05	7.66E-07
20	4.12E-05	2.19E-05	2.25E-05	2.95E-05	6.88E-06	8.09E-06	1.69E-06	4.60E-05	5.17E-05	3.31E-05	1.13E-06
25	5.16E-05	2.45E-05	2.88E-05	3.80E-05	8.79E-06	1.04E-05	2.15E-06	5.78E-05	6.41E-05	3.68E-05	1.25E-06
30	6.33E-05	2.72E-05	3.51E-05	3.95E-05	9.16E-06	1.08E-05	2.62E-06	7.16E-05	7.90E-05	4.05E-05	1.31E-06
35	7.54E-05	2.98E-05	4.24E-05	4.10E-05	9.54E-06	1.12E-05	3.18E-06	8.47E-05	9.47E-05	4.31E-05	1.39E-06
40	9.14E-05	3.36E-05	4.91E-05	4.25E-05	9.86E-06	1.16E-05	3.63E-06	1.02E-04	1.14E-04	4.68E-05	1.45E-06
45	1.05E-04	3.69E-05	5.92E-05	4.39E-05	1.02E-05	1.20E-05	4.36E-06	1.19E-04	1.32E-04	5.09E-05	1.52E-06
50	1.24E-04	4.04E-05	6.86E-05	4.53E-05	1.05E-05	1.24E-05	4.99E-06	1.37E-04	1.56E-04	5.62E-05	1.59E-06
55	1.45E-04	4.46E-05	8.19E-05	4.63E-05	1.08E-05	1.27E-05	5.81E-06	1.61E-04	1.83E-04	6.05E-05	1.66E-06
60	1.77E-04	5.05E-05	9.89E-05	4.73E-05	1.10E-05	1.30E-05	6.84E-06	1.99E-04	2.23E-04	6.48E-05	1.73E-06
65	2.11E-04	5.68E-05	1.19E-04	4.82E-05	1.12E-05	1.32E-05	8.31E-06	2.35E-04	2.65E-04	7.19E-05	1.80E-06
70	2.39E-04	6.30E-05	1.37E-04	4.92E-05	1.14E-05	1.35E-05	9.76E-06	2.71E-04	3.02E-04	7.77E-05	1.92E-06
75	2.94E-04	7.10E-05	1.60E-04	5.02E-05	1.17E-05	1.37E-05	1.14E-05	3.28E-04	3.69E-04	8.61E-05	2.04E-06
80	3.64E-04	8.56E-05	2.04E-04	5.28E-05	1.23E-05	1.45E-05	1.43E-05	4.04E-04	4.59E-04	9.70E-05	2.18E-06
85	4.59E-04	1.02E-04	2.58E-04	5.55E-05	1.29E-05	1.52E-05	1.80E-05	5.15E-04	5.78E-04	1.15E-04	2.42E-06
90	6.19E-04	1.32E-04	3.44E-04	5.84E-05	1.37E-05	1.60E-05	2.38E-05	6.95E-04	7.76E-04	1.42E-04	2.81E-06
95	9.14E-04	1.83E-04	5.03E-04	6.40E-05	1.50E-05	1.75E-05	3.45E-05	1.04E-03	1.21E-03	1.95E-04	3.61E-06
Mean	2.61E-04	6.29E-05	1.44E-04	4.14E-05	9.64E-06	1.14E-05	9.97E-06	2.89E-04	3.31E-04	7.55E-05	1.79E-06
σ	4.39E-04	8.01E-05	2.40E-04	1.67E-05	3.90E-06	4.57E-06	1.58E-05	4.84E-04	5.67E-04	8.68E-05	1.49E-06
Mean + 2σ	1.14E-03	2.23E-04	6.24E-04	7.47E-05	1.74E-05	2.05E-05	4.17E-05	1.26E-03	1.46E-03	2.49E-04	4.77E-06

[a] The most restrictive DSR is based on a small commercial building (area = 36 m^2, height = 2.4 m, shielding thickness = 5 cm, and shielding density = 2.4 g/cm^3 for concrete).

[b] The most restrictive DSR is based on a large commercial building (area = 900 m^2, height = 3.7 m, shielding thickness = 10 cm, and shielding density = 2.4 g/cm^3 for concrete).

[c] For strontium-90, the values listed are based on a small commercial building. However, the most restrictive DSR at 50th percentile occurs for a large commercial building (see Table 9.C.5).

TABLE 9.9 Operational Guidelines (pCi/m^2) for Contaminated Buildings Obtained by Using the 50th-Percentile Values from Dose-to-Source Ratio Distributions

	Residential Buildings		Commercial Buildings	
Radionuclide	100 mrem/yr	4 mrem/yr	100 mrem/yr	4 mrem/yr
Am-241	3.5E+05	1.4E+04	8.06E+05	3.22E+04
Cf-252	4.5E+05	1.8E+04	2.48E+06	9.91E+04
Cm-244	6.2E+05	2.5E+04	1.46E+06	5.83E+04
Co-60	7.8E+05	3.1E+04	2.21E+06	8.83E+04
Cs-137	3.2E+06	1.3E+05	9.52E+06	3.81E+05
Ir-192	2.8E+06	1.1E+05	8.06E+06	3.23E+05
Po-210	8.4E+06	3.4E+05	2.01E+07	8.02E+05
Pu-238	3.1E+05	1.2E+04	7.29E+05	2.92E+04
Pu-239	2.8E+05	1.1E+04	6.43E+05	2.57E+04
Ra-226	6.6E+05	2.7E+04	1.78E+06	7.12E+04
Sr-90	2.2E+07	9.0E+05	4.98E+07	1.99E+06

TABLE 9.10 Operational Guidelines (pCi/m^2) for Contaminated Buildings Obtained by Using the Mean + 2σ Values from Dose-to-Source Ratio Distributions

	Residential Buildings		Commercial Buildings	
Radionuclide	100 mrem/yr	4 mrem/yr	100 mrem/yr	4 mrem/yr
Am-241	4.1E+04	1.6E+03	8.79E+04	3.52E+03
Cf-252	5.5E+04	2.2E+03	4.48E+05	1.79E+04
Cm-244	7.5E+04	3.0E+03	1.60E+05	6.41E+03
Co-60	4.6E+05	1.8E+04	1.34E+06	5.35E+04
Cs-137	1.9E+06	7.5E+04	5.75E+06	2.30E+05
Ir-192	1.7E+06	6.7E+04	4.88E+06	1.95E+05
Po-210	1.1E+06	4.4E+04	2.40E+06	9.60E+04
Pu-238	3.7E+04	1.5E+03	7.96E+04	3.18E+03
Pu-239	3.2E+04	1.3E+03	6.83E+04	2.73E+03
Ra-226	1.6E+05	6.4E+03	4.01E+05	1.60E+04
Sr-90	8.2E+06	3.3E+05	2.10E+07	8.38E+05

9.3 APPLICATION OF THE SUM OF FRACTIONS RULE

The operational guidelines presented in Tables 9.5, 9.6, 9.9, and 9.10 were derived by considering a single contamination source in soils and buildings independently. In reality, it is very likely that residual contamination would exist both in the buildings and in the soils surrounding the buildings. Under such conditions, the operational guidelines would need to be reduced to ensure that the total dose a potential receptor would receive does not exceed the dose criterion. The revised operational guidelines (OG) would need to satisfy the following expression:

$$\frac{(OG_{soil})_{revised}}{OG_{soil}} + \frac{(OG_{building})_{revised}}{OG_{building}} \leq 1 \ .$$

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APPENDIX 9.A:

COMPARISON OF RELEASE OF REAL PROPERTY FROM RADIOLOGICALLY CONTROLLED AREA (GROUP F-4) OPERATIONAL GUIDELINES WITH PUBLISHED RELEASE OR CLEARANCE CRITERIA

APPENDIX 9.A:

COMPARISON OF RELEASE OF REAL PROPERTY FROM RADIOLOGICALLY CONTROLLED AREA (GROUP F-4) OPERATIONAL GUIDELINES WITH PUBLISHED RELEASE OR CLEARANCE CRITERIA

This appendix compares the Group F-4 operational guidelines with published screening criteria for release of real properties or contaminated materials. Tables 9.A.1 and 9.A.3 list the comparison of the operational guidelines for soil with the U.S. Nuclear Regulatory Commission's (NRC's) screening guidelines for unrestricted release of soil (Schmidt et al. 2003), the U.S. Environmental Protection Agency's (EPA's) soil screening levels (EPA 2000), the National Council on Radiation Protection and Measurements' (NCRP's) soil screening limits (NCRP 1999), and the International Atomic Energy Agency's (IAEA's) Safety Guide No. RS-G-1.7 for clearance of material containing radionuclides (IAEA 2004). While the NRC's, NCRP's, and IAEA's guideline values are dose-based, the EPA's screening levels are risk-based, which would protect human health against a lifetime cancer risk of 1E-6. The dose criteria used to derive the NRC's, NCRP's, and IAEA's guidelines/standards are 25, 25, and 1 mrem/yr, respectively. Note that the IAEA's RS-G-1.7 also uses 100 mrem/yr for radionuclides of natural origin and for low-probability events leading to higher radiation exposures. Tables 9.A.2 and 9.A.4 list the cancer risks corresponding to the operational guidelines derived on the basis of the 50th-percentile and the mean + 2σ peak dose-to-source ratios, respectively, at t = 0, 50, and 100 years after the release of the contaminated area. They were obtained by setting the initial soil concentration to the guideline value, then performing a probabilistic analysis with the same input parameter distributions. The cancer risks reported correspond to the exposure duration of 30 years and were the 50th-percentile values from distributions.

The operational guidelines for residential and commercial buildings were compared with the American National Standards Institute/Health Physics Society (ANSI/HPS) N13.12 standards (ANSI/HPS 1999) for release of surface contaminated materials and NRC's screening guidelines (Schmidt et al. 2003) for release of contaminated buildings. They are listed in Tables 9.A.5–9.A.8. While the dose limits used in ANSI/HPS N13.12 standards range from 1 to 10 mrem/yr, the NRC's screening guidelines were developed on the basis of 25 mrem/yr.

TABLE 9.A.1 Comparison of Group F-4 Operational Guidelines for Contaminated Soils (Based on 50th-Percentile Peak Dose-to-Source Ratios) with Published Screening Guidelines or Limits

	Operational Guideline[a] (pCi/g)		NRC Screening Guideline[b] (pCi/g)	EPA Soil Screening Limit[c,d] (pCi/g)	NCRP Soil Screening Limit[e] (pCi/g)	IAEA Safety Standard[f] (pCi/g)
Radionuclide	100 mrem/yr	4 mrem/yr				
Am-241	2.49E+03	9.96E+01	2.1E+00	2.6E+00	8.9E+00	2.7E+00
Cf-252	8.61E+01	3.44E+00	2.4E+00[g]	NA[h]	9.2E+00	2.7E+01
Cm-244	8.14E+03	3.25E+02	4.2E+00	7.4E+00	1.3E+01	2.7E+01
Co-60	1.55E+01	6.20E-01	3.8E+00	3.6E-02	6.2E-01	2.7E+00
Cs-137	6.22E+01	2.49E+00	1.1E+01	6.1E-02	3.0E+00	2.7E+00
Ir-192	1.70E+02	6.78E+00	4.1E+01	NA[h]	1.2E+01	2.7E+01
Po-210	5.50E+02	2.20E+01	8.9E+00[g]	NA[h]	1.2E+00	2.7E+01[i]
Pu-238	4.21E+03	1.68E+02	2.5E+00	1.8E+00	8.6E+00	2.7E+00
Pu-239	3.83E+03	1.53E+02	2.3E+00	1.6E+00	7.8E+00	2.7E+00
Ra-226	2.67E+00	1.07E-01	7.0E-01	1.3E-02	1.0E-01	2.7E+01[i]
Sr-90	2.52E+02	1.01E+01	1.7E+00[g]	6.9E-02	3.8E-01	2.7E+01

[a] The operational guidelines were developed on the basis of two dose criteria, 100 and 4 mrem/yr, and a residential farmer scenario.

[b] The NRC's screening guidelines were developed on the basis of 25 mrem/yr. The values were obtained from NUREG-1757, Vol.2, Table H.2 (Schmidt et al. 2003), or were calculated by using DandD (McFadden et al. 2001) by following the NRC guidance.

[c] The EPA's soil screening limits were developed on the basis of a lifetime cancer risk of 1E-6. They were obtained from the EPA's *Soil Screening Guidance for Radionuclides: Appendix A*, which is available at http://www.epa.gov/superfund/resources/radiation/tbd-appendix-a-clean.pdf (EPA 2000).

[d] The screening limits were the smallest (most conservative) values among different exposure pathways, including ingestion of homegrown produce, direct ingestion of soil, inhalation of fugitive dusts, external radiation, and ingestion of groundwater (migration to groundwater). Radioactive decay was accounted for, and the dilution factor for the migration to groundwater was 20.

[e] The NCRP's soil screening limits (NCRP 1999) were developed on the basis of 25 mrem/yr and considered different land uses. The values listed are the most restrictive ones.

[f] The IAEA Safety Standards RS-G1.7 (IAEA 2004) were developed for clearance of material containing radionuclides. The dose limit used was 1 mrem/yr for radionuclides of artificial origin.

footnotes continued on next page.

TABLE 9.A.1 (Cont.)

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[g] The value was calculated by using DandD (McFadden et al. 2001) by following the NRC guidance (Schmidt et al. 2003). The value was also verified/confirmed by Ralph Cady of NRC (Cady 2005).

[h] The value is not available from the EPA document.

[i] The clearance level for radionuclides of natural origin. The dose limit was 100 mrem/yr for radionuclides of natural origin.

TABLE 9.A.2 Excess Cancer Risks Corresponding to the Operational Guidelines (Based on 50th-Percentile Peak Dose-to-Source Ratios)

Radionuclides	Operational Guideline Based on 100 mrem/yr (pCi/g)	Cancer Risk[a] t = 0 yr	Cancer Risk[a] t = 50 yr	Cancer Risk[a] t = 100 yr	Operational Guideline Based on 4 mrem/yr (pCi/g)	Cancer Risk[a] t = 0 yr	Cancer Risk[a] t = 50 yr	Cancer Risk[a] t = 100 yr
Am-241	2.49E+03	1.2E-03	4.2E-04	6.8E-09	9.96E+01	4.8E-05	1.7E-05	2.7E-10
Cf-252	8.61E+01	1.4E-06	1.5E-10	5.2E-14	3.44E+00	5.4E-08	6.2E-12	2.1E-15
Cm-244	8.14E+03	3.6E-04	2.0E-05	6.1E-09	3.25E+02	1.4E-05	8.1E-07	2.4E-10
Co-60	1.55E+01	5.5E-04	1.2E-07	0.0E+00	6.20E-01	2.2E-05	4.9E-09	0.0E+00
Cs-137	6.22E+01	1.4E-03	1.1E-04	7.2E-26	2.49E+00	5.7E-05	4.5E-06	2.9E-27
Ir-192	1.70E+02	8.2E-05	0.0E+00	0.0E+00	6.78E+00	3.3E-06	0.0E+00	0.0E+00
Po-210	5.50E+02	6.0E-05	0.0E+00	0.0E+00	2.20E+01	2.4E-06	0.0E+00	0.0E+00
Pu-238	4.21E+03	4.0E-04	8.0E-05	2.6E-08	1.68E+02	1.6E-05	3.2E-06	1.0E-09
Pu-239	3.83E+03	4.2E-04	1.2E-04	6.4E-10	1.53E+02	1.7E-05	4.8E-06	2.6E-11
Ra-226	2.67E+00	1.6E-03	7.4E-04	3.7E-07	1.07E-01	6.3E-05	3.0E-05	1.5E-08
Sr-90	2.52E+02	8.0E-04	2.0E-06	4.4E-22	1.01E+01	3.2E-05	8.2E-08	1.7E-23

[a] The cancer risks are for t = 0, t = 50, and t = 100 years, respectively, after the release of the contaminated area. They were calculated by assuming an exposure duration of 30 years. The risk values reported are the 50th-percentile values from distributions.

TABLE 9.A.3 Comparison of Group F-4 Operational Guidelines for Contaminated Soils (Based on Mean + 2σ Peak Dose-to-Source Ratios) with Published Screening Guidelines or Limits

	Operational Guideline[a] (pCi/g)		NRC Screening Limit[b] (pCi/g)	EPA Soil Screening Limit[c,d] (pCi/g)	NCRP Soil Screening Limit[e] (pCi/g)	IAEA Safety Standard[f] (pCi/g)
Radionuclide	100 mrem/yr	4 mrem/yr				
Am-241	9.80E+02	3.92E+01	2.1E+00	2.6E+00	8.9E+00	2.7E+00
Cf-252	5.13E+01	2.05E+00	2.4E+00[g]	NA[h]	9.2E+00	2.7E+01
Cm-244	2.44E+03	9.77E+01	4.2E+00	7.4E+00	1.3E+01	2.7E+01
Co-60	9.28E+00	3.71E-01	3.8E+00	3.6E-02	6.2E-01	2.7E+00
Cs-137	3.70E+01	1.48E+00	1.1E+01	6.1E-02	3.0E+00	2.7E+00
Ir-192	1.01E+02	4.05E+00	4.1E+01	NA[h]	1.2E+01	2.7E+01
Po-210	1.87E+02	7.48E+00	8.9E+00[g]	NA[h]	1.2E+00	2.7E+01[i]
Pu-238	1.11E+03	4.43E+01	2.5E+00	1.8E+00	8.6E+00	2.7E+00
Pu-239	1.01E+03	4.04E+01	2.3E+00	1.6E+00	7.8E+00	2.7E+00
Ra-226	1.63E+00	6.53E-02	7.0E-01	1.3E-02	1.0E-01	2.7E+01[i]
Sr-90	2.89E+01	1.16E+00	1.7E+00[g]	6.9E-02	3.8E-01	2.7E+01

[a] The operational guidelines were developed on the basis of two dose criteria, 100 and 4 mrem/yr, and a residential farmer scenario.

[b] The NRC's screening guidelines were developed on the basis of 25 mrem/yr. The values were obtained from NUREG-1757, Vol.2, Table H.2 (Schmidt et al. 2003), or were calculated by using DandD (McFadden et al. 2001) by following the NRC guidance.

[c] The EPA's soil screening limits were developed on the basis of a lifetime cancer risk of 1E-6. They were obtained from the EPA's *Soil Screening Guidance for Radionuclides: Appendix A*, which is available at http://www.epa.gov/superfund/resources/radiation/tbd-appendix-a-clean.pdf (EPA 2000).

[d] The screening limits were the smallest (most conservative) values among different exposure pathways, including ingestion of homegrown produce, direct ingestion of soil, inhalation of fugitive dusts, external radiation, and ingestion of groundwater (migration to groundwater). Radioactive decay was accounted for, and the dilution factor for the migration to groundwater was 20.

[e] The NCRP's soil screening limits (NCRP 1999) were developed on the basis of 25 mrem/yr and considered different land uses. The values listed are the most restrictive ones.

[f] The IAEA Safety Standards RS-G1.7 (IAEA 2004) were developed for clearance of material containing radionuclides. The dose limit used was 1 mrem/yr for radionuclides of artificial origin.

footnotes continued on next page.

TABLE 9.A.3 (Cont.)

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[g] The value was calculated by using DandD (McFadden et al. 2001) by following the NRC guidance (Schmidt et al. 2003). The value was also verified/confirmed by Ralph Cady of NRC (Cady 2005).

[h] The value is not available from the EPA document.

[i] The clearance level for radionuclides of natural origin. The dose limit was 100 mrem/yr for radionuclides of natural origin.

TABLE 9.A.4 Excess Cancer Risks Corresponding to the Operational Guidelines (Based on Mean + 2σ Peak Dose-to-Source Ratios)

Radionuclides	Operational Guideline Based on 100 mrem/yr (pCi/g)	Cancer Risk[a]			Operational Guideline Based on 4 mrem/yr (pCi/g)	Cancer Risk[a]		
		t = 0 yr	*t* = 50 yr	*t* = 100 yr		*t* = 0 yr	*t* = 50 yr	*t* = 100 yr
Am-241	9.80E+02	4.7E-04	1.6E-04	2.7E-09	3.92E+01	1.9E-05	6.5E-06	1.1E-10
Cf-252	5.13E+01	8.1E-07	9.2E-11	3.1E-14	2.05E+00	3.2E-08	3.7E-12	1.2E-15
Cm-244	2.44E+03	1.1E-04	6.1E-06	1.8E-09	9.77E+01	4.3E-06	2.4E-07	7.3E-11
Co-60	9.28E+00	3.3E-04	7.3E-08	0.0E+00	3.71E-01	1.3E-05	2.9E-09	0.0E+00
Cs-137	3.70E+01	8.4E-04	6.8E-05	4.3E-26	1.48E+00	3.4E-05	2.7E-06	1.7E-27
Ir-192	1.01E+02	4.9E-05	0.0E+00	0.0E+00	4.05E+00	2.0E-06	0.0E+00	0.0E+00
Po-210	1.87E+02	2.0E-05	0.0E+00	0.0E+00	7.48E+00	8.1E-07	0.0E+00	0.0E+00
Pu-238	1.11E+03	1.1E-04	2.1E-05	6.9E-09	4.43E+01	4.2E-06	8.4E-07	2.8E-10
Pu-239	1.01E+03	1.1E-04	3.2E-05	1.7E-10	4.04E+01	4.4E-06	1.3E-06	6.8E-12
Ra-226	1.63E+00	9.7E-04	4.5E-04	2.3E-07	6.53E-02	3.9E-05	1.8E-05	9.0E-09
Sr-90	2.89E+01	9.1E-05	2.3E-07	5.0E-23	1.16E+00	3.7E-06	9.4E-09	2.0E-24

[a] The cancer risks are for *t* = 0, *t* = 50, and *t* = 100 years, respectively, after the release of the contaminated area. They were calculated by assuming an exposure duration of 30 years. The risk values reported are the 50th-percentile values from distributions.

TABLE 9.A.5 Comparison of Group F-4 Operational Guidelines for Residential Buildings (Based on 50th-Percentile Dose-to-Source Ratios) with the ANSI/HPS N13.12 Standards and NRC's Screening Guidelines

Radionuclide	Operational Guidelines[a] (pCi/m^2) 100 mrem/yr	Operational Guidelines[a] (pCi/m^2) 4 mrem/yr	ANSI/HPS N13.12 Standard (pCi/m^2)	NRC Screening Guidelines[b] (pCi/m^2)
Am-241	3.5E+05	1.4E+04	2.7E+04	1.2E+03[c]
Cf-252	4.5E+05	1.8E+04	2.7E+04	3.9E+03[c]
Cm-244	6.2E+05	2.5E+04	2.7E+04	2.2E+03[c]
Co-60	7.8E+05	3.1E+04	2.7E+05	3.20E+05
Cs-137	3.2E+06	1.3E+05	2.7E+05	1.30E+06
Ir-192	2.8E+06	1.1E+05	2.7E+05	3.30E+06
Po-210	8.4E+06	3.4E+05	2.7E+04	1.1E+05[c]
Pu-238	3.1E+05	1.2E+04	2.7E+04	1.4E+03[c]
Pu-239	2.8E+05	1.1E+04	2.7E+04	1.3E+03[c]
Ra-226	6.6E+05	2.7E+04	2.7E+04	5.0E+04[c]
Sr-90	2.2E+07	9.0E+05	2.7E+05	3.90E+05

[a] The operational guidelines were developed for two different dose criteria, 100 and 4 mrem/yr.

[b] The NRC screening guidelines were developed on the basis of 25 mrem/yr. The values were obtained from NUREG-1757, Vol.2, Table H.1 (Schmidt et al. 2003), or were calculated by using DandD (McFadden et al. 2001) by following the NRC guidance.

[c] The value was calculated by using DandD (McFadden et al. 2001).

TABLE 9.A.6 Comparison of Group F-4 Operational Guidelines for Residential Buildings (Based on Mean + 2σ Dose-to-Source Ratios) with the ANSI/HPS N13.12 Standards and NRC's Screening Guidelines

Radionuclide	Operational Guidelines[a] (pCi/m^2)		ANSI/HPS N13.12 Standard (pCi/m^2)	NRC Screening Guidelines[b] (pCi/m^2)
	100 mrem/yr	4 mrem/yr		
Am-241	4.1E+04	1.6E+03	2.7E+04	1.2E+03[c]
Cf-252	5.5E+04	2.2E+03	2.7E+04	3.9E+03[c]
Cm-244	7.5E+04	3.0E+03	2.7E+04	2.2E+03[c]
Co-60	4.6E+05	1.8E+04	2.7E+05	3.20E+05
Cs-137	1.9E+06	7.5E+04	2.7E+05	1.30E+06
Ir-192	1.7E+06	6.7E+04	2.7E+05	3.30E+06
Po-210	1.1E+06	4.4E+04	2.7E+04	1.1E+05[c]
Pu-238	3.7E+04	1.5E+03	2.7E+04	1.4E+03[c]
Pu-239	3.2E+04	1.3E+03	2.7E+04	1.3E+03[c]
Ra-226	1.6E+05	6.4E+03	2.7E+04	5.0E+04[c]
Sr-90	8.2E+06	3.3E+05	2.7E+05	3.90E+05

[a] The operational guidelines were developed for two different dose criteria, 100 and 4 mrem/yr.

[b] The NRC screening guidelines were developed on the basis of 25 mrem/yr. The values were obtained from NUREG-1757, Vol.2, Table H.1 (Schmidt et al. 2003), or were calculated by using DandD (McFadden et al. 2001) by following the NRC guidance.

[c] The value was calculated by using DandD (McFadden et al. 2001).

TABLE 9.A.7 Comparison of Group F-4 Operational Guidelines for Commercial Buildings (Based on 50th-Percentile Dose-to-Source Ratios) with the ANSI/HPS N13.12 Standards and NRC's Screening Guidelines

Radionuclide	Operational Guideline[a] (pCi/m^2) 100 mrem/yr	Operational Guideline[a] (pCi/m^2) 4 mrem/yr	ANSI/HPS N13.12 Standard (pCi/m^2)	NRC Screening Guidelines[b] (pCi/m^2)
Am-241	8.06E+05	3.22E+04	2.7E+04	1.2E+03[c]
Cf-252	2.48E+06	9.91E+04	2.7E+04	3.9E+03[c]
Cm-244	1.46E+06	5.83E+04	2.7E+04	2.2E+03[c]
Co-60	2.21E+06	8.83E+04	2.7E+05	3.20E+05
Cs-137	9.52E+06	3.81E+05	2.7E+05	1.30E+06
Ir-192	8.06E+06	3.23E+05	2.7E+05	3.30E+06
Po-210	2.01E+07	8.02E+05	2.7E+04	1.1E+05[c]
Pu-238	7.29E+05	2.92E+04	2.7E+04	1.4E+03[c]
Pu-239	6.43E+05	2.57E+04	2.7E+04	1.3E+03[c]
Ra-226	1.78E+06	7.12E+04	2.7E+04	5.0E+04[c]
Sr-90	4.98E+07	1.99E+06	2.7E+05	3.90E+05

[a] The operational guidelines were developed for two different dose criteria, 100 and 4 mrem/yr.

[b] The NRC screening guidelines were developed on the basis of 25 mrem/yr. The values were obtained from NUREG-1757, Vol. 2, Table H.1 (Schmidt et al. 2003), or were calculated by using DandD (McFadden et al. 2001) by following the NRC guidance.

[c] The value was calculated by using DandD (McFadden et al. 2001).

TABLE 9.A.8 Comparison of Group F-4 Operational Guidelines for Commercial Buildings (Based on Mean + 2σ Dose-to-Source Ratios) with the ANSI/HPS N13.12 Standards and NRC's Screening Guidelines

	Operational Guideline[a] (pCi/m^2)		ANSI/HPS N13.12 Standard (pCi/m^2)	NRC Screening Guidelines[b] (pCi/m^2)
Radionuclide	100 mrem/yr	4 mrem/yr		
Am-241	8.79E+04	3.52E+03	2.7E+04	1.2E+03[c]
Cf-252	4.48E+05	1.79E+04	2.7E+04	3.9E+03[c]
Cm-244	1.60E+05	6.41E+03	2.7E+04	2.2E+03[c]
Co-60	1.34E+06	5.35E+04	2.7E+05	3.20E+05
Cs-137	5.75E+06	2.30E+05	2.7E+05	1.30E+06
Ir-192	4.88E+06	1.95E+05	2.7E+05	3.30E+06
Po-210	2.40E+06	9.60E+04	2.7E+04	1.1E+05[c]
Pu-238	7.96E+04	3.18E+03	2.7E+04	1.4E+03[c]
Pu-239	6.83E+04	2.73E+03	2.7E+04	1.3E+03[c]
Ra-226	4.01E+05	1.60E+04	2.7E+04	5.0E+04[c]
Sr-90	2.10E+07	8.38E+05	2.7E+05	3.90E+05

[a] The operational guidelines were developed for two different dose criteria, 100 and 4 mrem/yr.

[b] The NRC screening guidelines were developed on the basis of 25 mrem/yr. The values were obtained from NUREG-1757, Vol. 2, Table H.1 (Schmidt et al. 2003), or were calculated by using DandD (McFadden et al. 2001) by following the NRC guidance.

[c] The value was calculated by using DandD (McFadden et al. 2001).

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APPENDIX 9.B:

DISTRIBUTION FUNCTIONS USED IN DOSE ANALYSES

APPENDIX 9.B:

DISTRIBUTION FUNCTIONS USED IN DOSE ANALYSES

The distribution functions used in dose analyses are listed in this appendix. Tables 9.B.1 and 9.B.2 list the distribution functions used by RESRAD to consider soil contamination. Depending on the dominant pathways, the most sensitive parameters for different radionuclides are not the same. Generally speaking, the most sensitive physical parameters include the soil/water distribution coefficient (Kd), mass loading for inhalation, external gamma shielding factor, contaminated zone erosion rate, density of the contaminated zone, saturated zone hydraulic conductivity, saturated zone hydraulic gradient, unsaturated zone thickness, depth of roots, and transfer factors for plants, meat, and milk. Exposure parameters such as time fraction indoors, inhalation rate, soil ingestion rate, and drinking water intake rate also affect the dose results.

Table 9.B.3 lists the distribution functions used by RESRAD-BUILD to consider building contamination. It was found that in building occupancy scenarios, for strong gamma emitting radionuclides (Co-60, Cs-137, and Ir-192), indoor time fraction was the most sensitive parameter and had the most influence on the calculated dose results. For other radionuclides, in addition to the indoor time fraction, the building air exchange rate, removable fraction, fraction of removable material released to air, and lifetime of removable fraction were also identified as sensitive parameters.

TABLE 9.B.1 Distribution Functions Assigned to RESRAD Parameters for the Residential Farmer Scenario

Parameters	Distribution Function[a]
Density of contaminated zone	Truncated normal (1.52, 0.23, 0.001, 0.999)
Density of saturated zone	Truncated normal (1.52, 0.23, 0.001, 0.999)
Density of unsaturated zone	Truncated normal (1.52, 0.23, 0.001, 0.999)
Depth of roots	Uniform (0.3, 4)
Contaminated zone total porosity	Truncated normal (0.425, 0.0867, 0.001, 0.999)
Unsaturated zone total porosity	Truncated normal (0.425, 0.0867, 0.001, 0.999)
Saturated zone total porosity	Truncated normal (0.425, 0.0867, 0.001, 0.999)
Unsaturated zone effective porosity	Truncated normal (0.355, 0.0906, 0.001, 0.999)
Saturated zone effective porosity	Truncated normal (0.355, 0.0906, 0.001, 0.999)
Contaminated zone hydraulic conductivity	Bounded lognormal-N (2.3, 2.11, 0.004, 9250)
Unsaturated zone hydraulic conductivity	Bounded lognormal-N (2.3, 2.11, 0.004, 9250)
Saturated zone hydraulic conductivity	Bounded lognormal-N (2.3, 2.11, 0.004, 9250)
Contaminated zone b-parameter	Bounded lognormal-N (1.06, 0.66, 0.5, 30)
Unsaturated zone b-parameter	Bounded lognormal-N (1.06, 0.66, 0.5, 30)
Saturated zone b-parameter	Bounded lognormal-N (1.06, 0.66, 0.5, 30)
Saturated zone hydraulic gradient	Bounded lognormal-N (-5.11, 1.77, 0.00007, 0.5)
Thickness of unsaturated zone	Bounded lognormal-N (2.296, 1.276, 0.18, 320)
Contaminated zone erosion rate	Continuous logarithmic[b]
Well pumping rate	Uniform (250, 1519)
Well pumping intake depth	Triangular (6, 10, 30)
Depth of soil mixing layer	Triangular (0., 0.15, 0.6)
Runoff coefficient	Uniform (0.1, 0.8)
Evapotranspiration coefficient	Uniform (0.5, 0.75)
Wind speed	Bounded lognormal-N (1.445, 0.2419, 1.4, 12)
Mass loading for inhalation	Continuous linear[c]
Inhalation rate	Triangular (4380, 8400, 13100)
Drinking water intake rate	Truncated lognormal-N (6.015, 0.489, 0.001, 0.999)
Milk consumption rate	Triangular (60, 102, 200)
Fruit, vegetable, and grain consumption rate	Triangular (135, 178, 318)
Aquatic food contamination fraction	Triangular (0., 0.39, 1)
Soil ingestion rate	Triangular (0., 18.3, 36.5)
Wet-weight crop yield for fruit, grain, and nonleafy vegetables	Truncated lognormal-N (0.56, 0.48, 0.001, 0.999)
Weathering removal constant of all vegetation	Triangular (5.1, 18, 84)
Wet foliar interception fraction of leafy vegetables	Triangular (0.06, 0.67, 0.95)
Indoor dust filtration factor	Uniform (0.15, 0.95)
Indoor time fraction	Continuous linear[d]
External gamma shielding factor	Bounded lognormal-N (-1.3, 0.59, 0.044, 1)
Plant transfer factor	Nuclide dependent
Meat transfer factor	Nuclide dependent
Milk transfer factor	Nuclide dependent
Fish transfer factor	Nuclide dependent
Kd in contaminated zone	Nuclide dependent
Kd in unsaturated zone	Nuclide dependent
Kd in saturated zone	Nuclide dependent

footnotes on next page.

TABLE 9.B.1 (Cont.)

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[a] The parameters assigned to different distribution functions are:

- Truncated normal (mean, standard deviation, lower quantile, upper quantile);
- Uniform (minimum, maximum);
- Bounded lognormal-N (mean of underlying normal distribution, standard deviation of underlying normal distribution, minimum, maximum);
- Triangular (minimum, mode, maximum);
- Truncated lognormal-N (mean of underlying normal distribution, standard deviation of underlying normal distribution, lower quantile, upper quantile); and
- Lognormal-N (mean of underlying normal distribution, standard deviation of underlying normal distribution).

[b] The parameter values for the continuous logarithmic function are (5.0E-8, 0), (0.0007, 0.22), (0.005, 0.95), and (0.2, 1), where the first number in parenthesis is value, and the second number in parenthesis is cumulative probability.

[c] The parameter values for the continuous linear function are (0, 0), (8E-6, 0.0151), (1.6E-5, 0.1365), (3E-5, 0.8119), (4E-5, 0.9495), (6E-5, 0.9937), (7.6E-5, 0.9983), and (1E-4, 1), where the first number in parenthesis is value, and the second number in parenthesis is cumulative probability.

[d] The parameter values for the continuous linear function are (0, 0), (0.375, 0.05), (0.521, 0.25), (0.625, 0.5), (0.809, 0.75), (0.938, 0.9), (0.992, 0.95), and (1, 1), where the first number in parenthesis is value, and the second number in parenthesis is cumulative probability.

TABLE 9.B.2 Distribution Functions Assigned to Kd and Plant, Meat, and Milk Transfer Factor Parameters

	Lognormal-N Distribution[a]				
Radionuclide	Kd	Plant	Meat	Milk	Fish
Ac-227[b]	(6.72, 3.22)	(-6.91, 1.10)	(-10.82, 1.03)	(-13.12, 0.92)	(2.7, 1.1)
Am-241	(7.28, 3.15)	(-6.91, 0.92)	(-9.9, 0.2)	(-13.12, 0.69)	(3.4, 1.1)
Cf-252	(7.23, 3.22)	(-6.91, 1.10)	(-9.72, 1.03)	(-13.12, 0.92)	(3.2, 1.1)
Cm-244, Cm-248[c]	(8.82, 1.82)	(-6.91, 0.92)	(-10.82, 1.03)	(-13.12, 0.92)	(3.4, 1.1)
Co-60	(5.46, 2.53)	(-2.53, 0.92)	(-3.51, 1.03)	(-6.21, 0.7)	(5.7, 1.1)
Cs-137	(6.1, 2.33)	(-3.22, 0.99)	(-3, 0.41)	(-4.61, 0.47)	(7.6, 0.7)
Ir-192	(5.32, 3.22)	(-3.51, 1.10)	(-6.21, 1.03)	(-13.12, 0.92)	(2.3, 1.1)
Np-237[d]	(2.84, 2.25)	(-3.91, 0.92)	(-6.91, 0.69)	(-11.51, 0.69)	(3.4, 1.1)
Pa-231[b]	(5.94, 3.22)	(-4.61, 1.10)	(-12.21, 1.03)	(-12.21, 0.92)	(2.3, 1.1)
Pb-210[e]	(7.78, 2.76)	(-5.52, 0.92)	(-7.13, 0.69)	(-8.11, 0.92)	(5.7, 1.1)
Po-210[e]	(5.2, 1.68)	(-6.9, 0.9)	(-5.3, 0.69)	(-7.82, 0.69)	(4.6, 1.1)
Pu-238, Pu-239, Pu-240,[c,f] Pu-244[c]	(6.86, 1.89)	(-6.91, 0.92)	(-9.21, 0.2)	(-13.82. 0.47)	(3.4, 1.1)
Ra-226,[e] Ra-228[c,f]	(8.17, 1.7)	(-3.22, 0.92)	(-6.91, 0.69)	(-6.91, 0.47)	(3.9, 1.1)
Sr-90	(3.45, 2.12)	(-1.2, 0.99)	(-4.61, 0.41)	(-6.21, 0.47)	(4.1, 1.1)
Th-228,[c,f] Th-229,[d] Th-230,[e] Th-232[c,f]	(8.68, 3.62)	(-6.91, 0.92)	(-9.21, 1.03)	(-12.21, 0.92)	(4.6, 1.1)
U-233,[d] U-234,[e] U-235,[b] U-236[c,f]	(4.84, 3.13)	(-6.21, 0.92)	(-7.13, 0.69)	(-7.82, 0.59)	(2.3, 1.1)

[a] The parameters assigned to a lognormal-N distribution function are the mean and standard deviation of the underlying normal distribution.

[b] Ac-227, Pa-231, and U-235 are decay products of Pu-239.

[c] Cm-248, Pu-240, Pu-244, Ra-228, Th-228, Th-232, and U-236 are decay products of Cf-252.

[d] Np-237, Th-229, and U-233 are decay products of Am-241.

[e] Pb-210, Po-210, Ra-226, Th-230, and U-234 are decay products of Pu-238.

[f] Pu-240, Ra-228, Th-228, Th-232, and U-236 are decay products of Cm-244.

TABLE 9.B.3 Distribution Functions Assigned to RESRAD-BUILD Parameters for the Building Occupancy Scenario

Parameters	Distribution Function[a]
Indoor time fraction	Continuous linear[b]
Deposition velocity	Loguniform (2.7E-06, 2.7E-03)
Resuspension rate	Loguniform (2.8E-10, 1.4E-05)
Building air exchange rate	Truncated lognormal-N (0.4187, 0.88, 0.001, 0.999)
Removable fraction	Triangular (0, 0.2, 1)
Lifetime of removable fraction	Triangular (1,000, 10,000, 100,000)
Breathing rate of receptor	Triangular (12, 33.6, 46)
Ingestion rate of deposited dust particles	Loguniform (0.000028, 0.00029)
Fraction of removable material released to air	Triangular (1E-06, 0.07, 1)

[a] The parameters assigned to different distribution functions are as follows:

- Loguniform (minimum, maximum);
- Truncated lognormal-N (mean of underlying normal distribution, standard deviation of underlying normal distribution, lower quantile, upper quantile); and
- Triangular (minimum, mode, maximum).

[b] The parameter values for the continuous linear function are (0.003, 0), (0.0347, 0.05), (0.306, 0.25), (0.365, 0.5), (0.403, 0.75), (0.469, 0.9), (0.542, 0.98), and (0.692, 1) for workers; (0, 0), (0.375, 0.05), (0.521, 0.25), (0.625, 0.5), (0.809, 0.75), (0.938, 0.9), (0.992, 0.95), and (1, 1) for residents; where the first number in parenthesis is value, and the second number in parenthesis is cumulative probability.

APPENDIX 9.C:

DOSE RESULTS FOR DIFFERENT TYPES OF CONTAMINATED BUILDINGS

APPENDIX 9.C:

DOSE RESULTS FOR DIFFERENT TYPES OF CONTAMINATED BUILDINGS

To capture the variability in building characteristics, three different residential buildings and two different commercial buildings were analyzed. The residential buildings considered were an apartment in an urban area, a single-family house in a suburban area, and a small house in a rural area. The commercial buildings considered were a large warehouse and a small store/office. Table 9.C.1 provides the characteristics of these residential and commercial buildings.

The operational guidelines for releasing contaminated buildings were derived by using the most conservative dose-to-source ratios (DSRs) among the buildings with different characteristics. The percentile values, mean, and standard deviation obtained for each radionuclide are listed in the following tables. Tables 9.C.2–9.C.4 list the results for the residential buildings — an urban apartment, a suburban house, and a rural house, respectively. For strong gamma emitting radionuclides, occupancy in a suburban house resulted in the most restrictive dose-to-source ratios; for other radionuclides, occupancy in a small rural house resulted in the most restrictive ratios. Tables 9.C.5 and 9.C.6 list the results for the commercial buildings — a warehouse and a small store/office, respectively. For strong gamma-emitting radionuclides, working at a large warehouse resulted in the most restrictive dose-to-source ratios; for other radionuclides, working at a small store/office resulted in the most restrictive ratios. The most restrictive dose-to-source ratios for the residential and commercial buildings are listed in Tables 9.7 and 9.8, respectively, in Chapter 9.

