Residual Radioactive Contamination From Decommissioning

Technical Basis for Translating
Contamination Levels to Annual Dose

Draft Report for Comment

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ABSTRACT

This document describes the generic modeling of the total effective dose equivalent (TEDE) to an individual in a population from a unit concentration of residual radioactive contamination. Radioactive contamination inside buildings and soil contamination are considered. Unit concentration TEDE factors by radionuclide, exposure pathway, and exposure scenario are calculated. Reference radiation exposure scenarios are used to derive unit concentration TEDE factors for about 200 individual radionuclides and parent-daughter mixtures. For buildings, these unit concentration factors list the annual TEDE for volume and surface contamination situations. For soil, annual TEDE factors are presented for unit concentrations of radionuclides in soil during residential use of contaminated land and the TEDE per unit total inventory for potential use of drinking water from a ground-water source. Because of the generic treatment of potentially complex ground-water systems, the annual TEDE factors for drinking water for a given inventory may only indicate when additional site data or modeling sophistication are warranted. Descriptions are provided of the models, exposure pathways, exposure scenarios, parameter values, and assumptions used. An analysis of the potential annual TEDE resulting from reference mixtures of residual radionuclides is provided to demonstrate application of the TEDE factors.

FOREWORD

The following report was prepared at the request of the U.S. Nuclear Regulatory Commission (NRC) to provide a technical basis for calculating the residual radioactive contamination limits allowable for the unrestricted release of decommissioned facilities. The conversion factors and annual doses contained in the report are not intended for uses beyond the scope of this report, and accordingly, should not be applied to other circumstances. Even within the proper scope of decommissioning, it is emphasized that external dose rates should be determined from actual survey measurements, wherever practical, rather than calculating the dose rates from the models used in this report.

This report is now published in draft to afford the benefit of comments from a broad spectrum of readers. After responding to the comments, the report will be re-issued as a final report. In the interim, the NRC staff will use the report as a technical basis document. Publication of this report will be followed by a companion document for use in implementation of the Commission Policy Statement on Exemptions from Regulatory Control. The NRC staff expects that the radionuclide-specific values that correspond to the individual dose criterion of the policy statement will serve as the basis for future decommissioning decisions. As such, these values would replace the values in Option 1 of the NRC Office of Nuclear Material Safety and Safeguards, Branch Technical Position (Federal Register, Vol. 46, No. 205, October 23, 1981, pp. 52061-3) and the numerical values contained in Regulatory Guide 1.86. Thus, this technical basis report serves as the foundation for the revised decommissioning criteria.

Comments on this report will be accepted for 90 days after publication and should be directed to:

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U.S. Nuclear Regulatory Commission

EXECUTIVE SUMMARY

This document describes a generic method for evaluating conditions of unrestricted release of slightly radioactive material in buildings and soil following decommissioning of licensed facilities. The generic evaluation utilizes a radiation exposure scenario analysis that addresses the major exposure pathways of direct exposure to penetrating radiation, inhalation, and ingestion. The result of the evaluation is the total effective dose equivalent (TEDE) to an average individual in a population group exposed to a unit concentration of residual radioactive material after decommissioning. Unit concentration TEDE factors are provided for each exposure pathway and scenario for about 200 individual radionuclides, including key parent-daughter chains. For long-lived parents with short-lived daughters, and for decay chains in equilibrium, the factors are presented in terms of activity of the total parent-daughter mixture. Additional values for the parents and daughters are listed separately so that the annual TEDE can be estimated for non-equilibrium cases.

The annual TEDE resulting from a specific concentration of a radionuclide or mixture of radionuclides can be estimated using the unit concentration TEDE factors provided in this document. The input parameters for each exposure pathway and scenario were selected to provide a reasonable (not worst case) estimate of the likely radiation dose to an average individual in a limited population group exposed to residual radioactive contamination. However, the TEDE factors are still thought to produce overestimates of the potential dose an average individual in the general public (not a limited population group) may receive. Whenever practical, external dose rates determined from actual survey measurements, instead of the results from generic modeling, should be used when estimating the external radiation doses resulting from the conditions found at specific sites.

For unrestricted release of buildings, two sets of generically derived unit concentration annual TEDE factors are provided. They include a set of factors for building renovation (accounting for volume sources), relating the TEDE mrem per pCi/g (or μSv per Bq/g), and a set of factors for building occupancy (accounting for surface sources), relating the TEDE in mrem per dpm/100 cm² (or μSv per Bq/100 cm²) of surface activity. Each of the derived sets of annual TEDE factors for buildings is developed in a manner designed to independently describe a specific situation (i.e., volume or surface contamination). The resulting unit concentration annual TEDE factors are listed by radionuclide and exposure pathway. Modifications can be made to the scenario assumptions, including the exposure durations, ingestion rates, or air concentrations to account for site-specific conditions.

For unrestricted use of land, residual radioactive soil contamination may be described in a thin or thick soil layer, on the surface or stabilized under a clean soil layer, over a large or small area, and may consist of many different radionuclides or mixtures of radionuclides. The derived unit soil concentration annual TEDE factors provided in this document, in units of mrem per pCi/g (or μSv per Bq/g) of soil, relate to surface soils and are based on

a residential use scenario that considers a combination of the following pathways: inhalation, external exposure, and agricultural food product ingestion. Additional annual TEDE factors related to potential ingestion of contaminated drinking water are also provided. These factors account for the potential effect of the total radionuclide inventory at the site, in the soil or in building materials left onsite that potentially may be demolished and disposed of as buried rubble. Because of the generic treatment of potentially complex ground-water systems, the annual TEDE for the drinking water scenario for a given inventory may only indicate when additional site data or more sophisticated modeling are warranted. Modifications can be made to the TEDE factors to account for contaminated soil that is isolated from the surface by a layer of clean soil or overburden, or to account for site-specific ground-water conditions.