TABLE 9.C.1 Building Characteristics Used in the Building Occupancy Scenario

	Residential Buildings			Commercial Buildings	
Parameter	Urban Apartment	Suburban House	Small Rural House	Large Warehouse	Small Store/Office
Floor area, m^2	100	196	36	900	36
Building height, m	2.4	2.4	2.4	3.7	2.4
Shielding thickness, cm	10	3.5	3.5	10	5
Shielding material	Concrete	Concrete	Concrete	Concrete	Concrete
Shielding density, g/cm^3	2.4	1	1	2.4	2.4

TABLE 9.C.2 Dose-to-Source Ratio Distributions for a Residential Building: Urban Apartment

Percentile (%)	DSR (mrem/yr per pCi/m^2) for Radionuclides in an Urban Residential Building[a]										
	Am-241	Cf-252	Cm-244	Co-60	Cs-137	Ir-192	Po-210	Pu-238	Pu-239	Ra-226	Sr-90
5	2.85E-05	3.03E-05	1.51E-05	5.31E-05	1.23E-05	1.46E-05	1.18E-06	3.12E-05	3.47E-05	4.91E-05	2.20E-06
10	4.39E-05	3.87E-05	2.44E-05	5.97E-05	1.38E-05	1.63E-05	1.91E-06	4.90E-05	5.45E-05	6.30E-05	2.54E-06
15	6.12E-05	4.43E-05	3.39E-05	6.49E-05	1.49E-05	1.78E-05	2.58E-06	6.74E-05	7.52E-05	7.03E-05	2.82E-06
20	7.63E-05	4.90E-05	4.29E-05	7.04E-05	1.63E-05	1.93E-05	3.30E-06	8.55E-05	9.48E-05	7.66E-05	3.10E-06
25	9.30E-05	5.36E-05	5.12E-05	7.56E-05	1.74E-05	2.07E-05	3.89E-06	1.04E-04	1.16E-04	8.22E-05	3.31E-06
30	1.14E-04	5.79E-05	6.33E-05	7.86E-05	1.80E-05	2.16E-05	4.74E-06	1.27E-04	1.41E-04	8.87E-05	3.46E-06
35	1.36E-04	6.25E-05	7.53E-05	8.16E-05	1.88E-05	2.24E-05	5.64E-06	1.52E-04	1.69E-04	9.67E-05	3.64E-06
40	1.58E-04	6.71E-05	8.87E-05	8.47E-05	1.95E-05	2.32E-05	6.71E-06	1.78E-04	1.98E-04	1.04E-04	3.86E-06
45	1.79E-04	7.36E-05	9.97E-05	8.77E-05	2.02E-05	2.41E-05	7.49E-06	2.02E-04	2.24E-04	1.11E-04	4.06E-06
50	2.09E-04	7.89E-05	1.16E-04	9.06E-05	2.10E-05	2.49E-05	8.55E-06	2.33E-04	2.63E-04	1.20E-04	4.25E-06
55	2.44E-04	8.63E-05	1.34E-04	9.61E-05	2.22E-05	2.64E-05	9.83E-06	2.71E-04	3.06E-04	1.27E-04	4.51E-06
60	2.88E-04	9.46E-05	1.63E-04	1.01E-04	2.34E-05	2.78E-05	1.14E-05	3.24E-04	3.61E-04	1.38E-04	4.72E-06
65	3.34E-04	1.03E-04	1.86E-04	1.07E-04	2.47E-05	2.93E-05	1.34E-05	3.72E-04	4.19E-04	1.47E-04	4.92E-06
70	3.93E-04	1.15E-04	2.20E-04	1.12E-04	2.59E-05	3.07E-05	1.56E-05	4.42E-04	4.95E-04	1.59E-04	5.17E-06
75	4.74E-04	1.29E-04	2.64E-04	1.18E-04	2.70E-05	3.22E-05	1.86E-05	5.27E-04	5.93E-04	1.76E-04	5.43E-06
80	5.78E-04	1.51E-04	3.22E-04	1.24E-04	2.84E-05	3.39E-05	2.27E-05	6.45E-04	7.35E-04	1.99E-04	5.70E-06
85	7.63E-04	1.77E-04	4.11E-04	1.30E-04	2.99E-05	3.56E-05	2.88E-05	8.42E-04	9.66E-04	2.29E-04	6.05E-06
90	1.01E-03	2.22E-04	5.38E-04	1.37E-04	3.16E-05	3.74E-05	3.79E-05	1.12E-03	1.31E-03	2.77E-04	6.69E-06
95	1.50E-03	3.00E-04	8.04E-04	1.44E-04	3.28E-05	3.94E-05	5.48E-05	1.64E-03	1.96E-03	3.77E-04	8.33E-06
Mean	4.34E-04	1.16E-04	2.38E-04	9.45E-05	2.18E-05	2.59E-05	1.67E-05	4.81E-04	5.51E-04	1.58E-04	4.73E-06
σ	7.59E-04	1.41E-04	4.21E-04	2.98E-05	7.02E-06	8.16E-06	2.82E-05	8.43E-04	9.73E-04	1.60E-04	3.01E-06
Mean + 2σ	1.95E-03	3.98E-04	1.08E-03	1.54E-04	3.59E-05	4.22E-05	7.31E-05	2.17E-03	2.50E-03	4.78E-04	1.07E-05

[a] For an urban residential building: area = 100 m^2, height = 2.4 m, shielding thickness = 10 cm, and shielding density = 2.4 g/cm^3 concrete.

TABLE 9.C.3 Dose-to-Source Ratio Distributions for a Residential Building: Suburban House

Percentile (%)	DSR (mrem/yr per pCi/m^2) for Radionuclides in a Suburban Residential Building[a]										
	Am-241	Cf-252	Cm-244	Co-60	Cs-137	Ir-192	Po-210	Pu-238	Pu-239	Ra-226	Sr-90
5	2.33E-05	5.87E-05	1.27E-05	7.49E-05	1.84E-05	2.06E-05	9.85E-07	2.53E-05	2.76E-05	6.40E-05	2.38E-06
10	3.64E-05	7.53E-05	1.96E-05	8.44E-05	2.06E-05	2.31E-05	1.50E-06	4.03E-05	4.42E-05	8.07E-05	2.70E-06
15	4.90E-05	9.29E-05	2.74E-05	9.17E-05	2.26E-05	2.52E-05	2.08E-06	5.42E-05	5.99E-05	8.97E-05	2.98E-06
20	6.31E-05	1.07E-04	3.48E-05	9.93E-05	2.44E-05	2.72E-05	2.66E-06	6.88E-05	7.76E-05	9.71E-05	3.29E-06
25	7.66E-05	1.20E-04	4.17E-05	1.07E-04	2.61E-05	2.93E-05	3.18E-06	8.47E-05	9.46E-05	1.03E-04	3.48E-06
30	9.35E-05	1.38E-04	5.09E-05	1.11E-04	2.71E-05	3.05E-05	3.86E-06	1.04E-04	1.15E-04	1.11E-04	3.66E-06
35	1.11E-04	1.56E-04	6.16E-05	1.15E-04	2.83E-05	3.16E-05	4.57E-06	1.25E-04	1.38E-04	1.19E-04	3.83E-06
40	1.32E-04	1.77E-04	7.32E-05	1.20E-04	2.93E-05	3.28E-05	5.33E-06	1.47E-04	1.63E-04	1.28E-04	4.04E-06
45	1.53E-04	2.01E-04	8.40E-05	1.24E-04	3.04E-05	3.40E-05	6.29E-06	1.70E-04	1.90E-04	1.37E-04	4.25E-06
50	1.74E-04	2.24E-04	9.74E-05	1.28E-04	3.15E-05	3.51E-05	7.16E-06	1.95E-04	2.18E-04	1.44E-04	4.46E-06
55	2.05E-04	2.53E-04	1.12E-04	1.36E-04	3.33E-05	3.72E-05	8.18E-06	2.28E-04	2.57E-04	1.53E-04	4.73E-06
60	2.39E-04	2.88E-04	1.33E-04	1.43E-04	3.51E-05	3.93E-05	9.55E-06	2.66E-04	2.99E-04	1.61E-04	4.93E-06
65	2.81E-04	3.31E-04	1.57E-04	1.51E-04	3.70E-05	4.13E-05	1.10E-05	3.11E-04	3.53E-04	1.71E-04	5.17E-06
70	3.25E-04	3.81E-04	1.82E-04	1.58E-04	3.88E-05	4.34E-05	1.33E-05	3.63E-04	4.10E-04	1.81E-04	5.42E-06
75	4.02E-04	4.49E-04	2.21E-04	1.66E-04	4.06E-05	4.55E-05	1.55E-05	4.45E-04	5.03E-04	1.98E-04	5.70E-06
80	4.97E-04	5.41E-04	2.73E-04	1.74E-04	4.28E-05	4.79E-05	1.93E-05	5.53E-04	6.27E-04	2.15E-04	5.98E-06
85	6.22E-04	6.77E-04	3.52E-04	1.83E-04	4.50E-05	5.03E-05	2.46E-05	7.02E-04	8.00E-04	2.37E-04	6.26E-06
90	8.75E-04	8.79E-04	4.66E-04	1.93E-04	4.73E-05	5.28E-05	3.22E-05	9.62E-04	1.12E-03	2.80E-04	6.74E-06
95	1.26E-03	1.30E-03	7.09E-04	2.03E-04	4.95E-05	5.57E-05	4.78E-05	1.42E-03	1.61E-03	3.69E-04	8.24E-06
Mean	3.73E-04	4.15E-04	2.05E-04	1.33E-04	3.27E-05	3.66E-05	1.43E-05	4.13E-04	4.73E-04	1.73E-04	4.87E-06
σ	6.95E-04	6.97E-04	3.88E-04	4.20E-05	1.04E-05	1.15E-05	2.61E-05	7.76E-04	8.86E-04	1.43E-04	2.80E-06
Mean + 2σ	1.76E-03	1.81E-03	9.82E-04	2.17E-04	5.35E-05	5.96E-05	6.64E-05	1.96E-03	2.25E-03	4.59E-04	1.05E-05

[a] For a suburban residential building: area = 196 m^2, height = 2.4 m, shielding thickness = 3.5 cm, and shielding density = 1 g/cm^3 concrete.

TABLE 9.C.4 Dose-to-Source Ratio Distributions for a Residential Building: Rural House

Percentile (%)	DSR (mrem/yr per pCi/m^2) for Radionuclides in a Rural Residential Building[a]										
	Am-241	Cf-252	Cm-244	Co-60	Cs-137	Ir-192	Po-210	Pu-238	Pu-239	Ra-226	Sr-90
5	3.89E-05	3.92E-05	2.20E-05	6.46E-05	1.61E-05	1.77E-05	1.68E-06	4.29E-05	4.74E-05	6.08E-05	2.05E-06
10	6.26E-05	5.01E-05	3.42E-05	7.27E-05	1.80E-05	1.99E-05	2.71E-06	6.86E-05	7.65E-05	7.90E-05	2.44E-06
15	8.56E-05	5.78E-05	4.70E-05	7.90E-05	1.95E-05	2.17E-05	3.65E-06	9.55E-05	1.07E-04	8.80E-05	2.70E-06
20	1.05E-04	6.37E-05	5.92E-05	8.57E-05	2.12E-05	2.35E-05	4.49E-06	1.16E-04	1.30E-04	9.58E-05	2.98E-06
25	1.33E-04	6.92E-05	7.30E-05	9.21E-05	2.27E-05	2.52E-05	5.53E-06	1.49E-04	1.66E-04	1.04E-04	3.16E-06
30	1.60E-04	7.53E-05	8.86E-05	9.56E-05	2.35E-05	2.62E-05	6.61E-06	1.78E-04	2.00E-04	1.12E-04	3.37E-06
35	1.89E-04	8.09E-05	1.04E-04	9.94E-05	2.46E-05	2.73E-05	7.79E-06	2.12E-04	2.36E-04	1.22E-04	3.56E-06
40	2.20E-04	8.90E-05	1.22E-04	1.03E-04	2.54E-05	2.82E-05	9.08E-06	2.44E-04	2.74E-04	1.32E-04	3.77E-06
45	2.50E-04	9.54E-05	1.38E-04	1.07E-04	2.64E-05	2.93E-05	1.03E-05	2.76E-04	3.13E-04	1.42E-04	3.97E-06
50	2.90E-04	1.04E-04	1.60E-04	1.10E-04	2.74E-05	3.03E-05	1.18E-05	3.23E-04	3.62E-04	1.51E-04	4.20E-06
55	3.39E-04	1.13E-04	1.87E-04	1.17E-04	2.90E-05	3.21E-05	1.33E-05	3.74E-04	4.26E-04	1.63E-04	4.42E-06
60	4.01E-04	1.26E-04	2.24E-04	1.23E-04	3.05E-05	3.38E-05	1.58E-05	4.45E-04	5.02E-04	1.75E-04	4.64E-06
65	4.58E-04	1.38E-04	2.57E-04	1.30E-04	3.21E-05	3.56E-05	1.85E-05	5.11E-04	5.75E-04	1.90E-04	4.85E-06
70	5.36E-04	1.53E-04	2.99E-04	1.37E-04	3.37E-05	3.74E-05	2.13E-05	6.01E-04	6.73E-04	2.04E-04	5.08E-06
75	6.43E-04	1.72E-04	3.57E-04	1.43E-04	3.53E-05	3.92E-05	2.55E-05	7.12E-04	8.09E-04	2.26E-04	5.36E-06
80	8.00E-04	2.00E-04	4.48E-04	1.51E-04	3.71E-05	4.13E-05	3.15E-05	8.87E-04	1.01E-03	2.55E-04	5.74E-06
85	9.96E-04	2.35E-04	5.55E-04	1.58E-04	3.91E-05	4.33E-05	3.93E-05	1.13E-03	1.24E-03	2.97E-04	6.20E-06
90	1.32E-03	2.93E-04	7.34E-04	1.66E-04	4.13E-05	4.55E-05	5.07E-05	1.46E-03	1.69E-03	3.68E-04	7.16E-06
95	1.99E-03	3.96E-04	1.05E-03	1.75E-04	4.29E-05	4.80E-05	7.04E-05	2.27E-03	2.54E-03	4.79E-04	9.28E-06
Mean	5.77E-04	1.52E-04	3.17E-04	1.15E-04	2.85E-05	3.15E-05	2.22E-05	6.39E-04	7.33E-04	2.03E-04	4.83E-06
σ	9.36E-04	1.71E-04	5.11E-04	3.63E-05	9.16E-06	9.93E-06	3.42E-05	1.03E-03	1.21E-03	2.12E-04	3.67E-06
Mean + 2σ	2.45E-03	4.93E-04	1.34E-03	1.88E-04	4.68E-05	5.14E-05	9.06E-05	2.70E-03	3.16E-03	6.28E-04	1.22E-05

[a] For a rural residential building: area = 36 m^2, height = 2.4 m, shielding thickness = 3.5 cm, and shielding density = 1 g/cm^3 concrete.

TABLE 9.C.5 Dose-to-Source Ratio Distributions for a Commercial Building: Large Warehouse

Percentile (%)	DSR (mrem/yr per pCi/m^2) for Radionuclides in a Large Commercial Building[a]										
	Am-241	Cf-252	Cm-244	Co-60	Cs-137	Ir-192	Po-210	Pu-238	Pu-239	Ra-226	Sr-90
5	3.21E-06	2.77E-06	1.69E-06	4.21E-06	9.83E-07	1.16E-06	1.26E-07	3.30E-06	3.63E-06	4.48E-06	1.99E-07
10	6.29E-06	6.73E-06	3.44E-06	1.26E-05	2.99E-06	3.45E-06	2.62E-07	6.81E-06	7.42E-06	1.19E-05	5.55E-07
15	9.65E-06	1.15E-05	5.25E-06	2.11E-05	4.89E-06	5.81E-06	4.04E-07	1.04E-05	1.15E-05	2.13E-05	9.50E-07
20	1.36E-05	1.48E-05	7.43E-06	2.95E-05	6.88E-06	8.09E-06	5.71E-07	1.49E-05	1.65E-05	2.96E-05	1.38E-06
25	1.69E-05	1.67E-05	9.36E-06	3.80E-05	8.79E-06	1.04E-05	7.05E-07	1.84E-05	2.08E-05	3.32E-05	1.64E-06
30	2.07E-05	1.79E-05	1.16E-05	3.95E-05	9.16E-06	1.08E-05	8.66E-07	2.29E-05	2.53E-05	3.51E-05	1.73E-06
35	2.41E-05	1.91E-05	1.35E-05	4.10E-05	9.54E-06	1.12E-05	1.02E-06	2.67E-05	3.01E-05	3.71E-05	1.82E-06
40	2.93E-05	2.03E-05	1.61E-05	4.25E-05	9.86E-06	1.16E-05	1.23E-06	3.24E-05	3.60E-05	3.88E-05	1.89E-06
45	3.51E-05	2.16E-05	1.98E-05	4.39E-05	1.02E-05	1.20E-05	1.50E-06	3.92E-05	4.36E-05	4.08E-05	1.95E-06
50	4.18E-05	2.34E-05	2.33E-05	4.53E-05	1.05E-05	1.24E-05	1.76E-06	4.60E-05	5.16E-05	4.31E-05	2.01E-06
55	4.88E-05	2.50E-05	2.74E-05	4.63E-05	1.08E-05	1.27E-05	2.03E-06	5.49E-05	6.06E-05	4.52E-05	2.06E-06
60	5.75E-05	2.68E-05	3.29E-05	4.73E-05	1.10E-05	1.30E-05	2.40E-06	6.44E-05	7.19E-05	4.73E-05	2.11E-06
65	6.91E-05	2.90E-05	3.93E-05	4.82E-05	1.12E-05	1.32E-05	2.85E-06	7.79E-05	8.61E-05	5.00E-05	2.17E-06
70	8.31E-05	3.16E-05	4.71E-05	4.92E-05	1.14E-05	1.35E-05	3.46E-06	9.38E-05	1.04E-04	5.33E-05	2.25E-06
75	1.05E-04	3.52E-05	5.77E-05	5.02E-05	1.17E-05	1.37E-05	4.14E-06	1.16E-04	1.31E-04	5.65E-05	2.34E-06
80	1.30E-04	3.97E-05	7.27E-05	5.28E-05	1.23E-05	1.45E-05	5.22E-06	1.43E-04	1.62E-04	6.06E-05	2.45E-06
85	1.64E-04	4.74E-05	9.24E-05	5.55E-05	1.29E-05	1.52E-05	6.48E-06	1.82E-04	2.06E-04	6.69E-05	2.60E-06
90	2.30E-04	5.82E-05	1.27E-04	5.84E-05	1.37E-05	1.60E-05	8.90E-06	2.58E-04	2.92E-04	7.65E-05	2.82E-06
95	3.44E-04	7.89E-05	1.89E-04	6.40E-05	1.50E-05	1.75E-05	1.36E-05	3.83E-04	4.29E-04	9.82E-05	3.22E-06
Mean	9.76E-05	3.16E-05	5.45E-05	4.14E-05	9.64E-06	1.14E-05	3.88E-06	1.09E-04	1.23E-04	4.81E-05	1.96E-06
σ	2.00E-04	3.91E-05	1.14E-04	1.67E-05	3.90E-06	4.57E-06	7.82E-06	2.25E-04	2.54E-04	3.84E-05	1.02E-06
Mean + 2σ	4.99E-04	1.10E-04	2.82E-04	7.47E-05	1.74E-05	2.05E-05	1.95E-05	5.59E-04	6.30E-04	1.25E-04	3.99E-06

[a] For a large commercial building: area = 900 m^2, height = 3.7 m, shielding thickness = 10 cm, and shielding density = 2.4 g/cm^3 concrete.

TABLE 9.C.6 Dose-to-Source Ratio Distributions for a Commercial Building: Small Store/Office

Percentile (%)	DSR (mrem/yr per pCi/m^2) for Radionuclides in a Small Commercial Building[a]										
	Am-241	Cf-252	Cm-244	Co-60	Cs-137	Ir-192	Po-210	Pu-238	Pu-239	Ra-226	Sr-90
5	8.82E-06	4.60E-06	5.10E-06	3.90E-06	9.42E-07	1.07E-06	3.78E-07	9.88E-06	1.08E-05	6.55E-06	1.74E-07
10	2.02E-05	1.19E-05	1.09E-05	1.16E-05	2.81E-06	3.18E-06	8.37E-07	2.26E-05	2.49E-05	1.61E-05	4.44E-07
15	2.98E-05	1.86E-05	1.65E-05	1.95E-05	4.68E-06	5.35E-06	1.24E-06	3.28E-05	3.67E-05	2.65E-05	7.66E-07
20	4.12E-05	2.19E-05	2.25E-05	2.73E-05	6.59E-06	7.47E-06	1.69E-06	4.60E-05	5.17E-05	3.31E-05	1.13E-06
25	5.16E-05	2.45E-05	2.88E-05	3.52E-05	8.31E-06	9.61E-06	2.15E-06	5.78E-05	6.41E-05	3.68E-05	1.25E-06
30	6.33E-05	2.72E-05	3.51E-05	3.65E-05	8.67E-06	9.99E-06	2.62E-06	7.16E-05	7.90E-05	4.05E-05	1.31E-06
35	7.54E-05	2.98E-05	4.24E-05	3.79E-05	9.04E-06	1.04E-05	3.18E-06	8.47E-05	9.47E-05	4.31E-05	1.39E-06
40	9.14E-05	3.36E-05	4.91E-05	3.92E-05	9.37E-06	1.07E-05	3.63E-06	1.02E-04	1.14E-04	4.68E-05	1.45E-06
45	1.05E-04	3.69E-05	5.92E-05	4.05E-05	9.68E-06	1.11E-05	4.36E-06	1.19E-04	1.32E-04	5.09E-05	1.52E-06
50	1.24E-04	4.04E-05	6.86E-05	4.19E-05	9.97E-06	1.15E-05	4.99E-06	1.37E-04	1.56E-04	5.62E-05	1.59E-06
55	1.45E-04	4.46E-05	8.19E-05	4.28E-05	1.02E-05	1.17E-05	5.81E-06	1.61E-04	1.83E-04	6.05E-05	1.66E-06
60	1.77E-04	5.05E-05	9.89E-05	4.37E-05	1.04E-05	1.20E-05	6.84E-06	1.99E-04	2.23E-04	6.48E-05	1.73E-06
65	2.11E-04	5.68E-05	1.19E-04	4.45E-05	1.07E-05	1.22E-05	8.31E-06	2.35E-04	2.65E-04	7.19E-05	1.80E-06
70	2.39E-04	6.30E-05	1.37E-04	4.54E-05	1.08E-05	1.24E-05	9.76E-06	2.71E-04	3.02E-04	7.77E-05	1.92E-06
75	2.94E-04	7.10E-05	1.60E-04	4.64E-05	1.12E-05	1.27E-05	1.14E-05	3.28E-04	3.69E-04	8.61E-05	2.04E-06
80	3.64E-04	8.56E-05	2.04E-04	4.89E-05	1.17E-05	1.34E-05	1.43E-05	4.04E-04	4.59E-04	9.70E-05	2.18E-06
85	4.59E-04	1.02E-04	2.58E-04	5.14E-05	1.23E-05	1.40E-05	1.80E-05	5.15E-04	5.78E-04	1.15E-04	2.42E-06
90	6.19E-04	1.32E-04	3.44E-04	5.41E-05	1.31E-05	1.48E-05	2.38E-05	6.95E-04	7.76E-04	1.42E-04	2.81E-06
95	9.14E-04	1.83E-04	5.03E-04	5.92E-05	1.42E-05	1.62E-05	3.45E-05	1.04E-03	1.21E-03	1.95E-04	3.61E-06
Mean	2.61E-04	6.29E-05	1.44E-04	3.83E-05	9.18E-06	1.05E-05	9.97E-06	2.89E-04	3.31E-04	7.55E-05	1.79E-06
σ	4.39E-04	8.01E-05	2.40E-04	1.54E-05	3.75E-06	4.21E-06	1.58E-05	4.84E-04	5.67E-04	8.68E-05	1.49E-06
Mean + 2σ	1.14E-03	2.23E-04	6.24E-04	6.91E-05	1.67E-05	1.89E-05	4.17E-05	1.26E-03	1.46E-03	2.49E-04	4.77E-06

[a] For a small commercial building: area = 36 m^2, height = 2.4 m, shielding thickness = 5 cm, and shielding density = 2.4 g/cm^3 concrete.

10 GROUP G: FOOD CONSUMPTION

10.1 INTRODUCTION

Four subgroups of operational guidelines for food are presented here. These guidelines complement and supplement the DILs published by the FDA (FDA 1998). The first subgroup of guidelines is in terms of limiting concentration in food, which is similar to the FDA DILs, but includes additional radionuclides and utilizes updated dose conversion factors. The other three subgroups of operational guidelines are expressed as limiting concentrations in surface soil. They were developed by considering consumption of crops (vegetables, fruits, and grains) and animal products (meat and milk) that are linked to contaminated soils through uptake pathways. The ingestion of crops and animal products from affected areas would not result in radiation doses that exceed the corresponding PAGs, if their concentrations or the soil concentrations in which they grow are below the Group G operational guidelines.

The first subgroup of operational guidelines was derived by using a methodology consistent with the one used by the FDA for developing the DILs for foods after a nuclear accident (FDA 1998). It considers potential radiation exposure from food ingestion and is based on a food PAG of either 5,000 mrem/yr committed equivalent dose to an individual organ or tissue, or 500 mrem/yr committed effective dose (CED), whichever is more limiting. Age-dependent food ingestion rates and ICRP 72 (ICRP 1996) dose conversion factors were used in the derivation. The final operational guidelines were expressed in terms of food concentrations and were the most conservative values among the different age groups considered. To differentiate from the published FDA DILs, the derived food concentration values that use the FDA methodology are called planning values (PVs). These PVs are used as Group G, Subgroup 1, operational guidelines. These PVs could be used as an alternative to FDA DILs in the early phase of response after an RDD event.

In deriving the Group G, Subgroups 2 and 3, operational guidelines, the PVs for Subgroup 1 were applied for comparison with calculated concentrations in crops harvested or animal products produced after an RDD event. The operational guidelines of Subgroup 2 were developed by considering crops or fodder that had been growing during the event and became contaminated as a result of a passing contamination plume from the event. The methodology developed by FRMAC (Rhodes et al. 2003) was used to relate the plant/fodder concentration to the deposited concentration on the ground surface. The operational guidelines are the concentrations in surface soil that would result in plant/milk concentrations equivalent to the PVs of Subgroup 1. Subgroup 2 soil operational guidelines supplement the PVs and are also intended for use in the early phase of response when measured concentrations of crops or animal products are not readily available.

Subgroup 3 soil operational guidelines consider crops planted after an RDD event that are intended for use in the intermediate phase of response after the event. Deposited soil and air concentrations, which were caused by resuspension from soil, were adjusted for weathering and radiological decay during the plant growing period. The RESRAD methodology (Yu et al. 2001) that accounts for foliar deposition and root uptake was used to calculate plant-to-soil concentration ratios, which were then used to back-calculate the soil operational guidelines.

Subgroup 4 soil operational guidelines also were developed by using the RESRAD methodology, except that they are based on a PAG of 500 mrem/yr (CED) rather than the PVs. To obtain the average concentrations in crops and animal products that are consumed over a year, the deposited soil and air concentrations were corrected for weathering and radiological decay over a 1-year period. The ingestion dose-to-source ratios were calculated and then were used to back-calculate the soil operational guidelines. The Subgroup 4 operational guidelines are dose (CED) based rather than PV based. They can be used for estimating the potential radiation doses that correspond to the Subgroup 3 soil operational guidelines. The Subgroup 4 operational guidelines are intended for use in the intermediate-to-late phase of response after an RDD event.

For Subgroups 2 to 4 operational guidelines, different types of plants (fodder, leafy vegetable, and grain and nonleafy vegetable) that link to the production of different types of food (meat, milk, and vegetables) were modeled. The most limiting food-to-soil concentration ratio (for Subgroups 2 and 3) or the sum of dose-to-source ratios (for Subgroup 4) was used to determine the final soil guideline.

It is important to note that Group G soil operational guidelines (Subgroups 2, 3, and 4) were developed by considering radiation exposure only through the food ingestion pathway. They can be used to determine whether ingestion of agricultural products (plant foods, meat, and milk) that are exposed to the contamination plume during an RDD event (Subgroup 2) or that will be cultivated and produced after an RDD event (Subgroups 3 and 4) would result in unacceptable human health risks. Because radiation exposure that would result from cultivating crops or raising livestock was not considered, Group G soil operational guidelines should not be used to replace Group B operational guidelines for evacuation/sheltering or Group C operational guidelines for relocation. They can, however, be used in conjunction with the Group B or Group C operational guidelines to determine whether restriction on food ingestion or agricultural activities should be imposed on a contaminated area where residents are allowed to stay after an RDD event.

Comparisons of operational guidelines for the four subgroups in terms of their applications and derivations are presented in Appendix 10.A.

10.2 SUBGROUP 1 FOOD OPERATIONAL GUIDELINES FOR THE EARLY PHASE

For Subgroup 1, the derived food concentration PVs are used as operational guidelines. The derivation of PVs was based on the methodology used by the FDA for developing the DILs after a nuclear accident (FDA 1998). The PVs are not the same as the DILs, because updated dose conversion factors were used.

The FDA DIL for a specific radionuclide was calculated by using Equations 10.1−10.3:

$$DIL = \frac{PAG}{f \times FI \times DC} \tag{10.1}$$

$$FI = Annual\ Intake\ Rate \times IPC \tag{10.2}$$

$$IPC = \min \left[1 \ \ or \ \ -\frac{Ln\,(0.01)}{\lambda} \right] \tag{10.3}$$

where:

DIL = derived intervention levels (Bq/kg);

DC = dose coefficient, the radiation dose received per unit of radioactivity ingested (mSv/Bq);

f = fraction of the food ingested assumed to be contaminated;

IPC = ingestion period correction (yr);

λ = radionuclide decay constant (yr^{-1});

FI = food intake (kg); and

PAG = protective action guide for food ingestion (mSv).

Two PAGs were used in the calculation: 500 mrem (5 mSv) for CEDE, and 5 rem (50 mSv) for committed dose equivalent to an individual tissue or organ. The FDA DILs were calculated for nine radionuclides (I-131, Cs-134, Cs-137, Ru-103, Ru-106, Sr-90, Pu-238, Pu-239, and Am-241) and considered the receptors of six different age groups. In the calculation, age-dependent food ingestion rates and dose coefficients were used. The age groups considered were 3 months, 1 year, 5 years, 10 years, 15 years, and adult (>17 years).

The dose coefficients used by the FDA were from the International Commission on Radiation Protection (ICRP) Publication 56 (ICRP 1989). The food ingestion rates were based on the "entire diet" for each age group, which included tap water used for drinking. In deriving DILs, it was assumed that 30% of the food intake was contaminated (i.e., $f = 0.3$ in Equation 10.1). An exception was made for I-131 in the diets of the 3-month and 1-year age groups, for which the entire intake over a 60-day period was assumed to be contaminated. Table 10.1 provides the annual intake rates for the six age groups considered in deriving DILs. In the derivation of DILs, correction for radiological decay was not applied. However, the intake period was selected to be either 1 year or the time required for a radionuclide to decay to ~1% of its initial activity, whichever is smaller. As a result, for short-lived radionuclides, the intake period considered could be less than 1 year, and the yearly intake rate would be adjusted by the intake period correction factor (IPC in Equation 10.2). None of the radionuclides concerned for an RDD event in this report has a half-life short enough to require this correction. Appendix D in the FDA report (FDA 1998) describes in detail how DILs were calculated and lists the values of dose coefficients used. Among all the DILs that were calculated, combining different PAGs and age groups, the most limiting one was selected by FDA to be the recommended value for use after a nuclear accident.

TABLE 10.1 Dietary Intake Rates for Different Age Groups

Age Group	Annual Intake Rate (kg)
3-months	418
1-year	506
5-years	660
10-years	779
15-years	869
Adult	943

Later, the FDA calculated DILs for 15 more radionuclides by using the same equations. Among all the radionuclides considered by the FDA (FDA 1998), six are among the RDD radionuclide list analyzed in this report. Table 10.2 lists the FDA DILs for those six radionuclides.

In deriving the DILs, the FDA followed the principles and general guidance provided by the ICRP Publication 40 (ICRP 1984). The ICRP has since updated its general concepts on intervention and has documented them in ICRP Publication 63 (ICRP 1991). The PVs for Subgroup 1 were calculated on the basis of the FDA methodology described previously, but with the updated concept (ICRP 1991) and revised dose coefficients obtained from ICRP Publication 72 (ICRP 1996). The dietary intake rates used for different age groups were the same as those listed in Table 10.1. Table 10.3 lists the dose coefficients from ICRP 72. Table 10.4 lists the calculated PVs for different age groups and different PAGs. The most restrictive value was selected to be the final operational guideline for Subgroup 1. The values are listed in Table 10.5, along with the corresponding age group and PAG. Measured radionuclide concentrations in crops or animal products produced from the affected area after an RDD event should be compared with the Subgroup 1 operational guidelines.

10.3 SUBGROUP 2 SOIL OPERATIONAL GUIDELINES FOR THE EARLY PHASE

Subgroup 2 soil operational guidelines were intended for use in the early phase of response after an RDD event. For this purpose, they consider the crops that have been growing during the event. As for the animal products, they consider those from livestock that fed on fodders grown in the field during the event. Because the crops or fodders are already growing during the event, the main contamination mechanism would be the uptake of radionuclides that

TABLE 10.2 FDA DILs with Corresponding PAG and Age Group for RDD Radionuclides

Radionuclide	DIL (Bq/kg)	Limiting Age Group	PAG (mSv)
Am-241	2	3-month	50
Cm-244	2	3-month	50
Cs-137	1,400	Adult	5
Pu-238	2	3-month	50
Pu-239	2	3-month	50
Sr-90	160	15-year	50

TABLE 10.3 Dose Coefficients (mSv/Bq)[a] from ICRP Publication 72 Used in Deriving the PVs for Food Operational Guidelines for the Early Phase (Subgroup 1)

Radionuclide	3-month	1-year	5-year	10-year	15-year	Adult
Am-241(BS)[b]	8.30E-02	8.30E-03	7.40E-03	7.30E-03	8.00E-03	9.00E-03
Am-241	3.70E-03	3.70E-04	2.70E-04	2.20E-04	2.00E-04	2.00E-04
Cf-252(BS)	0.11	9.90E-03	6.90E-03	4.00E-03	2.90E-03	2.90E-03
Cf-252	5.00E-03	5.10E-04	3.20E-04	1.90E-04	1.00E-04	9.00E-05
Cm-244(BS)	5.90E-02	5.80E-03	4.50E-03	3.90E-03	4.20E-03	4.90E-03
Cm-244	2.90E-03	2.90E-04	1.90E-04	1.40E-04	1.20E-04	1.20E-04
Co-60(LLI)[b]	9.9E-5(L)[b]	6.30E-05	3.70E-05	2.40E-05	1.5E-5(L)[b]	1.20E-05
Co-60	5.40E-05	2.70E-05	1.70E-05	1.10E-05	7.90E-06	3.40E-06
Cs-137(LLI)	4.90E-05	3.10E-05	1.90E-05	1.60E-05	1.60E-05	1.70E-05
Cs-137	2.10E-05	1.20E-05	9.60E-06	1.00E-05	1.30E-05	1.30E-05
Ir-192 (LLI)	1.40E-04	8.90E-05	4.60E-05	2.80E-05	1.60E-05	1.30E-05
Ir-192	1.30E-05	8.70E-06	4.60E-06	2.80E-06	1.70E-06	1.40E-06
Po-210 (Spleen)	2.20E-01	7.60E-02	4.10E-02	2.50E-02	1.60E-02	1.3E-02(K)[b]
Po-210	2.60E-02	8.80E-03	4.40E-03	2.60E-03	1.60E-03	1.20E-03
Pu-238(BS)	6.80E-02	6.90E-03	6.20E-03	5.90E-03	6.30E-03	7.40E-03
Pu-238	4.00E-03	4.00E-04	3.10E-04	2.40E-04	2.20E-04	2.30E-04
Pu-239(BS)	7.40E-02	7.60E-03	7.00E-03	6.80E-03	7.20E-03	8.20E-03
Pu-239	4.20E-03	4.20E-04	3.30E-04	2.70E-04	2.40E-04	2.50E-04
Ra-226(BS)	1.60E-01	2.90E-02	2.30E-02	3.90E-02	9.40E-02	1.20E-02
Ra-226	4.70E-03	9.60E-04	6.20E-04	8.00E-04	1.50E-03	2.80E-04
Sr-90(BS)	2.30E-03	7.30E-04	6.30E-04	1.00E-03	1.80E-03	4.10E-04
Sr-90	2.30E-04	7.30E-05	4.70E-05	6.00E-05	8.00E-05	2.80E-05

[a] The first listed value for each radionuclide is the most restrictive committed equivalent dose to an individual organ or tissue, $h_T(\tau)$. The second listed value for each radionuclide is the committed effective dose, $e(\tau)$. (τ is the time period over which the dose is calculated; that is, 50 years for adults and $(70-t_0)$ for children, where t_0 is the age considered for the age group.)

[b] BS = bone surface; LLI = lower large intestine; L = liver; K = kidney.

TABLE 10.4 PVs[a] (Bq/kg) for Different Age Groups and PAGs

Radionuclide	PAGs (mSv/yr)	3-month	1-year	5-year	10-year	15-year	Adult
Am-241(BS)[b]	50	4.8E+00	4.0E+01	3.4E+01	2.9E+01	2.4E+01	2.0E+01
Am-241	5	1.1E+01	8.9E+01	9.4E+01	9.7E+01	9.6E+01	8.8E+01
Cf-252(BS)	50	3.6E+00	3.3E+01	3.7E+01	5.3E+01	6.6E+01	6.1E+01
Cf-252	5	8.0E+00	6.5E+01	7.9E+01	1.1E+02	1.9E+02	2.0E+02
Cm-244(BS)	50	6.8E+00	5.7E+01	5.6E+01	5.5E+01	4.6E+01	3.6E+01
Cm-244	5	1.4E+01	1.1E+02	1.3E+02	1.5E+02	1.6E+02	1.5E+02
Co-60(LLI)[b]	50	4.0E+03	5.2E+03	6.8E+03	8.9E+03	1.3E+04	1.5E+04
Co-60	5	7.4E+02	1.2E+03	1.5E+03	1.9E+03	2.4E+03	5.2E+03
Cs-137(LLI)	50	8.1E+03	1.1E+04	1.3E+04	1.3E+04	1.2E+04	1.0E+04
Cs-137	5	1.9E+03	2.7E+03	2.6E+03	2.1E+03	1.5E+03	1.4E+03
Ir-192 (LLI)	50	2.8E+03	3.7E+03	5.5E+03	7.6E+03	1.2E+04	1.4E+04
Ir-192	5	3.1E+03	3.8E+03	5.5E+03	7.6E+03	1.1E+04	1.3E+04
Po-210 (Spleen)	50	1.8E+00	4.3E+00	6.2E+00	8.6E+00	1.2E+01	1.4E+01
Po-210	5	1.5E+00	3.7E+00	5.7E+00	8.2E+00	1.2E+01	1.5E+01
Pu-238(BS)	50	5.9E+00	4.8E+01	4.1E+01	3.6E+01	3.0E+01	2.4E+01
Pu-238	5	1.0E+01	8.2E+01	8.1E+01	8.9E+01	8.7E+01	7.7E+01
Pu-239(BS)	50	5.4E+00	4.3E+01	3.6E+01	3.1E+01	2.7E+01	2.2E+01
Pu-239	5	9.5E+00	7.8E+01	7.7E+01	7.9E+01	8.0E+01	7.1E+01
Ra-226(BS)	50	2.5E+00	1.1E+01	1.1E+01	5.5E+00	2.0E+00	1.5E+01
Ra-226	5	8.5E+00	3.4E+01	4.1E+01	2.7E+01	1.3E+01	6.3E+01
Sr-90(BS)	50	1.7E+02	4.5E+02	4.0E+02	2.1E+02	1.1E+02	4.3E+02
Sr-90	5	1.7E+02	4.5E+02	5.4E+02	3.6E+02	2.4E+02	6.3E+02

[a] The PVs are based on a PAG of either 50 mSv/yr committed equivalent dose to an individual organ or tissue (first listed value) or 5 mSv/yr committed effective dose (the second listed value).

[b] BS = bone surface; LLI = lower large intestine.

TABLE 10.5 Final Food Operational Guidelines (or PVs) for the Early Phase (Subgroup 1)

Radionuclide	Operational Guideline (PVs) Bq/kg	pCi/kg	Age Group	PAG (mSv)
Am-241	4.8E+00	1.30E+02	3-month	50
Cf-252	3.6E+00	9.72E+01	3-month	50
Cm-244	6.8E+00	1.84E+02	3-month	50
Co-60	7.4E+02	2.00E+04	3-month	5
Cs-137	1.4E+03	3.78E+04	Adult	5
Ir-192	2.8E+03	7.56E+04	3-month	50
Po-210	1.5E+00	4.05E+01	3-month	5
Pu-238	5.9E+00	1.59E+02	3-month	50
Pu-239	5.4E+00	1.46E+02	3-month	50
Ra-226	2.0E+00	5.40E+01	15 year	50
Sr-90	1.1E+02	2.97E+03	15 year	50

were directly deposited on foliage from a contamination plume that passed the agriculture field. The potential contamination mechanism caused by root uptake of radionuclides deposited on surface soil would be much less because (1) it takes time for radionuclides to infiltrate to deeper soil, and the plants would be harvested or consumed before that occurs; and (2) the radionuclide concentration in the root zone would be greatly diluted by the bulk volume of soil. Although the root uptake mechanism would not contribute significantly to plant contamination during the plume phase, it was included in the modeling for completeness.