Example calculations are provided using the annual TEDE factors. Example TEDE values are calculated for representative mixtures and quantities of radionuclides associated with radiopharmaceutical/industrial-source manufacturing plants, uranium fuel fabrication facilities, depleted and enriched uranium sources, and light-water power reactors. The examples consider residual radioactive contamination in both buildings and soils. Finally, a summary discussion of the scenario pathway analysis and the resulting unit concentration annual TEDE factors is provided.

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1.0 INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) is considering an expansion of its current criteria governing the release of slightly radioactive property for unrestricted use. Current NRC staff criteria are in two forms: 1) acceptable volumetric concentrations of source material contamination in soil, provided in pCi/g (Federal Register 1981), and 2) acceptable levels of surface contamination, provided in units of dpm/100 cm² for average, maximum, and removable contamination conditions (NRC 1974). Both of these NRC staff criteria for release of slightly radioactive material have limitations. The criteria for volumetric concentrations in soil, for instance, are limited to the uranium and thorium chain of radionuclides and are only applicable to current contamination resulting from past operations. The NRC staff criteria governing surface contamination, although appropriate for all radionuclides, are often difficult to apply because of the wide variation in surface and volumetric contamination conditions and the varying mixture of radionuclides usually found in many licensed facilities. In addition, the values found in both sets of criteria are not consistent with the revised dosimetry system recommended by the International Commission on Radiological Protection (ICRP) in Publications 26 (1977) and 30 (1979-1988).

To ensure a uniform approach and consistent regulatory decisions, therefore, comprehensive guidance needs to be developed to include release criteria for radioactive contamination found within soil, structures, materials, and equipment. Initial guidance developed by the NRC will cover the unrestricted release of buildings and land; future NRC efforts will be devoted to developing a system for releasing contaminated tools and equipment and recycling other materials. All of this new guidance is being developed in terms of radiation dose and will be consistent with the revised dose system recommended by the ICRP.

As a contribution to the development of revised guidance by the NRC, this document provides information on the generic pathway model used to derive the potential total effective dose equivalent (TEDE)^(a) to an average individual in a given population group from unit radionuclide concentrations of residual contamination. The methodology used to calculate doses from unit concentrations of radionuclides is consistent with the recommendations of the ICRP in Publication No. 30 (1979-1988). The input parameters for each exposure pathway and scenario are selected to provide a reasonable estimate of the likely radiation dose to an average individual in a limited population exposed to residual contamination in buildings or soil. They are not selected to perform a worst case (overly conservative) analysis of the potential radiation dose, and do not represent the average dose to all members of the public. Still, the resulting annual TEDE factors likely provide an overestimate of the actual dose that individuals may receive. The models, pathways, scenarios, and parameters given here can be modified and used to develop screening values for the release of buildings and soils.

(a) As defined in Appendix E--Glossary.

They should also be useful in determining when more detailed site-specific assessments or modifications to the generic scenarios are required.

Two sets of derived unit concentration annual TEDE factors for residual radioactive materials in buildings are needed to adequately describe the potential contamination conditions found at actual facilities. These include derived unit concentration annual TEDE factors accounting for: 1) building renovation (subsurface or volume sources), and 2) normal building occupancy (thin layer and removable surface contamination). For building renovation (volume sources), the derived unit concentration annual TEDE factors, in mrem per pCi/g (and μSv per Bq/g), account for residual contamination contained within walls or floors. Estimates of the subsurface inventory are important to account for residual inventories of difficult-to-measure alpha-emitters or beta-emitters. The set of building occupancy (surface activity) TEDE factors (in units of mrem per dpm/100 cm^2 and μSv per Bq/100 cm^2) is intended to model the situation where the residual inventory is present as a thin layer of fixed and removable surface contamination.

The two sets of generically derived annual TEDE factors for soil contained in this document may be applied to contaminated surface soil conditions and total inventory conditions that lead to potential drinking-water contamination. Methods are also provided to modify the factors to account for dilution by clean overburden soil, modified dietary intakes, modified air concentrations, and more sophisticated ground-water modeling efforts. The derived unit concentration annual TEDE factors for soil are in units of mrem per pCi/g (and μSv per Bq/g) of surface soil, and the inventory factors are in units of mrem per pCi (and μSv per Bq) for the total inventory through the potential pathway of drinking contaminated ground water. Maximum organ-specific dose conversion factors are also provided (using ICRP 30 methods) for the drinking water ingestion pathway to permit a rough comparison with current drinking water standards.

As a demonstration of the use of the derived unit concentration annual TEDE factors, example TEDEs are calculated for representative mixtures and quantities for selected reference licensed facilities. For these calculations, annual TEDEs for residual contamination in both buildings and soil are included. The reference facilities considered include a light-water power reactor, an industrial source and radiopharmaceutical manufacturing facility, a uranium fuel fabrication facility, and reference depleted and enriched uranium sources. Finally, a discussion of the information contained in this document is provided.

2.0 MODELING APPROACH

A radiation exposure pathway analysis is required before calculation of the annual TEDE factors describing exposure to residual radioactivity present at the time of unrestricted release of decommissioned buildings and land. In this analysis, computerized models are used with radiation exposure scenarios that describe conditions that may exist after the release of buildings or land for unrestricted use. This section discusses the computerized models, the equations used to describe the significant radiation exposure pathways, and the calculated dose conversion or committed effective dose conversion factors for those exposure pathways. The pathway dose rate conversion factors are used to develop the scenario-specific annual TEDE factors discussed in Section 3.0. Additional information on a sensitivity study for determining external exposure dose rate conversion factors and more detailed descriptions of modeling other exposure pathways are found in Appendixes A and B, respectively.

2.1 DESCRIPTION OF REFERENCE METHODS

This section describes the computerized model used in calculating unit-concentration pathway dose conversion factors. Dosimetric information for the reference (adult) man, as described by the ICRP (1975), was used in all calculations. After an initial review of existing radiation pathway analysis models, the ONSITE/MAXI1 (Kennedy et al. 1987) computer program was initially selected because of its flexibility in allowing the user to define various exposure scenarios. This flexibility extends to scenarios describing exposures within structures and to user-defined scenarios. During the development of this report, the capabilities of the ONSITE/MAXI1 computer program were included as part of a newer computerized model, the GENII software package (Napier et al. 1988). The GENII software is designed for estimating individual and population doses from releases of radionuclides to air, water, or soil and includes an enhanced user-defined scenario capability. The software package was developed and documented under a strict quality assurance (QA) program based on the American National Standards Institute (ANSI) standard NQA-1 (ASME 1986). All steps of the code development have been extensively tested. The tests have included comparison of results generated by hand calculations and other computer software. Hand calculation worksheets are provided in Volume 3 of the documentation (Napier et al. 1988). These worksheets were used to benchmark the code output to other environmental dosimetry programs, including ONSITE/MAXI1. A 10-volume set of test documentation is available for review from the authors, upon request. During development, the program was reviewed by an external peer-review panel of national and international environmental health physicists with pathway modeling experience. Following this review, the code was placed under configuration management providing for change control and documentation updates to all identified users.

The GENII software is described in three volumes of documentation (Napier et al. 1988). The first volume describes the theoretical considerations of the system, including conceptual diagrams, mathematical

representations of the solutions. Descriptions of the solution techniques are also included, where appropriate. The second volume is a user manual, which provides code structure, user instructions, required system configurations, and topics related to QA. The third volume is a code maintenance manual for the user who may require knowledge of the code details, including code logic diagrams, global dictionary, worksheets, example hand calculations, and listings of the code and its associated data libraries.

The GENII software includes modules for calculating environmental transport and dilution of and/or accumulation of radionuclides in environmental media, external radiation dose rate factors for various source geometries, and internal radiation dose rate factors for inhalation and ingestion exposures consistent with those recommended by the ICRP (1979-1988). The software package comprises several computer programs and data libraries. The computer programs fall into three categories: user interface (i.e., interactive menu-driven program to assist the user with scenario generation), internal and external dose factor generators, and the environmental dosimetry programs. APPRENTICE is the user interface for the short-term environmental dosimetry programs. INDIF and EXTDF are programs that generate internal and external dose rate factors, respectively. For maximum flexibility, the short-term environmental dosimetry portion has been divided into three interrelated but separate programs (ENVIN, ENV, and DOSE) that handle input organization and checking, environmental exposure, and dose calculations, respectively. The software package can be used for routine or accidental releases, or for exposures to contaminated surface soil or subsoil. It also permits the user to define scenario conditions that can be used to model exposures in structures after their unrestricted release.

2.2 EXPOSURE PATHWAY ANALYSIS

The potential routes through which people may be exposed to radiation or radionuclides are called exposure pathways. A collection of exposure pathways, with specific modeling assumptions, are used to construct radiation exposure scenarios. These scenarios are designed to be conceptual models of potential patterns of human activity (actions, events, and other processes) that result in radiation exposures to individuals or groups of people.

The exposure pathways considered for buildings include:

- direct external exposure to penetrating radiation
- inhalation of airborne materials
- secondary ingestion.

The exposure pathways considered for residual radioactivity in soil include:

- direct external exposure to penetrating radiation
- inhalation of airborne materials
- ingestion of agricultural food products grown in contaminated soil
- ingestion of drinking water from a ground-water source.

This section describes the mathematical equations and parameters necessary to calculate radiation dose conversion factors for each of the major exposure pathways. Listings by radionuclide are provided of the pathway-specific dose conversion or committed effective dose conversion factors used to construct scenario-specific TEDE factors. Daughters with half-lives less than 10 minutes are always assumed to be in equilibrium with their parent and are referred to as implicit daughters. Because the pathway-specific dose conversion or committed effective dose conversion factors are based on unit activity, it is important to note that the unit activity includes contributions from both the parent and implicit daughters. To accomplish this, a +I notation for the radionuclide listings and an appropriate footnote are included with all dose factor tables. Daughters with half-lives greater than 10 minutes that may not be in equilibrium with their parents are referred to as explicit daughters. These are shown in equilibrium conditions with the parent by a +D listing and footnote in the dose factor tables. Separate values are also included for parents and daughters so that values for non-equilibrium cases can be determined. For cases where there is a short-lived parent with a long-lived daughter, separate listings for parent and daughter are included so that any initial ratio may be evaluated. Finally, for decay chains, the listings include parents alone, parents with +D and +I notations (to include both implicit and explicit daughters) and daughters alone so that equilibrium and non-equilibrium cases can be considered. This notation is used consistently in this document to provide maximum flexibility for consideration of all parent-daughter and decay chain situations. The dose factor and annual TEDE listings contain over 200 entries for individual radionuclides and parent-daughter decay chains. For completeness, several short-lived radionuclides that are considered by the ICRP (1979-1988) are also considered in the listings in this document. A further description of chain decay and implicit and explicit daughters is found in Appendix D.

2.2.1 External Exposure To Penetrating Radiation

The first pathway considered is external exposure to direct penetrating radiation. The fundamental relationship for calculating radiation dose rates to people from any radionuclide in an exposure pathway is given in Equation 2.1 (Soldat, Robinson, and Baker 1974).

$$R_{ip} = C_{ip} U_p D_{ip} \quad (2.1)$$

where R_{ip} = the radiation dose equivalent or committed radiation dose equivalent from radionuclide i via exposure pathway p , in mrem (μ Sv) per year of exposure

C_{ip} = concentration of radionuclide i in the media of exposure in pathway p , in pCi/L (Bq/L) for water or milk, pCi/kg (Bq/kg) for food, pCi/m³ (Bq/m³) for air, pCi/g (Bq/g) for volume contamination in buildings and soil, and dpm/100 cm² (Bq/100 cm²) for surface contamination in buildings

U_p = usage parameter (exposure rate or intake rate) associated with exposure pathway p , in h/yr for external, L/yr for water or milk, or kg/yr for food

D_{ip} = dose rate equivalent factor or the committed effective dose equivalent factor for radionuclide i and exposure pathway p , used to convert the concentration and usage parameters to the radiation dose equivalent or to the committed effective dose equivalent, in mrem/pCi•h ($\mu\text{Sv/Bq}\cdot\text{h}$) for external and mrem/pCi ($\mu\text{Sv/Bq}$) for internal pathways.