For the early phase of response (Subgroup 2), modeling of plant concentration was performed by using the FRMAC methodology (Rhodes et al. 2003). The crops considered for human consumption were leafy vegetables that were assumed to have a growing period of 0.2 year and a productivity of 2 kg/m^2. Both are RESRAD default values (Yu et al. 2001). The radionuclide concentrations that were intercepted and retained on the foliage of crops during the plume phase were assumed to be 20% of those deposited on surface soil. This 20% value is the default used by FRMAC (Rhodes et al. 2003). The animal product considered for human consumption was milk. Contamination of meat products was not considered because it was not included in the FRMAC methodology. The growing period of fodder grazed by milk cows was assumed to be 0.08 year and the productivity to be 0.7 kg/m^2. Both are RESRAD default values (Yu et al. 2001). The radionuclide concentrations directly deposited on the fodder were 50% of those deposited on surface soil, which was the default value used by FRMAC (Rhodes et al.

2003), and all fodder consumed by milk cows was assumed contaminated. The root uptake transfer factors and food-to-milk transfer factors used in the modeling were the default values used by FRMAC (Rhodes et al. 2003), and these are listed in Table 10.6. Note that the plant/soil transfer factors for root uptake used by FRMAC are taken from the RESRAD database (Yu et al. 2001).

Table 10.7 lists the calculated food-to-soil concentration ratios and soil operational guidelines corresponding to the PVs listed in Table 10.5. The calculated milk concentration was converted from pCi/L to pCi/kg by using an assumed milk density of 1 kg/L. For the plant concentration, washing or rinsing vegetables to remove radionuclides deposited on leaves was not considered. For each radionuclide, two operational guidelines were calculated on the basis of crop and milk consumption. The more conservative value from these two (the smaller one) was selected for use in the early response phase after an RDD event. For all radionuclides except Cs-137, the final operational guidelines were derived on the basis of leafy vegetable consumption. For Cs-137, the final operational guideline was derived on the basis of milk consumption because of the large fodder-to-milk transfer factor (0.0079 d/L) for Cs.

TABLE 10.6 Transfer Factors Used by the FRMAC and RESRAD Methodologies

	FRMAC Methodology		RESRAD Methodology		
Radionuclide	Plant/Soil Transfer Factor for Root Uptake	Milk Transfer Factor (d/L)	Plant/Soil Transfer Factor for Root Uptake	Meat Transfer Factor (d/kg)	Milk Transfer Factor (d/L)
Am-241	1.0E-03	1.5E-06	1.0E-03	5.0E-05	2.0E-06
Cf-252	1.0E-03	2.0E-06	1.0E-03	6.0E-05	7.5E-07
Cm-244	1.0E-03	2.0E-06	1.0E-03	2.0E-05	2.0E-06
Co-60	8.0E-02	2.0E-03	8.0E-02	2.0E-02	2.0E-03
Cs-137	4.0E-02	7.9E-03	4.0E-02	3.0E-02	8.0E-03
Ir-192	3.0E-02	2.0E-06	3.0E-02	2.0E-03	2.0E-06
Po-210	1.0E-03	3.4E-04	1.0E-03	5.0E-03	3.4E-04
Pu-238	1.0E-03	1.1E-06	1.0E-03	1.0E-04	1.0E-06
Pu-239	1.0E-03	1.1E-06	1.0E-03	1.0E-04	1.0E-06
Ra-226	4.0E-02	1.3E-03	4.0E-02	1.0E-03	1.0E-03
Sr-90	3.0E-01	2.8E-03	3.0E-01	8.0E-03	2.0E-03

TABLE 10.7 Subgroup 2 Soil Operational Guidelines for the Early Phase of Response after an RDD Incident

Radionuclide	Food/Soil Concentration Ratio [(pCi/kg)/(pCi/m^2)]		Operational Guideline for Individual Food Category (pCi/m^2)		Final Soil Operational Guideline (pCi/m^2)
	Vegetable	Milk	Vegetable	Milk	
Am-241	1.00E-01	5.36E-05	1.30E+03	2.42E+06	1.30E+03
Cf-252	9.99E-02	7.13E-05	9.73E+02	1.36E+06	9.73E+02
Cm-244	1.00E-01	7.14E-05	1.84E+03	2.57E+06	1.84E+03
Co-60	1.00E-01	7.14E-02	2.00E+05	2.80E+05	2.00E+05
Cs-137	1.00E-01	2.82E-01	3.78E+05	1.34E+05	1.34E+05
Ir-192	9.91E-02	7.01E-05	7.63E+05	1.08E+09	7.63E+05
Po-210	9.95E-02	1.20E-02	4.07E+02	3.37E+03	4.07E+02
Pu-238	1.00E-01	3.93E-05	1.59E+03	4.06E+06	1.59E+03
Pu-239	1.00E-01	3.93E-05	1.46E+03	3.71E+06	1.46E+03
Ra-226	1.00E-01	4.64E-02	5.40E+02	1.16E+03	5.40E+02
Sr-90	1.00E-01	1.00E-01	2.97E+04	2.97E+04	2.97E+04

10.4 SUBGROUP 3 SOIL OPERATIONAL GUIDELINES FOR THE INTERMEDIATE PHASE

Subgroup 3 operational guidelines were intended for use in the intermediate phase of response after an RDD event. They consider crops or fodders that grow after the passage of the contamination plume. Plants become contaminated as a result of foliage deposition of airborne radionuclides that originate from the ground surface through resuspension. In addition to foliage deposition, radionuclides that infiltrate from the ground surface to deeper soils could also be taken up by root systems and transferred to plant tissues. Modeling of plant concentrations was performed by using the RESRAD methodology (Yu et al. 2001), because the consideration of direct plume deposition by the FRMAC methodology does not apply to the plants grown after the plume phase.

Two types of crops were modeled: (1) leafy vegetables and (2) grain and nonleafy vegetables. For animal products, meat and milk produced by livestock feeding on fodders grown after the plume phase were considered. The Subgroup 3 soil operational guidelines were derived in terms of the concentrations of radionuclide deposited surface soil that would result in the production of crops or animal products with contamination levels equivalent to the PVs (i.e., Subgroup 1 operational guidelines). In the modeling, average soil and air concentrations over the growing periods of vegetables and fodders were used to calculate the respective plant concentrations. The use of average plant concentrations accounts for the decrease with time due to radiological decay and weathering. The methodology for calculating the average soil and air concentrations is consistent with that used in the operational guidelines for Groups B–E, which is described in Chapter 2.

The other assumptions used in the modeling include the following:

1. The growing period for leafy vegetables is 0.25 year, 0.17 year for grain and nonleafy vegetables, and 0.08 year for fodder.

2. The ingestion rate of fodder by meat cows is 68 kg/d and 55 kg/d by milk cows.

3. The ingestion rate of soil by meat and milk cows is 0.5 kg/d.

4. The storage times for grain and nonleafy vegetables, leafy vegetables, meat, and milk are 14, 1, 20, and 1 day, respectively.

5. The depth of soil mixing layer is the plow depth of 0.15 m.

6. The depth of roots is the same as the plow depth, 0.15 m.

7. The soil density is 1.5 g/cm^3.

The root uptake transfer factors and fodder-to-meat and -milk transfer factors are listed in Table 10.6. Except for the depth of roots, all parameter values used in the modeling are RESRAD default values. The depth of roots is taken from FRMAC (Rhodes et al. 2003).

Table 10.8 lists the Subgroup 3 soil operational guidelines for different food categories. The food category that resulted in the minimum soil concentration was selected to be the final soil guideline value. For most of the radionuclides, except for Co-60, Cs-137, and Po-210, the final guidelines were determined by consumption of leafy vegetables. For Co-60, Cs-137, and Po-210, the final guidelines were determined by consumption of meat products.

TABLE 10.8 Subgroup 3 Soil Operational Guidelines for the Intermediate Phase of Response after an RDD Incident

	Food/Soil Concentration Ratio [(pCi/kg)/(pCi/m^2)]				Soil Operational Guideline for Individual Food Category (pCi/m^2)				
Radionuclide	Nonleafy Vegetable	Leafy Vegetable	Meat	Milk	Nonleafy Vegetable	Leafy Vegetable	Meat	Milk	Final Soil Operational Guideline (pCi/m^2)
Am-241	8.84E-06	2.00E-05	2.70E-07	9.59E-09	1.47E+07	6.49E+06	4.79E+08	1.35E+10	6.49E+06
Cf-252	8.62E-06	1.96E-05	3.18E-07	3.57E-09	1.13E+07	4.95E+06	3.06E+08	2.72E+10	4.95E+06
Cm-244	8.81E-06	1.99E-05	1.08E-07	9.58E-09	2.08E+07	9.21E+06	1.70E+09	1.92E+10	9.21E+06
Co-60	3.48E-04	3.56E-04	5.75E-04	4.76E-05	5.74E+07	5.61E+07	3.48E+07	4.20E+08	3.48E+07
Cs-137	1.79E-04	1.88E-04	5.12E-04	1.14E-04	2.12E+08	2.01E+08	7.39E+07	3.32E+08	7.39E+07
Ir-192	9.10E-05	1.00E-04	2.09E-05	2.08E-08	8.31E+08	7.53E+08	3.62E+09	3.63E+12	7.53E+08
Po-210	7.44E-06	1.79E-05	2.33E-05	1.54E-06	5.44E+06	2.26E+06	1.74E+06	2.63E+07	1.74E+06
Pu-238	8.83E-06	2.00E-05	5.41E-07	4.80E-09	1.80E+07	7.98E+06	2.95E+08	3.32E+10	7.98E+06
Pu-239	8.84E-06	2.00E-05	5.41E-07	4.80E-09	1.65E+07	7.30E+06	2.69E+08	3.04E+10	7.30E+06
Ra-226	1.79E-04	1.89E-04	1.71E-05	1.42E-05	3.02E+05	2.86E+05	3.16E+06	3.79E+06	2.86E+05
Sr-90	1.31E-03	1.31E-03	7.58E-04	1.54E-04	2.27E+06	2.27E+06	3.92E+06	1.92E+07	2.27E+06

10.5 SUBGROUP 4 SOIL OPERATIONAL GUIDELINES FOR THE INTERMEDIATE-TO-LATE PHASE

Subgroup 4 soil operational guidelines were developed on the basis of a PAG of 500 mrem/yr, rather than the PVs of Subgroup 1. They can be used for estimating the potential radiation doses that correspond to the Subgroup 3 soil operational guidelines and are intended for use during the intermediate-to-late phases of response after an RDD event. Like Subgroup 3 operational guidelines, they consider crops or fodders that grow in a contaminated area after an RDD event. The methodology used to calculate the concentrations in crops and fodder was consistent with that used in Subgroup 3, except that the soil and air concentrations were corrected for weathering and radiological decay for a 1-year period. This was done to calculate the average concentrations in food products that were assumed to be produced continuously throughout a year for consumption. The total radioactivity ingested within a year was calculated by multiplying the average concentrations in food products by the annual consumption rate of the products. The annual ingestion of radioactivity was then converted to annual dose with the use of dose conversion factors.

An average adult was considered as the general receptor and was assumed to ingest 160 kg/yr of grain and nonleafy vegetables, 14 kg/yr of leafy vegetables, 92 L/yr of milk, and 63 kg/yr of meat. Among all food ingested, 30% was assumed to be contaminated, which was also the assumption used by the FDA when deriving the DILs. These consumption rates are consistent with RESRAD default values. Dose conversion factors were obtained from ICRP 72 (ICRP 1996). The derived soil operational guidelines for different food categories for Subgroup 4 are listed in Table 10.9. They are the surface soil concentrations that would produce contaminated crops and animal products through uptake pathways that, after consumption, individually would result in a radiation dose of 500 mrem/yr (CED).

The final soil operational guidelines were obtained by considering consumption of all the different types of food are produced from the same contaminated area. In reality, because of the limitation in size or location of the contaminated area, the agricultural activities may be limited to produce only a certain type, or types, of food. In that case, the final soil operational guidelines can be increased to reflect the real situations. The last column of Table 10.9 shows the soil operational guidelines that pertain to consumption of only leafy and nonleafy vegetables.

TABLE 10.9 Subgroup 4 Soil Operational Guidelines for the Intermediate-to-Late Phase of Response after an RDD Incident

	Annual Dose/Soil Concentration Ratio ([mrem/yr)/(pCi/m^2])				Soil Operational Guidelines for Individual Food Category (pCi/m^2)					
Radionuclides	Nonleafy Vegetable	Leafy Vegetable	Meat	Milk	Nonleafy Vegetable	Leafy Vegetable	Meat	Milk	Final Soil Operational Guideline (all foods combined) (pCi/m^2)	Soil Operational Guideline (leafy and nonleafy vegetables combined) (pCi/m^2)
Am-241	1.78E-07	2.74E-08	1.85E-09	1.03E-10	2.80E+09	1.82E+10	2.71E+11	4.86E+12	2.41E+09	2.43E+09
Cf-252	7.15E-08	1.15E-08	8.80E-10	1.55E-11	6.99E+09	4.37E+10	5.68E+11	3.23E+13	5.96E+09	6.03E+09
Cm-244	1.79E-07	1.63E-08	4.35E-10	6.07E-11	2.79E+09	3.07E+10	1.15E+12	8.23E+12	2.55E+09	2.56E+09
Co-60	1.82E-07	1.62E-08	1.08E-07	1.30E-08	2.75E+09	3.09E+10	4.65E+09	3.83E+10	1.57E+09	2.52E+09
Cs-137	3.69E-07	3.31E-08	3.58E-07	1.17E-07	1.35E+09	1.51E+10	1.39E+09	4.27E+09	5.70E+08	1.24E+09
Ir-192	7.98E-09	8.49E-10	5.37E-10	7.88E-13	6.26E+10	5.89E+11	9.31E+11	6.35E+14	5.34E+10	5.66E+10
Po-210	5.42E-07	1.09E-07	5.22E-07	5.36E-08	9.22E+08	4.58E+09	9.58E+08	9.32E+09	4.07E+08	7.67E+08
Pu-238	2.04E-07	3.15E-08	4.23E-09	5.90E-11	2.45E+09	1.59E+10	1.18E+11	8.47E+12	2.08E+09	2.12E+09
Pu-239	2.23E-07	3.43E-08	4.62E-09	6.44E-11	2.24E+09	1.46E+10	1.08E+11	7.77E+12	1.91E+09	1.94E+09
Ra-226	8.05E-06	7.21E-07	2.61E-07	3.19E-07	6.21E+07	6.93E+08	1.92E+09	1.57E+09	5.35E+07	5.70E+07
Sr-90	6.50E-06	5.71E-07	1.43E-06	4.25E-07	7.69E+07	8.75E+08	3.49E+08	1.18E+09	5.60E+07	7.07E+07

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APPENDIX 10.A:

COMPARISON OF OPERATIONAL GUIDELINES FOR GROUP G

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Comparisons of operational guidelines among the four subgroups are presented in this appendix. Table 10.A.1 compares the intended applications and the methodology used in the guideline derivation. Table 10.A.2 compares the parameter values used in the derivation.

TABLE 10.A.1 Comparison of Intended Uses and Derivation of Operational Guidelines for Subgroups 1–4

Parameters	Subgroup 1	Subgroup 2	Subgroup 3	Subgroup 4
Expression form	In terms of limiting concentrations in food (pCi/kg)	In terms of limiting concentrations in surface soil (pCi/m^2)	In terms of limiting concentrations in surface soil (pCi/m^2)	In terms of limiting concentrations in surface soil (pCi/m^2)
PAG	5,000 mrem/yr committed equivalent dose to an individual organ or 500 mrem/yr CED	Not required – use PVs (operational guidelines for Subgroup 1) as target food concentrations	Not required – use PVs (operational guidelines for Subgroup 1) as target food concentrations	500 mrem/yr CED
Intended uses	For placing embargo and consumption restriction on plant food or animal products that are exposed during an RDD event	For placing embargo and consumption restriction on plant food or animal products that are exposed during an RDD event	For placing land use restriction for agricultural activities after an RDD event	For (1) evaluating potential radiation doses corresponding to Subgroup 3 operational guidelines, and (2) placing land use restriction for agricultural activities after an RDD event
When to apply	In the early phase of response	In the early phase of response	In the intermediate phase of response	In the intermediate-to-late phase of response
How to apply	Compare with measured concentrations taken from food that was exposed during an RDD event	Compare with measured concentrations taken from surface soil in which plant foods/fodder were growing during an RDD event	Compare with measured concentrations taken from surface soil in the contaminated area	Compare with measured concentrations taken from surface soil in the contaminated area
Methodology	Based on FDA methodology for deriving DILs, but with updated dose coefficients	Used FRMAC methodology to relate concentrations in plant food/milk to the deposited surface soil concentration during the plume phase	Used RESRAD model to relate concentrations in plant food/meat/milk to the residual surface soil concentration; soil and air concentrations were corrected for weathering and radiological decay during the growing period	Used RESRAD model to relate the potential annual ingestion dose to the residual surface soil concentration, through the calculation of average concentrations in plant food/meat/milk; soil and air concentrations were corrected for weathering and radiological decay for 1-year period
Specific consideration/ comments	Different age groups and the respective dose coefficients	Foliar deposition results from a passing plume	Foliar deposition results from airborne contaminants that originate from ground surface due to resuspension	Same as Subgroup 3

TABLE 10.A.2 Comparison of Parameter Values Used in the Derivation of Operational Guidelines for Subgroups 1–4

Parameters	Subgroup 1	Subgroup 2	Subgroup 3	Subgroup 4
Contaminated food types	All food types, including water	Leafy vegetables and milk	Grain and nonleafy vegetables, leafy vegetables, meat, and milk	Grain and nonleafy vegetables, leafy vegetables, meat, and milk
Contaminated soil	NR[a]	Mixing depth – 15 cm; soil density – 1.5 g/cm^3	Same as Subgroup 2	Same as Subgroup 2
Dietary intake of human	Age-dependent: 3-month – 418 kg; 1-yr – 506 kg; 5-yr – 660 kg; 10-yr – 779 kg; 15-yr – 869 kg; adult – 943 kg.	NR	NR	Adult – 160 kg/yr of grain and nonleafy vegetables; 14 kg/yr of leafy vegetables; 93 L/yr of milk; and 63 kg/yr of meat
Dietary intake of livestock	NR	Milk cow – 50 kg/d fodder	Meat cows – 68 kg/d fodder and 0.5 kg/d soil; milk cows – 55 kg/d fodder and 0.5 kg/d soil	Meat cows – 68 kg/d fodder and 0.5 kg/d soil; milk cows – 55 kg/d fodder and 0.5 kg/d soil
Contaminated fraction of human food	0.3	NR	NR	0.3
Contaminated fraction of animal fodder	NR	1	1	1
Food growing period	NR	Leafy vegetables – 0.25 yr; fodder – 0.08 yr	Grain and nonleafy vegetables – 0.17 yr; leafy vegetables – 0.25 yr; fodder – 0.08 yr	Same as Subgroup 3
Crop productivity	NR	Leafy vegetables – 2 kg/m^2; fodder – 0.7 kg/m^2	Grain and nonleafy vegetables – 0.7 kg/m2; leafy vegetables – 1.5 kg/m2; fodder – 1.1 kg/m^2	Same as Subgroup 3
Storage time	NR	Leafy vegetables – 1 d; fodder – 0 d; and milk – 2 d	Grain and nonleafy vegetables – 14 d; leafy vegetables – 1 d; fodder – 0 d; meat – 20 d; milk – 1 d	Same as Subgroup 3

TABLE 10.A.2 (Cont.)

Parameters	Subgroup 1	Subgroup 2	Subgroup 3	Subgroup 4
Transfer factors	NR	Root uptake transfer factors and milk transfer factors are listed in Table 10.6	Root uptake transfer factors and meat and milk transfer factors are listed in Table 10.6; root uptake transfer factors are the same as Subgroup 2; milk transfer factors are slightly different from Subgroup 2	Same as Subgroup 3
Deposition velocity	NR	NR	0.001 m/s	0.001 m/s
Weathering removal constant	NR	NR	20 yr^{-1} for plants	20 yr^{-1} for plants
Foliage to food transfer factor	NR	1	Nonleafy – 0.1; leafy – 1; fodder – 1	Nonleafy – 0.1; leafy – 1; fodder – 1
Fraction of the initially retained deposition at harvest	NR	1	1	1
Fraction of deposition initially retained	NR	0.2 for crops, 0.5 for fodder	0.25	0.25

[a] NR indicates the information is not required.

11 ADDITIONAL EXPOSURE SCENARIOS AND OPERATIONAL GUIDELINES

During the development of RDD operational guidelines for Groups A through G, some additional exposure scenarios were analyzed and the corresponding operational guidelines were derived. These potential exposure scenarios included flushing contaminated streets, cleaning contaminated vehicles, and releasing contaminated vehicles. These scenarios are discussed in this chapter; however, they are not included in the companion software described in Chapter 12.

For the analysis of scenarios discussed in this chapter, results from previous work were used in the calculation of operational guidelines. It should be noted that the dose calculations for some of the previous work were based on the ICRP 30 (ICRP 1982) dose conversion factors published in the Federal Guidance Reports 11 (Eckerman et al. 1988) and 12 (Eckerman and Ryman 1993). Hence, the dose reported in this chapter is total effective dose equivalent (TEDE) rather than total effective dose (TED).

11.1 STREET FLUSHING

11.1.1 Introduction

Potential radiation exposures resulting from flushing radionuclides off a contaminated street after an RDD event were analyzed by considering three destinations for the flushed radionuclides. The first destination is a publicly owned treatment works (POTW). The radionuclides and contaminated dust particles were assumed to be carried by the flushing water, enter the underground sewage lines, and then travel to a POTW where wastewater is collected and treated. The second destination is a surface water body. Rather than entering a sewage line, the radionuclides were assumed to infiltrate or run off to a stormwater collecting system and be discharged to a stream, lake, or river. The last destination is a detention pond. The radionuclides were assumed to be carried by the flushing water that runs to a nearby stormwater detention pond and to settle at the bottom of the detention pond by being adsorbed into the surface soils. Potential exposure scenarios associated with each destination were developed, and radiation doses were analyzed.

11.1.2 Scenario Descriptions

11.1.2.1 POTW Destination

For simplicity and conservativeness, radionuclides that are flushed to a POTW were assumed to concentrate in the sludge that is generated from wastewater treatment. Potential radiation exposures would result from handling and using the sludge material. Seven exposure scenarios (for seven receptors) were considered. These scenarios were taken from the dose assessment report prepared by the Interagency Steering Committee on Radiation Standards (ISCORS) Sewage Sludge Committee (ISCORS 2005). The seven scenarios are as follows:

1. On-site residents — residents of houses built on agricultural fields formerly applied with sludge;

2. Recreational users — users of a park where sludge has been used for land reclamation;

3. Nearby town residents — residents of a town near fields on which sludge has been applied;

4. Landfill neighbors — neighbors of a landfill that contains sludge and/or ash;

5. Incinerator neighbors — neighbors of a sludge incinerator;

6. Sludge application workers — agricultural workers who operate equipment to apply sludge to agricultural lands; and

7. POTW workers — workers at a POTW involved in sampling, transport, and biosolids loading operations.

The exposure pathways considered were external radiation; inhalation of dust particles and radon; and ingestion of plant food, meat, milk, aquatic food, soil, and water. Table 11.1 lists the pathways considered for each scenario.

TABLE 11.1 Exposure Pathways Considered for Various Sewage Sludge Exposure Receptors/Scenarios[a]

	Exposure Pathways								
Sewage Sludge Exposure Receptors/Scenarios	External Radiation	Inhalation of Dust Particles	Ingestion of Plant Foods	Ingestion of Meat	Ingestion of Milk	Ingestion of Fish	Ingestion of Soil	Ingestion of Water	Inhalation of Radon
On-site resident	x	x	x	x	x	x	x	x	x
Recreational user	x	x		x		x	x	x	x
Nearby town resident	x	x	x	x	x	x	x		x
Landfill neighbor	x	x	x	x	x	x	x	x	x
Incinerator neighbor	x	x	x	x	x		x		x
Sludge application worker	x	x							x
POTW worker	x	x							x

[a] Note: An “x” indicates that the exposure pathway was considered.

11.1.2.2 Surface Water Destination

When flushing water runs off or infiltrates a stormwater collecting system, it is most likely to be discharged to a surface water body, such as a stream, lake, or river. Potential radiation exposures could result from using the surface water body for recreational purposes, such as swimming, fishing, and boating.

Upon entering the surface water body, concentrations of radionuclides would be greatly diluted. Because the flushing activity is a one-time event and would not last long (ranging from a few hours to a few days), the contamination of surface water is expected to be temporary.

Further dilution would occur between the stormwater discharge point and the location where potential exposures could occur. Therefore, the surface water concentrations at the exposure location are expected to be very small. The resulting radiation exposures would be much smaller than those associated with a POTW or detention pond destination, where radionuclides are collected and concentrated in a finite volume and the exposure duration of potential receptors is longer.

Based on the above discussion, dose analyses were not conducted for the surface water body destination.

11.1.2.3 Detention Pond Destination

When a stormwater detention pond is located near a radioactively contaminated street, radionuclides flushed off of the street could flow to the detention pond with runoff water. They could settle and adsorb to soil at the bottom of the pond and form a secondary contamination area. Potential human radiation exposures could occur if the detention pond is also used for recreational or sporting activities after water drains out. Radiation exposures could occur through external radiation, inhalation of dust particles, and ingestion of soil.

11.1.3 Main Assumptions and Parameters

11.1.3.1 POTW Destination

Potential radiation doses for the sewage sludge exposure scenarios were obtained by scaling the dose results either presented in the ISCORS report or calculated using the ISCORS assumptions with the amount of sludge material generated each day at a POTW and the amount of radioactivity flushed from the street. The dose results presented in the ISCORS report (ISCORS 2005, Chapter 6) or calculated with the ISCORS assumptions were 95th-percentile values from the distribution of the peak doses within a timeframe of 1,000 years. The distributions of the peak doses were obtained by conducting probabilistic analyses using the RESRAD family of codes. The 95th-percentile values were selected as conservative measures for the potential exposures.

The daily amount of sludge generated by a POTW was developed based on information for a medium-sized POTW, which has a daily wastewater treatment rate of 13 million gallons. The amount of sludge generated each day was estimated to be about 43,500 kg. The area of the contaminated street was assumed to be 4,000 m^2 (200 m × 20 m). Additional assumptions include (1) 100% flushing efficiency, whereby all radionuclides are flushed off the street; and (2) 100% collection of radionuclides at the POTW.

11.1.3.2 Detention Pond Destination

Table 11.2 lists the parameter values used by RESRAD in dose calculations. Soil concentrations were calculated based on the assumptions that (1) 100% of the radionuclides flushed off the contaminated street flow to the detention pond; (2) after getting to the detention pond, 90% of the radionuclides drain out with water to a stormwater collecting system; (3) the remaining radionuclides settle at the bottom of the detention pond covering an area of 2,500 m^2; and (4) radionuclides concentrate on the top 1 cm of soil. The soil concentration would depend on the size of the contaminated area and contamination thickness. When the contamination thickness is fixed, a larger area would result in a lower concentration. An area of 2,500 m^2 was selected as a realistic, conservative assumption. The selection of a 1-cm thickness reflects the fact that the accumulation of water in the detention pond would result in infiltration of water and radionuclides to deeper soils.

11.1.4 Results

11.1.4.1 POTW Destination

Dose results for the various sewage sludge scenarios are listed in Table 11.3. They were obtained by assuming a unit surface concentration of 1 pCi/m^2 for the contaminated street. For Am-241, Cf-252, Cm-244, Pu-238, and Pu-239, the incinerator scenario has the highest

TABLE 11.2 RESRAD Input Parameters for the Detention Pond Scenario

Parameter	Value	Comment
Area of contamination (m^2)	2,500	A realistic conservative assumption
Thickness of contaminated zone (m)	0.01	Radionuclides concentrate on the surface at the beginning
Concentration of radionuclides (pCi/g)	1.07E-05	Calculated assuming 4,000 pCi (4,000 m^2 × 1 pCi/m^2) of radioactivity is flushed off, 10% is detained, and the secondary source has the above area and thickness
Density of contaminated zone (g/cm^3)	1.5	RESRAD default
Contaminated zone total porosity	0.4	RESRAD default
Contaminated zone hydraulic conductivity (m/yr)	10	RESRAD default
Contaminated zone b parameter	3	RESRAD default
Runoff coefficient	0	Water would only go down to deeper soils
Erosion rate (m/yr)	0	Erosion prevented by grass cover
Evapotranspiration coefficient	0.5	RESRAD default
Wind speed (m/s)	2	RESRAD default
Irrigation rate (m/yr)	0	No irrigation.
Precipitation rate (m/yr)	1	RESRAD default
Mass loading for inhalation (g/m^3)	2.45E-05	Mean of the NUREG/CR-6697 distribution
Inhalation rate (m^3)	12,264	Values for light industrial workers recommended by the EPA
Time fraction spent outdoors on-site	0.0285	Corresponds to 1 h/d and 250 d/yr
Time fraction spent indoors on-site	0	No indoor time
Soil ingestion rate (g/yr)	55	Gives a daily ingestion rate of 6.25 mg/d (1/8 of 50 mg/d, the EPA value for industrial workers)
Depth of soil mixing layer (m)	0.01	Surface covered with grass and no plowing activity
Radionuclide distribution coefficients, Kd (cm^3/g)		
Ac-227	20	RESRAD default
Am-241	1,378	RESRAD default
Cf-252	1,380	RESRAD default
Cm-244	1,378	RESRAD default

TABLE 11.2 (Cont.)

Parameter	Value	Comment
Cm-248	1,378	RESRAD default
Co-60	1,000	RESRAD default
Cs-137	1,000	RESRAD default
Ir-192	10	RESRAD default
Np-237	257	RESRAD default
Pa-231	50	RESRAD default
Pb-210	100	RESRAD default
Po-210	10	RESRAD default
Pu-238	2,000	RESRAD default
Pu-239	2,000	RESRAD default
Pu-240	2,000	RESRAD default
Pu-244	2,000	RESRAD default
Ra-226	70	RESRAD default
Ra-228	70	RESRAD default
Sr-90	30	RESRAD default
Th-228	60,000	RESRAD default
Th-229	60,000	RESRAD default
Th-230	60,000	RESRAD default
Th-232	60,000	RESRAD default
U-233	50	RESRAD default
U-234	50	RESRAD default
U-235	50	RESRAD default
U-236	50	RESRAD default

TABLE 11.3 DSRs (mrem/yr per pCi/m^2) Associated with Various Sewage Sludge Exposure Scenarios Resulting from Flushing a Contaminated Street with an Area of 4,000 m^2

	Exposure Scenarios							
Radionuclide	On-Site Resident	Recreational User	Nearby Town Resident	Landfill Neighbor	Incinerator Neighbor	Sludge Application Worker	POTW Worker	Maximum Values
Am-241	1.41E-08	1.84E-10	4.15E-11	2.53E-10	6.72E-07	4.35E-09	4.75E-09	6.72E-07
Cf-252	4.45E-09	4.28E-11	1.07E-11	1.38E-20	2.05E-07	1.29E-09	1.38E-09	2.05E-07
Cm-244	7.23E-09	7.76E-11	2.21E-11	1.03E-15	3.62E-07	2.30E-09	2.45E-09	3.62E-07
Co-60	3.99E-07	1.11E-08	1.34E-13	2.01E-35	2.23E-09	9.71E-08	1.42E-07	3.99E-07
Cs-137	1.33E-07	2.89E-09	4.21E-13	1.88E-15	3.37E-09	2.21E-08	2.95E-08	1.33E-07
Ir-192	3.47E-08	1.02E-09	2.36E-15	0.00E+00	2.16E-11	8.60E-09	1.11E-08	3.47E-08
Po-210	6.03E-08	4.20E-10	9.52E-13	0.00E+00	1.38E-08	4.09E-11	8.80E-12	6.03E-08
Pu-238	1.21E-08	1.30E-10	3.56E-11	3.47E-12	5.92E-07	3.69E-09	3.64E-09	5.92E-07
Pu-239	1.33E-08	1.47E-10	3.89E-11	3.80E-10	6.51E-07	4.09E-09	4.81E-09	6.51E-07
Ra-226	1.91E-06	8.82E-09	1.17E-09	1.33E-08	1.68E-08	7.29E-08	5.46E-07	1.91E-06
Sr-90	3.18E-07	1.47E-09	5.67E-13	2.08E-16	3.74E-08	1.64E-10	2.12E-10	3.18E-07

doses of all the scenarios. For Co-60, Cs-137, Ir-192, Po-210, Ra-226, and Sr-90, the on-site resident scenario has the highest doses.

11.1.4.2 Detention Pond Destination

Table 11.4 lists the dose results calculated using the contaminated detention pond. The flushed street area was assumed to be 4,000 m^2, with a surface contamination level of 1 pCi/m^2.

TABLE 11.4 DSRs (mrem/yr per pCi/m^2) for the Detention Pond User Scenario Resulting from Flushing a Contaminated Street with an Area of 4,000 m^2

Radionuclide	External	Inhalation	Soil Ingestion	Total
Am-241	2.95E-09	2.95E-09	3.02E-08	3.61E-08
Cf-252	3.16E-11	1.85E-09	1.59E-08	1.78E-08
Cm-244	3.62E-11	3.26E-09	3.32E-08	3.65E-08
Co-60	6.22E-07	2.74E-12	4.20E-10	6.22E-07
Cs-137	1.56E-07	4.21E-13	8.23E-10	1.57E-07
Ir-192	3.53E-08	5.72E-14	1.45E-11	3.53E-08
Po-210	4.64E-13	2.49E-11	6.28E-09	6.30E-09
Pu-238	3.54E-11	5.26E-09	5.35E-08	5.88E-08
Pu-239	2.85E-11	5.77E-09	5.94E-08	6.52E-08
Ra-226	3.83E-07	9.55E-11	1.91E-08	4.02E-07
Sr-90	8.74E-10	1.07E-11	1.55E-09	2.44E-09

Except for Co-60, Cs-137, Ir-192, and Ra-226, radiation exposures mainly occur from the incidental ingestion of soil. For Co-60, Cs-137, Ir-192, and Ra-226, radiation exposures mainly result from external radiation.

11.1.5 Conclusions on Street Flushing

Potential radiation exposures resulting from flushing a contaminated street after an RDD event were analyzed by considering the potential destinations of radionuclides and the various exposure scenarios pertaining to the destinations. The largest dose results among the various exposure scenarios should be selected for deriving screening criteria (operational guidelines).

Table 11.5 lists the calculated DSRs from flushing a contaminated street of 4,000 m^2. To obtain dose estimates for an actual RDD event, the results should be multiplied by the actual measured concentrations for the contaminated street. Table 11.5 also lists the derived operational guidelines for a contaminated street on the basis of 100 mrem/yr.

Three key assumptions are tied to the development of the operational guidelines listed in Table 11.5. They are (1) the contaminated street area is 4,000 m^2, (2) the flushing efficiency is 100%, and (3) all flushed radionuclides can be carried by water to either a POTW or a detention pond. Most likely, these assumptions would ensure that the radiation doses estimated for each destination scenario are conservative, thereby yielding conservative operational guidelines;

TABLE 11.5 Summary of DSRs and Operational Guidelines for Street Flushing Scenario

	DSR (mrem/yr per pCi/m^2)			
Radionuclide	POTW	Detention Pond	DSR for Screening (mrem/yr per pCi/m^2)	Operational Guidelines (pCi/m^2)[a]
Am-241	6.72E-07	3.61E-08	6.72E-07	1.49E+08
Cf-252	2.05E-07	1.78E-08	2.05E-07	4.88E+08
Cm-244	3.62E-07	3.65E-08	3.62E-07	2.76E+08
Co-60	3.99E-07	6.22E-07	6.22E-07	1.61E+08
Cs-137	1.33E-07	1.57E-07	1.57E-07	6.37E+08
Ir-192	3.47E-08	3.53E-08	3.53E-08	2.83E+09
Po-210	6.03E-08	6.30E-09	6.03E-08	1.66E+09
Pu-238	5.92E-07	5.88E-08	5.92E-07	1.69E+08
Pu-239	6.51E-07	6.52E-08	6.51E-07	1.53E+08
Ra-226	1.91E-06	4.43E-06	4.43E-06	2.26E+07
Sr-90	3.18E-07	2.44E-09	3.18E-07	3.15E+08

[a] Based on 100 mrem/yr.

however, if the real situations are quite different from the assumptions, the operational guidelines should be adjusted. For a contaminated street with a different area, the operational guidelines should be adjusted linearly with the ratio of 4,000 m^2 to the area. For a flushing efficiency smaller than 100%, the operational guidelines should be adjusted linearly with the ratio of 100% to the efficiency. The remaining radioactivity level on the street surface would need to be compared with the operational guidelines developed for a street vendor scenario before the street can be released for unrestricted use. If the final destination of the flushed radionuclides is known, rather than using the operational guidelines listed in Table 11.5, the DSRs pertaining to the final destination (also listed in Table 11.5) should be used to derive the guideline values. The DSRs of the detention pond destination should be adjusted linearly with (1) the ratio of 2,500 m^2 to the size of the detention pond, and (2) the fraction of the flushed radionuclides that would end up in the detention pond. The DSRs of the POTW destination should be adjusted linearly with the fraction of the flushed radionuclides that would end up in the detention pond.

11.2 CLEANING CONTAMINATED VEHICLES

11.2.1 Introduction

Derivation of operational guidelines for washing contaminated vehicles is presented in this chapter. Vehicles with an exterior surface contamination level less than the operational guidelines can be washed with water to reduce the contamination level to meet the vehicle release guidelines, because potential radiation exposures to the radionuclides removed by water would not result in a dose greater than 100 mrem/yr to any receptor. If the exterior contamination level is greater than the operational guidelines, the vehicles would need to be cleaned by a different method, or if they are washed, the used water would need to be collected and treated before the final disposal.

Assuming that the used water is not collected, a wide range of exposure to contaminants removed by washing the exterior surfaces of a vehicle is possible. The exposures would depend on the destinations of the contaminants, which can be identified by the destinations of the used water. The water could carry contaminants to either an underground sewer line or stormwater collecting system. If a detention pond was located nearby, they could be carried by water and runoff to the detention pond. They could also adhere to the ground surface and become a secondary contamination source. The destinations of the removed contaminants would depend on where the vehicle is cleaned. Cleaning a vehicle can also involve vacuuming its interior surfaces. After the interior is cleaned, the vacuum bag is assumed to be collected and sent to an approved or appropriate facility for disposal so that radiation exposure to the removed contaminants is controlled and limited.

Potential radiation exposures to contaminants removed by washing vehicles were analyzed. The radiation doses were estimated for the various exposure scenarios considered applicable to each contaminant destination. For some exposure scenarios that were analyzed previously in deriving the operational guidelines for flushing contaminated streets, the dose estimates were made on the basis of the previously calculated results. The amount of contaminants that would be removed through washing was calculated by considering two types of vehicles — a passenger bus and a midsized car, which were considered in deriving the operational guidelines for vehicle release. The dimensions of the vehicles and the distributions of contaminants inside and outside of the vehicles were also made consistent with those assumed in the vehicle release analyses.

The vehicle cleaning analyses focused on potential exposures to the contaminants after they were removed from the vehicles. Potential exposures associated with the cleaning activities to remove contaminants were not analyzed. In situations where contamination levels are significant, the washing of vehicles would be done under controlled conditions and (1) the cleaning workers would wear protective equipment or clothing to reduce potential radiation exposures, if necessary, when cleaning the vehicle; and (2) the exposures of the cleaning workers can be controlled and monitored by using dosimeters.

11.2.2 Main Assumptions and Parameters

11.2.2.1 Cleaning Locations

Considering the destinations of the washed-off contaminants, cleaning was assumed to take place in one of the three following locations:

1. *On a private driveway or along a street*. The vehicle was parked on a driveway of a suburban house or along a street in an urban area. Because the ground surface is slightly sloped at the edge of a driveway or street, water would flow toward the drainage hole and enter an underground stormwater or sewage collecting system. If a detention pond was located near the street, the water could flow to the detention pond. The ground area that the water flows over would not be large. Secondary contamination of the ground surface would be possible, as some contaminants may adsorb to the ground surface and not travel with the water.

2. *In a large parking lot*. The vehicle was parked in a parking lot that has a capacity for a large number of vehicles. Because the ground surface of the parking lot is flat, water could flow in different directions and spread over a large area before entering a drainage system or reaching a nearby detention pond. As a result, the secondary contamination, if formed, could cover a large area.

3. *In a car washing facility*. The vehicle was washed and cleaned at a car washing facility. The washing facility was designed to control the drainage of water and to collect and discharge the water to a municipal sewer system. The control design prevents overflow of the water; therefore, secondary contamination of the ground surface was negligible.

11.2.2.2 Cleaning Process

The following assumptions were made regarding the cleaning process:

- 100% of the contamination from both inside and outside of the vehicle was removed.

- The vacuum bag that collected the dust particles from inside the vehicle was sent to an approved or appropriate facility for disposal.

- 10% of the washed-off contaminants deposited and were retained on the ground surface, where secondary contamination was considered. The rest (90%) was carried by water and entered an underground stormwater or sewage collecting system, or ran off to a nearby stormwater detention pond.

- When the vehicle was cleaned in a washing facility, 100% of the washed-off contaminants were carried by water to a sewage system.

- The area of secondary contamination equaled 100 m^2 when the cleaning took place on a driveway or along a street. The area of secondary contamination was 1,000 m^2 when the vehicle was cleaned in a large parking lot.