For external exposure, U_p is given in units of h/yr and D_{ip} in mrem/pCi•h ($\mu\text{Sv/Bq}\cdot\text{h}$) or mrem/dpm•h/100 cm² ($\mu\text{Sv/Bq}\cdot\text{h}/100\text{cm}^2$). Preliminary studies, as discussed in Appendix A, determined that:

- for buildings with non-homogeneous distributions of source materials (i.e., higher concentrations on the floor than on the walls or ceiling), dose factors for an infinite flat plane provide an approximate solution over a wide variation of room volumes--for situations where the ceiling may be a significant source, the infinite flat plane conversion factors may be doubled to account for two-plane sources.
- for surface soils, the use of a large cylinder source solution, with an assumed radius of 5 m and a contamination depth of 15 cm (the assumed plow layer) will provide an adequate modeling basis for source areas greater than about 80 m². Although subsurface sources may be important, for this study the external exposure pathway dose rate factors are derived to represent a surface soil, volume source.

The external dose rate conversion factors are calculated using the GENII software package (Napier et al. 1988). They are given in terms of the deep dose equivalent (i.e., photon energies that penetrate to a depth of 1 cm of tissue) using the methods of Kocher (1981a). Table 2.1 shows external dose rate conversion factors for surface and volume sources in buildings and for a surface layer of soil to a depth of 15 cm (the approximate plow layer). For surface sources in buildings, the dose rate conversion factors are in units of mrem/h of exposure per dpm/100 cm² and $\mu\text{Sv/h}$ of exposure per Bq/100 cm². For volume sources in buildings or soils, the dose rate conversion factors are in units of mrem/h of exposure per pCi/g and $\mu\text{Sv/h}$ of exposure per Bq/g. These factors can be multiplied by the scenario-specific exposure duration (h/yr) and the initial activity level (dpm/100 cm², Bq/100 cm², pCi/g, or Bq/g) to obtain the annual external dose for a given exposure scenario.

External exposure rates for unit quantities of individual radionuclides are calculated considering contributions from electromagnetic radiation from gamma- and x-rays; bremsstrahlung from the slowing-down of beta particles, auger electrons, and conversion electrons; and annihilation radiation from positrons. Alpha particles are not calculated to contribute to the exposure rates. The source of the radionuclide data is the DRALIST file (Oak Ridge National Laboratory 1981), which was adapted for GENII by including implicit daughter energies with their parents. This is an extremely comprehensive list, containing most known radiations, including many with very low

frequencies of occurrence (e.g., a 0.8 MeV gamma ray from Po-210 which only occurs once in every 10^5 decays). Some radionuclides are pure alpha emitters (e.g. Sm-147). These nuclides will have a calculated exposure rate of zero. Some radionuclides are considered to have "no" emissions, but in actuality have very infrequent or very low-energy radiations. Examples of these types are Fe-55 or Ni-59, which usually decay via internal conversion. Each of these two radionuclides actually has a number of low-energy auger or internal conversion electrons, which may lead to low-energy bremsstrahlung, and also have a few very-low-energy gamma or x-rays associated with their decays. Bremsstrahlung is calculated as a function of the energy of the electron emitted, and the atomic number of the source matrix, using the procedure of the ISOSHLD shielding code (Engel, Greenborg, and Hendrickson 1966). This technique assigns a number and energy of emitted photons as a function of the electron energy. Energies less than 5 keV do not result in emitted photons. An example radionuclide with a beta particle emitted 100% of the time, but at a very low energy, is Re-187. The maximum beta energy per decay of Re-187 is 0.0026 keV, and thus no contribution from bremsstrahlung is included. For radionuclides which emit positrons, the energy of the annihilation gamma is treated as if the gamma were from any other source.

The ISOSHLD model works on 25 discrete energy groups, rather than individual energies. The lowest energy group is from 0.01 to 0.02 MeV (10 to 20 keV), with photon radiations of energies lower than this value lumped into the 0.01 to 0.02 MeV group. This tends to overestimate the resultant exposure rate, because the average energy of this group, 0.015 MeV, may over-represent the actual value for a given radionuclide. This procedure provides a conservative value of the dose response. However, for such radionuclides, even the overestimation will be a very small number, relative to those radionuclides with significant emissions.

Hand calculations were conducted for key radionuclides, including ^{60}Co , ^{137}Cs , ^{152}Eu , and ^{154}Eu to compare with the external dose conversion factors used in other pathway analysis studies. The calculations consisted mainly of unit conversions. When compared to the data base used for surface contamination supporting 10 CFR 61 (Oztunali and Roles 1986), the values used in this study were lower by factors ranging from 2 to 3. For example, for ^{60}Co the 10 CFR 61 data base reported $2.14\text{E-}04$ and our value is $8.2\text{E-}05$ mrem/yr per pCi/m². For volume soil sources, the values used in this study were all very close to the 10 CFR 61 data, lower within a factor of 1.2 to 2. For example, for ^{60}Co the 10 CFR 61 data base reported $1.6\text{E-}05$ and our value is $1.3\text{E-}05$ mrem/yr per pCi/g. Other comparisons of the factors used in this study with the external exposure factors found in Regulatory Guide 1.109 (NRC 1977) were conducted and showed similar results: the external dose factors used in this study were consistently about a factor of 2 lower than the Regulatory Guide 1.109 values. For example, for ^{60}Co the Regulatory Guide 1.109 surface soil value was $1.7\text{E-}08$ and our value is $9.4\text{E-}09$ mrem/h per pCi/m². For completeness, surface values from Regulatory Guide 1.109 and the 10 CFR 61 data base were also compared. The results were within factors of 2, with the Regulatory Guide 1.109 values being lower. For example, for ^{60}Co Regulatory Guide 1.109 reported $1.7\text{E-}08$ and the data base for 10 CFR 61 reported $2.4\text{E-}08$ mrem/h per pCi/m². The results of these calculations show close agreement for all three data sets for this type of modeling analysis.