11.2.3 DSRs and Discussions

11.2.3.1 Landfill Destination

The vacuum bag that contained the contaminated dust particles collected from cleaning the interior of the vehicle may be qualified for disposal in a municipal landfill. The qualification implies that the radioactivity level contained in the bag would be below applicable standards for landfill disposal. Otherwise, it would be sent to a disposal site designated for radioactive wastes and be handled by certified radiation workers. Potential receptors for the landfill destination include the landfill disposal workers and residents living close to the landfill (landfill neighbors). The volume of the vacuum bag was expected to be very small compared with the volume of the waste materials that would be disposed of in the same disposal cell. The shielding provided by the waste materials, the on-top capping, as well as the engineering liner was expected to minimize release of contaminants to the surrounding environment, thereby reducing the potential radiation exposures of the disposal workers and landfill neighbors.

According to previous assumptions regarding the distribution of contaminants, the total radioactivity deposited inside the vehicle would be a small fraction of the total radioactivity deposited outside the vehicle (3% vs. 97%). Furthermore, the exposure scenarios associated with the removed outside contamination do not involve installing shielding materials to prevent the contaminants from reaching the potential receptors (see discussions in following paragraphs); as a result, radiation exposures for scenarios concerning removed outside contamination were expected to be greater than for scenarios concerning removed inside contamination.

Based on the reasons given, potential exposures of the landfill workers and nearby residents were not evaluated further.

11.2.3.2 POTW and Surface Water Body Destinations

The contaminants flushed off from outside the vehicle could be carried by water and enter a sewer line or an underground stormwater collecting system. If collected by a stormwater collecting system, they would be discharged to a surface water body. If the contaminants enter a sewer line, they would be collected at a POTW and assumed to concentrate in the sludge material generated from treating the wastewater. Potential radiation exposures could result from handling and using the sludge material.

According to the previous analyses of radiation exposures from flushing a contaminated street, radiation exposures associated with a surface water body destination would be much smaller than the exposures associated with a POTW destination. Among the seven groups of receptors analyzed for the POTW destination, the on-site residents (residents of houses built on agricultural fields formerly applied with sludge) and the incinerator neighbors (neighbors of a sludge incinerator) would receive higher exposures than the other five groups of receptors. Therefore, this study considers only these two critical groups of receptors.

Potential radiation doses resulting from flushing 1 pCi of radioactivity to a POTW are listed in Table 11.6. The results were taken from the previous analyses of radiation exposures from flushing a contaminated street. For each radionuclide, the listed value is the larger one of the two critical scenarios.

11.2.3.3 Detention Pond Destination

Flushed contaminants that were carried by water and flowed to a detention pond could settle and adsorb to soil at the bottom of the detention pond. Potential radiation exposures could occur if the detention pond was also used for recreational or sporting activities after water drains out. Potential radiation doses resulting from flushing 1 pCi of radioactivity to the detention pond are also listed in Table 11.6. They were obtained from previous analyses of radiation exposures from flushing a contaminated street. The exposures occurred through external radiation, inhalation of dust particles, and ingestion of soil.

TABLE 11.6 DSRs (mrem/yr per pCi) for the POTW and Detention Pond Destinations

Radionuclide	POTW Destination DSR	POTW Destination Associated Scenario	Detention Pond Destination DSR
Am-241	1.68E-10	Incinerator neighbor	9.03E-12
Cf-252	5.13E-11	Incinerator neighbor	4.45E-12
Cm-244	9.05E-11	Incinerator neighbor	9.13E-12
Co-60	1.00E-10	On-site resident	1.56E-10
Cs-137	3.33E-11	On-site resident	3.93E-11
Ir-192	8.68E-12	On-site resident	8.83E-12
Po-210	1.51E-11	On-site resident	1.58E-12
Pu-238	1.48E-10	Incinerator neighbor	1.47E-11
Pu-239	1.63E-10	Incinerator neighbor	1.63E-11
Ra-226	4.77E-10	On-site resident	1.00E-10
Sr-90	7.95E-11	On-site resident	6.10E-13

11.2.3.4 Ground Surface Destination

Secondary contamination would result when contaminants flushed off from the vehicle adsorb to ground surface while traveling with water. To assess potential radiation exposures, the area of the secondary source was assumed to be either 100 m^2 or 1,000 m^2, depending on where the washing activities were conducted. Radiation exposure was evaluated for a person who lives or works close to the washing location (e.g., driveway, street, or parking lot) and has the opportunity of getting close to the secondary contamination source. Potential exposure was considered to result from direct external radiation and inhalation.

Dose conversion factors obtained from the RESRAD-BUILD computer code (Yu et al. 2003) were used in dose calculations. It was assumed that the contamination was uniformly distributed on the ground surface and that receptors would spend 500 hours in a year close to the contaminated area. Because of contaminant absorption on the ground surface, potential resuspension of the contaminants in the air was assumed to be slow and stable. The initial resuspension factor of 1×10^{-6} m^{-1} used in deriving operational guidelines for Groups A−E was reduced by a factor of 10 to account for the slow release from a large area. Because the contaminated area is also smaller (in this case, 100 m^2 and 1,000 m^2) compared with the area assumed in Groups A−E analyses (10,000 m^2), the resuspension factor was further corrected by an area factor. The area factor was calculated using the RESRAD computer code (Yu et al. 2001). A respirable fraction of 0.1 was assumed. The inhaled contaminated dust particles that were greater than respirable size were assumed to reach the gastrointestinal tract and result in ingestion doses. To consider the influence of radiological ingrowth and decay, the radiation doses obtained with the initial ground-surface and air concentrations were multiplied by an average decay factor over 1 year to get the final dose results.

Table 11.7 lists the parameters used in dose calculations for the secondary source with a small and large area (100 m^2 and 1,000 m^2). Tables 11.8 and 11.9 provide the DSRs (mrem/yr per pCi).

11.2.4 Operational Guidelines

The DSRs listed in Tables 11.6, 11.8, and 11.9 can be multiplied by the amount of radioactivity washed off a vehicle and distributed to a specific destination, to get an estimate of the potential radiation exposure resulting from vehicle cleaning. Table 11.10 lists information on

TABLE 11.7 Parameters Used in Dose Calculations for the Secondary Contamination Source with a Small and Large Area

Parameter	Small Area	Large Area
Area (m^2)	100	1,000
Exposure duration (h/yr)	500	500
Inhalation rate (m^3/h)	1.4	1.4
Resuspension factor without correction for size (m^{-1})	1.0E-07	1.0E-07
Respirable fraction	0.1	0.1
Area factor	0.10	0.13

TABLE 11.8 DSRs (mrem/yr per pCi) for the Secondary Contamination Source with a Small Area

Radionuclide	External	Inhalation	Ingestion	Total before Correction for Ingrowth and Decay	Total after Correction for Ingrowth and Decay
Am-241	8.96E-10	3.23E-09	2.38E-10	4.37E-09	4.36E-09
Cf-252	1.70E-11	1.14E-09	7.08E-11	1.23E-09	1.08E-09
Cm-244	1.87E-11	1.81E-09	1.32E-10	1.96E-09	1.92E-09
Co-60	5.13E-08	1.59E-12	1.76E-12	5.13E-08	4.81E-08
Cs-137	1.22E-08	2.32E-13	3.28E-12	1.22E-08	1.21E-08
Ir-192	1.77E-08	2.05E-13	3.76E-13	1.77E-08	5.01E-09
Po-210	1.83E-13	6.84E-11	1.24E-10	1.93E-10	8.86E-11
Pu-238	4.77E-11	2.85E-09	2.10E-10	3.11E-09	3.10E-09
Pu-239	2.31E-11	3.12E-09	2.32E-10	3.38E-09	3.38E-09
Ra-226	3.65E-08	6.29E-11	8.76E-11	3.67E-08	3.67E-08
Sr-90	1.24E-10	9.54E-12	1.00E-11	1.44E-10	1.42E-10

the amount of radioactivity from cleaning a passenger bus and a midsized car. The highest radiation exposures estimated among the different destinations should be used with an applicable dose limit, to derive the final operational guidelines for vehicle cleaning.

Tables 11.11 and 11.12 list the estimated dose results for a passenger bus and a midsized car, respectively, with an outside contamination level of 1 pCi/m^2. The dose results can be multiplied by the measured outside activity concentration to get dose estimates for a real situation. If cleaning involves more than one vehicle, estimates of cumulative exposures can be obtained by multiplying the dose estimates for one vehicle by the number of vehicles.

TABLE 11.9 DSRs (mrem/yr per pCi) for the Secondary Contamination Source with a Large Area

Radionuclide	External	Inhalation	Ingestion	Total before Correction for Ingrowth and Decay	Total after Correction for Ingrowth and Decay
Am-241	1.46E-10	4.13E-10	3.05E-11	5.90E-10	5.89E-10
Cf-252	3.05E-12	1.46E-10	9.05E-12	1.58E-10	1.39E-10
Cm-244	2.26E-12	2.31E-10	1.69E-11	2.50E-10	2.45E-10
Co-60	8.44E-09	2.04E-13	2.25E-13	8.44E-09	7.91E-09
Cs-137	2.02E-09	2.97E-14	4.19E-13	2.02E-09	2.00E-09
Ir-192	2.93E-09	2.63E-14	4.81E-14	2.93E-09	8.29E-10
Po-210	3.01E-14	8.75E-12	1.59E-11	2.47E-11	1.13E-11
Pu-238	5.67E-12	3.65E-10	2.68E-11	3.97E-10	3.96E-10
Pu-239	2.46E-12	3.99E-10	2.97E-11	4.32E-10	4.32E-10
Ra-226	6.01E-09	8.03E-12	1.12E-11	6.03E-09	6.03E-09
Sr-90	2.04E-11	1.22E-12	1.28E-12	2.29E-11	2.26E-11

TABLE 11.10 Amount of Radioactivity (pCi) Washed off and Distributed to Various Destinations Resulting from Cleaning a Contaminated Vehicle with an Outside Concentration of 1 pCi/m^2

Original Source/Destination	Passenger Bus[a]	Midsized Car[a]
Total radioactivity washed off	121.7	21.5
Amount of radioactivity ending in a POTW		
From a washing facility	121.7	21.5
From a driveway or a street	109.5	19.4
Amount of radioactivity ending in a detention pond		
From a driveway or a street	109.5	19.4
Amount of radioactivity ending in ground surface	12.2	2.1

[a] The outside surface area assumed for a passenger bus was 121.7 m^2. The assumed outside surface area for a midsized car was 21.5 m^2.

TABLE 11.11 Dose Results (mrem/yr) for Different Destinations Resulting from Washing a Contaminated Passenger Bus with an Outside Contamination Level of 1 pCi/m^2

Radionuclide	From a Driveway or a Street: Ground Surface: Small Area	From a Driveway or a Street: Ground Surface: Large Area	From a Driveway or a Street: POTW or Detention Pond[a]	From a Washing Facility: POTW	Most Conservative Value
Am-241	5.31E-08	7.17E-09	1.84E-08	2.04E-08	5.31E-08
Cf-252	1.32E-08	1.69E-09	5.61E-09	6.24E-09	1.32E-08
Cm-244	2.34E-08	2.99E-09	9.91E-09	1.10E-08	2.34E-08
Co-60	5.85E-07	9.63E-08	1.53E-08	1.22E-08	5.85E-07
Cs-137	1.47E-07	2.43E-08	3.87E-09	4.05E-09	1.47E-07
Ir-192	6.09E-08	1.01E-08	9.50E-10	1.06E-09	6.09E-08
Po-210	1.08E-09	1.38E-10	1.65E-09	1.83E-09	1.83E-09
Pu-238	3.77E-08	4.82E-09	1.62E-08	1.80E-08	3.77E-08
Pu-239	4.11E-08	5.25E-09	1.79E-08	1.98E-08	4.11E-08
Ra-226	4.47E-07	7.36E-08	5.22E-08	5.81E-08	4.47E-07
Sr-90	1.73E-09	2.75E-10	8.71E-09	9.68E-09	9.68E-09

[a] Dose results listed in the column “POTW or Detention Pond” are the largest values of the two destinations.

TABLE 11.12 Dose Results (mrem/yr) for Different Destinations Resulting from Washing a Midsized Car with an Outside Contamination Level of 1 pCi/m^2

Radionuclide	From a Driveway or a Street: Ground Surface: Small Area	From a Driveway or a Street: Ground Surface: Large Area	From a Driveway or a Street: POTW or Detention Pond[a]	From a Washing Facility: POTW	Most Conservative Value
Am-241	9.38E-09	1.27E-09	3.25E-09	3.61E-09	9.38E-09
Cf-252	2.33E-09	2.99E-10	9.92E-10	1.10E-09	2.33E-09
Cm-244	4.13E-09	5.27E-10	1.75E-09	1.95E-09	4.13E-09
Co-60	1.03E-07	1.70E-08	2.71E-09	2.15E-09	1.03E-07
Cs-137	2.59E-08	4.29E-09	6.84E-10	7.15E-10	2.59E-08
Ir-192	1.08E-08	1.78E-09	1.68E-10	1.87E-10	1.08E-08
Po-210	1.91E-10	2.44E-11	2.92E-10	3.24E-10	3.24E-10
Pu-238	6.66E-09	8.51E-10	2.87E-09	3.19E-09	6.66E-09
Pu-239	7.26E-09	9.28E-10	3.15E-09	3.50E-09	7.26E-09
Ra-226	7.67E-08	1.27E-08	9.25E-09	1.03E-08	7.67E-08
Sr-90	3.05E-10	4.87E-11	1.54E-09	1.71E-09	1.71E-09

[a] Dose results listed in the column “POTW or Detention Pond” are the largest values of the two destinations.

Regardless of the type of vehicle (a passenger bus or a midsized car) that is cleaned, the most restrictive dose result was found to be associated with the ground surface destination with a small area for all radionuclides, except for Po-210 and Sr-90. For these two radionuclides, the most restrictive dose results come from the POTW destination by washing the vehicle in a washing facility.

The final operational guidelines for vehicle cleaning are listed in Table 11.13, where they are also compared with the guidelines for releasing vehicles, which are discussed in Section 11.3 (see Table 11.24). The operational guidelines were derived on the basis of a dose limit of 100 mrem/yr.

11.2.5 Conclusions on Cleaning Contaminated Vehicles

The operational guidelines for vehicle cleaning were developed by considering different locations where the cleaning activities would take place and different destinations where the removed contaminants would be carried. Generally speaking, the parameter values and assumptions used in dose calculations are quite conservative; therefore, the conservativeness of the derived operational guidelines can be guaranteed. In reality, when the location of the cleaning

TABLE 11.13 Comparison of Derived Operational Guidelines (pCi/cm^2) for Releasing Vehicles and Cleaning Vehicles[a]

	Passenger Bus		Midsized Car	
Radionuclide	Releasing	Cleaning	Releasing	Cleaning
Am-241	78	1.88E+05	251	1.07E+06
Cf-252	266	7.59E+05	935	4.30E+06
Cm-244	143	4.28E+05	469	2.42E+06
Co-60	625	1.71E+04	990	9.68E+04
Cs-137	2,490	6.81E+04	3,950	3.86E+05
Ir-192	6,060	1.64E+05	9,620	9.29E+05
Po-210	5,850	5.45E+06	48,300	3.09E+07
Pu-238	89	2.65E+05	287	1.50E+06
Pu-239	81	2.43E+05	260	1.38E+06
Ra-226	613	2.24E+04	1080	1.30E+05
Sr-90	18,700	1.03E+06	57,500	5.85E+06

[a] The operational guidelines were derived on the basis of a dose limit of 100 mrem/yr.

activities and the destination of the contaminants are known, other than using the default operational guidelines listed in Table 11.13, operational guidelines can be derived using the pertaining dose results listed in Tables 11.11 and 11.12.

11.3 RELEASE OF CONTAMINATED VEHICLES

11.3.1 Introduction

The operational guidelines discussed in the following sections were derived for use in releasing vehicles contaminated during an RDD event. Vehicles with a contamination level less than the operational guideline were considered very unlikely to result in a radiation dose greater than 100 mrem/yr to the driver and passengers and can be released without further decontamination.

Preliminary analyses considering different types of vehicles were conducted, and the results showed that radiation dose rates received by drivers and passengers were not much different for different types of vehicles, because the larger the dimensions of a vehicle, the larger the exposure distance between the receptor and the radiation sources. As a result, in the final analyses, only two types of vehicles that are most commonly used by the general public for daily activities that also capture the variability of the time spent inside the vehicles by different receptors were considered. These are a passenger bus and a midsized car.

It was assumed that all outside surfaces of the vehicle were contaminated during an RDD event, and some contamination was deposited inside the vehicle (mostly on the floor) as a result of air exchange or being tracked inside by shoes. Radiation doses were calculated for a vehicle passenger and a vehicle driver by using the RESRAD-BUILD computer code (Yu et al. 2000, 2003). They were calculated for a 1-hour exposure duration because it is very likely that the source concentrations would change quickly due to the action of wind and air exchange. Radiation doses over the first year, however, were also calculated. They were based on a conservative assumption that the amount of contaminants deposited on the interior and exterior surfaces of the vehicle would not change over time, and that the radioactivity would decrease through radioactive decay.

The operational guidelines were derived on the basis of a dose limit of 100 mrem/yr. Sensitive parameters that affect the dose results were identified. The most restrictive operational guidelines were compared with published values, including ANSI/HPS N13.12 (ANSI/HPS 1999), NUREG-1640 (NRC 2003), and DOE Order 5400.5 (DOE 1990) concerning clearance of surface-contaminated materials.

11.3.2 Scenario Description

Two types of vehicles were analyzed: a passenger bus and a midsized car. The vehicles were modeled as a box with six surfaces. It was assumed that (1) all outside surfaces of the vehicle were contaminated at the same level during an RDD event, (2) the contamination level on the interior surfaces was 10% of the level on the exterior surfaces, and (3) the contamination was uniformly distributed. In a preliminary analysis, a convertible vehicle was considered for which the contamination level on the interior surfaces was the same as the contamination level on the exterior surfaces. However, because the areas of the exterior contaminated surfaces were much smaller than those for a nonconvertible vehicle, the resulting radiation doses for a convertible vehicle were not necessarily greater than those for a nonconvertible vehicle. Therefore, a separate dose calculation for convertible vehicles was not conducted in the final analysis.

Potential radiation doses resulting from seven exposure pathways were included in the analyses: (1) external exposure directly from the exterior surfaces, (2) external exposure to materials deposited on the interior surfaces, (3) external exposure due to air submersion, (4) inhalation of airborne radioactive particulates, (5) inhalation of aerosol radon progeny (when radon precursors are present), (6) inadvertent ingestion of radioactive materials directly from the interior surfaces, and (7) inadvertent ingestion of materials deposited on objects brought into the vehicle due to the resuspension of contaminants from the interior surfaces. To simplify the analysis, external exposure to materials deposited on the interior surfaces was calculated by considering all contaminants as deposited on the floor that has a surface area equivalent to the bottom dimensions of the vehicle. The RESRAD-BUILD computer code (Yu et al. 2003) was used in the dose analyses and both short-term (hourly) and long-term (1-year) doses were calculated.

11.3.3 Main Assumptions and Parameters

For dose calculations, all exterior surfaces (roof, floor, and four sides) were contaminated at the same concentration levels. It was further assumed that the concentration on the interior floor was 10% of that on exterior surfaces. Table 11.14 lists the characteristics of the vehicles used in the analysis.

A passenger bus was assumed to be 12.1 m long, 2.6 m wide, and 2 m high (dimensions were taken from the Mack-Blackwell Transportation Center's report on large school bus design [Gattis and Howard 1998]). Radiation doses were calculated for different receptors sitting at different positions in the bus. The receptor sitting at the center of the bus (at a height of 0.5 m from the floor) was found to receive the maximum external dose. Radiation doses were also calculated for a bus driver located 0.5 m away from three contaminated surfaces (the bottom, the front, and one of the two sides bordering the front). The exposure duration assumed for the bus driver was greater than that assumed for the other passenger receptors.

A midsized car was assumed to be 3 m long, 1.7 m wide, and 1.2 m high (dimensions were taken from NUREG-1717, Appendix A, Table A.1.2 [NRC 2001a]). Radiation doses were calculated only for the driver, because from preliminary analyses, it was found that radiation doses received by the driver and the passengers were about the same.

11.3.3.1 External Pathway

For both the passenger bus and midsized car, it was assumed that external radiation from radionuclides deposited on exterior surfaces of the vehicle was attenuated by the steel material

TABLE 11.14 Vehicle Characteristics Used in Deriving Operational Guidelines for Vehicles

Parameter	Bus	Car
Length, m	12.1	3
Width, m	2.6	1.7
Height, m	2	1.2
Air exchange rate, h^{-1}	5	3
Fraction of contamination on the interior floor of the vehicle	0.1	0.1

that made the body parts. For high-energy gamma emitters, this shielding would not change the external dose significantly. The steel material was assumed to have a thickness of 0.07 cm. For external radiation that comes from the radionuclides deposited on the interior floor, no shielding was assumed between the contaminants and the receptor.

11.3.3.2 Ingestion Pathway

The receptor was considered to ingest contaminants through two mechanisms: direct and indirect. The direct mechanism considers ingestion of contaminants that were deposited on the interior surfaces of the vehicle. (Contaminants may stick to the receptor's hand when the receptor touches the interior surfaces, such as the steering wheel, dashboard, or seat, and be accidentally ingested.) The indirect mechanism considers ingestion of contaminants that were deposited on objects that were brought into the vehicle (e.g., food items) after the RDD event; the deposition results from resuspension of the contaminants on the interior surfaces. For both direct and indirect ingestion, an ingestion area of 1 cm^2 was assumed. To make RESRAD-BUILD calculate the radiation dose from direct ingestion, the corresponding fraction of the ingestion area (1 cm^2) to the total area that the receptor may touch (assuming to be the total interior surface area) needs to be calculated and input to the code (see Table 11.15).

11.3.3.3 Inhalation, Deposition, and Immersion Pathways

The air concentration inside the vehicle was calculated assuming a resuspension factor of 1×10^{-6} m^{-1} (IAEA 2002; NRC 2001b; EPA 1991). The resuspension factor is defined as the ratio of the air concentration to the initial concentration on contaminated surfaces. To implement this assumption in RESRAD-BUILD, specific values were assigned to some input parameters pertaining to the contaminated floor (see Table 11.15).

For exterior contaminated sources, it was assumed that they would not contribute to the inside air concentration. Parameters used for deriving operational guidelines for vehicles are listed in Table 11.15. The rest of the parameters were not changed from their default values in the RESRAD-BUILD code.

TABLE 11.15 Some Other Input Parameters Used in Deriving Operational Guidelines for Vehicles

Parameter	Bus	Car	Comment/Reference
Inhalation rate, m^3/d	33.6	33.6	Biwer et al. 2002, Section A.3
Direct ingestion rate, h^{-1}	8.21×10^{-7}	4.66×10^{-6}	To simulate ingestion area of 1-cm^2
Air release fraction	0.45	0.17	To simulate resuspension factor of 1×10^{-6} m^{-1}
Removable fraction	0.2	0.2	To simulate resuspension factor of 1×10^{-6} m^{-1}
Shielding material	Steel	Steel	Scenario assumption
Shielding density, g/cm^3	7.8	7.8	Biwer et al. 2002, Table A.7
Time spent in the vehicle (short term), h/d	1	1	Scenario assumption
Time spent in the vehicle (long term), h/yr	2,000 (driver) 623 (passenger)	592	Exposure Factor Handbook (EPA 1997), Table 15-133

11.3.4 Results

Tables 11.16 and 11.17 provide the DSRs for short-term exposures (1 h) from a unit activity concentration on the exterior surfaces of a passenger bus for the maximally exposed passenger (sitting in the center of the vehicle) and the driver, respectively. Tables 11.18 and 11.19 provide the DSRs for long-term exposures. The radiation doses from all seven sources (six exterior surfaces plus one interior floor) were summed to get the total dose to the receptor. For Co-60, Cs-137, and Ir-192, the external radiation pathways contribute the most to the total dose. For Po-210 and Sr-90, both the ingestion and inhalation pathways contribute significantly to the dose. For Am-241, Cm-244, Cf-252, Pu-238, and Pu-239, the total dose was mostly from the inhalation pathway.

Table 11.20 provides the DSRs for short-term exposures (1 h) from a unit activity concentration on the exterior surfaces of a midsized car. Table 11.21 provides the DSRs for long-term exposures (1 yr). The radiation doses from all sources were summed to obtain the total dose to the receptor. For Co-60, Cs-137, and Ir-192, the external radiation pathways contribute the most to the total dose. For Po-210 and Sr-90, both the ingestion and inhalation pathways

TABLE 11.16 Short-Term DSRs (mrem/h per pCi/m^2) for a Bus Passenger

Radionuclide	Direct External	External from Deposition	External from Immersion	Inhalation	Radon	Ingestion	Total
Am-241	1.08E-10	2.57E-13	1.12E-15	6.39E-08	0	2.63E-09	6.66E-08
Cf-252	5.73E-13	4.38E-15	6.57E-18	2.13E-08	0	7.65E-10	2.21E-08
Cm-244	4.57E-13	5.80E-15	6.69E-18	3.54E-08	0.00E+00	1.46E-09	3.68E-08
Co-60	2.74E-08	1.40E-11	1.68E-13	3.06E-04	0	1.92E-11	2.75E-08
Cs-137	6.52E-09	3.44E-12	3.73E-14	4.57E-12	0	3.61E-11	6.56E-09
Ir-192	9.40E-09	2.50E-12	3.27E-14	2.47E-12	0	3.56E-12	9.41E-09
Po-210	9.69E-14	3.37E-17	4.15E-19	9.82E-10	0	1.23E-09	2.21E-09
Pu-238	1.23E-12	1.50E-14	6.70E-18	5.63E-08	3.08E-44	2.31E-09	5.86E-08
Pu-239	1.20E-12	8.37E-15	5.83E-18	6.18E-08	0	2.56E-09	6.43E-08
Sr-90	5.90E-11	3.49E-14	2.70E-16	1.88E-10	0	1.10E-10	3.57E-10

TABLE 11.17 Short-Term DSRs (mrem/h per pCi/m^2) for a Bus Driver

Radionuclide	Direct External	External from Deposition	External from Immersion	Inhalation	Radon	Ingestion	Total
Am-241	2.20E-11	2.57E-13	1.12E-15	6.39E-08	0	2.63E-09	6.65E-08
Cf-252	9.22E-14	4.38E-15	6.57E-18	2.13E-08	0	7.65E-10	2.21E-08
Cm-244	2.62E-14	5.80E-15	6.69E-18	3.54E-08	0.00E+00	1.46E-09	3.68E-08
Co-60	8.28E-09	1.40E-11	1.68E-13	3.06E-04	0	1.92E-11	8.35E-09
Cs-137	1.96E-09	3.44E-12	3.73E-14	4.57E-12	0	3.61E-11	2.00E-09
Ir-192	2.81E-09	2.50E-12	3.27E-14	2.47E-12	0	3.56E-12	2.82E-09
Po-210	2.92E-14	3.37E-17	4.15E-19	9.82E-10	0	1.23E-09	2.21E-09
Pu-238	7.48E-14	1.50E-14	6.70E-18	5.63E-08	3.08E-44	2.31E-09	5.86E-08
Pu-239	1.42E-13	8.37E-15	5.83E-18	6.18E-08	0	2.56E-09	6.43E-08
Sr-90	1.77E-11	3.49E-14	2.70E-16	1.88E-10	0	1.10E-10	3.16E-10

contribute significantly to the total dose. For Am-241, Cm-244, Cf-252, Pu-238, and Pu-239, the total dose was mostly from the inhalation pathway.

Table 11.22 provides the operational guidelines for the two types of vehicles analyzed. The operational guidelines were derived on the basis of a dose limit of 100 mrem/yr using the average DSRs over a 1-year exposure period.

TABLE 11.18 Long-Term DSRs (mrem/yr per pCi/m^2) for a Bus Passenger

Radionuclide	Direct External	External from Deposition	External from Immersion	Inhalation	Radon	Ingestion	Total
Am-241	6.64E-08	1.56E-10	6.85E-13	3.89E-05	0	1.04E-06	4.00E-05
Cf-252	2.95E-10	2.36E-12	3.53E-15	1.15E-05	0	2.70E-07	1.17E-05
Cm-244	2.52E-10	3.47E-12	4.00E-15	2.12E-05	7.40E-38	5.67E-07	2.17E-05
Co-60	1.60E-05	8.00E-09	9.60E-11	1.75E-08	0	7.19E-09	1.60E-05
Cs-137	4.00E-06	2.07E-09	2.25E-11	2.75E-09	0	1.41E-08	4.01E-06
Ir-192	1.65E-06	4.40E-10	5.75E-12	4.35E-10	0	4.92E-10	1.65E-06
Po-210	2.77E-11	9.59E-15	1.18E-16	2.79E-07	0	2.53E-07	5.33E-07
Pu-238	6.91E-10	9.14E-12	4.07E-15	3.42E-05	5.78E-29	9.12E-07	3.51E-05
Pu-239	6.97E-10	5.10E-12	3.55E-15	3.76E-05	0	1.01E-06	3.87E-05
Sr-90	3.62E-08	2.10E-11	1.63E-13	1.13E-07	0	4.33E-08	1.92E-07

TABLE 11.19 Long-Term DSRs (mrem/yr per pCi/m^2) for a Bus Driver

Radionuclide	Direct External	External from Deposition	External from Immersion	Inhalation	Radon	Ingestion	Total
Am-241	4.35E-08	5.01E-10	2.20E-12	1.25E-04	0	3.34E-06	1.28E-04
Cf-252	1.55E-10	7.55E-12	1.13E-14	3.68E-05	0	8.67E-07	3.76E-05
Cm-244	4.62E-11	1.11E-11	1.28E-14	6.79E-05	2.37E-37	1.82E-06	6.97E-05
Co-60	1.55E-05	2.56E-08	3.08E-10	5.61E-08	0	2.31E-08	1.56E-05
Cs-137	3.87E-06	6.64E-09	7.21E-11	8.83E-09	0	4.53E-08	3.92E-06
Ir-192	1.58E-06	1.41E-09	1.84E-11	1.39E-09	0	1.58E-09	1.59E-06
Po-210	2.68E-11	3.07E-14	3.78E-16	8.95E-07	0	8.12E-07	1.71E-06
Pu-238	1.36E-10	2.93E-11	1.30E-14	1.10E-04	1.85E-28	2.92E-06	1.13E-04
Pu-239	2.80E-10	1.64E-11	1.14E-14	1.21E-04	0	3.25E-06	1.24E-04
Sr-90	3.48E-10	6.74E-11	5.21E-13	3.62E-07	0	1.39E-07	5.36E-07

11.3.5 Conclusions on Release of Contaminated Vehicles

To account for the uncertainties regarding the extent of contamination, the exposure patterns, and the interaction between the contamination sources and the surrounding atmosphere, conservatism was incorporated in the dose calculations. Table 11.23 lists the sensitive parameters that have great impact on the dose results and the operational guidelines.

Table 11.24 compares the most restrictive operational guidelines for vehicle release with published screening values from ANSI/HPS N13.12 (ANSI/HPS 1999), NUREG-1640

TABLE 11.20 Short-Term DSRs (mrem/h per pCi/m²) for the Car Receptor

Radionuclide	Direct External	External from Deposition	External from Immersion	Inhalation	Radon	Ingestion	Total
Am-241	8.78E-11	1.10E-13	1.18E-15	6.70E-08	0	2.51E-09	6.96E-08
Cf-252	3.63E-13	1.65E-15	6.27E-18	2.04E-08	0	7.10E-10	2.11E-08
Cm-244	2.72E-13	2.63E-15	6.91E-18	3.66E-08	0	1.38E-09	3.80E-08
Co-60	1.82E-08	5.62E-12	1.67E-13	3.06E-11	0	1.81E-11	1.82E-08
Cs-137	4.30E-09	1.44E-12	3.88E-14	4.75E-12	0	3.44E-11	4.34E-09
Ir-192	6.22E-09	6.23E-15	2.03E-14	1.53E-12	0	3.09E-12	6.22E-09
Po-210	6.41E-14	9.62E-18	2.94E-19	6.96E-10	0	1.08E-09	1.78E-09
Pu-238	7.58E-13	6.99E-15	7.01E-18	5.89E-08	1.88E-43	2.21E-09	6.11E-08
Pu-239	8.51E-13	4.78E-15	6.12E-18	6.48E-08	0	2.45E-09	6.73E-08
Sr-90	3.89E-11	1.46E-14	2.81E-16	1.95E-10	0	1.05E-10	3.39E-10

TABLE 11.21 Long-Term DSRs (mrem/yr per pCi/m²) for the Car Receptor

Radionuclide	Direct External	External from Deposition	External from Immersion	Inhalation	Radon	Ingestion	Total
Am-241	5.13E-08	6.36E-11	6.82E-13	3.88E-05	0	9.66E-07	3.98E-05
Cf-252	1.79E-10	8.44E-13	3.20E-15	1.04E-05	0	2.40E-07	1.07E-05
Cm-244	1.42E-10	1.50E-12	3.93E-15	2.08E-05	5.15E-38	5.22E-07	2.13E-05
Co-60	1.00E-05	3.05E-09	9.10E-11	1.66E-08	0	6.51E-09	1.01E-05
Cs-137	2.51E-06	8.24E-10	2.22E-11	2.72E-09	0	1.31E-08	2.53E-06
Ir-192	1.04E-06	1.04E-10	3.38E-12	2.56E-10	0	4.00E-10	1.04E-06
Po-210	2.22E-11	2.59E-15	7.92E-17	1.88E-07	0	2.07E-07	3.94E-07
Pu-238	4.04E-10	4.04E-12	4.04E-15	3.40E-05	7.65E-29	8.45E-07	3.49E-05
Pu-239	4.71E-10	2.77E-12	3.54E-15	3.75E-05	0	9.40E-07	3.85E-05
Sr-90	2.27E-08	8.36E-12	1.61E-13	1.12E-07	0	3.99E-08	1.74E-07

(NRC 2003), and DOE Order 5400.5 (DOE 1990) concerning clearance of surface-contaminated materials. It should be noted that the screening values from ANSI N13.12 and NUREG-1640 were derived to provide a reasonable expectation that doses would be generally less than 1 mrem/yr, while DOE Order 5400.5 screening values are not specifically dose-based but provide reasonable assurance that public doses will be a small fraction of the 100 mrem in a year public dose limit (i.e., a few mrem or less in a year). Furthermore, the exposure scenarios considered in deriving the material clearance screening values are not the same as those considered in deriving the operational guidelines for vehicles. For instance, ANSI N13.12 considers scenarios related to clearance of personal properties, whereas NUREG-1640 considers

TABLE 11.22 Operational Guidelines (pCi/cm^2) for Different Vehicle Receptors

Radionuclide	Bus Driver	Bus Passenger	Midsized Car
Am-241	7.81E+01	2.50E+02	2.51E+02
Cf-252	2.66E+02	8.55E+02	9.35E+02
Cm-244	1.43E+02	4.61E+02	4.69E+02
Co-60	6.41E+02	6.25E+02	9.90E+02
Cs-137	2.55E+03	2.49E+03	3.95E+03
Ir-192	6.29E+03	6.06E+03	9.62E+03
Po-210	5.85E+03	1.88E+04	2.54E+04
Pu-238	8.85E+01	2.85E+02	2.87E+02
Pu-239	8.06E+01	2.58E+02	2.60E+02
Sr-90	1.87E+04	5.21E+04	5.75E+04

TABLE 11.23 Sensitive Parameters That Have Great Impacts on the Vehicle Release Operational Guidelines

Parameter	Bus (long term)	Bus (short term)	Car (long term)	Car (short term)
Exposure duration, d	365	1	365	1
Time spent in the vehicle over the exposure duration, h	2,000 (driver) 623 (passenger)	1	592	1
Resuspension factor, m^{-1}	1.0E-06	1.0E-06	1.00E-06	1.00E-06
Ratio of activity concentrations (interior/exterior surfaces)	0.1	0.1	0.1	0.1
Inhalation rate, m^3/d	33.6	33.6	33.6	33.6

exposure scenarios related to recycling processes of contaminated metals and concrete and use of recycled materials.

The operational guidelines listed in Table 11.24 are for individual radionuclides, assuming no other radionuclides are present. In case multiple radionuclides are found on the surface of a vehicle, the sum of fractions rule should be applied in releasing the vehicle. Separate values are provided for cars and buses where the former are illustrative of values that might be used to establish protective action recommendations for personal use vehicles and the latter for mass transit-type vehicles.

TABLE 11.24 Comparison of Vehicle Release Operational Guidelines with Published Screening Values for Clearance of Surface Contaminated Materials[a] (pCi/cm^2)

	Operational Guidelines for Release of Vehicles						
	Car	Bus					
Radionuclide	Operational Guidelines	Operational Guidelines	The Maximally Exposed Receptor	ANSI N13.12	NUREG-1640	DOE 5400.5
Am-241	251	78	Bus driver	2.7	15	0.45
Cf-252	935	266	Bus driver	2.7	43	0.45
Cm-244	469	143	Bus driver	2.7	27	0.45
Co-60	990	625	Bus passenger	27	27	22.5
Cs-137	3,950	2,490	Bus passenger	27	84	22.5
Ir-192	9,620	6,060	Bus passenger	27	122	22.5
Po-210	25,400	5,850	Bus driver	2.7	405	22.5
Pu-238	287	89	Bus driver	2.7	22	0.45
Pu-239	260	81	Bus driver	2.7	22	0.45
Sr-90	57,500	18,700	Bus driver	27	2,243	4.5

[a] Vehicle release operational guidelines were derived on the basis of a 100-mrem/yr dose limit. The screening levels from ANSI N13.12 (ANSI/HPS 1999) and NUREG-1640 (NRC 2003) are based on a 1-mrem/yr dose limit. The DOE Order 5400.5 values are not based on a specific dose limit and are the allowable total residual surface contamination levels.

11.4 REFERENCES

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12 RESRAD-RDD USER'S GUIDE

The methodology described in Chapters 2 through 10 and the parameters used in each subgroup and scenario are initially coded in Microsoft Excel® spreadsheets for easy calculation of stay times and operational guidelines by the OGT members. A user-friendly graphical user interface was developed later so that the software tool (RESRAD-RDD) could be used by emergency first responders and dose/risk assessors. It is anticipated that this tool could be used in conjunction with or integrated within other tools available for radiological emergency response (e.g., FRMAC's Turbo FRMAC) and with other radiological dose and risk assessment tools (e.g., RESRAD-BIOTA, for evaluating potential ecological impacts to aquatic and terrestrial biota resulting from RDD-related radionuclides during the intermediate- to long-term recovery phase). This chapter provides a brief instruction to the installation and use of the RESRAD-RDD software.

12.1 REQUIREMENTS

With a user friendly interface, using the RESRAD-RDD software tool to derive operational guidelines or stay times is easy and straightforward. The procedure of data entry and result viewing is self-explanatory, because common window maneuvering features and text instructions were incorporated in the interface design. However, Microsoft Excel must be installed in a computer prior to the use of RESRAD-RDD, because all the calculations are embedded in several Excel spreadsheets, which are included in the distribution package. In addition, a disk space of approximately 45 megabytes (MB) is needed to store the entire program. In order to interpret the calculation results, the users also need to familiarize themselves with the groupings and applications of the operational guidelines, as well as some of the assumptions and methodology involved in the derivation of operational guidelines. This information is provided in Chapters 1 and 2 of this report. The RESRAD-RDD was developed on a Windows XP computer, and it runs on Windows 2000 and later computers with at least 45 MB of disk space.

12.2 INSTALLATION

Insert the RESRAD-RDD distribution CD to a CD drive, and run the application program "RESRAD-RDD-Setup." This will start the InstallShield wizard that helps install the RESRAD-RDD code. Follow the instructions of the wizard.

For the first-time installation of RESRAD-RDD, choosing the "complete" option for the Setup Type will instruct the InstallShield wizard to install the complete program in the default directory, c:\program files\RESRAD-family\RESRAD-RDD. If a different directory is planned for RESRAD-RDD, then choose the "custom" option for the Setup Type and specify the destination directory in the subsequent steps. Click "Install" to start the installation.

If RESRAD-RDD has been installed in the computer, choose the "modify" option for Program Maintenance to update the existent program; or choose the "repair" option to fix missing or corrupted files and shortcuts. Select the "remove" option will remove the entire RESRAD-RDD program. The "remove" option can also be selected to store RESRAD-RDD in a different directory other than the current one. After removing RESRAD-RDD, the "RESRAD-RDD-Setup" program can be run again to install and save RESRAD-RDD in a new directory following the procedure for first-time installation. No matter which option is selected for Program Maintenance, the result files that were generated in previous RESRAD-RDD runs will be kept and not be affected by the installation.

In the directory where RESRAD-RDD was stored after the installation, two subdirectories, "data" and "help," were also generated. "Data" contains the working spreadsheets that perform the actual calculations and the result spreadsheets that are updated as calculations proceed. "Help" contains explanation messages for several input parameters that are accessible to the users while running the RESRAD-RDD code. The files in these two subdirectories should not be removed or modified to ensure successful execution of the code. Any input or result files generated by running the RESRAD-RDD code should be saved in a different directory or subdirectory.

12.3 STARTING RESRAD-RDD

After installation, the RESRAD-RDD program can be started by one of the following three methods: (1) double click the "RESRAD-RDD" shortcut icon on the main screen,

(2) choose “RESRAD-RDD” from the list of “programs” after clicking the “start” icon located at the lower left corner of the main screen, or (3) go to the directory where RESRAD-RDD is located and double click the “RESRAD-RDD” application program. An introduction screen listing the version number, creation date, and background and contact information will appear (Figure 12.1). Press the “Start” button to run the program.

12.4 INPUT AND SAVE DATA

The first input required by RESRAD-RDD is the selection of dose conversion factors (DCFs) (see Fig.12.2). The user can choose either ICRP 30 (ICRP 1982) or ICRP 60 (ICRP 1991) based DCFs for dose calculation. By default, ICRP 60 DCFs are used. The window showing the selection of DCFs will also appear in subsequent screens and can be modified later on. The ICRP-30 based or ICRP-60 based DCFs can be viewed by clicking the “View DCFs” button.