**TABLE 2.1. External Dose Rate Conversion Factors for
Exposure to Residual Radioactive Materials**

Radio-nuclide	Building Surface Sources		Building Volume Sources		Soil Volume Sources	
	mrem/h per dpm/100 cm ²	μSv/h per Bq/100 cm ²	mrem/h per pCi/g	μSv/h per Bq/g	mrem/h per pCi/g	μSv/h per Bq/g
³ H	2.4E-16	4.0E-17	1.0E-14	2.7E-12	1.1E-14	2.8E-12
¹⁰ Be	8.5E-11	1.4E-11	1.4E-08	3.8E-06	1.3E-07	3.6E-05
¹⁴ C	5.0E-12	8.4E-13	4.1E-10	1.1E-07	2.3E-09	6.1E-07
¹⁸ F	1.6E-07	2.7E-08	6.0E-05	1.6E-02	1.0E-03	2.7E-01
²² Na	3.6E-07	6.0E-08	1.4E-04	3.7E-02	2.1E-03	5.8E-01
²⁴ Na	6.7E-07	1.1E-07	2.7E-04	7.4E-02	4.1E-03	1.1E+00
³² P	7.7E-10	1.3E-10	2.3E-07	6.1E-05	2.9E-06	7.9E-04
³³ P	1.5E-11	2.5E-12	1.5E-09	4.1E-07	1.0E-08	2.8E-06
³⁵ S	5.7E-12	9.5E-13	4.8E-10	1.3E-07	2.7E-09	7.3E-07
³⁶ Cl	1.3E-10	2.2E-11	2.5E-08	6.9E-06	2.6E-07	7.1E-05
⁴⁰ K	2.7E-08	4.5E-09	1.1E-05	2.9E-03	1.6E-04	4.2E-02
⁴¹ Ca	3.2E-10	5.4E-11	1.4E-08	3.7E-06	1.4E-08	3.9E-06
⁴⁵ Ca	1.6E-11	2.6E-12	1.6E-09	4.3E-07	1.1E-08	2.9E-06
⁴⁶ Sc	3.6E-07	6.0E-08	1.4E-04	3.8E-02	2.0E-03	5.4E-01
⁵¹ Cr	6.7E-09	1.1E-09	2.2E-06	6.0E-04	3.5E-05	9.5E-03
⁵⁴ Mn	1.5E-07	2.5E-08	5.6E-05	1.5E-02	7.9E-04	2.1E-01
⁵⁶ Mn	2.9E-07	4.9E-08	1.2E-04	3.1E-02	1.7E-03	4.6E-01
⁵⁵ Fe	7.4E-10	1.2E-10	3.1E-08	8.5E-06	3.3E-08	8.8E-06
⁵⁹ Fe	1.9E-07	3.2E-08	7.5E-05	2.0E-02	1.1E-03	3.0E-01
⁵⁷ Co	2.4E-08	3.9E-09	6.8E-06	1.8E-03	7.6E-05	2.0E-02
⁵⁸ Co	1.7E-07	2.9E-08	6.6E-05	1.8E-02	9.6E-04	2.6E-01
⁶⁰ Co	4.2E-07	7.0E-08	1.7E-04	4.5E-02	2.4E-03	6.4E-01
⁵⁹ Ni	9.0E-10	1.5E-10	3.8E-08	1.0E-05	4.0E-08	1.1E-05
⁶³ Ni	4.0E-13	6.7E-14	2.0E-11	5.3E-09	5.7E-11	1.5E-08
⁶⁵ Ni	9.7E-08	1.6E-08	3.8E-05	1.0E-02	5.5E-04	1.5E-01
⁶⁴ Cu	3.1E-08	5.2E-09	1.1E-05	3.1E-03	1.9E-04	5.2E-02
⁶⁵ Zn	1.1E-07	1.8E-08	4.3E-05	1.2E-02	6.2E-04	1.7E-01

TABLE 2.1. External Dose Rate Conversion Factors for
Exposure to Residual Radioactive Materials (contd)

Radio- nuclide	Building Surface Sources		Building Volume Sources		Soil Volume Sources	
	mrem/h per dpm/100 cm ²	μSv/h per Bq/100 cm ²	mrem/h per pCi/g	μSv/h per Bq/g	mrem/h per pCi/g	μSv/h per Bq/g
^{69m} Zn+D (a)	3.7E-08	6.2E-09	1.4E-05	3.9E-03	2.4E-04	6.5E-02
^{69m} Zn	7.9E-08	1.3E-08	2.9E-05	7.9E-03	5.0E-04	1.3E-01
⁶⁹ Zn	2.2E-10	3.6E-11	4.6E-08	1.3E-05	5.0E-07	1.4E-04
⁷⁶ As	8.6E-08	1.4E-08	3.3E-05	8.8E-03	4.9E-04	1.3E-01
⁷⁶ Se	6.6E-08	1.1E-08	2.2E-05	5.9E-03	2.9E-04	7.9E-02
⁷⁹ Se	3.9E-12	6.5E-13	3.0E-10	8.2E-08	1.6E-09	4.3E-07
⁸² Br	4.8E-07	8.0E-08	1.9E-04	5.0E-02	2.7E-03	7.3E-01
⁸³ Br+D (a)	9.8E-10	1.6E-10	2.5E-07	6.7E-05	3.9E-06	1.0E-03
⁸³ Br	1.4E-09	2.3E-10	4.8E-07	1.3E-04	7.9E-06	2.1E-03
⁸⁴ Br	2.8E-07	4.7E-08	1.1E-04	3.1E-02	1.7E-03	4.7E-01
⁸⁶ Rb	1.6E-08	2.7E-09	6.3E-06	1.7E-03	9.2E-05	2.5E-02
⁸⁸ Rb	1.1E-07	1.9E-08	4.6E-05	1.2E-02	7.0E-04	1.9E-01
⁸⁹ Rb+D (a)	1.7E-07	2.8E-08	6.7E-05	1.8E-02	9.6E-04	2.6E-01
⁸⁹ Rb	3.4E-07	5.7E-08	1.4E-04	3.7E-02	2.0E-03	5.5E-01
⁸⁵ Sr	8.4E-08	1.4E-08	3.1E-05	8.3E-03	5.2E-04	1.4E-01
⁸⁹ Sr	6.4E-10	1.1E-10	1.7E-07	4.6E-05	2.1E-06	5.7E-04
⁹⁰ Sr+D (a)	7.8E-10	1.3E-10	2.2E-07	6.1E-05	3.0E-06	8.0E-04
⁹⁰ Sr	7.2E-11	1.2E-11	1.2E-08	3.2E-06	1.1E-07	2.9E-05
⁹¹ Sr+D (a)	6.8E-08	1.1E-08	2.7E-05	7.2E-03	4.1E-04	1.1E-01
⁹¹ Sr	1.2E-07	2.0E-08	4.5E-05	1.2E-02	6.7E-04	1.8E-01
⁹² Sr+D (a)	1.4E-07	2.4E-08	5.7E-05	1.5E-02	8.0E-04	2.2E-01
⁹² Sr	2.4E-07	4.0E-08	9.7E-05	2.6E-02	1.4E-03	3.8E-01
⁹⁰ Y	1.6E-09	2.6E-10	4.6E-07	1.2E-04	6.0E-06	1.6E-03
^{91m} Y+D (a)	5.4E-08	9.0E-09	2.1E-05	5.6E-03	3.1E-04	8.5E-02
^{91m} Y	1.1E-07	1.9E-08	4.2E-05	1.1E-02	6.4E-04	1.7E-01
⁹¹ Y	1.3E-09	2.2E-10	4.2E-07	1.1E-04	5.7E-06	1.5E-03
⁹² Y	5.0E-08	8.3E-09	1.9E-05	5.3E-03	2.9E-04	7.8E-02
⁹³ Y	1.8E-08	2.9E-09	6.6E-06	1.8E-03	9.7E-05	2.6E-02
⁹³ Zr+D (a)	1.7E-10	2.9E-11	7.5E-09	2.0E-06	7.7E-09	2.1E-06
⁹³ Zr	3.2E-13	5.3E-14	1.5E-11	4.1E-09	4.0E-11	1.1E-08
⁹⁵ Zr+D (a)	1.3E-07	2.2E-08	5.2E-05	1.4E-02	7.4E-04	2.0E-01
⁹⁵ Zr	1.3E-07	2.2E-08	5.0E-05	1.4E-02	7.3E-04	2.0E-01
⁹⁷ Zr+D (a)	8.7E-08	1.5E-08	3.3E-05	8.8E-03	5.0E-04	1.3E-01
⁹⁷ Zr	3.2E-08	5.4E-09	1.2E-05	3.4E-03	1.9E-04	5.0E-02
^{93m} Nb	3.6E-10	6.0E-11	1.5E-08	4.1E-06	1.6E-08	4.3E-06
⁹⁴ Nb	2.6E-07	4.4E-08	1.0E-04	2.7E-02	1.5E-03	4.0E-01

TABLE 2.1. External Dose Rate Conversion Factors for
Exposure to Residual Radioactive Materials (contd)

Radio- nuclide	Building Surface Sources		Building Volume Sources		Soil Volume Sources	
	mrem/h per dpm/100 cm ²	μSv/h per Bq/100 cm ²	mrem/h per pCi/g	μSv/h per Bq/g	mrem/h per pCi/g	μSv/h per Bq/g
^{95m} Nb+D (a)	8.0E-08	1.3E-08	2.9E-05	7.8E-03	4.0E-04	1.1E-01
^{95m} Nb	1.2E-08	2.0E-09	3.7E-06	1.0E-03	5.0E-05	1.3E-02
⁹⁵ Nb	1.5E-07	2.4E-08	5.6E-05	1.5E-02	7.9E-04	2.1E-01
^{97m} Nb+D (a)	1.1E-07	1.9E-08	4.3E-05	1.2E-02	6.5E-04	1.8E-01
^{97m} Nb	1.2E-07	1.9E-08	4.3E-05	1.2E-02	6.6E-04	1.8E-01
⁹⁷ Nb	1.2E-07	2.0E-08	4.5E-05	1.2E-02	6.8E-04	1.8E-01
⁹³ Mo+D (a)	1.0E-09	1.7E-10	4.3E-08	1.2E-05	4.5E-08	1.2E-05
⁹³ Mo	1.7E-09	2.9E-10	7.4E-08	2.0E-05	7.6E-08	2.1E-05
⁹⁹ Mo+D (a)	2.3E-08	3.8E-09	7.8E-06	2.1E-03	1.0E-04	2.8E-02
⁹⁹ Mo	2.6E-08	4.3E-09	9.5E-06	2.6E-03	1.4E-04	3.7E-02
^{99m} Tc	2.0E-08	3.4E-09	6.2E-06	1.7E-03	6.9E-05	1.9E-02
⁹⁹ Tc	1.9E-11	3.1E-12	2.1E-09	5.7E-07	1.5E-08	4.1E-06
¹⁰¹ Tc	6.6E-08	1.1E-08	2.4E-05	6.5E-03	3.8E-04	1.0E-01
¹⁰³ Ru+D (a)	4.1E-08	6.8E-09	1.5E-05	4.1E-03	2.5E-04	6.7E-02
¹⁰³ Ru	8.2E-08	1.4E-08	3.0E-05	8.2E-03	5.1E-04	1.4E-01
¹⁰⁵ Ru+D (a)	5.0E-08	8.3E-09	1.9E-05	5.1E-03	2.8E-04	7.7E-02
¹⁰⁵ Ru+I (b)	1.4E-07	2.4E-08	5.1E-05	1.4E-02	7.8E-04	2.1E-01
¹⁰⁶ Ru+I (b)	3.9E-08	6.6E-09	1.5E-05	3.9E-03	2.3E-04	6.2E-02
^{103m} Rh	6.1E-10	1.0E-10	2.7E-08	7.4E-06	1.0E-07	2.7E-05
¹⁰⁵ Rh	1.5E-08	2.5E-09	5.5E-06	1.5E-03	8.7E-05	2.4E-02
¹⁰³ Pd+D (a)	2.6E-09	4.3E-10	1.2E-07	3.3E-05	5.1E-07	1.4E-04
¹⁰³ Pd	4.7E-09	7.8E-10	2.1E-07	5.8E-05	9.5E-07	2.6E-04
¹⁰⁷ Pd	2.5E-14	4.1E-15	1.0E-12	2.8E-10	1.3E-12	3.4E-10
¹⁰⁹ Pd+I (b)	3.2E-09	5.3E-10	3.2E-07	8.7E-05	2.9E-06	7.9E-04
^{110m} Ag+I (b)	4.9E-07	8.1E-08	1.9E-04	5.1E-02	2.8E-03	7.5E-01
¹¹¹ Ag	5.0E-09	8.3E-10	1.8E-06	4.8E-04	2.7E-05	7.4E-03
¹⁰⁹ Cd	4.4E-09	7.4E-10	2.0E-07	5.3E-05	7.9E-07	2.1E-04
^{113m} Cd	8.1E-11	1.4E-11	1.4E-08	3.7E-06	1.3E-07	3.5E-05
^{115m} Cd+D (a)	2.2E-09	3.7E-10	8.0E-07	2.2E-04	1.2E-05	3.3E-03
^{115m} Cd	4.6E-09	7.7E-10	1.7E-06	4.6E-04	2.5E-05	6.7E-03
¹¹⁵ Cd	3.3E-08	5.5E-09	1.2E-05	3.3E-03	2.0E-04	5.5E-02
¹¹¹ In	6.6E-08	1.1E-08	2.0E-05	5.4E-03	2.6E-04	6.9E-02
^{114m} In+I (b)	2.4E-08	4.0E-09	7.8E-06	2.1E-03	1.1E-04	3.0E-02
^{115m} In	3.1E-08	5.2E-09	1.1E-05	2.9E-03	1.7E-04	4.5E-02
^{117m} Sn	2.4E-08	4.1E-09	6.4E-06	1.7E-03	6.9E-05	1.9E-02