There are seven operational guideline groups (Groups A, B, C, D, E, F-4, and G) (Figure 12.2) for users to choose from. A group must be selected before input data can be entered or operational guideline/stay time results can be viewed. Detailed descriptions of the operational guideline groups are provided in Section 1.2 of this report. Depending on the operational guideline group selected, a corresponding input data selection screen will be brought up. However, for Group F-4, modification of input parameters is not allowed; therefore, the results selection screen will be brought up after this group is selected.

Group F-4 deals with real property release in the late response phase after necessary remediation was completed. By then, site-specific characterization data should be available for conducting a comprehensive analysis to derive site-specific operational guidelines. Risk assessment computer tools such as RESRAD and RESRAD-BUILD can be used for such analyses. Because of the complexity of RESRAD and RESRAD-BUILD, they were not incorporated into RESRAD-RDD. Nevertheless, generic operational guidelines were still developed so that they can be applied to any geographic locations in case site-specific guidelines were not derived. The generic operational guidelines were developed by conducting probabilistic analyses with RESRAD and RESRAD-BUILD in which input parameters were assigned generic distribution functions developed with data from across the country. The final operational guidelines selected correspond to top percentile (~95th percentile) values from the distribution of

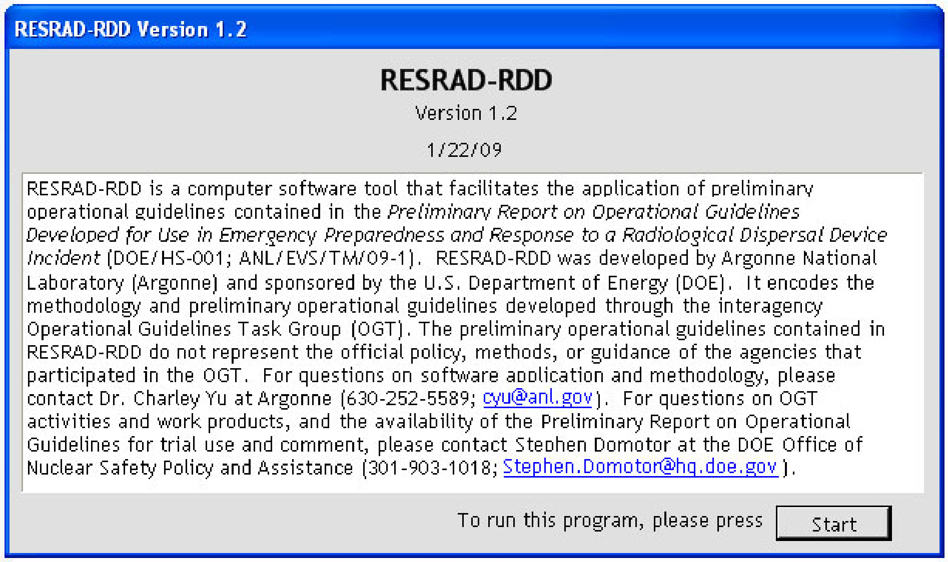


FIGURE 12.1 Introduction Screen of the RESRAD-RDD Code

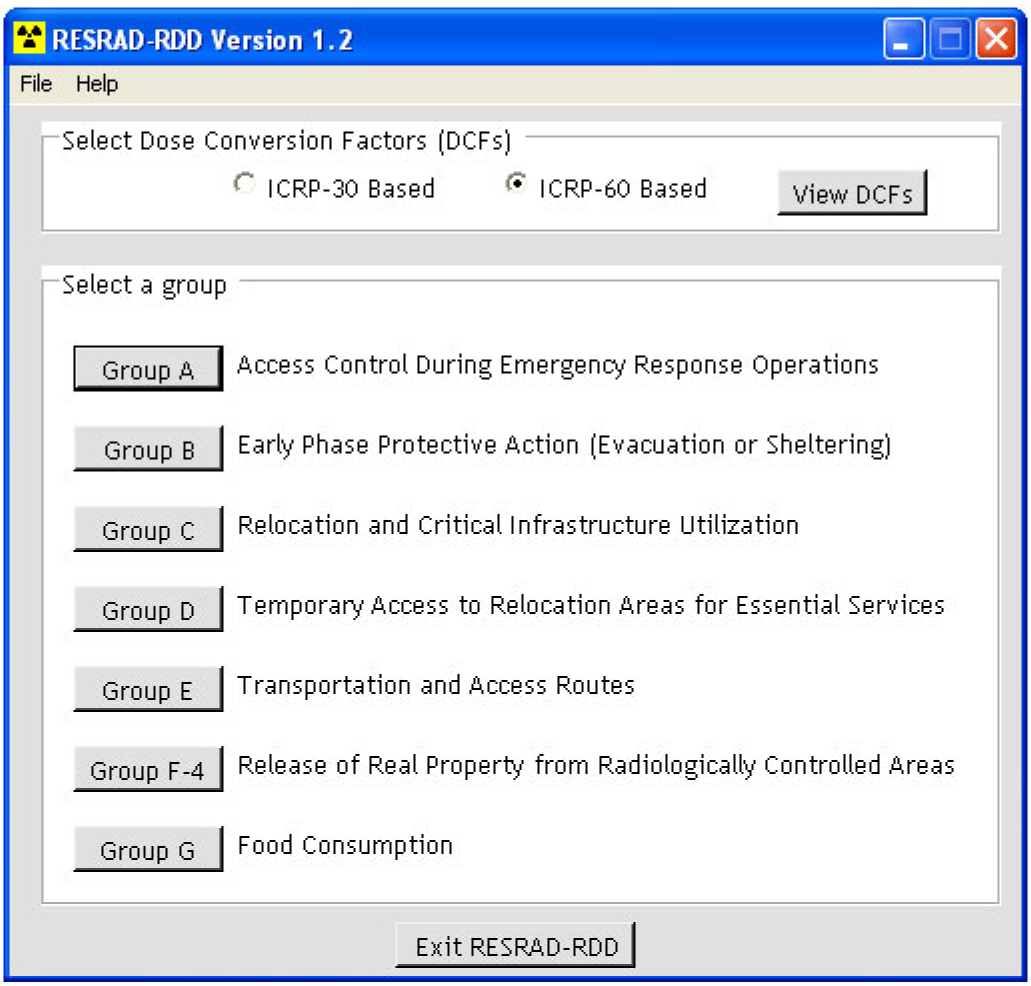


FIGURE 12.2 Group Selection Screen of the RESRAD-RDD Code

the calculated dose results. Because of the use of generic distribution functions for input parameters, modification of input data is not an option for Group F-4 in RESRAD-RDD.

Group A concerns access control during emergency response operations. Generic stay times can be developed for limting the access to an RDD event location when little site- and receptor-specific information is available. The default generic stay times were developed with conservative input parameter values, so that they can be applied in any situation and still provide sufficient protection for human health. The parameters that are used to develop generic stay times can be modified by accessing the input data screens. On the input data selection screen (Figure 12.3), the user can choose the category of input parameters to be modified, execute calculations, view the calculation results (by clicking "View Guidelines"), and view the input summary report (by clicking "View Input Report"). Otherwise, by clicking "Change Guideline Group," the user can go back to the group selection screen and choose another group for data entry and result viewing. It is also possible to modify the selection of DCFs at this time. The calculated results would reflect the DCF selection.

The input data used to derive generic stay times for Group A are categorized as (1) correction/resuspension/conversion factors, or (2) exposure and respirator protection parameters. By clicking on either category, a corresponding input data screen will be brought up (see Figures 12.4 and 12.5). In addition to generic stay times, specific stay times corresponding to radioactivity measurement data can also be developed. Five different types of measurement data are accepted: (1) gross alpha ground surface measurement, (2) β, γ ground surface measurement, (3) air concentration measurement, (4) gamma exposure rate measurement, and (5) radionuclide concentration measurement. However, only one type of measurement data, i.e., the one selected from the drop-down list, will be used for developing specific stay times (Figure 12.6). For the first three types of measurement data, radioactivity can be specified in terms of dpm, Bq, or pCi for the entered value (Figure 12.7). For the last type of measurement data, ground surface and air concentration measurements can be specified for the 11 radionuclides considered by RESRAD-RDD (Figure 12.8). The specific stay times developed for this type of measurement data consider the presence of all radionuclides with non-zero concentration values. If only one concentration value (either for ground surface or air) is specified for a radionuclide, the resuspension factor (accessible through the correction/resuspention/conversion factors input screen) will be used to derive the concentration of that radionuclide in the other medium. When concentrations for both media are specified, they will be used directly for stay time calculation.

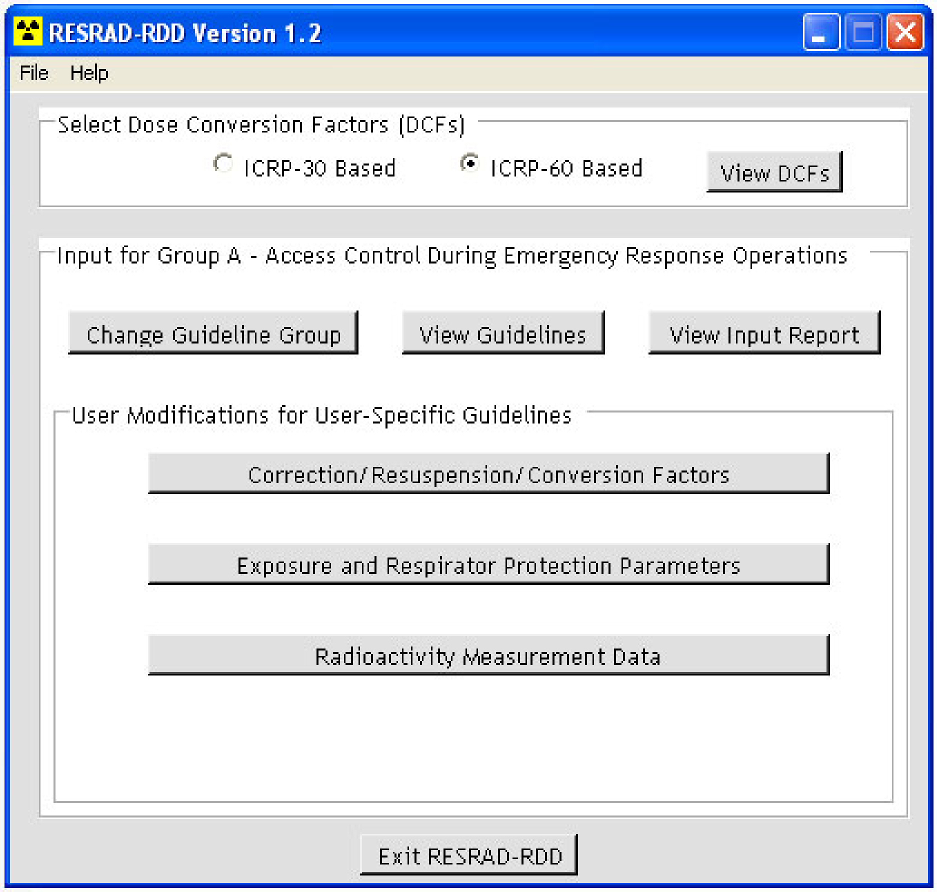


FIGURE 12.3 Input Data Selection Screen for Group A in RESRAD-RDD

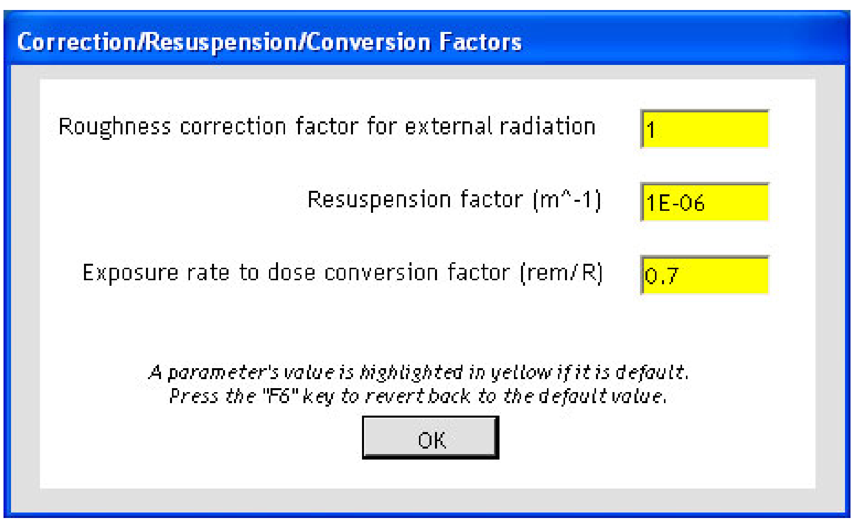


FIGURE 12.4 Input Data Screen for Correction/Resuspension/ Conversion Factors Used by Group A

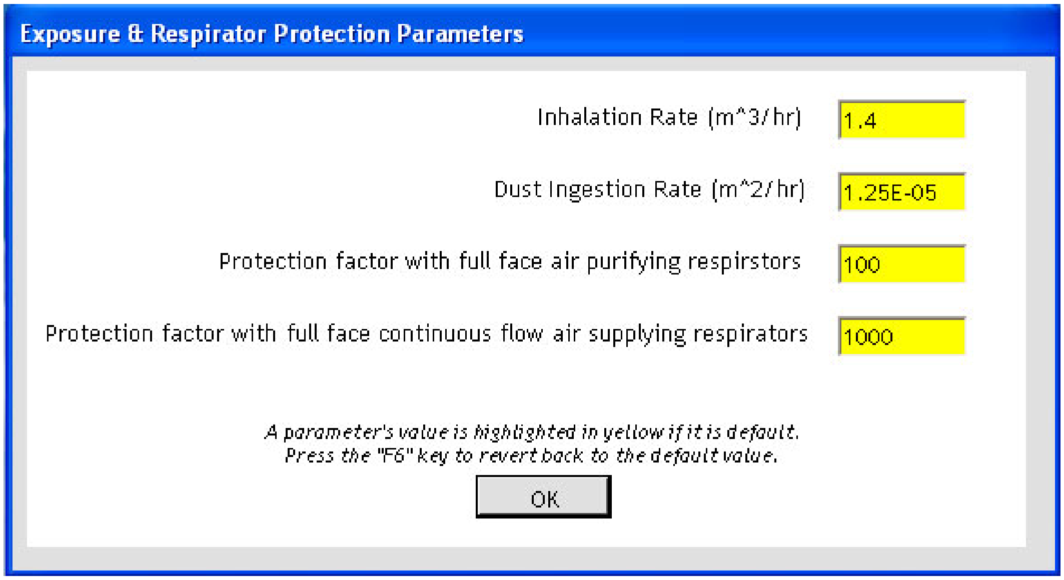


FIGURE 12.5 Input Data Screen for Exposure and Respirator Protection Parameters Used by Group A

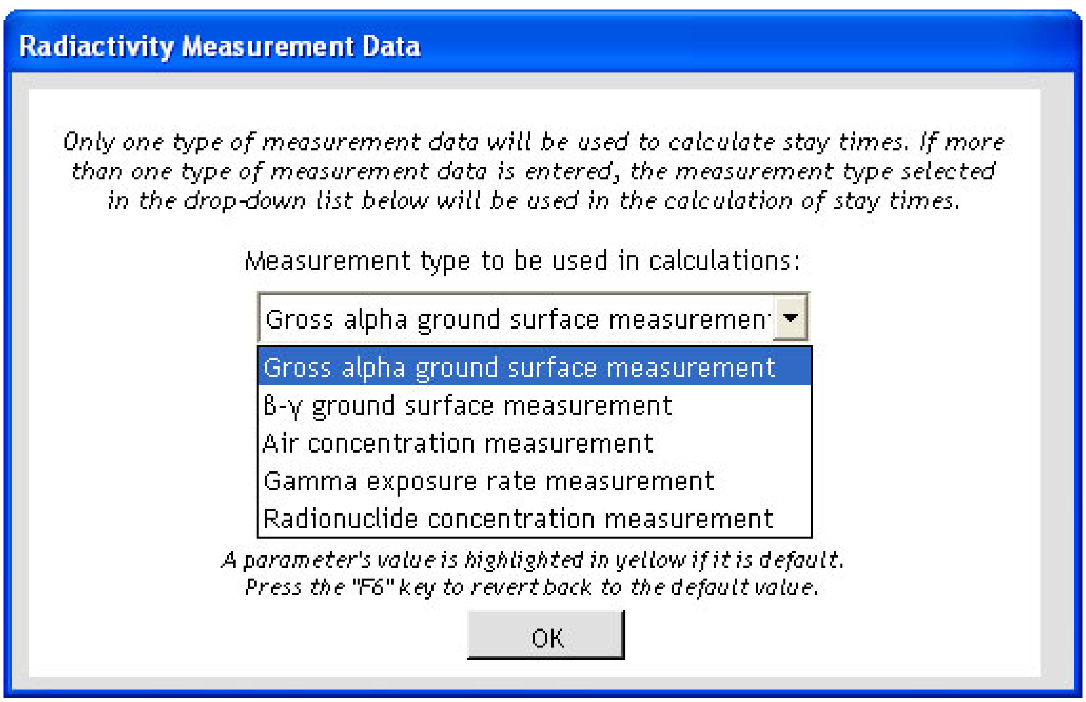


FIGURE 12.6 Group A Radioactivity Measurement Data Input Screen Showing Different Types of Measurement Data Accepted by RESRAD-RDD

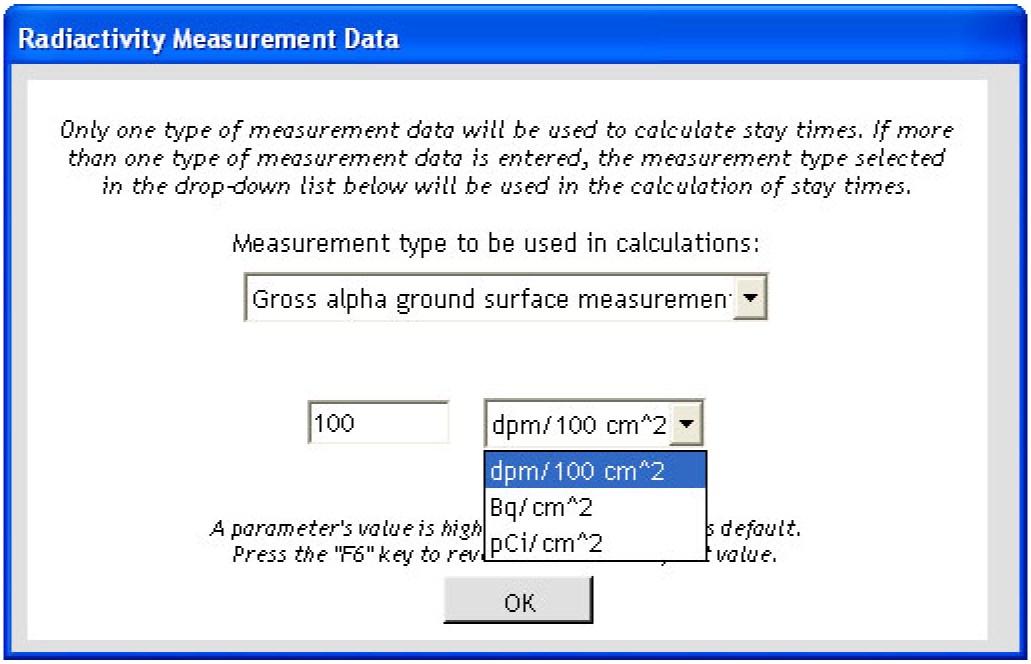


FIGURE 12.7 Group A Radioactivity Measurement Data Input Screen Showing Different Units Available for Data Entry

For Groups C, D, and E, the input data selection screens are the same as that for Group B, shown in Figure 12.9. The categories of input data for Groups B, C, D, and E are (1) correction factors for external radiation, (2) source partitioning/weathering parameters, (3) parameters for air concentrations, and (4) exposure parameters. The list of parameters under each category can be displayed by clicking on that category. The input parameters listed under categories (1), (2), and (3) are the same for the four groups; therefore, once the value of a parameter is changed under the selected group, the new value will be reflected and displayed under the other groups. The exposure parameters under category (4) are scenario and location dependent; they are different for different groups.

Four categories of input data can be found for Group G: (1) parameters for air concentrations, (2) growth and consumption data for food, (3) deposition/transfer parameters for plants, and (4) root uptake/meat/milk transfer factors. The parameters listed under the first group are the same as those listed under category (3) for Groups B, C, D, and E. However, only two of the four parameters (the outdoor resuspension coefficients) are used in calculations, and their values can be modified; the other two parameters are displayed but their values are shaded and cannot be overwritten. Because the outdoor resuspension coefficient parameters are also used by

Groups B, C, D, and E, any change made to them under Group G will be reflected under Groups B, C, D, and E, and vice versa.

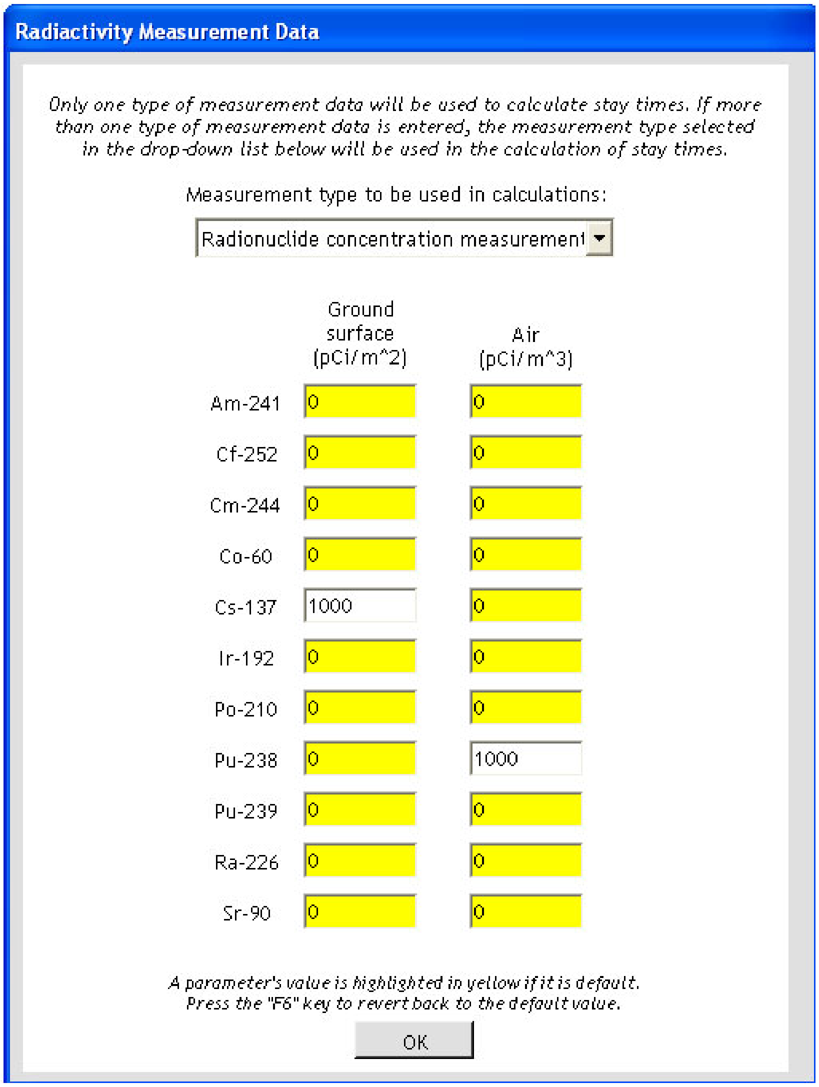


FIGURE 12.8 Group A Radioactivity Measurement Data Input Screen Showing Entry of Radionuclide Concentrations

Figures 12.10 through 12.15 show the input data screens for different data categories. In each input data screen, the values of input parameters can be modified. The data field is highlighted in yellow if a parameter has the default value. No highlight indicates deviation from the default. For most cases, in order to exit the input data screen, the "OK" button must be selected. Exceptions are made for the "exposure parameters" and "growth and consumption parameters" input screens, in which a "close screen" button is also available on the upper right corner and can be selected to exit the screen. However, clicking on the "OK" button will save the modifications made to the screen, while clicking on the "close screen" button will not. Modification of the input data is saved for the current execution.

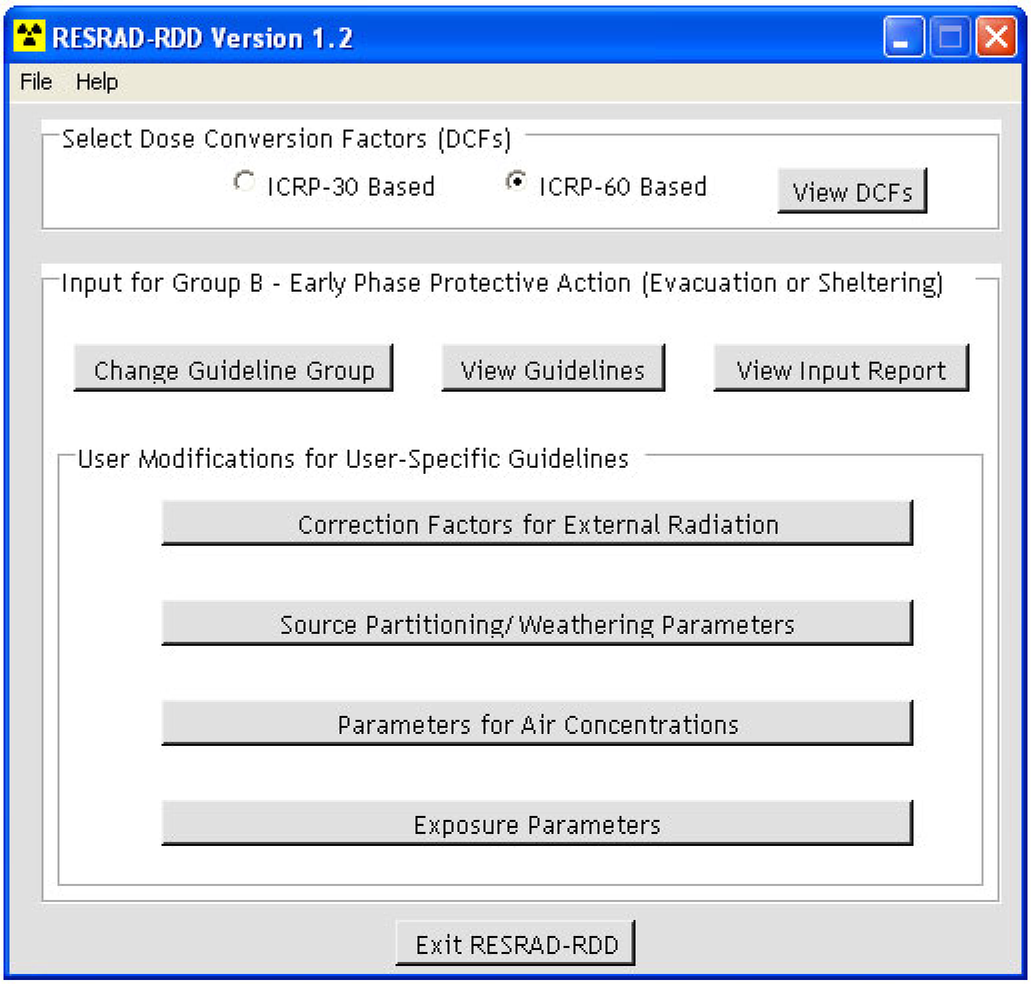


FIGURE 12.9 Input Data Selection Screen for Group B in RESRAD-RDD

On the exposure parameters input data screen, different exposure scenarios considered for developing the operation guidelines/stay times are listed. These exposure scenarios are grouped under different subgroups according to the characteristics of receptors, contamination locations, or modeling methods. Operational guidelines/stay times are developed for each subgroup. Input parameters for the first subgroup are automatically displayed on the screen. To modify the exposure parameters of a different subgroup, the subgroup (listed in the subgroup bar along with other subgroups at the top of the input data screen) has to be selected first. Upon the selection of the subgroup, the exposure scenarios grouped under that subgroup will be displayed and their exposure parameters can be modified. Figure 12.13 shows the exposure parameters input data screen for subgroup C5. When the exposure scenarios cannot fit into the input screen, a scroll bar will appear along the right edge of the screen and can be used to scroll up and down to view all of the exposure scenarios.

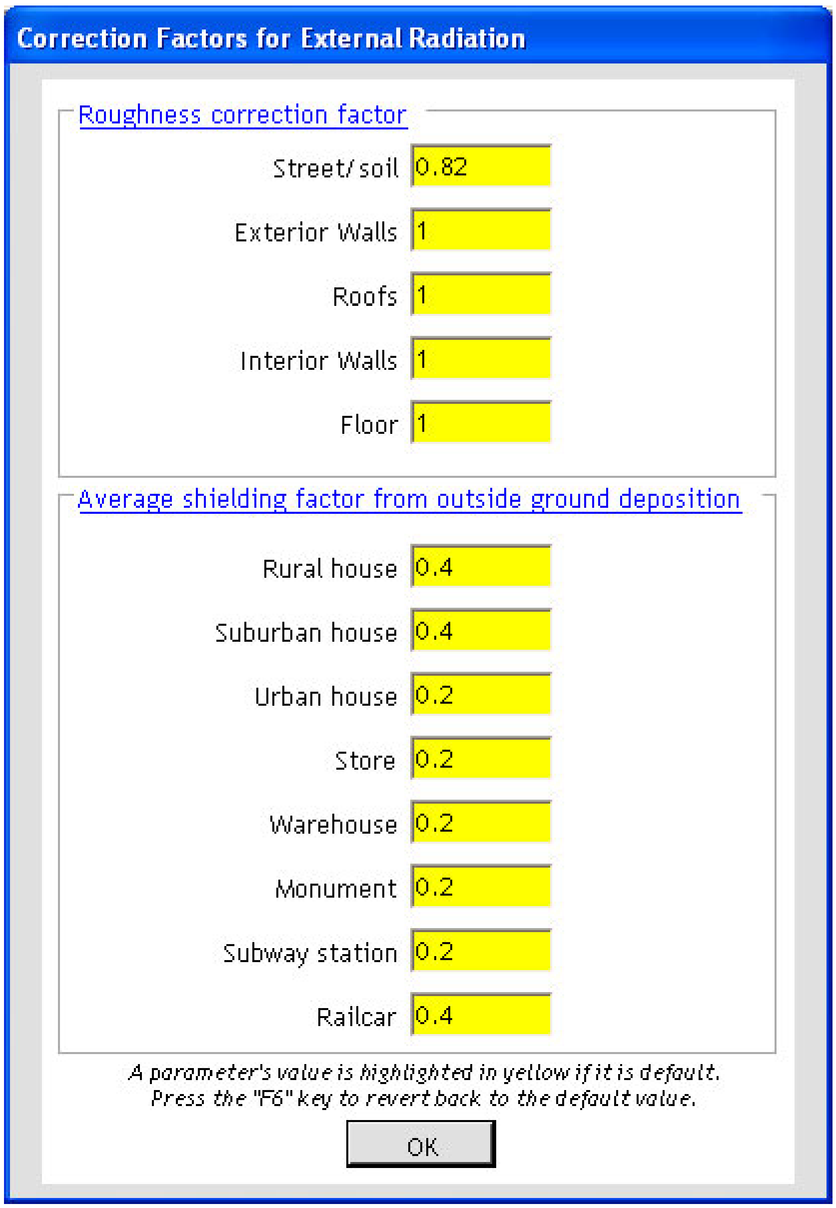


FIGURE 12.10 Data Input Screen for Correction Factors for External Radiation

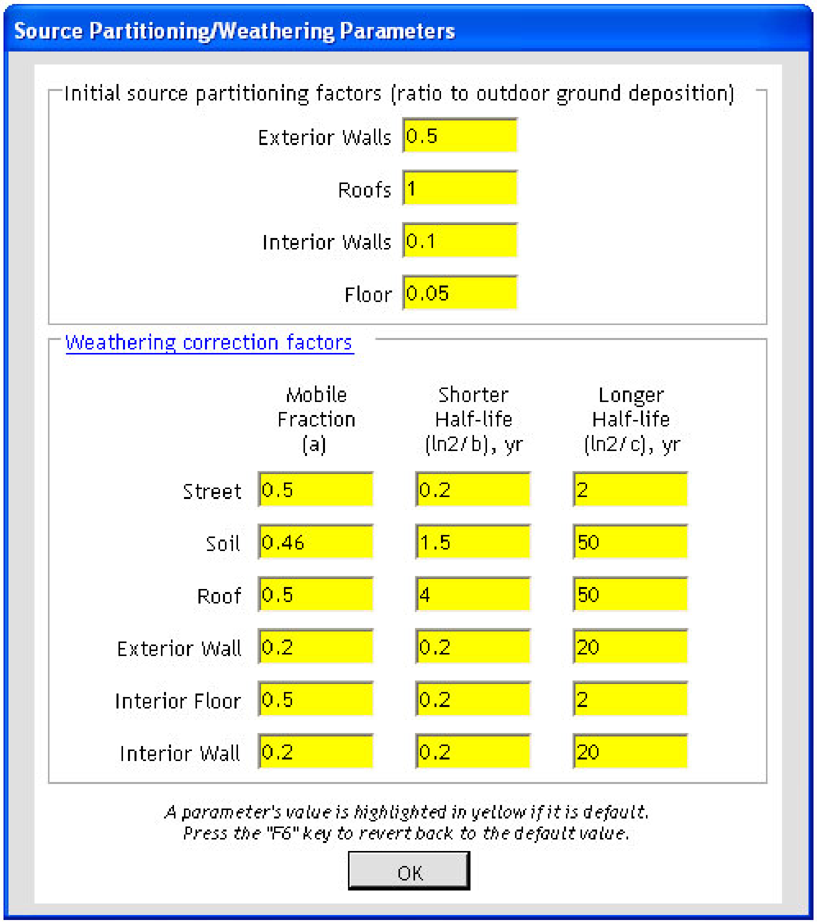


FIGURE 12.11 Data Input Screen for Source Partitioning/ Weathering Parameters

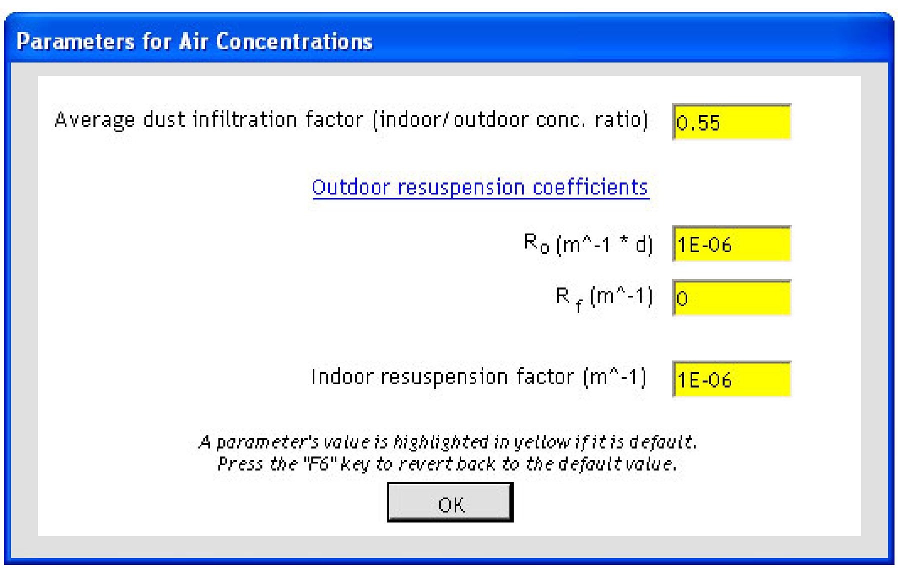


FIGURE 12.12 Data Input Screen for Parameters for Air Concentrations

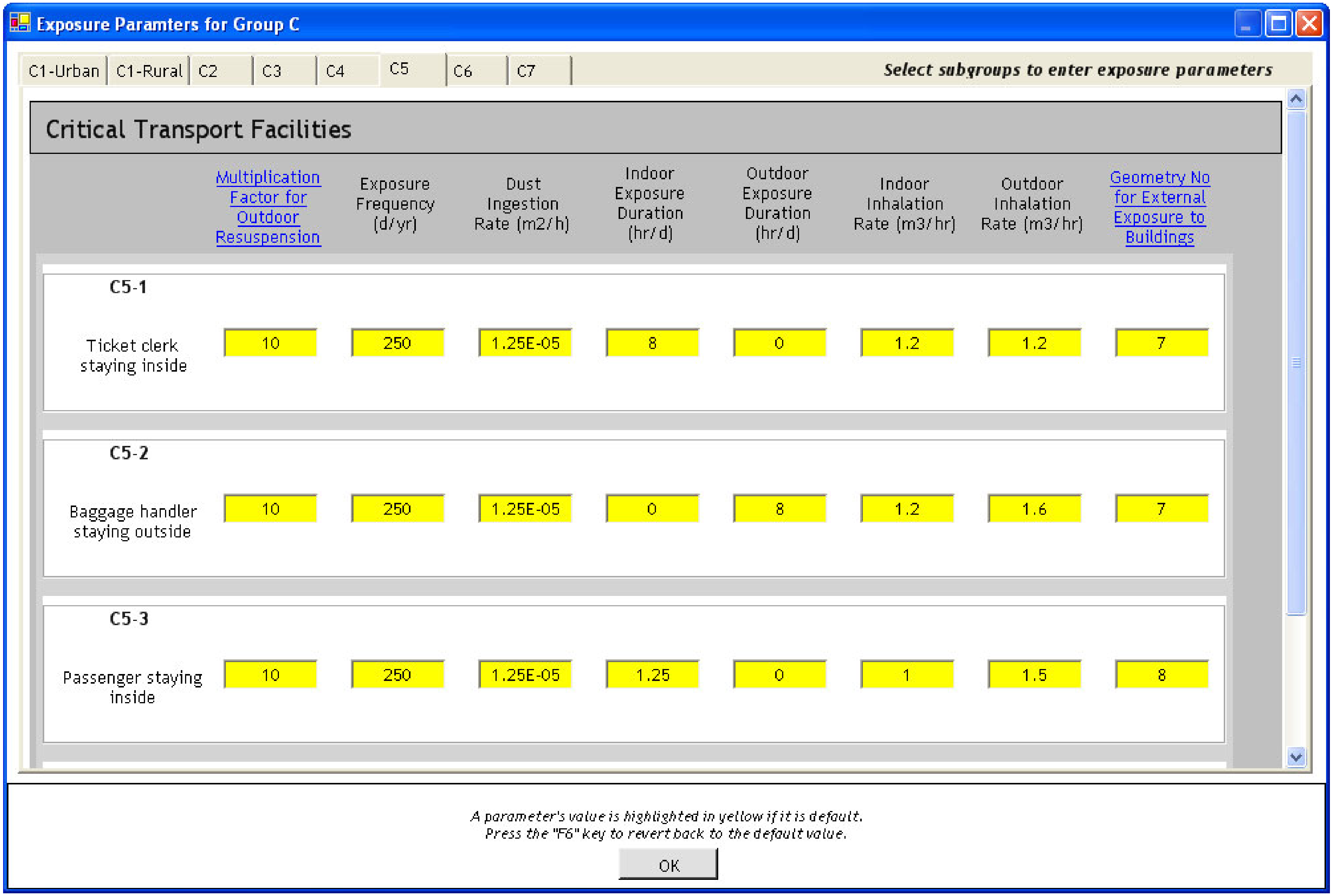


FIGURE 12.13 Data Input Screen for Exposure Parameters for Group C5

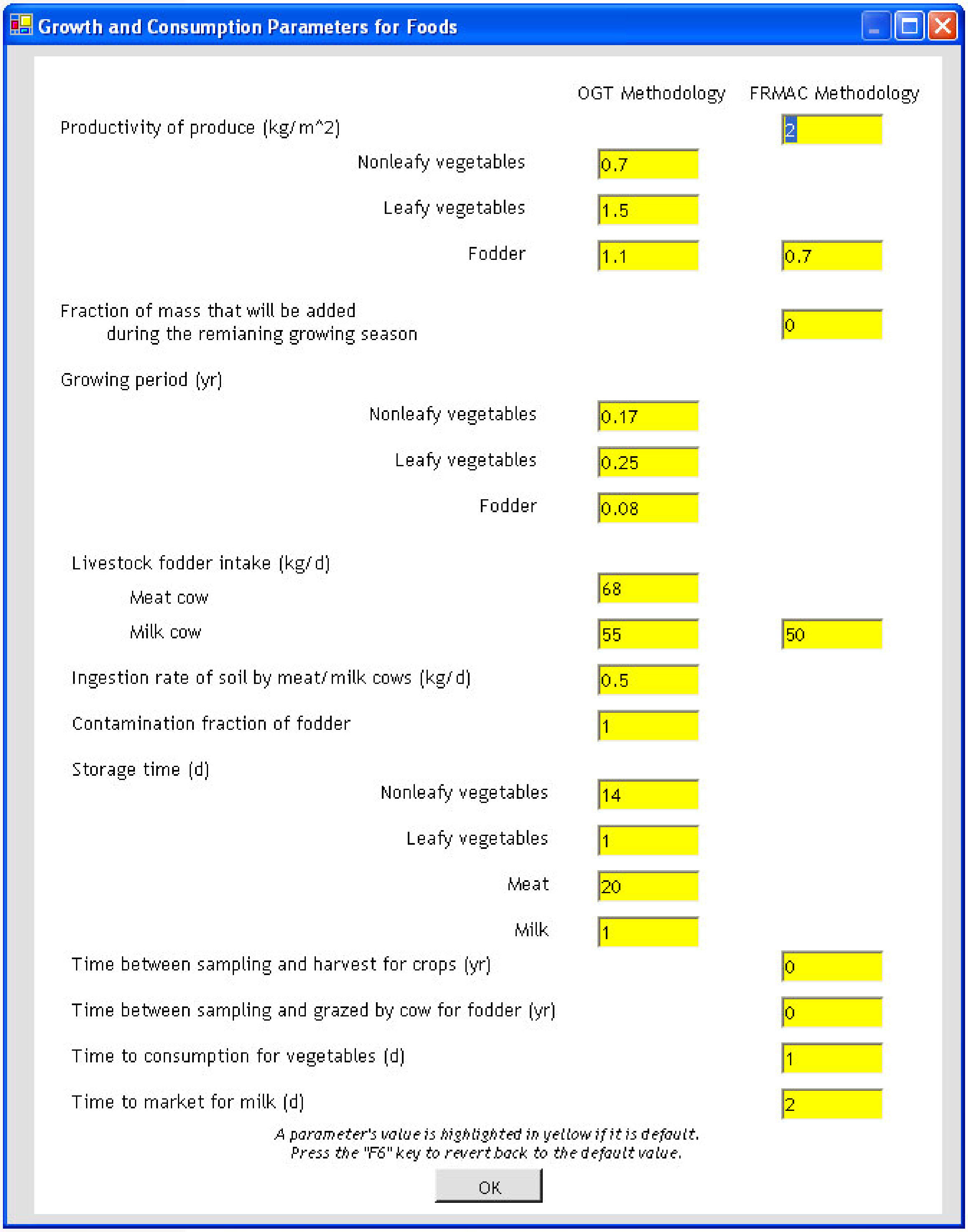


FIGURE 12.14 Input Data Screen for Growth and Consumption Parameters for Foods

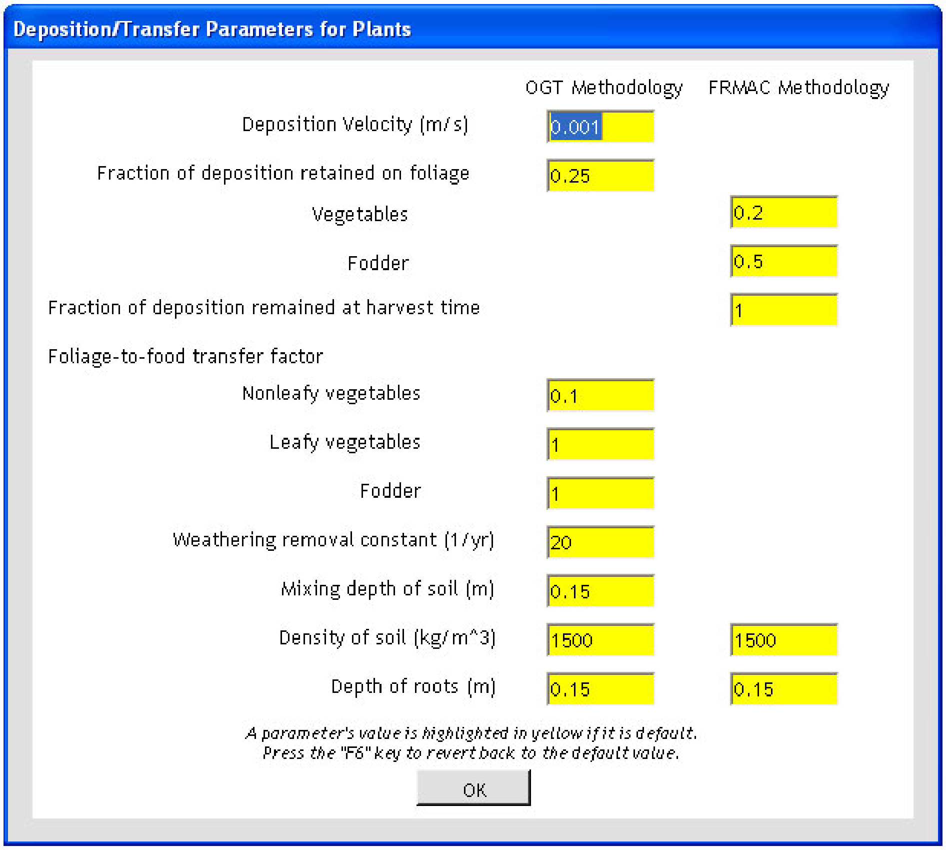


FIGURE 12.15 Input Data Screen for Deposition/Transfer Parameters for Plants

To reset to default value for a specific parameter after its value was changed, move the cursor to the input field of that parameter, then press “F6” on the keyboard. To reset to default values for all parameters, go to the menu bar located at the top of the screen, select “file,” and choose “reset to defaults” or “new” from the drop down list. The “reset to defaults” option returns default values to all input parameters within the current input file. The “new” option will close the current input file and start a new file.