TABLE 2.1. External Dose Rate Conversion Factors for
Exposure to Residual Radioactive Materials (contd)

Radio- nuclide	Building Surface Sources		Building Volume Sources		Soil Volume Sources	
	mrem/h per dpm/100 cm ²	μSv/h per Bq/100 cm ²	mrem/h per pCi/g	μSv/h per Bq/g	mrem/h per pCi/g	μSv/h per Bq/g
^{119m} Sn	3.2E-09	5.3E-10	1.4E-07	3.8E-05	5.4E-07	1.5E-04
^{121m} Sn+D (a)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
^{121m} Sn	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
¹²¹ Sn	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
¹²³ Sn	1.6E-09	2.7E-10	5.7E-07	1.5E-04	8.1E-06	2.2E-03
¹²⁵ Sn+D (a)	6.1E-08	1.0E-08	2.2E-05	6.0E-03	3.4E-04	9.1E-02
¹²⁵ Sn	5.3E-08	8.9E-09	2.1E-05	5.6E-03	3.1E-04	8.4E-02
¹²⁶ Sn+D (a)	1.6E-07	2.7E-08	6.1E-05	1.6E-02	9.8E-04	2.6E-01
¹²⁶ Sn	8.6E-09	1.4E-09	1.7E-06	4.7E-04	1.6E-05	4.2E-03
¹²⁴ Sb	3.3E-07	5.6E-08	1.3E-04	3.5E-02	1.9E-03	5.2E-01
¹²⁵ Sb+D (a)	6.6E-08	1.1E-08	2.3E-05	6.3E-03	3.7E-04	9.9E-02
¹²⁵ Sb	8.2E-08	1.4E-08	3.0E-05	8.0E-03	4.7E-04	1.3E-01
^{126m} Sb+D (a)	3.0E-07	5.0E-08	1.1E-04	3.0E-02	1.7E-03	4.6E-01
^{126m} Sb	2.8E-07	4.7E-08	1.1E-04	2.9E-02	1.7E-03	4.5E-01
¹²⁶ Sb	4.8E-07	8.0E-08	1.8E-04	4.9E-02	2.8E-03	7.5E-01
¹²⁷ Sb+D (a)	5.3E-08	8.9E-09	2.0E-05	5.4E-03	3.0E-04	8.2E-02
¹²⁷ Sb	1.2E-07	2.0E-08	4.4E-05	1.2E-02	6.7E-04	1.8E-01
^{123m} Te	2.3E-08	3.8E-09	6.0E-06	1.6E-03	6.6E-05	1.8E-02
^{125m} Te	8.6E-09	1.4E-09	5.2E-07	1.4E-04	2.6E-06	7.1E-04
^{127m} Te+D (a)	1.9E-09	3.1E-10	2.6E-07	7.0E-05	3.4E-06	9.2E-04
^{127m} Te	2.8E-09	4.6E-10	1.7E-07	4.5E-05	8.6E-07	2.3E-04
¹²⁷ Te	1.0E-09	1.8E-10	3.6E-07	9.8E-05	6.0E-06	1.6E-03
^{129m} Te+D (a)	8.7E-09	1.5E-09	2.8E-06	7.5E-04	4.1E-05	1.1E-02
^{129m} Te	7.5E-09	1.3E-09	2.2E-06	5.8E-04	3.1E-05	8.5E-03
¹²⁹ Te	1.1E-08	1.9E-09	3.7E-06	1.0E-03	5.9E-05	1.6E-02
^{131m} Te+D (a)	1.5E-07	2.5E-08	5.6E-05	1.5E-02	7.9E-04	2.1E-01
^{131m} Te	2.6E-07	4.3E-08	9.9E-05	2.7E-02	1.4E-03	3.8E-01
¹³¹ Te+D (a)	6.7E-08	1.1E-08	2.5E-05	6.7E-03	3.7E-04	9.9E-02
¹³¹ Te	7.4E-08	1.2E-08	2.7E-05	7.2E-03	3.9E-04	1.1E-01
¹³² Te+D (a)	2.2E-07	3.7E-08	8.0E-05	2.2E-02	1.2E-03	3.3E-01
¹³² Te	4.4E-08	7.3E-09	1.3E-05	3.6E-03	1.8E-04	4.8E-02
^{133m} Te+D (a)	1.6E-07	2.7E-08	6.1E-05	1.6E-02	9.7E-04	2.6E-01
^{133m} Te	4.0E-07	6.7E-08	1.6E-04	4.2E-02	2.3E-03	6.2E-01
¹³³ Te+D (a)	8.7E-08	1.5E-08	3.3E-05	8.9E-03	5.1E-04	1.4E-01
¹³³ Te	1.7E-07	2.8E-08	6.5E-05	1.7E-02	9.9E-04	2.7E-01
¹³⁴ Te+D (a)	3.0E-07	5.0E-08	1.1E-04	3.0E-02	1.7E-03	4.6E-01
¹³⁴ Te	1.6E-07	2.6E-08	5.8E-05	1.6E-02	8.6E-04	2.3E-01
¹²⁵ I	1.0E-08	1.7E-09	5.9E-07	1.6E-04	2.9E-06	7.8E-04
¹²⁹ I	5.5E-09	9.2E-10	3.4E-07	9.1E-05	1.7E-06	4.5E-04
¹³⁰ I	3.6E-07	6.0E-08	1.3E-04	3.6E-02	2.1E-03	5.7E-01
¹³¹ I+D (a)	6.2E-08	1.0E-08	2.2E-05	6.0E-03	3.5E-04	9.4E-02