To permanently save the changes to a data file, either click on “Exit RESRAD-RDD” then answer the follow-up questions or choose the “file” option on the menu bar, then choose “save” or “save as” from the drop down list. The first method saves the changes and terminates the RESRAD-RDD execution. The second method saves the changes but continues the RESRAD-RDD execution. The default RESRAD-RDD input file has the *.rdd extension. It is recommended that the same file extension be retained for any input file created by the user.

After input data were saved to a file, the saved data can be retrieved at any time after RESRAD-RDD is started. This can be accomplished by selecting the “file” option on the menu bar, then choosing “open” from the drop down list, and selecting the desired file.

Except for a brief text description on the input data screen, additional explanation can be accessed for some input parameters during the execution of RESRAD-RDD. The brief text descriptions for these parameters are underlined and displayed in blue in the input data screens. Clicking on the text description will open another screen with additional explanation (Figure 12.16). Close the explanation screen to continue data modification.

Another feature of the input data screen is that internal bounds were set for the value of each parameter. If the value entered is outside the range set for the parameter, a red warning sign will appear next to the input value upon clicking the “OK” button (Figure 12.17). The entered value cannot be saved unless rectification is made and the “OK” button is clicked again. The internal bounds were selected to prevent mathematical overflow or underflow problems and physically impossible situations (e.g., spending 25 hours per day indoors). They do not correspond to the range of statistical distribution under normal conditions.

After all the input parameters are modified, an input summary report can be generated and viewed. This can be done by clicking the “view input report” button on the input data selection screens. The input summary report (Figure 12.18) groups input parameters in the same manner as seen on the input data screens, so that tracking input parameters is easy. In addition to listing input parameters used by all guideline groups, the report also provides information linking the parameters to the guideline groups. To ensure correspondence between the input summary report and the calculation results, it is advised that the “view guidelines” button be selected (to initiate calculations and generate results) prior to the selection of “view input report.”

12.5 PERFORM CALCULATION AND VIEW RESULTS

In order to view operational guideline/stay time results, for operational guideline Groups A, B, C, D, E, and G, the “view guidelines” option on the input data selection screen must be selected first. For Group F-4, input data screens are not available; therefore, results can be selected for viewing immediately after the group selection. If input parameter values or the DCF selection have been modified since the last calculations, the selection to view calculation results will initiate new calculations to update the guideline/stay time results. During the calculations, the progress is displayed through a status bar, which will disappear when calculations are completed. Depending on the operational guideline group selected, either the calculation results will be displayed directly on the screen or a result selection screen will appear (Figure 12.19), and users will need to make another selection.

The results generated by RESRAD-RDD are presented in tabular (Figures 12.20 and 12.21) or graphic format (Figure 12.22) supported by Internet browsers. Viewing, saving,

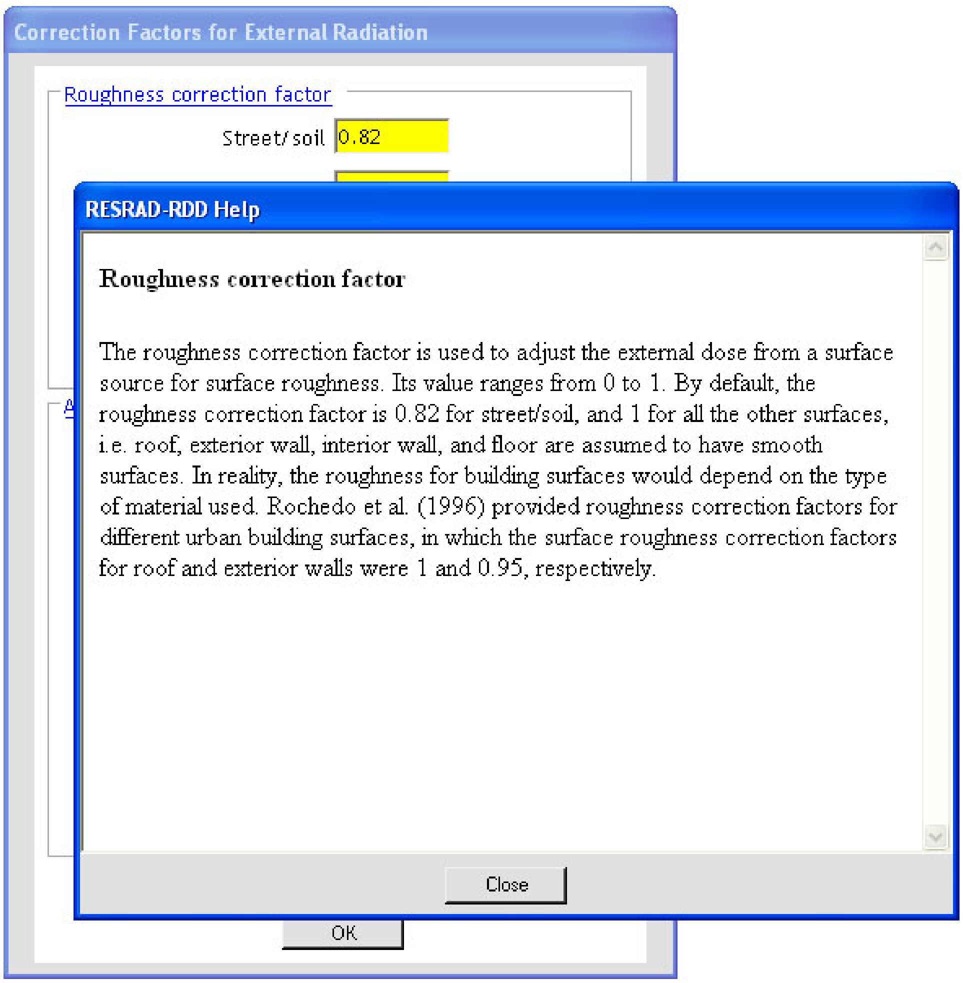


FIGURE 12.16 Additional Explanation for Roughness Correction Factor

editing, or printing the results can then be performed with the same procedures used by the Internet browser installed in the computer. To return to the RESRAD-RDD code, close the

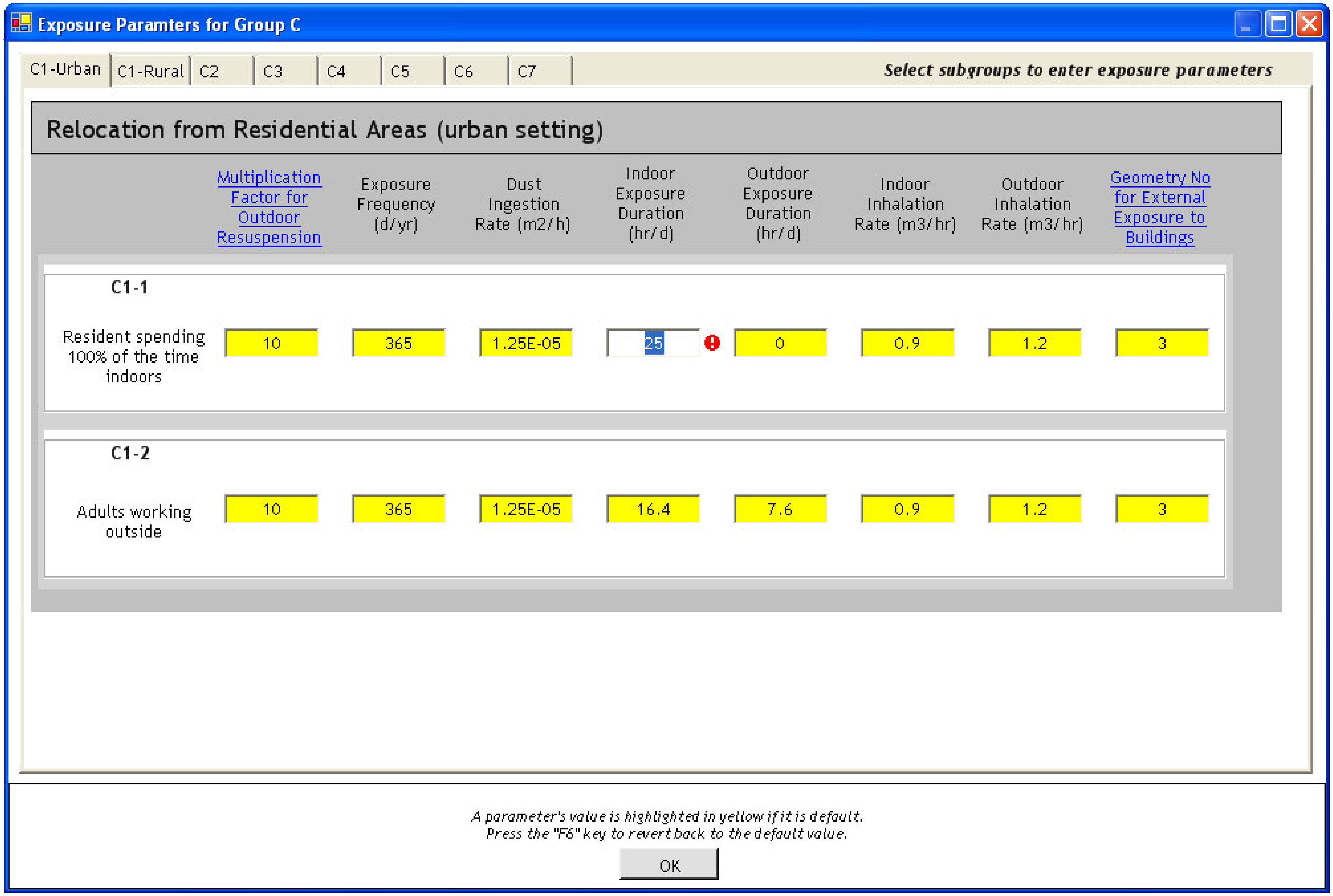
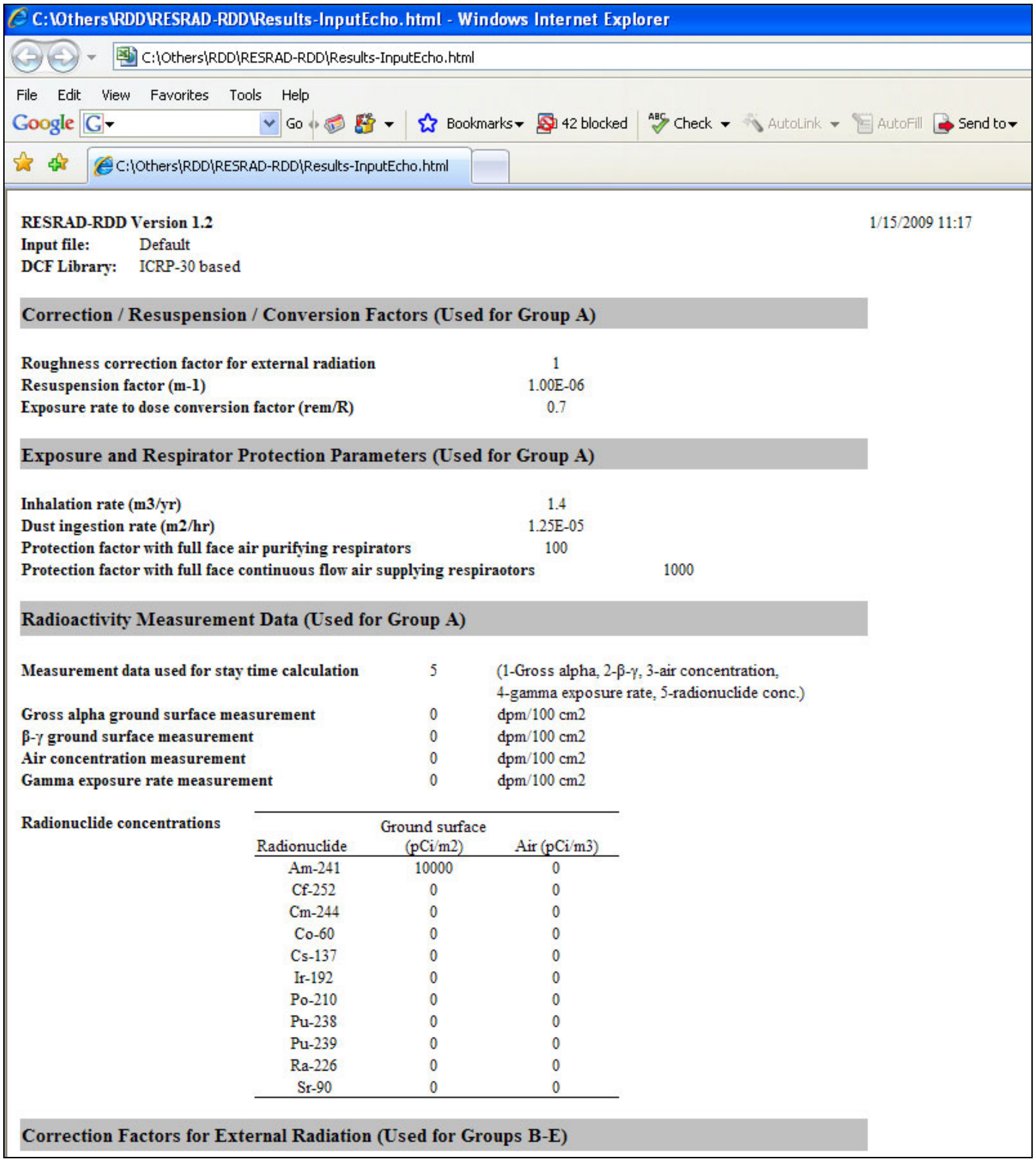


FIGURE 12.17 Warning Sign Appears for an Entered Value outside the Range Set for a Parameter



RESRAD-RDD Version 1.2 1/15/2009 11:17
Input file: Default
DCF Library: ICRP-30 based

Correction / Resuspension / Conversion Factors (Used for Group A)

Roughness correction factor for external radiation	1
Resuspension factor (m-1)	1.00E-06
Exposure rate to dose conversion factor (rem/R)	0.7

Exposure and Respirator Protection Parameters (Used for Group A)

Inhalation rate (m3/yr)	1.4
Dust ingestion rate (m2/hr)	1.25E-05
Protection factor with full face air purifying respirators	100
Protection factor with full face continuous flow air supplying respiraotors	1000

Radioactivity Measurement Data (Used for Group A)

Measurement data used for stay time calculation	5	(1-Gross alpha, 2-β-γ, 3-air concentration, 4-gamma exposure rate, 5-radionuclide conc.)
Gross alpha ground surface measurement	0	dpm/100 cm2
β-γ ground surface measurement	0	dpm/100 cm2
Air concentration measurement	0	dpm/100 cm2
Gamma exposure rate measurement	0	dpm/100 cm2

Radionuclide concentrations

Radionuclide	Ground surface (pCi/m2)	Air (pCi/m3)
Am-241	10000	0
Cf-252	0	0
Cm-244	0	0
Co-60	0	0
Cs-137	0	0
Ir-192	0	0
Po-210	0	0
Pu-238	0	0
Pu-239	0	0
Ra-226	0	0
Sr-90	0	0

Correction Factors for External Radiation (Used for Groups B-E)

FIGURE 12.18 Input Summary Report

Internet browser by clicking on the "close screen" or "minimize screen" button located at the upper right corner of the screen.

RESRAD-RDD generates the same results presented in Chapters 3 through 10 for Groups A to G. Except for the stay times expressed as functions of street concentrations (see Figure 12.21) in Groups A and D, the other results are expressed as surface concentration limits in tables, in which all 11 radionuclides considered in the analyses are listed. Graphics are generated displaying the relationship between stay time and street concentration for Group D. In each graphic, only one radionuclide is considered. Therefore, another result selection screen is needed (Figure 12.23). Select a radionuclide of interest by moving the cursor over the radionuclide name and clicking the left mouse button. Multiple radionuclides can be selected one by one. Click on a selected radionuclide will deselect it. After the radionuclide selection, click “Show Figures” to view the graphic results. Multiple figures will be displayed for multiple radionuclides. If the results for all the 11 radionuclides are desired, click on “select all” to select them all at once. Click “cancel” to return to the previous result selection screen.

As mentioned previously, the calculation results can be saved to a file while they are displayed and viewed with the Internet browser. The *.htm or *.html file type should be selected when saving the results to a file. This will enable opening a saved file with the Internet browser at a later time.

The calculation results that a user chooses to view with an Internet browser were copied from the result spreadsheets that are updated constantly. All copied and viewed results are saved in an HTML file with a name reflecting the group and result selection in the root directory of the code. Once such a file is created, the results contained within are not updated (copied from the result spreadsheets) until the user chooses to view them again within the execution of RESRAD-RDD. Therefore, caution should be taken to make sure that the results are up to date and correspond to the latest input data, if such files are to be used outside the RESRAD-RDD domain for other purposes.

To exit RESRAD-RDD, return to the input data selection screen or the group selection screen, then select “Exit RESRAD-RDD.”

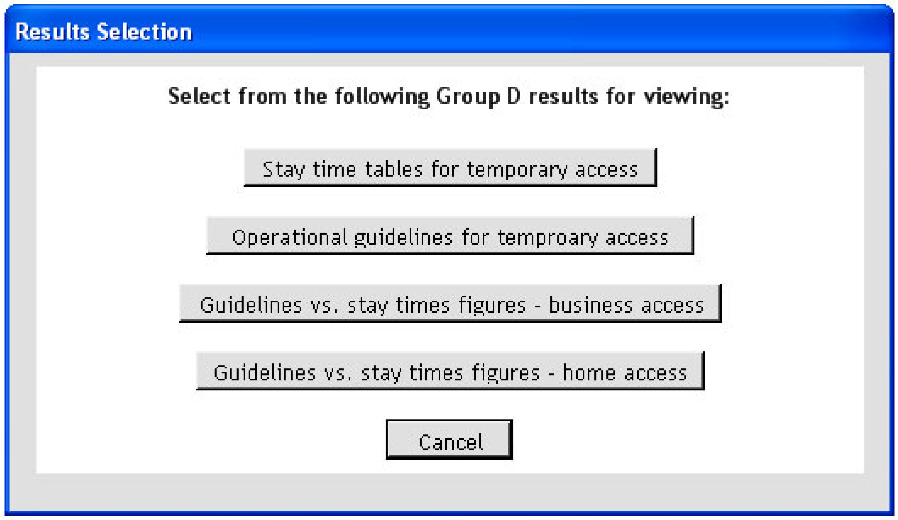
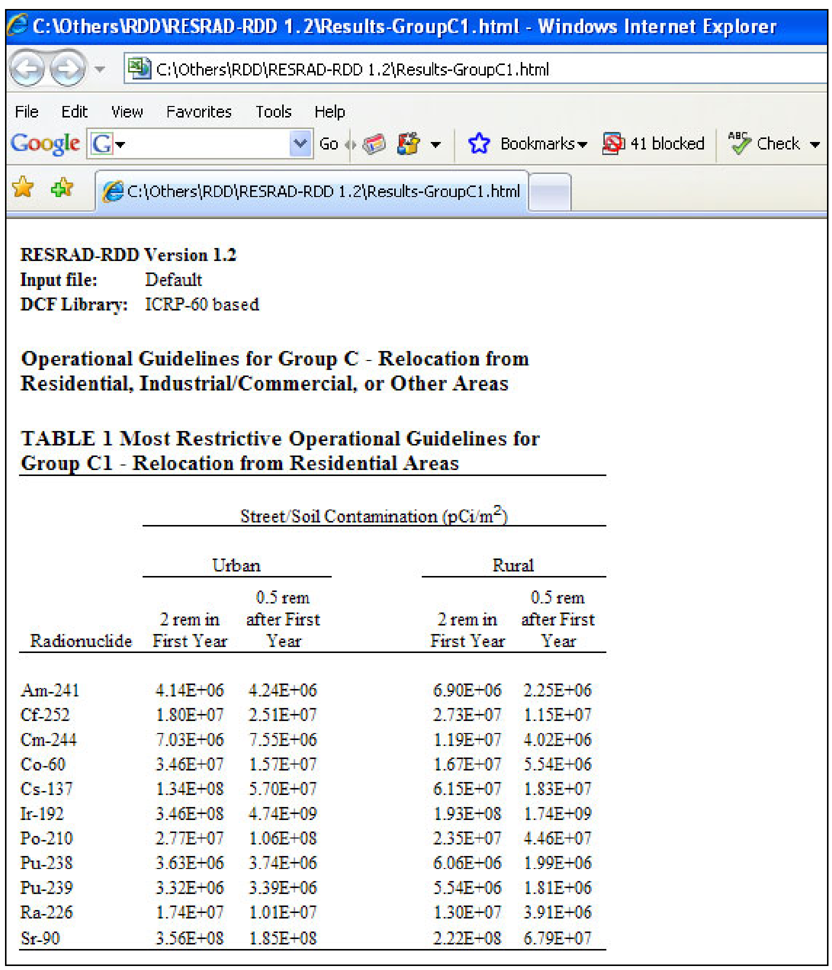


FIGURE 12.19 Result Selection Screen for Group D



RESRAD-RDD Version 1.2
Input file: Default
DCF Library: ICRP-60 based

Operational Guidelines for Group C - Relocation from Residential, Industrial/Commercial, or Other Areas

TABLE 1 Most Restrictive Operational Guidelines for Group C1 - Relocation from Residential Areas

	Street/Soil Contamination (pCi/m^2)			
	Urban		Rural	
Radionuclide	2 rem in First Year	0.5 rem after First Year	2 rem in First Year	0.5 rem after First Year
Am-241	4.14E+06	4.24E+06	6.90E+06	2.25E+06
Cf-252	1.80E+07	2.51E+07	2.73E+07	1.15E+07
Cm-244	7.03E+06	7.55E+06	1.19E+07	4.02E+06
Co-60	3.46E+07	1.57E+07	1.67E+07	5.54E+06
Cs-137	1.34E+08	5.70E+07	6.15E+07	1.83E+07
Ir-192	3.46E+08	4.74E+09	1.93E+08	1.74E+09
Po-210	2.77E+07	1.06E+08	2.35E+07	4.46E+07
Pu-238	3.63E+06	3.74E+06	6.06E+06	1.99E+06
Pu-239	3.32E+06	3.39E+06	5.54E+06	1.81E+06
Ra-226	1.74E+07	1.01E+07	1.30E+07	3.91E+06
Sr-90	3.56E+08	1.85E+08	2.22E+08	6.79E+07

FIGURE 12.20 Operational Guideline Results for Group C

C:\Others\RDD\RESRAD-RDD 1.2\Results-GroupD1.html - Windows Internet Explorer

RESRAD-RDD Version 1.2 1/8/2009 10:56

Input file: Default

DCF Library: ICRP-60 based

Stay Times for Group D - Temporary Access to Business or Houses

Table 1 Stay Times for Group D1-1 Scenario: Worker Access to Business (Outdoor Exposure)

Radionuclide Concentration				Stay Time (continuous exposure time in hours) to Receive 0.5 rem (500 mrem)										
pCi/cm^2	pCi/m^2	Bq/cm^2	dpm/100 cm^2	Am-241	Cf-252	Cm-244	Co-60	Cs-137	Ir-192	Po-210	Pu-238	Pu-239	Ra-226	Sr-90
1.00E+01	1.00E+05	3.70E-01	2.22E+03	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760
1.00E+02	1.00E+06	3.70E+00	2.22E+04	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760
1.00E+03	1.00E+07	3.70E+01	2.22E+05	3.00E+02	6.92E+03	1.99E+03	3.74E+03	> 8760	> 8760	1.05E+03	1.98E+02	1.55E+02	1.94E+03	> 8760
1.00E+04	1.00E+08	3.70E+02	2.22E+06	8.68E+00	4.57E+01	1.46E+01	2.72E+02	1.09E+03	1.42E+03	6.89E+01	7.57E+00	6.94E+00	7.82E+01	2.71E+03
1.00E+05	1.00E+09	3.70E+03	2.22E+07	8.68E-01	3.94E+00	1.46E+00	2.63E+01	9.60E+01	9.86E+01	6.21E+00	7.57E-01	6.94E-01	6.03E+00	1.90E+02
1.00E+06	1.00E+10	3.70E+04	2.22E+08	8.68E-02	3.94E-01	1.46E-01	2.63E+00	9.36E+00	9.61E+00	6.21E-01	7.57E-02	6.94E-02	6.03E-01	1.53E+01
1.00E+07	1.00E+11	3.70E+05	2.22E+09	8.68E-03	3.94E-02	1.46E-02	2.63E-01	9.36E-01	9.61E-01	6.21E-02	7.57E-03	6.94E-03	6.03E-02	1.53E+00

Table 2 Stay Times for Group D1-2 Scenario: Worker Access to Business (Indoor Exposure)

Radionuclide Concentration				Stay Time (continuous exposure time in hours) to Receive 0.5 rem (500 mrem)										
pCi/cm^2	pCi/m^2	Bq/cm^2	dpm/100 cm^2	Am-241	Cf-252	Cm-244	Co-60	Cs-137	Ir-192	Po-210	Pu-238	Pu-239	Ra-226	Sr-90
1.00E+02	1.00E+06	3.70E+00	2.22E+04	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760	> 8760
1.00E+03	1.00E+07	3.70E+01	2.22E+05	6.51E+02	7.39E+03	1.52E+03	> 8760	> 8760	> 8760	> 8760	5.17E+02	4.44E+02	6.23E+03	> 8760
1.00E+04	1.00E+08	3.70E+02	2.22E+06	1.80E+01	1.57E+02	3.26E+01	6.74E+02	3.53E+03	> 8760	6.06E+02	1.57E+01	1.44E+01	2.85E+02	> 8760
1.00E+05	1.00E+09	3.70E+03	2.22E+07	1.80E+00	8.41E+00	3.04E+00	6.38E+01	2.81E+02	2.47E+02	2.89E+01	1.57E+00	1.44E+00	1.46E+01	1.08E+03
1.00E+06	1.00E+10	3.70E+04	2.22E+08	1.80E-01	8.41E-01	3.04E-01	6.34E+00	2.65E+01	2.31E+01	2.80E+00	1.57E-01	1.44E-01	1.46E+00	6.63E+01
1.00E+07	1.00E+11	3.70E+05	2.22E+09	1.80E-02	8.41E-02	3.04E-02	6.34E-01	2.65E+00	2.31E+00	2.80E-01	1.57E-02	1.44E-02	1.46E-01	5.77E+00

FIGURE 12.21 Stay Time Table Results for Group D

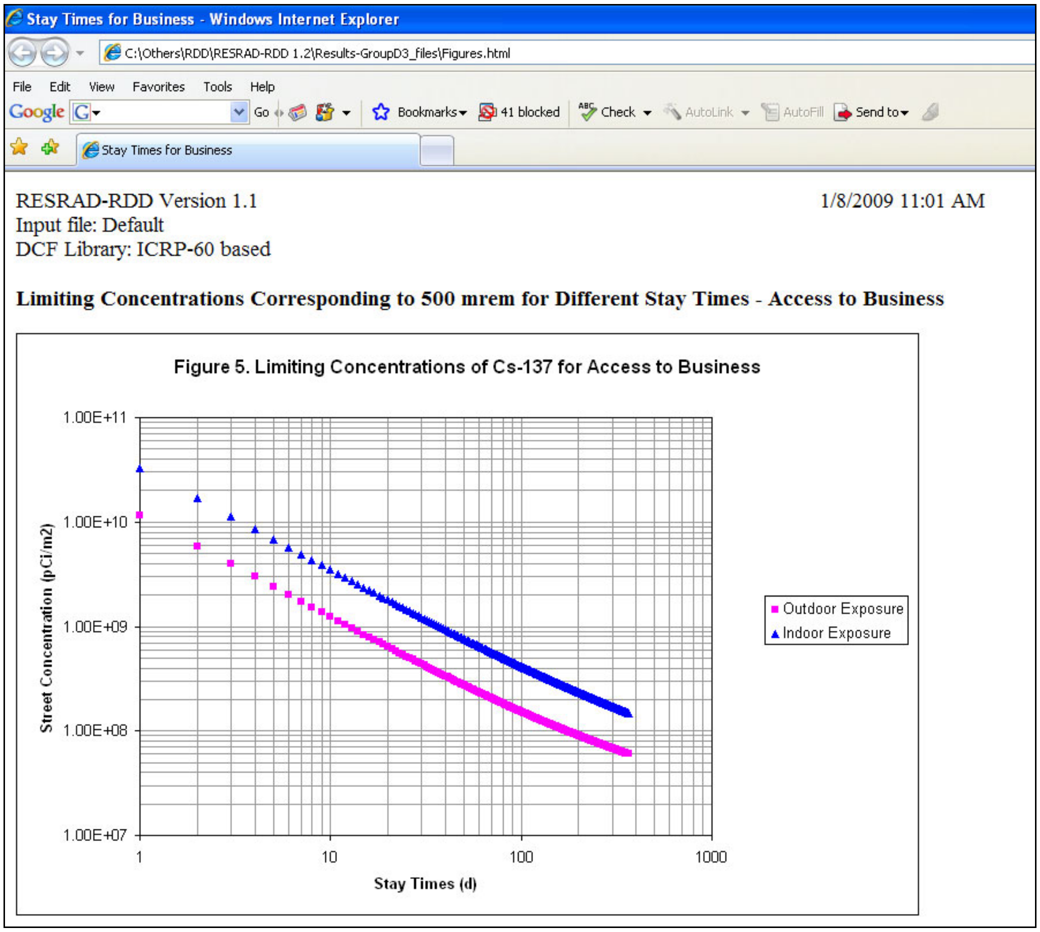


FIGURE 12.22 Stay Time Graphic Results for Group D

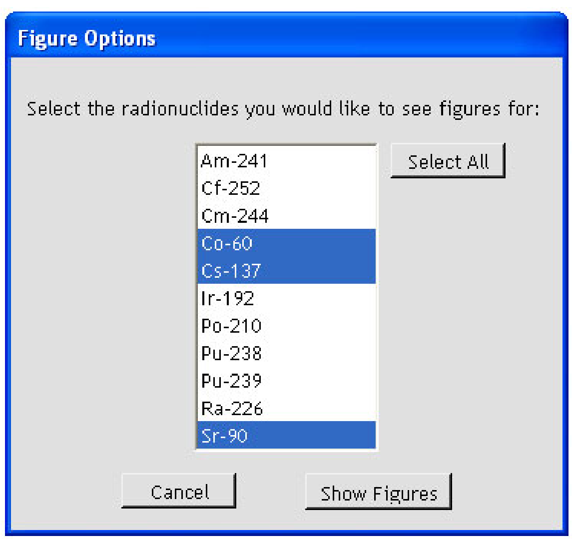


FIGURE 12.23 Figure Option Screen for Group D Results

12.6 VERIFICATION AND QUALITY CONTROL OF RESRAD-RDD

The RESRAD-RDD software was developed following the RESRAD Program Quality Assurance (QA) and Quality Control (QC) procedures. The software was verified by hand calculations and/or other separately developed spreadsheets for most of the equations used in the software. Many parameter values used in the RESRAD-RDD software were taken from the RESRAD database. These include soil to plant transfer factors, meat and milk transfer factors, dose conversion factors, decay half-lives, and scenario-specific occupancy factors. The RESRAD database is well documented and verified (Yu et al. 2000, 2001, 2003). The exercise presented in Section 13.3 also serves the purpose of verification of the RESRAD-RDD software. The results indicated that using three different methods: (1) using the old spreadsheet results as listed in tabular form throughout the report, (2) hand calculations using equations, and (3) using the RESRAD-RDD software, exactly same results were obtained.

The RESRAD-RDD software has been successfully applied by OGT members, and it is expected that lessons learned from end-user applications will result in further improvements to the software. The RESRAD-RDD software has also been applied in support of the Department of Energy's participation in the International Atomic Energy Agency's (IAEA's) Environmental Modeling for Radiation Safety (EMRAS) program. The OGT methodology encoded in RESRAD-RDD was used to analyze a hypothetical RDD scenario developed by EMRAS (Thiessen et al. 2008; Kamboj et al. 2008).

12.7 REFERENCES

ICRP (International Commission on Radiological Protection), 1982, *Limits for Intakes of Radionuclides by Workers, Part 3*, ICRP Publication 30, Ann. ICRP 6, No. 2-3, Pergamon Press, Oxford, England.

ICRP, 1991, *1990 Recommendations of the International Commission on Radiological Protection,* ICRP Publication 60, Volume 21, No. 1-3, Pergamon Press, Oxford, England.

Kamboj, S., J.-J. Cheng, and C. Yu, 2008, Modeling of the EMRAS Urban Working Group Hypothetical Scenario Using RESRAD-RDD Methodology. Presented at the International Conference on Radioecology & Environmental Radioactivity. Bergen, Norway, Oral & Oral Poster Presentations, Proceedings Part 1, pp. 48-51, June 15-20.

Thiessen, K.M., et al., 2008, "Improvement of modeling capabilities for assessing urban contamination: The EMRAS Urban Remediation Working Group," Applied Radiation and Isotopes, 66 (*11*):1741-1744, November.

13 TESTING/APPLICATION OF THE OGT METHODOLOGY AND THE RESRAD-RDD SOFTWARE

The methodology, stay time tables, and operational guidelines developed for various scenarios and subgroups and the companion RESRAD-RDD software are tested by using hypothetical scenarios jointly developed by FRMAC and the OGT. Consistent with the OGT's guiding principles, operational guidelines development efforts were coordinated with FRMAC. The goals of the coordination were (1) to identify areas of consistency between OGT methods and operational guidelines with existing FRMAC assessment methods for response to more traditional radiological incidents (e.g., nuclear power plant accidents); and (2) to determine the rationale and benefits of OGT approaches that might differ from, or represent refinements to, FRMAC methodologies, which might be applied in the future to improve currently available FRMAC methodologies. A key activity that resulted from this coordination and set of goals was a method comparison exercise that involved independent OGT and FRMAC analysis of mutually agreed upon predefined, assessment scenarios, sample data, and decision-support questions that could likely be expected in the event of a radiological incident. Two questions were selected for analysis from a set of questions jointly developed by FRMAC and OGT. The OGT analysis of and results from the OGT/FRMAC methods comparison exercise are presented in the following two sections. The analysis involved the use of the operational guidelines and stay time tables presented in previous chapters for different RDD exposure scenarios and the application of the companion software, RESRAD-RDD.

13.1 QUESTION NO. 1 (PROPOSED BY FRMAC)

What is the derived response level (DRL) in terms of $\mu Ci/m^2$ for the following mixture for early phase, intermediate phase and second-year time frames using Cs-137 as marker?

The mixture is determined from the following sample results:

Cs-137: 10 $\mu Ci/m^2$
Sr-90: 10 $\mu Ci/m^2$
Pu-239: 2 $\mu Ci/m^2$

13.2 SOLUTION TO QUESTION NO. 1

Three methods are used to solve this question. All three methods render the same results. Method 1 uses the tabulated values listed in this report; Method 2 uses the RESRAD-RDD software; and Method 3 uses the methodology and equations described in this report. The general approach and assumptions for all three methods are the same; they are described first, followed by the solution using each method.

13.2.1 Approach and General Assumptions

- The radiological contamination is assumed to be the result of an RDD event, which occurred in an outdoor environment.
- Surface contamination exists on the outside streets (soil), the exterior walls and roof of buildings, and indoor floors and walls of buildings. The relative concentration ratios for soil (street)/outdoor walls/roof/indoor floor/indoor walls are 1 : 0.5 : 1 : 0.1 : 0.05.
- Surface concentrations are corrected for weathering and radioactive decay.
- Outdoor resuspension factor decreases over time. Indoor resuspension factor is constant at 1E-6 m^{-1}.
- For outdoor air concentration in an urban environment, the baseline resuspension factor was multiplied by a factor of 10 to account for vehicular traffic.
- Dust filtration factor is 0.55.
- Soil ingestion rate is 1.25×10^{-5} m^2/h for both indoors and outdoors.
- The residential building considered for external exposure was a rural house in the case of rural environment and an urban apartment in the case of urban environment. The characteristics for the buildings are listed in Table 2.4 in Chapter 2.

- A homogenously contaminated surface area of 10,000 m^2 was assumed for the outdoor street/soil source. A surface roughness correction factor of 0.82 was applied for external dose calculation.

- External dose conversion factors used in dose calculation were calculated using RESRAD-BUILD; submersion dose conversion factors are calculated by DCAL software (Eckerman et al. 2006); inhalation and ingestion dose conversion factors were taken from ICRP 72 (ICRP 1996). It was assumed that Cs-137 is in equilibrium with its short-lived progeny Ba-137m and Sr-90 is in equilibrium with its short-lived progeny Y-90. The dose conversion factors for Cs-137 include the contribution from Ba-137m, and the dose conversion factors for Sr-90 include the contribution from Y-90.

- Potential exposure pathways included (1) external radiation from deposited contamination on outside street/soil, roof, exterior walls, interior floor, and interior walls; (2) submersion in contaminated air both indoors and outdoors; (3) inhalation of contaminated air both indoors and outdoors; and (4) ingestion of contaminated dust particles indoors and outdoors.

13.2.2 Specific Assumptions for the Early Phase

- "Early phase" is defined as the first 4 days following the RDD event. The 4-day integrated dose was calculated.

- During the early phase, indoor contamination (on floors and interior walls) has not yet been established and would be neglected in dose calculation.

- PAG = 1 rem.

- Three different receptors were analyzed: (1) resident spending 100% of the time (24 h/d) indoors, (2) resident spending time both indoors and outdoors, and (3) worker spending 100% of the time outdoors. The maximally exposed individual (MEI) was found to be a worker spending 100% of the time outdoors for 4 days and 24 h/d.

- The RDD event was assumed to occur in an urban environment.

- The inhalation rate of the worker was 1.2 m^3/h.

13.2.3 Specific Assumptions for the Intermediate Phase and Second-Year Time Frames

- Two different receptors, both in the urban and the rural environment, were analyzed: (1) resident spending 100% of the time (24 h/d) indoors, and (2) resident spending time both indoors and outdoors. The MEI was found to be an adult resident living in the contaminated area who spends some time working outdoors. The RDD event was assumed to occur in both an urban and rural environment.

- The MEI was assumed to spend all his time in the contaminated area, 16.4 h/d indoors and 7.6 h/d outdoors, and incur radiation exposures through external radiation, submersion, inhalation, and ingestion.

- The inhalation rate was assumed to be 0.9 m^3/h indoors and 1.2 m^3/h outdoors.

- Intermediate phase PAG = 2 rem; second-year PAG = 500 mrem.

13.2.4 General Solution Procedure and Methods

To calculate radiation doses using the OGT method, first the individual pathway DSRs were calculated for each radionuclide, then the pathway DSRs were added for each radionuclide to get the radionuclide-specific total DSR. The radionuclide specific total DSR was multiplied by the radionuclide concentration to get the dose from each radionuclide. Finally the doses from all radionuclides were added to get the total dose. The DSRs can be calculated using three methods:

Method 1: Using tables in this report
Method 2: Using the RESRAD-RDD software
Method 3: Using the methodology/equations described in this report

All three methods calculated the same results, as expected.

13.2.5 Method 1: Using Tables in This Report

In this report, the DSRs for Cs-137, Sr-90, and Pu-239 were obtained using Table 4.6 for the early phase and Table 5.1 for the intermediate phase and for the second year time frame in both urban and rural settings. The results are listed in Table 13.1.

The DSRs for the mixture using Cs-137 as marker can be easily calculated based on the DSRs for each individual radionuclide and their concentrations in the sample. The mixture DSRs using Cs-137 as a marker are listed in Table 13.2.

TABLE 13.1 Radionuclide DSRs for Different Time Frames

	DSRs [mrem/(pCi/m^2)]				
	Early Phase	Intermediate Phase		Second-Year Time Frame	
Radionuclide	Urban Setting (Table 4.6)	Urban Setting (Table 5.1)	Rural Setting (Table 5.1)	Urban Setting (Table 5.1)	Rural Setting (Table 5.1)
Cs-137	5.9E-07	1.49E-05	3.25E-05	8.77E-06	2.73E-05
Sr-90	6.3E-07	5.62E-06	9.02E-06	2.70E-06	7.36E-06
Pu-239	3.0E-04	6.03E-04	3.61E-04	1.48E-04	2.77E-04

The DRLs in units of μCi/m^2 for the mixture using Cs-137 as the marker are also provided in the last row of Table 13.2. The PAG used are 1 rem for the early phase, 2 rem for the first year, and 500 mrem for the second year (see Table 2.5 in Chapter 2).

The early phase DRL was estimated to be 16.3 μCi/m^2; for intermediate phase, it was 14.2 μCi/m^2; and for the second-year time frame, it was 5.6 μCi/m^2. The DRL for the intermediate phase was based on results for an urban setting; and the DRL for the second year was based on results for a rural setting.

TABLE 13.2 Mixture DSRs and DRLs Using Cs-137 as a Marker

	DSR [mrem/(pCi/m^2)]				
	Early Phase	Intermediate Phase		Second-Year Time Frame	
Radionuclide	Urban Setting	Urban Setting	Rural Setting	Urban Setting	Rural Setting
Mixture, Cs-137 as marker	6.1E-5	1.41E-4	1.14E-4	4.11E-5	9.01E-5

	DRL (μCi/m^2)		
Radionuclide	Early Phase	Intermediate Phase	Second Year
Mixture, Cs-137 as marker	16.3	14.2	5.6

The calculations of the DRLs follow:

Early phase calculations

Early phase dose = 5.9E-7*1E7 + 6.3E-7*1E7 + 3.0E-4*2E6 = 6.1E2 mrem.
DRL with Cs-137 as marker = 1000/6.1E2 * 10 μCi/m^2 = 16.3 μCi/m^2.

Intermediate phase calculations

Urban setting dose = 1.49E-5*1E7 + 5.62E-6*1E7 + 6.03E-4*2E6 = 1.41E3 mrem.
DRL with Cs-137 as marker = 2000/1.41E3 * 10 μCi/m^2 = 14.2 μCi/m^2.
Rural setting dose =3.25E-5*1E7 + 9.02E-6*1E7 + 3.61E-4*2E6 = 1.14E3 mrem.
DRL with Cs-137 as marker = 2000/1.14E3 * 10 μCi/m^2 = 17.6 μCi/m^2.
The most restrictive DRL for the intermediate phase is in the urban setting.

Second year calculations

Urban setting dose = 8.77E-6*1E7 + 2.70E-6*1E7 + 1.48E-4*2E6 = 4.11E2 mrem.
DRL with Cs-137 as marker = 500/4.11E2 * 10 μCi/m^2 = 12.2 μCi/m^2.
Rural setting dose =2.73E-5*1E7 + 7.36E-6*1E7 + 2.77E-4*2E6 = 9.01E2 mrem.
DRL with Cs-137 as marker = 500/9.01E2 * 10 μCi/m^2 = 5.6 μCi/m^2.
The most restrictive DRL for the second year is in the rural setting.

13.2.6 Method 2: Using the RESRAD-RDD Software

The DSRs can be obtained by the following four steps using the RESRAD-RDD software:

1. Open “RESRAD-RDD” software and press “START.”

2. For early phase select “Group B” click on “View Guidelines” and get the operational guidelines from Table 2, column titled “worker spending 100% time outdoors.” Convert guidelines to DSRs based on selected PAG.

3. For intermediate phase, select “Group C” click on “View Guidelines” select “Relocation from residential, commercial/industrial, or other areas” and get the operational guidelines from Table 1 for the urban resident and rural resident for the first year. Convert guidelines to DSRs based on PAG = 2 rem.

4. For second year, select “Group C” click on “View Guidelines” select “Relocation from residential, commercial/industrial, or other areas” and get the operational guidelines from Table 1 for the urban resident and rural resident for the second year. Convert guidelines to DSRs based on PAG = 0.5 rem.

The results obtained by using the RESRAD-RDD software are shown in Table 13.3. They are practically identical (except some minor rounding errors) to the results in Table 13.1 using the tabulated values listed in this report. Hence, the DRLs are identical to those derived using Method 1. (See Table 13.2 for results).

13.2.7 Method 3: Using the Methodology/Equations Described in This Report

<u>*DSR calculations for the early phase*</u>

To calculate DSRs, the average concentration of radionuclide on each contaminated surface as well as in the indoor and outdoor air need to be known. The average concentration on each surface was corrected for weathering and radioactive decay over time with Equation 2.2 in Chapter 2:

$$\overline{WCF} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} [a\, e^{-(bt)} + (1-a) e^{-(ct)}] e^{-\lambda t} dt \ , \tag{13.1}$$

where t_1 = 0, and t_2 = 0.01096 yr (4 days). The weathering coefficients listed in Table 13.4 are taken from Table 2.1 in Chapter 2.

TABLE 13.3 DSRs from the RESRAD-RDD Software

	DSR [mrem/(pCi/m^2)]				
	Early Phase	Intermediate phase		Second-year time frame	
Radionuclide	Results for Worker Spending 100% Time Outdoors	Results for Urban Resident (1st year)	Results for Rural Resident (1st year)	Results for Urban Resident (2nd year)	Results for Rural Resident (2nd year)
Cs-137	5.84E-07	1.49E-05	3.25E-05	8.77E-06	2.73E-05
Sr-90	6.28E-07	5.62E-06	9.01E-06	2.70E-06	7.36E-06
Pu-239	3.04E-04	6.02E-04	3.61E-04	1.47E-04	2.76E-04

TABLE 13.4 Weathering Coefficients for Different Surfaces

Surface	Mobile Fraction (a)	Shorter Half-Life (ln2/b), yr	Longer Half-Life (ln2/c), yr
Street (urban)	0.5	0.2	2
Soil (rural)	0.46	1.5	50
Roof	0.5	4	50
Exterior wall	0.2	0.2	20
Interior floor (urban)	0.5	0.2	2
Interior floor (rural)	0.46	1.5	50
Interior wall	0.2	0.2	20

The outdoor air concentration was calculated by considering the change of radionuclide concentration on the street surface over time, the change of resuspension factor over time, and the condition of vehicular traffic. Equations 2.3, 2.4, and 2.6 in Chapter 2 were used to calculate the outdoor air concentrations:

$$
\begin{aligned}
RF_0(t) &= 1.0E\text{-}06/t && \text{for } 1 < t < 1{,}000 \text{ days,} \\
&= 1.0E\text{-}06 && \text{for } t = 1 \text{ day,} \\
&= 1.0E\text{-}09 && \text{for } t \geq 1{,}000 \text{ days.}
\end{aligned}
\qquad (13.2)
$$

$$
\overline{WCF_s \times RF_o} = \frac{\int_{t_1}^{t_2} RF_o(t)[a\, e^{-(bt)} + (1-a)e^{-(ct)}]e^{-\lambda t}\, dt}{t_2 - t_1} \qquad (13.3)
$$

$$
C_o = C_s \times \overline{WCF_s \times RF_o} \times MF \ . \qquad (13.4)
$$

where C_O is the outdoor air concentration, C_S is the street/soil surface concentration, and MF is a modification factor to account for vehicular traffic. *MF*=10 for an urban setting.

The indoor air concentration (C_i) was calculated by using Equation 2.7 in Chapter 2:

$$
C_i = C_o \times SHF1 + C_{floor} \times RF_i \times \overline{WCF_{floor}} \ . \qquad (13.5)
$$

The dust filtration factor (*SHF*1) is 0.55. The indoor resuspension factor is 1E-06 m^{-1}.

Table 13.5 lists the average weathering correction factors calculated using Equation 13.1 for concentrations on different surfaces and the average correction factors calculated using Equation 13.3 for outdoor air. Table 13.6 lists the average concentrations in different media based on an outdoor ground surface concentration of 1 pCi/m^2 for each radionuclide.

TABLE 13.5 Average Weathering Correction Factors for the Early Phase

	Weathering Correction Factor (WCF) for 4 days					
Radionuclides	Streets	Exterior Walls	Roofs	Interior Floor	Interior Walls	Outdoor Air[a]
Cs-137	9.90E-01	9.96E-01	9.99E-01	9.99E-01	9.96E-01	5.92E-07
Pu-239	9.90E-01	9.96E-01	9.99E-01	9.99E-01	9.96E-01	5.92E-07
Sr-90	9.90E-01	9.96E-01	9.99E-01	9.99E-01	9.96E-01	5.92E-07

[a] Correction factors for outdoor air include consideration of resuspension (Equation 13.3).

The external pathway dose for individual radionuclide was calculated using Equation 2.5 in Chapter 2:

$$pathway\ dose_{ext,n,g} = C_s \times P_n \times \overline{WCF_n} \times OF_{n,g} \times SF_{n,g} \times GRC_{n,g} \times DCF_{n,g}\ , \qquad (13.6)$$

where:

P_n = partitioning factor;

n = index for media (1 and 6 for street/soil, 2 for roof, 3 for exterior walls, 4 for interior floor, and 5 for interior walls);

g = index for geometries;

$OF_{n,g}$ = occupancy factor (time fraction in a year);

$SF_{n,g}$ = shielding factor;

$GRC_{n,g}$ = ground roughness correction factor (0.82 for n = 1, 1 for n = 2 to 6); and

$DCF_{n,g}$ = external dose conversion factor (dose per unit exposure for 1 year from different contaminated media for receptor indoors and outdoors), (mrem/yr per pCi/m^2).

TABLE 13.6 Average Concentrations in Different Media for the Early Phase (Based on an Initial Outdoor Street Concentration of 1 pCi/m^2)

	Average Concentration for 4 days						
Radionuclide	Street (pCi/m^2)	Outdoor Air (pCi/m^3)	Exterior Walls (pCi/m^2)	Roofs (pCi/m^2)	Interior Walls[a] (pCi/m^2)	Interior Floor[a] (pCi/m^2)	Indoor Air (pCi/m^3)
Cs-137	9.90E-01	5.92E-06	4.98E-01	9.99E-01	0.00E+00	0.00E+00	3.26E-06
Pu-239	9.90E-01	5.92E-06	4.98E-01	9.99E-01	0.00E+00	0.00E+00	3.26E-06
Sr-90	9.90E-01	5.92E-06	4.98E-01	9.99E-01	0.00E+00	0.00E+00	3.26E-06

[a] The indoor contamination is not yet established in the early phase and is not included in dose calculation.

The DCF for the outdoor ground source was calculated for an area of 10,000 m^2 using RESRAD-BUILD. The values are 4.83E-5, 3.32E-8, and 9.55E-6 (mrem/yr)/(pCi/m^2) for Cs-137, Pu-239, and Sr-90, respectively. Therefore, the external DSRs are:

For Cs-137, $1 \times 1 \times 0.99 \times (4/365) \times 1 \times 0.82 \times 4.83\text{E-}05 = 4.29\text{E-}07$ mrem/(pCi/m^2).
for Pu-239, $1 \times 1 \times 0.99 \times (4/365) \times 1 \times 0.82 \times 3.32\text{E-}08 = 2.95\text{E-}10$ mrem/(pCi/m^2).
for Sr-90, $1 \times 1 \times 0.99 \times (4/365) \times 1 \times 0.82 \times 9.55\text{E-}06 = 8.50\text{E-}08$ mrem/(pCi/m^2).

The inhalation pathway dose for individual radionuclide while outdoors was calculated using Equation 2.8 in Chapter 2:

$$pathway\ dose_{inh-outdoor} = C_o \times OF_o \times IR_o \times DCF_{inh} \ . \tag{13.7}$$

The occupancy factor (OF_2) is the total time in hours spent outdoors. The inhalation rate is 1.2 m^3/h. The inhalation DCFs were taken from ICRP 72 (ICRP 1996); they are 1.44E-04, 4.44E-01, and 5.98E-04 mrem/pCi for Cs-137, Pu-239, and Sr-90, respectively. Therefore, the inhalation DSRs are:

For Cs-137, $5.92\text{E-}06 \times (4 \times 24) \times 1.2 \times 1.44\text{E-}04 = 9.82\text{E-}08$ mrem/(pCi/m^2).
For Pu-239, $5.92\text{E-}06 \times (4 \times 24) \times 1.2 \times 4.44\text{E-}01 = 3.03\text{E-}04$ mrem/(pCi/m^2).
For Sr-90, $5.92\text{E-}06 \times (4 \times 24) \times 1.2 \times 5.98\text{E-}04 = 4.08\text{E-}07$ mrem/(pCi/m^2).

The air submersion pathway dose while outdoors was calculated using Equation 2.10 in Chapter 2:

$$pathway\ dose_{sub-outdoor} = C_o \times OF_o \times DCF_{sub} \ . \tag{13.8}$$

The submersion DCFs were calculated using DCAL software (Eckerman et al. 2006); they are 2.98E-03, 4.08E-07, and 1.04E-04 (mrem/yr)/(pCi/m^3) for Cs-137, Pu-239, and Sr-90, respectively. Therefore, the submersion DSRs are:

For Cs-137, 5.92E-06 × (4/365) × 2.98E-03 = 1.93E-10 mrem/(pCi/m^2).
For Pu-239, 5.92E-06 × (4/365) × 4.08E-07 = 2.65E-14 mrem/(pCi/m^2).
For Sr-90, 5.92E-06 × (4/365) × 1.04E-04 = 6.75E-12 mrem/(pCi/m^2).

The dust ingestion pathway dose was calculated using Equation 2.12 in Chapter 2:

$$pathway\ dose_{ing} = C_s \times P \times WCF \times IngR \times OF \times DCF_{ing} \ . \tag{13.9}$$

The dust ingestion rate (*IngR*) is 1.25 × 10^{-5} m^2/h; the occupancy factor (*OF*) is the total time in hours spent outdoors. The ingestion DCFs were taken from FGR-11 (Eckerman et al. 1988); they are 4.81E-05, 9.25E-04, and 1.14E-04 mrem/pCi for Cs-137, Pu-239, and Sr-90, respectively. Therefore, the ingestion DSRs are:

For Cs-137, 1 × 1 × 0.99 × 1.25E-05 × (4 × 24) × 4.81E-05 = 5. 71E-08 mrem/(pCi/m^2).
For Pu-239, 1 × 1 × 0.99 × 1.25E-05 × (4 × 24) × 9.25E-04 = 1.10E-06 mrem/(pCi/m^2).
For Sr-90, 1 × 1 × 0.99 × 1.25E-05 × (4 × 24) × 1. 14E-04 = 1.35E-07 mrem/(pCi/m^2).

The total DSR is the sum of DSRs over exposure pathways. The total values for the three radionuclides are listed in Table 13.7, along with the component values from each exposure pathway. The total values are practically the same as those obtained by using Methods 1 and 2.

TABLE 13.7 DSRs (mrem per pCi/m^2) from Individual Exposure Pathways in the Early Phase

Radionuclide	External	Inhalation	Air Submersion	Dust Ingestion	Total
Cs-137	4.3E-07	9.8E-08	1.9E-10	5.7E-08	5.9E-07
Sr-90	8.5E-08	4.1E-07	6.8E-12	1.3E-07	6.3E-07
Pu-239	2.9E-10	3.0E-04	2.7E-14	1.1E-06	3.0E-04

13.2.8 DSR Calculations for the Intermediate Phase

The calculation of DSRs for the intermediate phase followed the procedure described for early phase, except that the time frame changed from 4 days to 1 year. The average weathering correction factors for different surfaces are listed in Table 13.8. Table 13.9 lists the average concentrations in different surfaces and in the indoor air and outdoor air for an urban environment. Table 13.10 lists the average concentrations in the same media for a rural environment.

External radiation comes from contaminants deposited on the ground surface when the receptor is outdoors. When the receptor is indoors, external radiation also comes from contaminants deposited on exterior walls, roof, interior floor, and interior walls. The indoor external DCFs for use in dose calculation depend on characteristics of the building. Table 13.11 lists the characteristics assumed for an urban apartment and a rural house. The indoor external DCFs for different contaminated surfaces were calculated using RESRAD-BUILD and are listed in Table 13.12.

The external pathway dose for individual radionuclide was calculated using Equation 13.6. The dose was calculated when the receptor was outdoors as well as when the receptor was indoors.

The inhalation pathway dose for individual radionuclide was calculated using Equation 13.7 while the receptor was outdoors. When the receptor was indoors, the inhalation pathway dose was calculated by using Equation 2.9 in Chapter 2:

$$pathway\ dose_{inh-indoor} = C_i \times OF_i \times IR_i \times DCF_{inh}\ . \tag{13.10}$$

The air submersion pathway dose for individual radionuclides was calculated using Equation 13.8 while the receptor was outdoors. When the receptor was indoors, the air submersion pathway dose was calculated by using Equation 2.11 in Chapter 2:

$$pathway\ dose_{sub-indoor} = C_i \times OF_i \times DCF_{sub}\ . \tag{13.11}$$

TABLE 13.8 Average Weathering Correction Factors for the Intermediate Phase

	Weathering Correction Factor (WCF) for First Year								
Radionuclides	Streets (urban setting)	Soil (rural setting)	Exterior Walls	Roofs	Interior Floor (urban setting)	Interior Floor (rural setting)	Interior Walls	Outdoor Air[a] (urban setting)	Outdoor Air[a] (rural setting)
Cs-137	5.57E-01	8.95E-01	8.33E-01	9.45E-01	5.57E-01	8.95E-01	8.33E-01	1.59E-08	1.83E-08
Pu-239	5.62E-01	9.05E-01	8.42E-01	9.56E-01	5.62E-01	9.05E-01	8.42E-01	1.60E-08	1.84E-08
Sr-90	5.57E-01	8.94E-01	8.33E-01	9.45E-01	5.57E-01	8.94E-01	8.33E-01	1.59E-08	1.83E-08

[a] Correction factors for outdoor air include consideration of resuspension.

TABLE 13.9 Average Concentrations in Different Media during the Intermediate Phase for an Urban Environment (Based on an Initial Outdoor Street Concentration of 1 pCi/m^2)

	Average Concentration for First Year (Urban Environment)							
Radionuclide	Street (pCi/m^2)	Outdoor Air (pCi/m^3)	Exterior Walls (pCi/m^2)	Roofs (pCi/m^2)	Interior Walls (pCi/m^2)	Interior Floor (pCi/m^2)	Indoor Air (from outdoor) (pCi/m^3)	Indoor Air (from floor) (pCi/m^3)
Cs-137	5.57E-01	1.59E-07	4.16E-01	9.45E-01	4.16E-02	5.57E-02	8.76E-08	5.57E-08
Pu-239	5.62E-01	1.60E-07	4.21E-01	9.56E-01	4.21E-02	5.62E-02	8.78E-08	5.62E-08
Sr-90	5.57E-01	1.59E-07	4.16E-01	9.45E-01	4.16E-02	5.57E-02	8.76E-08	5.57E-08

TABLE 13.10 Average Concentrations in Different Media during the Intermediate Phase for a Rural Environment (Based on an Initial Outdoor Soil Concentration of 1 pCi/m^2)

	Average Concentration for First Year (Soil Contamination)							
Radionuclide	Soil (pCi/m^2)	Outdoor Air (pCi/m^3)	Exterior Walls (pCi/m^2)	Roofs (pCi/m^2)	Interior Walls (pCi/m^2)	Interior Floor (pCi/m^2)	Indoor Air (from outdoor) (pCi/m^3)	Indoor Air (from floor) (pCi/m^3)
Cs-137	8.95E-01	1.83E-08	4.16E-01	9.45E-01	4.16E-02	8.95E-02	1.01E-08	8.95E-08
Pu-239	9.05E-01	1.84E-08	4.21E-01	9.56E-01	4.21E-02	9.05E-02	1.01E-08	9.05E-08
Sr-90	8.94E-01	1.83E-08	4.16E-01	9.45E-01	4.16E-02	8.94E-02	1.01E-08	8.94E-08

TABLE 13.11 Characteristics of Different Buildings Used in External Dose Calculations

Geometry	Shielding Factor	Floor Area (m^2)	Building Height (m)	Wall/roof Thickness (cm)	Building Material	Building Material Density (g/cm^3)
Rural house	0.4	36	2.4	3.5	Concrete	1
Urban apartment	0.2	100	2.4	10	Concrete	2.4

TABLE 13.12 External DCFs (mrem/yr)/(pCi/m^2) from Contaminants on Different Surfaces for an Indoor Receptor

	Rural House				Urban Apartment			
Radionuclide	Inside to Exterior Walls[a]	Inside to Roof[a]	Inside to Interior Walls	Inside to Interior Floor	Inside to Exterior Walls[a]	Inside to Roof[a]	Inside to Interior Walls	Inside to Interior Floor
Cs-137	8.33E-06	9.48E-06	9.91E-06	1.53E-05	2.52E-06	2.87E-06	6.38E-06	2.11E-05
Pu-239	8.92E-10	9.64E-10	1.05E-08	2.90E-08	1.28E-10	9.99E-11	3.19E-09	3.22E-08
Sr-90	6.93E-09	7.87E-09	1.97E-06	3.02E-06	1.07E-09	1.32E-09	1.27E-06	4.18E-06

[a] The DCFs for contaminants on exterior walls and roof have taken into account shielding from building materials.

The dust ingestion pathway dose for individual radionuclide was calculated by using Equation 13.9 while the receptor was both indoors and outdoors.

Tables 13.13 and 13.14 list the DSRs (mrem per pCi/m^2) from each individual pathway considered in dose calculation in an urban and rural environment, respectively. The last column of the tables lists the total DSRs; they are the same as the values obtained by using Methods 1 and 2.

13.2.9 DSR Calculations for the Second Year

Procedure and equations used to calculation DSRs for the second year time frame are the same as those used for the intermediate phase (i.e., first-year time frame). Therefore, they are not repeated here.

The average weathering correction factors for different surfaces are listed in Table 13.15. Table 13.16 lists the average concentrations in different surfaces and in the indoor air and outdoor air for an urban environment. Table 13.17 lists the average concentrations in the same media for a rural environment.

Tables 13.18 and 13.19 list the DSRs (mrem per pCi/m^2) from each individual pathway considered in dose calculation in an urban and rural environment, respectively. The last column of the tables lists the total DSRs; they are the same as the values obtained by using Method 1 or 2.

TABLE 13.13 DSRs from Individual Exposure Pathways for the Intermediate Phase in an Urban Setting

	DSR from Individual Exposure Pathways (mrem/yr per pCi/m^2 of Street Contamination)												
	External						Inhalation		Air Submersion		Dust Ingestion		
Radionuclide	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Outside	Inside	Outside	Inside	Total
Cs-137	6.99E-06	3.02E-06	7.18E-07	1.85E-06	1.82E-07	8.03E-07	7.65E-08	1.11E-07	1.50E-10	2.92E-10	9.29E-07	2.00E-07	1.49E-05
Pu-239	4.85E-09	2.09E-09	3.69E-11	6.53E-11	9.17E-11	1.24E-09	2.36E-04	3.45E-04	2.06E-14	4.02E-14	1.80E-05	3.89E-06	6.03E-04
Sr-90	1.38E-06	5.96E-07	3.03E-10	8.52E-10	3.60E-08	1.59E-07	3.17E-07	4.61E-07	5.25E-12	1.02E-11	2.19E-06	4.73E-07	5.62E-06

TABLE 13.14 DSRs from Individual Exposure Pathways for the Intermediate Phase in a Rural Setting

	DSR from Individual Exposure Pathways (mrem/yr per pCi/m^2 of Soil Contamination)												
	External						Inhalation		Air Submersion		Dust Ingestion		
Radionuclide	Soil, Outside	Soil, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Outside	Inside	Outside	Inside	Total
Cs-137	1.12E-05	9.69E-06	2.37E-06	6.12E-06	2.82E-07	9.35E-07	8.79E-09	7.74E-08	1.73E-11	2.03E-10	1.49E-06	3.22E-07	3.25E-05
Pu-239	0.00E+00	9.85E-09	3.76E-10	9.21E-10	4.42E-10	2.62E-09	0.00E+00	3.52E-04	0.00E+00	4.10E-14	0.00E+00	9.16E-06	3.61E-04
Sr-90	2.22E-06	1.91E-06	1.97E-09	5.08E-09	5.59E-08	1.84E-07	3.64E-08	3.20E-07	6.03E-13	7.07E-12	3.52E-06	7.60E-07	9.02E-06

TABLE 13.15 Average Weathering Correction Factors for the Second-Year Time Frame

	Weathering Correction Factor (WCF) for Second Year								
Radionuclides	Streets (urban setting)	Soil (rural setting)	Exterior Walls	Roofs	Interior Floor (urban setting)	Interior Floor (rural setting)	Interior Walls	Outdoor Air[a] (urban setting)	Outdoor Air[a] (rural setting)
Cs-137	2.93E-01	7.35E-01	7.35E-01	8.46E-01	2.93E-01	7.35E-01	7.35E-01	5.70E-10	1.41E-09
Pu-239	3.03E-01	7.61E-01	7.61E-01	8.76E-01	3.03E-01	7.61E-01	7.61E-01	5.89E-10	1.46E-09
Sr-90	2.93E-01	7.34E-01	7.35E-01	8.45E-01	2.93E-01	7.34E-01	7.35E-01	5.69E-10	1.41E-09

[a] Correction factors for outdoor air include consideration of resuspension.

TABLE 13.16 Average Concentrations in Different Media during the Second Year Time Frame for an Urban Environment (Based on an Initial Outdoor Street Concentration of 1 pCi/m^2)

	Average Concentration for Second Year (Urban Environment)							
Radionuclide	Street (pCi/m^2)	Outdoor Air (pCi/m^3)	Exterior Walls (pCi/m^2)	Roofs (pCi/m^2)	Interior Walls (pCi/m^2)	Interior Floor (pCi/m^2)	Indoor Air (from outdoor) (pCi/m^3)	Indoor Air (from floor) (pCi/m^3)
Cs-137	2.93E-01	5.70E-10	3.68E-01	8.46E-01	3.68E-02	2.93E-02	3.13E-10	3.68E-08
Pu-239	3.03E-01	5.89E-10	3.81E-01	8.76E-01	3.81E-02	3.03E-02	3.24E-10	3.81E-08
Sr-90	2.93E-01	5.69E-10	3.67E-01	8.45E-01	3.67E-02	2.93E-02	3.13E-10	3.67E-08

TABLE 13.17 Average Concentrations in Different Media during the Second-Year Time Frame for a Rural Environment (Based on an Initial Outdoor Soil Concentration of 1 pCi/m²)

	Average Concentration for Second Year (Rural Environment)							
Radionuclide	Soil (pCi/m²)	Outdoor Air (pCi/m³)	Exterior Walls (pCi/m²)	Roofs (pCi/m²)	Interior Walls (pCi/m²)	Interior Floor (pCi/m²)	Indoor Air (from outdoor) (pCi/m³)	Indoor Air (from floor) (pCi/m³)
Cs-137	7.35E-01	1.41E-09	3.68E-01	8.46E-01	3.68E-02	7.35E-02	7.76E-10	7.35E-08
Pu-239	7.61E-01	1.46E-09	3.81E-01	8.76E-01	3.81E-02	7.61E-02	8.02E-10	7.61E-08
Sr-90	7.34E-01	1.41E-09	3.67E-01	8.45E-01	3.67E-02	7.34E-02	7.75E-10	7.34E-08

TABLE 13.18 DSRs from Individual Exposure Pathways for the Second Year in an Urban Setting

	DSRs from Individual Exposure Pathways (mrem/yr per pCi/m² of Street Contamination)													
	External						Inhalation		Air Submersion		Dust Ingestion		
Radionuclide	Street, Outside	Street, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Outside	Inside	Outside	Inside	Total
Cs-137	3.68E-06	1.59E-06	6.34E-07	1.66E-06	1.60E-07	4.23E-07	2.74E-09	3.10E-08	5.38E-12	8.13E-11	4.89E-07	1.05E-07	8.77E-06
Pu-239	0.00E+00	1.65E-09	4.88E-11	8.75E-11	1.21E-10	9.76E-10	0.00E+00	1.45E-04	0.00E+00	1.68E-14	0.00E+00	3.07E-06	1.48E-04
Sr-90	7.26E-07	3.13E-07	2.68E-10	7.62E-10	3.18E-08	8.37E-08	1.13E-08	1.28E-07	1.87E-13	2.83E-12	1.15E-06	2.49E-07	2.70E-06

TABLE 13.19 DSRs from Individual Exposure Pathways for the Second Year in a Rural Setting

	DSRs from Individual Exposure Pathways (mrem/yr per pCi/m^2 of Soil Contamination)												
	External						Inhalation		Air Submersion		Dust Ingestion		
Radionuclide	Soil, Outside	Soil, Inside	Exterior Walls, Inside	Roof, Inside	Interior Walls, Inside	Interior Floor, Inside	Outside	Inside	Outside	Inside	Outside	Inside	Total
Cs-137	9.22E-06	7.96E-06	2.09E-06	5.48E-06	2.49E-07	7.68E-07	6.77E-10	5.78E-08	1.33E-12	1.51E-10	1.23E-06	2.65E-07	2.73E-05
Pu-239	0.00E+00	8.29E-09	3.40E-10	8.44E-10	3.99E-10	2.21E-09	0.00E+00	2.69E-04	0.00E+00	3.14E-14	0.00E+00	7.71E-06	2.77E-04
Sr-90	1.82E-06	1.57E-06	1.74E-09	4.54E-09	4.94E-08	1.51E-07	2.80E-09	2.39E-07	4.64E-14	5.27E-12	2.89E-06	6.24E-07	7.36E-06

13.3 QUESTION NO. 2 (PROPOSED BY OGT)

After an RDD event it was found that people live or work in the area needed to be relocated. However, permission may be granted for workers or residents to return to the area for retrieval of personal belongings or performing essential maintenance activities, as long as the duration is limited. Assuming the ground surface is contaminated with Am-241 of 25 μCi/m^2 and Sr-90 of 100 μCi/m^2, determine whether the following requests should be granted for:

1. A worker to return to perform outdoor maintenance activities for 8 hour per day for 10 days,

2. A worker to return to perform indoor maintenance activities for 8 hours per day for 12 days, and

3. A resident to return to retrieve personal belongings and spend 4 days inside a house.

13.4 SOLUTION TO QUESTION NO. 2

Three methods are used to solve this question. All three methods yield the same results. Method 1 uses the tabulated values listed in this report; Method 2 uses the RESRAD-RDD software; and Method 3 uses the methodology and equations described in this report. The approach and general assumptions listed in Solution to Question No. 1 also apply to Question No. 2. The additional assumptions and receptor-specific assumptions are described in the next section, followed by the solution using each method.

13.4.1 Additional Assumptions for Question No. 2

- The RDD was assumed to occur in an urban environment; however, because of relocation, vehicular traffic in the contaminated area would be limited. Therefore, the baseline resuspension factor (without the multiplication factor of 10) was used.

- To obtain the maximum exposure, the exposure was assumed to start from the first day and continued over the subsequent days after the ground surface concentrations were measured.

- Average concentrations for each day were used to estimate radiation doses.

- PAG = 500 mrem.

13.4.2 Specific Assumptions for Workers

- The building where the worker would perform maintenance activities is a warehouse with the characteristics listed in Table 2.4 in Chapter 2.

- For the worker performing outdoor maintenance activities, only outdoor exposure was considered. The inhalation rate for the outdoor worker was 1.6 m^3/h.

- For the worker performing indoor maintenance activities, only indoor exposure was considered. The inhalation rate for the indoor worker was assumed to be 1.2 m^3/h.

13.4.3 Specific Assumptions for Residents

- The building where the resident would incur radiation exposure is an urban apartment with the characteristics listed in Table 2.4 in Chapter 2 (also listed in Table 13.11).

- Only indoor exposure was considered. The inhalation rate for the resident was 1.2 m^3/h.

- The resident was assumed to spend 24 hours per day for 4 days inside the apartment.

13.4.4 General Solution Procedure and Methods

First, the dose to each receptor from each radionuclide was calculated for the given exposure situation. Then the doses from all radionuclides were added to get the total dose for each receptor. The total dose was compared with the PAG (500 mrem) to decide whether permission should be granted. As in solving Question No. 1, the calculations can be done by three methods:

Method 1: Using tables and figures in this report
Method 2: Using the RESRAD-RDD software
Method 3: Using the methodology/equations described in this report

All three methods provided the same results, as expected.

13.4.5 Method 1: Using Tables and Figures in This Report

Chapter 7 (Group D: Temporary Access to Relocation Areas for Essential Activities) of this report includes the data needed to solve this question. The allowable outside surface concentrations based on a dose of 500 mrem are listed in various tables and figures. The results for Am-241 and Sr-90 are listed in Table 13.20. Therefore, radiation doses to the three receptors can be calculated and compared with 500 mrem to determine whether the requests should be granted or not.

Case (a): The allowed outside ground surface concentration of individual radionuclides for a worker to perform outdoor maintenance activities for 8 hours per day for 10 days is 32.2 $\mu Ci/m^2$ for Am-241 and 2,440 $\mu Ci/m^2$ for Sr-90.

With given concentration of 25 $\mu Ci/m^2$ for Am-241 and 100 $\mu Ci/m^2$ for Sr-90, the total dose received = (25/32.2 + 100/2440)*500 = 409 mrem. That is, less than 500 mrem. Therefore, the *request should be granted for Case (a).*

TABLE 13.20 Allowable Concentrations Based on 500 mrem[a]

	Allowed Outside Surface Concentration (pCi/m^2)		
	Worker Outdoor (a)	Worker Indoor (b)	Resident Indoor (c)
Radionuclide	Figures 7.1 and 7.11	Table 7.4	Table 7.8
Am-241	3.22E7	4.77E7	2.86E7
Sr-90	2.44E9	9.11E9	7.70E9

[a] Obtained from Chapter 7 of this report.

Case (b): The allowed outside ground surface concentrations of individual radionuclides for a worker to perform indoor maintenance activities for 8 hours per day for 12 days are as follows (see Table 13.20):

Am-241: 47.7 $\mu Ci/m^2$ and Sr-90: 9110 $\mu Ci/m^2$

The total dose received = (25/47.7 + 100/9110)*500 = 268 mrem (i.e., less than 500 mrem). Therefore, the *request should be granted for Case (b)*.

Case (c): The allowed outside ground surface concentrations of individual radionuclides for a resident to retrieve personal belongings and spend 4 days inside a house are as follows (see Table 13.20):

Am-241: 28.6$\mu Ci/m^2$ and Sr-90: 7700 $\mu Ci/m^2$

The total dose received = (25/28.6 + 100/7700)*500 = 444 mrem (i.e., less than 500 mrem). Therefore, *the request should be granted for Case (c).*

13.4.6 Method 2: Using the RESRAD-RDD Software

Decisions can be made using the RESRAD-RDD software to determine whether requests for the three cases should be granted. Here are the steps to follow:

1. Open “RESRAD-RDD” software and press “START.”

2. For case (a), select “Group D” click on “View Guidelines” select “Guidelines vs. stay time figures – business access” select “Am-241 and Sr-90” click on “Show figures.” From the figures for Am-241 and Sr-90 find out the limiting concentration for access to business at stay time = 10 d for outdoor exposure.

3. For case (b), select “Group D” click on “View Guidelines” select “Operational guidelines for temporary access.” From Table 2 get the limiting concentration at stay time = 12 d for a worker for indoor exposure.

4. For case (c), select “Group D” click on “View Guidelines” select “Operational guidelines for temporary access.” From Table 4 get the limiting concentration at stay time = 4 d for a resident for indoor exposure.

The results obtained from the software are shown in Table 13.21.

These results are practically the same as those obtained using Method 1 (given in Table 13.20). Therefore, the conclusions using Method 2 are the same as those obtained using Method 1.

TABLE 13.21 Allowable Concentrations Based on 500 mrem Obtained from RESRAD-RDD Software

	Allowed Outside Surface Concentration (pCi/m^2)		
	Worker Outdoor (a)	Worker Indoor (b)	Resident Indoor (c)
Radionuclide	Limiting Concentration for Stay Time = 10 d	Limiting Concentration for Stay Time = 12 d	Limiting Concentration for Stay Time = 4 d
Am-241	3.2E7	4.77E7	2.86E7
Sr-90	2.4E9	9.11E9	7.70E9

13.4.7 Method 3: Using the Methodology/Equations Described in This Report

Calculation of radiation doses from the external radiation, inhalation, air submersion, and dust ingestion pathways followed the same procedure described in Method 3 for Question No. 1. First of all, the average weathering correction factors for different contamination surfaces and the average correction factors for outdoor air were calculated using Equations 13.1 and 13.3, respectively. Then the average concentrations in outdoor air and indoor air were calculated using Equations 13.4 and 13.5, respectively. After the average concentrations were obtained, calculation of radiation doses from the external radiation, inhalation, air submersion, and ingestion pathways were performed using Equations 13.6 through 13.11.

When calculating the average weathering correction factors and concentrations, instead of using three time periods of 4 days (t1=0, t2 =4 day), 10 days (t1=0, t2=10 day), and 12 days (t1=0, t2=12 day), to consider the three request cases separately, the day-to-day average values were calculated from day 1 up to day 12 (i.e., t1=0 and t2=1 day for day 1, t1=1 day and t2=2 day for day 2, t1=2 day and t2=3 day for day 3, etc). The application of Equations 13.6 through 13.11, with the daily average correction factors and concentrations, then resulted in daily doses. To consider the request in Case (a), daily doses from day 1 to day 10 were added; to consider the request in Case (b), daily doses from day 1 to day 12 were added; and to consider the request in Case (c), daily doses from day 1 to day 4 were added.

Tables 13.22 and 13.23 list the daily average concentrations for Am-241 and Sr-90, respectively, from day 1 to day 13. The daily average concentrations were based on an initial concentration of 1 pCi/m^2 on the street.

Characteristics of the warehouse where the worker would return to work were taken from Table 2.4 in Chapter 2, and these are listed in Table 13.24. Indoor external DCFs associated with the warehouse were calculated using RESRAD-BUILD, and these are listed in Table 13.25.

Table 13.26 lists the daily average DSRs per hour for Am-241 from different exposure pathways for a worker working outdoors. When summing the DSRs across different pathways, the daily total DSRs per hour of exposure were obtained, as listed in the last column of the table. When multiplying the DSRs by 8 (to account for 8 hours of exposure per day) and summing the products from day 1 to day 10, the total DSRs for 10-day period from each pathway were obtained (as shown in the last row of the table). Table 13.27 lists the daily average DSRs per hour for Sr-90 from different pathways for the same outdoor worker.

TABLE 13.22 Daily Average Concentrations for Am-241

Time (d)	Street (pCi/m^2)	Outdoor Air (pCi/m^3)	Exterior Walls (pCi/m^2)	Roofs (pCi/m^2)	Interior Walls (pCi/m^2)	Interior Floor (pCi/m^2)	Indoor Air (from Outdoor) (pCi/m^3)	Indoor Air (from Floor) (pCi/m^3)
1	9.97E-01	9.97E-07	5.00E-01	1.00E+00	5.00E-02	9.97E-02	5.49E-07	9.97E-08
2	9.92E-01	6.88E-07	4.99E-01	1.00E+00	4.99E-02	9.92E-02	3.78E-07	9.92E-08
3	9.87E-01	4.00E-07	4.98E-01	9.99E-01	4.98E-02	9.87E-02	2.20E-07	9.87E-08
4	9.82E-01	2.83E-07	4.97E-01	9.99E-01	4.97E-02	9.82E-02	1.55E-07	9.82E-08
5	9.77E-01	2.18E-07	4.96E-01	9.99E-01	4.96E-02	9.77E-02	1.20E-07	9.77E-08
6	9.72E-01	1.77E-07	4.95E-01	9.99E-01	4.95E-02	9.72E-02	9.75E-08	9.72E-08
7	9.67E-01	1.49E-07	4.94E-01	9.98E-01	4.94E-02	9.67E-02	8.20E-08	9.67E-08
8	9.62E-01	1.28E-07	4.93E-01	9.98E-01	4.93E-02	9.62E-02	7.07E-08	9.62E-08
9	9.57E-01	1.13E-07	4.92E-01	9.98E-01	4.92E-02	9.57E-02	6.20E-08	9.57E-08
10	9.52E-01	1.00E-07	4.91E-01	9.98E-01	4.91E-02	9.52E-02	5.52E-08	9.52E-08
11	9.48E-01	9.03E-08	4.90E-01	9.97E-01	4.90E-02	9.48E-02	4.97E-08	9.48E-08
12	9.43E-01	8.20E-08	4.89E-01	9.97E-01	4.89E-02	9.43E-02	4.51E-08	9.43E-08

TABLE 13.23 Daily Average Concentrations for Sr-90

Time (d)	Street (pCi/m^2)	Outdoor Air (pCi/m^3)	Exterior Walls (pCi/m^2)	Roofs (pCi/m^2)	Interior Walls (pCi/m^2)	Interior Floor (pCi/m^2)	Indoor Air (from Outdoor) (pCi/m^3)	Indoor Air (from Floor) (pCi/m^3)
1	9.97E-01	9.97E-07	4.99E-01	1.00E+00	4.99E-02	9.97E-02	5.49E-07	9.97E-08
2	9.92E-01	6.88E-07	4.98E-01	1.00E+00	4.98E-02	9.92E-02	3.78E-07	9.92E-08
3	9.87E-01	4.00E-07	4.97E-01	9.99E-01	4.97E-02	9.87E-02	2.20E-07	9.87E-08
4	9.82E-01	2.82E-07	4.96E-01	9.99E-01	4.96E-02	9.82E-02	1.55E-07	9.82E-08
5	9.77E-01	2.18E-07	4.96E-01	9.99E-01	4.96E-02	9.77E-02	1.20E-07	9.77E-08
6	9.72E-01	1.77E-07	4.95E-01	9.98E-01	4.95E-02	9.72E-02	9.74E-08	9.72E-08
7	9.67E-01	1.49E-07	4.94E-01	9.98E-01	4.94E-02	9.67E-02	8.20E-08	9.67E-08
8	9.62E-01	1.28E-07	4.93E-01	9.98E-01	4.93E-02	9.62E-02	7.06E-08	9.62E-08
9	9.57E-01	1.13E-07	4.92E-01	9.97E-01	4.92E-02	9.57E-02	6.20E-08	9.57E-08
10	9.52E-01	1.00E-07	4.91E-01	9.97E-01	4.91E-02	9.52E-02	5.52E-08	9.52E-08
11	9.47E-01	9.03E-08	4.90E-01	9.97E-01	4.90E-02	9.47E-02	4.96E-08	9.47E-08
12	9.42E-01	8.20E-08	4.89E-01	9.96E-01	4.89E-02	9.42E-02	4.51E-08	9.42E-08

Table 13.28 lists the daily average DSRs per hour for Am-241 from different exposure pathways for a worker working indoors. To consider the request in Case (b), the daily total DSRs from day 1 to day 12 were added. Table 13.29 lists the DSRs for Sr-90 for the same indoor worker.

TABLE 13.24 Characteristics of the Warehouse Used in External Dose Calculations

Geometry	Shielding Factor	Floor Area (m^2)	Building Height (m)	Wall/roof Thickness (cm)	Building Material	Building Material Density (g/cm^3)
Warehouse	0.2	900	3.7	10	Concrete	2.4

TABLE 13.25 External DCFs (mrem/yr)/(pCi/m^2) from Contaminants on Different Surfaces for an Indoor Receptor in a Warehouse

	Warehouse			
Radionuclide	Inside to Exterior Walls[a]	Inside to Roof[a]	Inside to Interior Walls	Inside to Interior Floor
Am-241	2.04E-10	1.55E-10	2.22E-07	2.13E-06
Sr-90	5.87E-10	1.31E-09	6.93E-07	6.75E-06

[a] The DCFs for contaminants on exterior walls and roof have taken into account shielding from building materials.

TABLE 13.26 Daily DSRs per Hour (mrem/hr per pCi/m^2) from Am-241 for Workers Accessing Business for Outdoor Maintenance Activities

	DSR from Individual Exposure Pathway (mrem/hr per pCi/m^2)				
Time (d)	External	Inhalation	Submersion	Ingestion of Dust	Total Hourly Dose for Outdoor Workers
1	2.54E-10	5.67E-07	9.01E-15	9.23E-09	5.76E-07
2	2.53E-10	3.91E-07	6.21E-15	9.18E-09	4.00E-07
3	2.51E-10	2.27E-07	3.61E-15	9.13E-09	2.37E-07
4	2.50E-10	1.61E-07	2.55E-15	9.08E-09	1.70E-07
5	2.49E-10	1.24E-07	1.97E-15	9.04E-09	1.33E-07
6	2.47E-10	1.01E-07	1.60E-15	8.99E-09	1.10E-07
7	2.46E-10	8.47E-08	1.35E-15	8.94E-09	9.39E-08
8	2.45E-10	7.30E-08	1.16E-15	8.90E-09	8.22E-08
9	2.44E-10	6.41E-08	1.02E-15	8.85E-09	7.32E-08
10	2.42E-10	5.70E-08	9.06E-16	8.81E-09	6.61E-08
Total dose 8 h/d for 10 days	1.98E-08	1.48E-05	2.35E-13	7.21E-07	1.55E-05

TABLE 13.27 Daily DSRs per Hour (mrem/hr per pCi/m^2) from Sr-90 for Workers Accessing Business for Outdoor Maintenance Activities

	DSR from Individual Exposure Pathway (mrem/hr per pCi/m^2)				
Time (d)	External	Inhalation	Submersion	Ingestion of Dust	Total Hourly Dose for Outdoor Workers
1	8.92E-10	9.54E-10	1.18E-14	1.42E-09	3.26E-09
2	8.87E-10	6.58E-10	8.17E-15	1.41E-09	2.95E-09
3	8.82E-10	3.83E-10	4.75E-15	1.40E-09	2.67E-09
4	8.78E-10	2.70E-10	3.35E-15	1.39E-09	2.54E-09
5	8.73E-10	2.08E-10	2.59E-15	1.39E-09	2.47E-09
6	8.69E-10	1.69E-10	2.10E-15	1.38E-09	2.42E-09
7	8.64E-10	1.42E-10	1.77E-15	1.37E-09	2.38E-09
8	8.60E-10	1.23E-10	1.52E-15	1.37E-09	2.35E-09
9	8.55E-10	1.08E-10	1.34E-15	1.36E-09	2.32E-09
10	8.51E-10	9.59E-11	1.19E-15	1.35E-09	2.30E-09
Total dose 8 h/d for 10 days	6.97E-08	2.49E-08	3.09E-13	1.11E-07	2.05E-07

Table 13.30 lists the daily average DSRs per hour for Am-241 from different exposure pathways for a resident staying inside an apartment. To consider the request in Case (c), the daily total DSRs from day 1 to day 4 were added. Table 13.31 lists the DSRs for Sr-90 for the same resident.

Table 13.32 summarizes the DSRs for Am-241 and Sr-90, calculated for the three receptors considered in Cases (a) to (c). The total dose each receptor would receive from exposure to the Am-241 and Sr-90 mixture (25 μCi/m^2 of Am-241 and 100 μCi/m^2 of Sr-90), if their requests were granted, is also listed in the table. The total dose for an outdoor worker spending 10 days in the contaminated area would not exceed 500 mrem; therefore, *permission should be granted for the request in Case (a)*. For an indoor worker spending 12 days in the contaminated area, the total dose would not exceed 500 mrem. Therefore, *permission for the request in Cases (b) should be granted*. For a resident spending 4 days inside a residence, the total dose would not exceed 500 mrem. Therefore, *permission for the request in Case (c) should also be granted.*

TABLE 13.28 Daily DSRs per Hour (mrem/hr per pCi/m^2) from Am-241 for Workers Accessing Business for Indoor Maintenance Activities

Time (d)	DSR from Individual Exposure Pathway (mrem/hr per pCi/m^2)								Total Hourly Dose for Indoor Workers
	External, Street	External, Exterior Walls	External, Roof	External, Interior Walls	External, Interior Floor	Inhalation	Submersion	Ingestion of Dust	
1	5.08E-11	1.16E-14	1.77E-14	1.27E-12	2.42E-11	2.76E-07	5.85E-15	9.23E-10	2.77E-07
2	5.05E-11	1.16E-14	1.77E-14	1.26E-12	2.41E-11	2.04E-07	4.31E-15	9.18E-10	2.05E-07
3	5.03E-11	1.16E-14	1.77E-14	1.26E-12	2.39E-11	1.36E-07	2.88E-15	9.13E-10	1.37E-07
4	5.00E-11	1.16E-14	1.76E-14	1.26E-12	2.38E-11	1.08E-07	2.29E-15	9.08E-10	1.09E-07
5	4.97E-11	1.15E-14	1.76E-14	1.26E-12	2.37E-11	9.28E-08	1.96E-15	9.04E-10	9.37E-08
6	4.95E-11	1.15E-14	1.76E-14	1.25E-12	2.36E-11	8.30E-08	1.76E-15	8.99E-10	8.39E-08
7	4.92E-11	1.15E-14	1.76E-14	1.25E-12	2.35E-11	7.62E-08	1.61E-15	8.94E-10	7.71E-08
8	4.90E-11	1.15E-14	1.76E-14	1.25E-12	2.33E-11	7.11E-08	1.51E-15	8.90E-10	7.21E-08
9	4.87E-11	1.15E-14	1.76E-14	1.25E-12	2.32E-11	6.72E-08	1.42E-15	8.85E-10	6.82E-08
10	4.85E-11	1.14E-14	1.76E-14	1.24E-12	2.31E-11	6.41E-08	1.36E-15	8.81E-10	6.51E-08
11	4.83E-11	1.14E-14	1.76E-14	1.24E-12	2.30E-11	6.16E-08	1.30E-15	8.76E-10	6.25E-08
12	4.80E-11	1.14E-14	1.76E-14	1.24E-12	2.29E-11	5.94E-08	1.26E-15	8.72E-10	6.04E-08
Total dose 8 h/d for 12 days	4.74E-09	1.11E-12	1.69E-12	1.20E-10	2.26E-09	1.04E-05	2.20E-13	8.61E-08	1.05E-05

TABLE 13.29 Daily DSRs per Hour (mrem/hr per pCi/m^2) from Sr-90 for Workers Accessing Business for Indoor Maintenance Activities

	DSR from Individual Exposure Pathway (mrem/hr per pCi/m^2)								
Time (d)	External, Street	External, Exterior Walls	External, Roof	External, Interior Walls	External, Interior Floor	Inhalation	Submersion	Ingestion of Dust	Total Hourly Dose for Indoor Workers
1	1.78E-10	3.35E-14	1.50E-13	3.95E-12	7.69E-11	4.65E-10	7.70E-15	1.42E-10	8.66E-10
2	1.77E-10	3.34E-14	1.49E-13	3.95E-12	7.64E-11	3.42E-10	5.67E-15	1.41E-10	7.41E-10
3	1.76E-10	3.34E-14	1.49E-13	3.94E-12	7.60E-11	2.29E-10	3.79E-15	1.40E-10	6.25E-10
4	1.76E-10	3.33E-14	1.49E-13	3.93E-12	7.57E-11	1.82E-10	3.01E-15	1.39E-10	5.77E-10
5	1.75E-10	3.32E-14	1.49E-13	3.92E-12	7.53E-11	1.56E-10	2.58E-15	1.39E-10	5.49E-10
6	1.74E-10	3.32E-14	1.49E-13	3.91E-12	7.49E-11	1.40E-10	2.31E-15	1.38E-10	5.30E-10
7	1.73E-10	3.31E-14	1.49E-13	3.91E-12	7.45E-11	1.28E-10	2.12E-15	1.37E-10	5.17E-10
8	1.72E-10	3.30E-14	1.49E-13	3.90E-12	7.41E-11	1.20E-10	1.98E-15	1.37E-10	5.06E-10
9	1.71E-10	3.30E-14	1.49E-13	3.89E-12	7.37E-11	1.13E-10	1.87E-15	1.36E-10	4.98E-10
10	1.70E-10	3.29E-14	1.49E-13	3.88E-12	7.33E-11	1.08E-10	1.78E-15	1.35E-10	4.91E-10
11	1.69E-10	3.28E-14	1.49E-13	3.88E-12	7.30E-11	1.04E-10	1.71E-15	1.34E-10	4.84E-10
12	1.68E-10	3.28E-14	1.49E-13	3.87E-12	7.26E-11	9.99E-11	1.65E-15	1.34E-10	4.79E-10
Total dose 8 h/d for 12 days	1.66E-08	3.18E-12	1.43E-11	3.75E-10	7.17E-09	1.75E-08	2.89E-13	1.32E-08	5.49E-08

TABLE 13.30 Daily DSRs per Hour (mrem/hr per pCi/m^2) from Am-241 for Residents Accessing Residence to Retrieve Personal Belongings

	DSR from Individual Exposure Pathway (mrem/hr per pCi/m^2)								
Time (d)	External, Street	External, Exterior Walls	External, Roof	External, Interior Walls	External, Interior Floor	Inhalation	Submersion	Ingestion of Dust	Total Hourly Dose for Indoor Residents
1	5.08E-11	2.17E-14	1.82E-14	2.25E-12	1.52E-11	2.76E-07	5.85E-15	9.23E-10	2.77E-07
2	5.05E-11	2.17E-14	1.82E-14	2.24E-12	1.51E-11	2.04E-07	4.31E-15	9.18E-10	2.05E-07
3	5.03E-11	2.16E-14	1.82E-14	2.24E-12	1.50E-11	1.36E-07	2.88E-15	9.13E-10	1.37E-07
4	5.00E-11	2.16E-14	1.82E-14	2.24E-12	1.50E-11	1.08E-07	2.29E-15	9.08E-10	1.09E-07
Total dose 24 h/d for 4 days	4.84E-09	2.08E-12	1.75E-12	2.15E-10	1.45E-09	1.74E-05	3.68E-13	8.79E-08	1.75E-05

TABLE 13.31 Daily DSRs per Hour (mrem/hr per pCi/m^2) from Sr-90 for Residents Accessing Residence to Retrieve Personal Belongings

	DSR from Individual Exposure Pathway (mrem/hr per pCi/m^2)								
Time (d)	External, Street	External, Exterior Walls	External, Roof	External, Interior Walls	External, Interior Floor	Inhalation	Submersion	Ingestion of Dust	Total Hourly Dose for Indoor Residents
1	1.78E-10	6.08E-14	1.51E-13	7.22E-12	4.76E-11	4.65E-10	7.70E-15	1.42E-10	8.40E-10
2	1.77E-10	6.07E-14	1.51E-13	7.21E-12	4.74E-11	3.42E-10	5.67E-15	1.41E-10	7.16E-10
3	1.76E-10	6.06E-14	1.51E-13	7.19E-12	4.71E-11	2.29E-10	3.79E-15	1.40E-10	6.00E-10
4	1.76E-10	6.05E-14	1.51E-13	7.18E-12	4.69E-11	1.82E-10	3.01E-15	1.39E-10	5.51E-10
Total dose 24 h/d for 4 days	1.70E-08	5.82E-12	1.45E-11	6.91E-10	4.54E-09	2.92E-08	4.84E-13	1.35E-08	6.50E-08

TABLE 13.32 Summary of DSRs for Individual Radionuclide and Total Doses for the Mixture for Use in Cases (a) to (c)

	DSR [mrem/(pCi/m^2)]		
Radionuclide	Outdoor Worker	Indoor Worker	Resident
Am-241	1.55E-05	1.05E-05	1.75E-05
Sr-90	2.05E-07	5.49E-08	6.50E-08
	Total Dose (mrem)		
Radionuclide	Outdoor Worker	Indoor Worker	Resident
Mixture	4.08E+02	2.68E+02	4.44E+02

13.5 REFERENCES

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14 ANALYSIS OF DIFFERENCES BETWEEN THE FRMAC AND OGT METHODS

A thorough analysis of the differences between the FRMAC and OGT methods was conducted in response to review comments provided by DOE's Emergency Response FRMAC Team on the draft version of this report. This chapter presents the results of that analysis, including (1) discussions of parameters/assumptions that contribute to the differences, and (2) changes in the OGT operational guidelines if the FRMAC parameters/assumptions were applied.

After the comparison analysis, the OGT team determined to modify some of the input parameters (breathing rate, resuspension factor, and ground roughness factor) to maintain consistency with the FRMAC default values and to reduce conservatism as commented by the DOE FRMAC team (e.g., the soil ingestion rate). In addition, the OGT team decided to adopt the ICRP 60 (ICRP 1991) based dose conversion factors (DCFs) as the default values for dose calculation. At the same time, the soil ingestion pathway that was not included in the FRMAC method was considered by the FRMAC team and is being added to its companion computer tool (Turbo FRMAC). The discussion and results presented in this chapter correspond to the OGT and FRMAC methods prior to the implementation of the above changes; whereas, the results presented in Chapters 1 through 10 and Chapter 13 were obtained after the implementation of these changes.

14.1 ASSUMPTIONS AND PARAMETERS

Differences in assumptions and parameters employed by the OGT and FRMAC methods to derive the operational guidelines/response levels were explored. The focus was on the potential radiation exposures of a resident living in a rural area (the C1-4 scenario in this report), which was selected by the DOE Emergency Response FRMAC Team for comparison with the FRMAC derived response levels and for commenting on the draft version of this report.

Table 14.1 lists the causes identified as contributing to the differences between the OGT operational guidelines and FRMAC derived response levels. These causes are discussed below:

TABLE 14.1 Comparison of Parameters Used for a Rural Resident Scenario

Parameter	OGT Method	FRMAC Method
Radiation source	Surface soil (10,000 m^2) and roof, exterior walls, interior walls, and floor of the residence	Surface soil (infinitely large)
Pathway	Considers exposure from ingestion of contaminated particulates	Ingestion of particulates is not included
DCFs	Same as FGR-11 values for internal radiation and on the basis of FGR-12 effective dose equivalents for external radiation	On the basis of ICRP 72 values (defaults are for adults) for internal radiation; for external radiation, the values are effective doses calculated on the basis of ICRP 60 methodologies
Weathering factor	46% of the deposited radionuclides in soil have a half-life of 1.5 years; the others have a half-life of 50 years	40% of the deposited radionuclides have a half-life of 1.505 years; the others have a half-life of 49.5 years
Outdoor air concentration	Calculated with a time-dependent resuspension factor multiplied by a time-dependent surface soil concentration, i.e., the initial surface soil concentration corrected for weathering	Calculated with a time-dependent resuspension factor multiplied by the initial surface soil concentration
Breathing rate	1.4 m^3/hr outdoors, 0.958 m^3/hr indoors[a]	22.2 m^3/d = 0.929 m^3/hr
Exposure time	16.4 hours indoors, 7.6 hours outdoors	24 hours outdoors
Roughness correction factor for external radiation	0.7[b]	0.82

[a] The OGT members decided to change the breathing rates to 0.9 m^3/hr indoors and 1.2 m^3/hr outdoors after responding to comments from the DOE Emergency Response FRMAC Team. The new breathing rates were developed by considering different activity patterns which, in principle, are consistent with the FRMAC methodology.

[b] After responding to comments from the DOE Emergency Response FRMAC Team, a new roughness correction factor of 0.82 was adopted by the OGT methodology.

1. The OGT method considers multiple radiation sources (outdoor soil, walls, floor, and roof). The FRMAC method only considers a single radiation source (outdoor soil). The size of the soil sources assumed are also different; the OGT method assumes an area of 10,000 m^2 while the FRMAC method considers an infinitely large area. This could result in a difference in the calculated doses by a factor of 2 or more.

2. The OGT method considers the soil/dust ingestion dose; the FRMAC method does not. Note that the FRMAC Manual (Sandia National Laboratories 2003) discussed the soil ingestion pathway and acknowledged that it could be significant for some radionuclides. Soil ingestion rates of 6E-04 m^2/day and 3E-04 m^2/day were suggested in the FRMAC Manual. The OGT method includes soil/dust ingestion and uses the higher soil/dust ingestion rate recommended in the FRMAC Manual as the default value. Soil ingestion is the major contributor to the differences in the derived operational guidelines/DRLs for those radionuclides with high ingestion DCFs (alpha and beta emitters). The difference could be a factor of 1.02 (for Co-60) to 940 (for Po-210). Based on comments from the DOE Emergency Response FRMAC Team that the soil ingestion rate of 2.5E-05 m^2/hr may be too conservative (and perhaps more appropriate for children), the OGT team decided to reduce the default soil ingestion rate by half to 1.25E-05 m^2/hr and use it for calculating adult exposures (both residents and workers).

3. The DCFs used in the calculations are different. The OGT method uses FGR-11 (Eckerman et al. 1988) numbers for internal radiation and is based on FGR-12 (Eckerman and Ryman 1993) numbers for external radiation. Both FGR-11 and FGR-12 numbers are ICRP 30 (ICRP 1982) based DCFs. Turbo FRMAC 2.0 (the computer code that implements the FRMAC methodology) has both ICRP 30 and ICRP 60 (ICRP 1991) based DCFs, but the default is ICRP 60 based DCFs. So the DRLs reported in the FRMAC comments are ICRP 60 based values. Tables 14.2 to 14.5 compare the DCFs used in the two methods with values obtained from other standard sources. For some radionuclides, the difference in DCFs can be a factor of 2 or more. The ICRP 60 DCFs are based on effective doses, whereas ICRP 30 DCFs are based on effective dose equivalents. ICRP 60 and ICRP 30 have very different tissue weighting factors. This difference results in very different external dose coefficients being calculated for beta emitters such as Sr-90+D. It should be noted that the ICRP 60 based DCFs have been added to the current RESRAD-RDD software as the default DCFs. Users have the option to select either ICRP 60 based DCFs or ICRP 30 based DCFs when using the RESRAD-RDD software.

TABLE 14.2 Comparison of Inhalation Dose Conversion Factors (DCFs)

	Inhalation (mrem/pCi)				
Radionuclide	OGT	FGR-11	ICRP-72 Adult	FRMAC	OGT/FRMAC
Am-241	4.44E-01	4.40E-01	3.55E-01	3.57E-01	1.23E+00
Cf-252	1.57E-01	1.57E-01	7.40E-02	1.37E-01	1.15E+00
Cm-244	2.48E-01	2.48E-01	2.11E-01	2.11E-01	1.18E+00
Co-60	2.19E-04	2.19E-04	1.15E-04	1.14E-04	1.92E+00
Cs-137[a,b]	3.19E-05	3.19E-05	1.44E-04	1.45E-04	2.20E-01
Ir-192	2.82E-05	2.82E-05	2.44E-05	2.45E-05	1.15E+00
Po-210	9.40E-03	9.40E-03	1.59E-02	1.58E-02	5.95E-01
Pu-238	3.92E-01	3.92E-01	4.07E-01	4.00E-01	9.80E-01
Pu-239	4.29E-01	4.29E-01	4.44E-01	4.40E-01	9.75E-01
Ra-226[a,c]	8.59E-03	8.59E-03	3.53E-02	3.52E-02	2.44E-01
Sr-90[a,d]	1.31E-03	1.31E-03	5.98E-04	5.87E-04	2.23E+00

[a] The values listed for Cs-137, Ra-226, and Sr-90 were calculated with the information on decay chains as described in footnotes b, c, and d.

[b] The DCFs for Cs-137 were calculated as Cs-137+ 0.946 × Ba-137m.

[c] For OGT, FGR-11, and ICRP-72 methods, the DCFs for Ra-226 were calculated as: Ra-226 + Rn-222 + Po-218 + 0.9998 × Pb-214 + Bi-214 + 0.9998 × Po-214 + 0.0002 × At-218 + 0.0002 × Tl-210. For the FRMAC method, the DCFs for Ra-226 were calculated as: Ra-226 + Rn-222 + Po-218 + 0.0002 × At-218, according to Turbo FRMAC.

[d] The DCFs for Sr-90 were calculated as Sr-90 + Y-90.

4. There are significant differences in the DCFs used for Ra-226. The short-lived progeny radionuclides included in Turbo FRMAC 2.0 are different from those included in the OGT method. It is noticed that in Turbo FRMAC 2.0, the short-lived progeny radionuclides displayed in the "Radionuclide Input" screen are different from those listed in the "Radionuclide Viewer" program. See footnote c of Table 14.3 regarding the short-lived progenies that are included in the calculation of DCFs.

5. The OGT methodology assumes that progenies with half-lives less than 30 days are in equilibrium with the parent radionuclide. For example, Y-90 is assumed to be in equilibrium with Sr-90, and Ba-137m is assumed to be in equilibrium with Cs-137. The cut-off half-life used by Turbo FRMAC 2.0 for secular equilibrium is not clear.

TABLE 14.3 Comparison of Ingestion Dose Conversion Factors (DCFs)

	Ingestion (mrem/pCi)				
Radionuclide	OGT	FGR-11	ICRP-72 Adult	FRMAC	OGT/FRMAC
Am-241	3.64E-03	3.64E-03	7.40E-04	7.55E-04	4.82E+00
Cf-252	1.08E-03	1.08E-03	3.33E-04	3.52E-04	3.07E+00
Cm-244	2.02E-03	2.02E-03	4.44E-04	4.55E-04	4.44E+00
Co-60	2.69E-05	2.69E-05	1.26E-05	1.27E-05	2.12E+00
Cs-137[a,b]	5.00E-05	5.00E-05	4.81E-05	5.03E-05	9.94E-01
Ir-192	5.74E-06	5.74E-06	5.18E-06	5.07E-06	1.13E+00
Po-210	1.90E-03	1.90E-03	4.44E-03	4.48E-03	4.24E-01
Pu-238	3.20E-03	3.20E-03	8.51E-04	8.44E-04	3.79E+00
Pu-239	3.54E-03	3.54E-03	9.25E-04	9.29E-04	3.81E+00
Ra-226[a,c]	1.32E-03	1.32E-03	1.04E-03	1.04E-03	1.27E+00
Sr-90[a,d]	1.53E-04	1.53E-04	1.14E-04	1.13E-04	1.35E+00

[a] The values listed for Cs-137, Ra-226, and Sr-90 were calculated with the information on decay chains as described in footnotes b, c, and d.

[b] The DCFs for Cs-137 were calculated as Cs-137+ 0.946 × Ba-137m.

[c] For OGT, FGR-11, and ICRP-72 methods, the DCFs for Ra-226 were calculated as: Ra-226 + Rn-222 + Po-218 + 0.9998 × Pb-214 + Bi-214 + 0.9998 × Po-214 + 0.0002 × At-218 + 0.0002 × Tl-210. For the FRMAC method, the DCFs for Ra-226 were calculated as: Ra-226 + Rn-222 + Po-218 + 0.0002 × At-218, according to Turbo FRMAC.

[d] The DCFs for Sr-90 were calculated as Sr-90 + Y-90.

6. The OGT method uses a breathing rate of 1.2 m^3/hr to calculate outdoor inhalation exposure and 0.96 m^3/hr to calculate indoor inhalation exposure, whereas the FRMAC method uses an average breathing rate of 0.93 m^3/hr to calculate inhalation exposure. Therefore, there is a factor of 1.1 to 1.3 difference for the inhalation dose component.

7. For the rural resident scenario, the OGT method assumes the receptor spends 7.6 hr/d outdoors and 16.4 hr/d indoors. The FRMAC method assumes all 24 hr/d are spent outdoors. The OGT method accounts for indoor contamination sources, whereas FRMAC does not consider indoor contamination directly.

TABLE 14.4 Comparison of External Dose Conversion Factors (DCFs)

	External (mrem/yr)/(pCi/cm^2)				
Radionuclide	OGT[a]	FGR-12 (h_E)[b]	FGR-12 (E)[c]	FRMAC	OGT/FRMAC
Am-241	3.69E-02	3.21E-02	2.72E-02	2.72E-02	1.36E+00
Cf-252	8.44E-04	8.43E-04	4.98E-01	6.12E-04	1.38E+00
Cm-244	3.99E-04	1.03E-03	7.51E-04	7.52E-04	5.31E-01
Co-60	2.04E+00	2.74E+00	2.69E+00	2.69E+00	7.58E-01
Cs-137[d,e]	4.91E-01	6.48E-01	6.42E-01	6.43E-01	7.64E-01
Ir-192	7.24E-01	9.38E-01	9.06E-01	9.07E-01	7.98E-01
Po-210	7.32E-06	9.68E-06	9.43E-06	9.45E-06	7.75E-01
Pu-238	1.01E-03	9.79E-04	7.31E-04	7.31E-04	1.38E+00
Pu-239	4.39E-04	4.29E-04	3.32E-04	3.32E-04	1.32E+00
Ra-226[d,f]	1.47E+00	1.94E+00	1.97E+00	7.60E-03	1.93E+02
Sr-90[d,g]	4.97E-03	6.54E-03	1.30E-01	1.30E-01	3.83E-02

[a] The external DCFs used in the OGT method were based on the FGR-12 numbers but with corrections for a finite size of 10,000 m^2.

[b] The values listed are the effective dose equivalents obtained from the FGR-12 report.

[c] The values listed are the effective doses calculated by DCAL (Eckerman et al. 2006), which was used to generate the FGR-12 values. The effective doses were calculated using the ICRP 60 methodology

[d] The values listed for Cs-137, Ra-226, and Sr-90 were calculated with the information on decay chains as described in footnotes e, f, and g.

[e] The DCFs for Cs-137 were calculated as Cs-137+ 0.946 × Ba-137m.

[f] For OGT, FGR-12 methods, the DCFs for Ra-226 were calculated as: Ra-226 + Rn-222 + Po-218 + 0.9998 × Pb-214 + Bi-214 + 0.9998 × Po-214 + 0.0002 × At-218 + 0.0002 × Tl-210. For the FRMAC method, the DCFs for Ra-226 were calculated as: Ra-226 + Rn-222 + Po-218 + 0.0002 × At-218, according to Turbo FRMAC.

[g] The DCFs for Sr-90 were calculated as Sr-90 + Y-90.

8. The Weathering Correction Factors used by the two methods are not identical. Turbo FRMAC 2.0 just recently added this correction. The FRMAC Manual (Sandia National Laboratories 2003) does not include this correction. The difference in the correction factors may cause about a factor of 1.2 differences in the dose results.

9. The OGT method calculates the outdoor air concentration by multiplying a time-dependent surface soil concentration, which is obtained by correcting the initial concentration for weathering, with a time-dependent resuspension factor. The FRMAC

TABLE 14.5 Comparison of Air Submersion Dose Conversion Factors (DCFs)

Radionuclide	Air Submersion (mrem/yr)/(pCi/m^3)				
	OGT	FGR-12 (h_E)[a]	FGR-12 (E)[b]	FRMAC	OGT/FRMAC
Am-241	9.57E-05	9.57E-05	7.91E-05	7.87E-05	1.22E+00
Cf-252	5.92E-07	5.92E-07	2.70E-03	4.24E-07	1.40E+00
Cm-244	5.74E-07	5.74E-07	3.97E-07	3.97E-07	1.45E+00
Co-60	1.47E-02	1.47E-02	1.39E-02	1.39E-02	1.06E+00
Cs-137[c,d]	3.19E-03	3.19E-03	2.98E-03	2.97E-03	1.07E+00
Ir-192	4.57E-03	4.57E-03	4.23E-03	4.22E-03	1.08E+00
Po-210	4.86E-08	4.86E-08	4.54E-08	4.54E-08	1.07E+00
Pu-238	5.71E-07	5.71E-07	4.10E-07	4.09E-07	1.40E+00
Pu-239	4.96E-07	4.96E-07	4.08E-07	4.06E-07	1.22E+00
Ra-226[c,e]	1.04E-02	1.04E-02	9.79E-03	3.53E-05	2.95E+02
Sr-90[c,f]	2.31E-05	2.31E-05	1.04E-04	1.04E-4	2.22E-01

[a] The values listed are the effective dose equivalents obtained from the FGR-12 report.

[b] The values listed are the effective doses calculated by DCAL (Eckerman et al. 2006), which was used to generate the FGR-12 values. The effective doses were calculated using the ICRP 60 methodology.

[c] The values listed for Cs-137, Ra-226, and Sr-90 were calculated with the information on decay chains as described in footnotes d, e, and f.

[d] The DCFs for Cs-137 were calculated as Cs-137+ 0.946 × Ba-137m.

[e] For OGT and FGR-12 methods, the DCFs for Ra-226 were calculated as: Ra-226 + Rn-222 + Po-218 + 0.9998 × Pb-214 + Bi-214 + 0.9998 × Po-214 + 0.0002 × At-218 + 0.0002 × Tl-210. For the FRMAC method, the DCFs for Ra-226 were calculated as: Ra-226 + Rn-222 + Po-218 + 0.0002 × At-218, according to Turbo FRMAC.

[f] The DCFs for Sr-90 were calculated as Sr-90 + Y-90.

method also uses a time-dependent resuspension factor to obtain the outdoor air concentration; however, it uses the initial surface soil concentration directly, without correction for weathering. The resuspension factor used by both methods reaches a flat value of 1×10^{-9} m^{-1} at 1,000 days. With the FRMAC method, the outdoor air concentration would stay constant after 1,000 days, regardless of the status of the soil concentration. According to the OGT method, the outdoor air concentration would decrease continuously over time and eventually reach zero when the soil source is completed diminished, either by radioactive decay, leaching, or other means of removal. This difference in correcting the soil concentration with the weathering correction factor is insignificant for the short term (early- to intermediate-phase of response), but for the long term, it may be significant if the soil weathering, leaching, and removal are significant (such as for low distribution coefficient sandy soils).

10. FRMAC uses a Dose to Exposure conversion factor of 0.699 mrem/mR and a ground roughness factor of 0.82 to correct external doses. The OGT method only uses a ground roughness factor of 0.7 to correct external doses. This may cause a difference by a factor of 1.2.

11. Other differences include the dust filtration factor and indoor shielding factor for external radiation. These parameters are needed by the OGT method because of the consideration of indoor exposures.

14.2 RESULTS

After all the causes that contribute to differences in the results were identified, the RESRAD-RDD code was used to simulate the FRMAC calculations by eliminating the causes of difference one by one. This was accomplished by using either the FRMAC parameter values or specific parameter values that reflect the FRMAC assumption. After all the causes of difference were eliminated, the RESRAD-RDD code produced operational guidelines that are in agreement with the FRMAC derived response levels within 4% differences.

Tables 14.6 and 14.7 show the comparison of the FRMAC results, the RESRAD-RDD results obtained with the OGT parameters/assumptions, and the RESRAD-RDD results obtained with parameter/assumptions simulating the FRMAC method.

TABLE 14.6 Comparison of the 1st Year Operational Guidelines (pCi/m^2) Illustrating Harmonization of OGT and FRMAC Methods by Utilizing FRMAC Default Parameter Values

		RESRAD-RDD Results								
Radionuclide	FRMAC Results	With Default OGT Parameters	With Modified OGT Parameters[a]	With Modified OGT Parameters[b]	With modified OGT parameters[c]	With Modified OGT Parameters[d]	With Modified OGT Parameters[e]	With Modified OGT Parameters[f]	With Modified OGT Parameters[g]	Ratio RESRAD-RDD Results with FRMAC Parameters/ FRMAC Results[h]
Am-241	3.50E+07	3.53E+06	6.97E+06	3.40E+07	3.05E+07	3.81E+07	3.62E+07	3.60E+07	3.51E+07	1.00E+00
Cf-252	9.90E+07	1.22E+07	2.52E+07	1.02E+08	9.12E+07	1.05E+08	1.01E+08	1.01E+08	9.82E+07	9.92E-01
Cm-244	6.20E+07	6.46E+06	1.28E+07	6.27E+07	5.61E+07	6.59E+07	6.34E+07	6.34E+07	6.19E+07	9.98E-01
Co-60	1.10E+07	1.77E+07	2.73E+07	2.79E+07	2.76E+07	2.09E+07	1.23E+07	1.05E+07	1.05E+07	9.58E-01
Cs-137	4.20E+07	6.19E+07	9.41E+07	1.10E+08	1.09E+08	8.30E+07	4.90E+07	4.18E+07	4.18E+07	9.96E-01
Ir-192	1.00E+08	1.56E+08	2.46E+08	2.49E+08	2.48E+08	1.98E+08	1.17E+08	9.96E+07	9.96E+07	9.96E-01
Po-210	1.00E+09	2.79E+07	3.49E+07	1.98E+09	1.78E+09	1.06E+09	1.02E+09	1.02E+09	1.00E+09	1.00E+00
Pu-238	3.30E+07	4.03E+06	7.98E+06	3.95E+07	3.54E+07	3.47E+07	3.34E+07	3.34E+07	3.25E+07	9.85E-01
Pu-239	3.00E+07	3.65E+06	7.21E+06	3.61E+07	3.23E+07	3.15E+07	3.03E+07	3.03E+07	2.95E+07	9.85E-01
Ra-226	3.40E+08	1.04E+07	1.43E+07	3.57E+07	3.52E+07	3.72E+08	3.47E+08	3.42E+08	3.34E+08	9.83E-01
Sr-90	2.10E+08	1.58E+08	2.03E+08	5.68E+09	5.34E+09	4.04E+08	2.40E+08	2.05E+08	2.05E+08	9.77E-01

[a] Results were obtained with the OGT method by considering only the ground surface source.

[b] In addition to the consideration in footnote a, the ingestion of dust particle pathway was also suppressed.

[c] In addition to the considerations in footnote b, the FRMAC weathering coefficients for the ground surface source were used.

[d] In addition to the considerations in footnote c, the FRMAC dose conversion factors were used.

[e] In addition to the considerations in footnote d, the exposure was assumed to occur 100% outdoors with the FRMAC breathing rate.

[f] In addition to the considerations in footnote e, the FRMAC roughness correction factor was used.

[g] In addition to the considerations in footnote f, the outdoor air concentrations were obtained by multiplying the initial ground surface concentration, rather than the weathering-corrected ground surface concentration, with the resuspension factor.

[h] The ratios were obtained by dividing the results listed under “With Modified OGT Parameters[g]” with those listed under “FRMAC Results.”

TABLE 14.7 Comparison of the 2nd Year Operational Guidelines (pCi/m^2) Illustrating Harmonization of OGT and FRMAC Methods by Utilizing FRMAC Default Parameter Values

		RESRAD-RDD Results								
Radionuclide	FRMAC Results	With Default OGT Parameters	With Modified OGT Parameters[a]	With Modified OGT Parameters[b]	With Modified OGT Parameters[c]	With Modified OGT Parameters[d]	With Modified OGT Parameters[e]	With Modified OGT Parameters[f]	With Modified OGT Parameters[g]	Ratio RESRAD-RDD Results with FRMAC Parameters/ FRMAC Results[h]
Am-241	6.90E+07	1.16E+06	2.53E+06	8.77E+07	7.76E+07	9.80E+07	8.51E+07	8.15E+07	6.89E+07	9.98E-01
Cf-252	3.40E+08	5.28E+06	1.26E+07	4.44E+08	3.85E+08	4.43E+08	4.23E+08	4.22E+08	3.38E+08	9.94E-01
Cm-244	1.60E+08	2.20E+06	4.85E+06	2.07E+08	1.79E+08	2.09E+08	2.00E+08	2.00E+08	1.60E+08	9.98E-01
Co-60	3.50E+06	5.86E+06	9.27E+06	9.48E+06	9.13E+06	6.93E+06	4.09E+06	3.49E+06	3.49E+06	9.97E-01
Cs-137	1.20E+07	1.84E+07	2.86E+07	3.35E+07	3.23E+07	2.47E+07	1.46E+07	1.24E+07	1.24E+07	1.04E+00
Ir-192	8.90E+08	1.39E+09	2.26E+09	2.29E+09	2.22E+09	1.77E+09	1.05E+09	8.92E+08	8.92E+08	1.00E+00
Po-210	2.50E+10	5.27E+07	6.62E+07	6.24E+10	5.42E+10	3.23E+10	3.11E+10	3.10E+10	2.51E+10	1.01E+00
Pu-238	8.20E+07	1.33E+06	2.93E+06	1.25E+08	1.08E+08	1.06E+08	1.02E+08	1.02E+08	8.12E+07	9.90E-01
Pu-239	7.40E+07	1.19E+06	2.61E+06	1.13E+08	9.82E+07	9.58E+07	9.21E+07	9.21E+07	7.33E+07	9.91E-01
Ra-226	4.80E+08	3.06E+06	4.30E+06	1.08E+07	1.04E+07	7.53E+08	5.87E+08	5.41E+08	4.83E+08	1.01E+00
Sr-90	6.10E+07	4.87E+07	6.28E+07	3.05E+09	2.92E+09	1.22E+08	7.20E+07	6.15E+07	6.15E+07	1.01E+00

[a] Results were obtained with the OGT methodology by considering only the ground surface source.

[b] In addition to the consideration in footnote a, the ingestion of dust particle pathway was also suppressed.

[c] In addition to the considerations in footnote b, the FRMAC weathering coefficients for the ground surface source were used.

[d] In addition to the considerations in footnote c, the FRMAC dose conversion factors were used.

[e] In addition to the considerations in footnote d, the exposure was assumed to occur 100% outdoors with the FRMAC breathing rate.

[f] In addition to the considerations in footnote e, the FRMAC roughness correction factor was used.

[g] In addition to the considerations in footnote f, the outdoor air concentrations were obtained by multiplying the initial ground surface concentration, rather than the weathering-corrected ground surface concentration, with the resuspension factor.

[h] The ratios were obtained by dividing the results listed under "With Modified OGT Parameters[g]" with those listed under "FRMAC Results."

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