TABLE 2.1. External Dose Rate Conversion Factors for
Exposure to Residual Radioactive Materials (contd)

Radio-nuclide	Building Surface Sources		Building Volume Sources		Soil Volume Sources	
	mrem/h per dpm/100 cm ²	μSv/h per Bq/100 cm ²	mrem/h per pCi/g	μSv/h per Bq/g	mrem/h per pCi/g	μSv/h per Bq/g
¹³¹ I	6.5E-08	1.1E-08	2.4E-05	6.4E-03	3.7E-04	1.0E-01
¹³² I	4.1E-07	6.9E-08	1.6E-04	4.3E-02	2.3E-03	6.3E-01
¹³³ I+D (a)	5.0E-08	8.3E-09	1.8E-05	4.9E-03	2.9E-04	7.9E-02
¹³³ I	9.7E-08	1.6E-08	3.6E-05	9.8E-03	6.0E-04	1.6E-01
¹³⁴ I	4.5E-07	7.6E-08	1.8E-04	4.7E-02	2.6E-03	6.9E-01
¹³⁵ I+D (a)	1.4E-07	2.4E-08	5.7E-05	1.5E-02	8.2E-04	2.2E-01
¹³⁵ I	2.7E-07	4.5E-08	1.1E-04	2.9E-02	1.6E-03	4.2E-01
^{134m} Cs+D (a)	2.7E-09	4.6E-10	5.7E-07	1.5E-04	5.6E-06	1.5E-03
^{134m} Cs	5.7E-09	9.5E-10	1.2E-06	3.1E-04	1.1E-05	3.1E-03
¹³⁴ Cs	3.0E-07	4.9E-08	1.1E-04	3.0E-02	1.6E-03	4.4E-01
¹³⁵ Cs	7.5E-12	1.3E-12	7.1E-10	1.9E-07	4.4E-09	1.2E-06
¹³⁶ Cs	3.7E-07	6.2E-08	1.4E-04	3.9E-02	2.1E-03	5.6E-01
¹³⁷ Cs+I (b)	1.0E-07	1.7E-08	3.8E-05	1.0E-02	5.7E-04	1.5E-01
¹³⁸ Cs	4.1E-07	6.8E-08	1.6E-04	4.4E-02	2.4E-03	6.5E-01
¹³⁹ Ba	6.6E-09	1.1E-09	2.0E-06	5.5E-04	2.4E-05	6.6E-03
¹⁴⁰ Ba+D (a)	2.0E-07	3.3E-08	7.8E-05	2.1E-02	1.2E-03	3.3E-01
¹⁴⁰ Ba	3.2E-08	5.3E-09	1.1E-05	3.0E-03	1.8E-04	5.0E-02
¹⁴¹ Ba+D (a)	5.6E-08	9.4E-09	2.1E-05	5.6E-03	3.0E-04	8.1E-02
¹⁴¹ Ba	1.5E-07	2.5E-08	5.7E-05	1.5E-02	8.4E-04	2.3E-01
¹⁴² Ba+D (a)	2.9E-07	4.8E-08	1.2E-04	3.3E-02	1.8E-03	4.8E-01
¹⁴² Ba	1.6E-07	2.6E-08	6.0E-05	1.6E-02	8.8E-04	2.4E-01
¹⁴⁰ La	3.8E-07	6.3E-08	1.5E-04	4.0E-02	2.2E-03	5.9E-01
¹⁴¹ La+D (a)	1.0E-08	1.7E-09	3.5E-06	9.5E-04	4.4E-05	1.2E-02
¹⁴¹ La	9.5E-09	1.6E-09	3.6E-06	9.8E-04	5.2E-05	1.4E-02
¹⁴² La	4.4E-07	7.3E-08	1.8E-04	4.8E-02	2.7E-03	7.4E-01
¹⁴¹ Ce	1.2E-08	2.1E-09	3.5E-06	9.5E-04	3.8E-05	1.0E-02
¹⁴³ Ce+D (a)	2.2E-08	3.6E-09	7.2E-06	2.0E-03	1.0E-04	2.8E-02
¹⁴³ Ce	4.5E-08	7.5E-09	1.5E-05	4.0E-03	2.1E-04	5.6E-02
¹⁴⁴ Ce+D (a)	5.4E-09	9.0E-10	1.8E-06	5.0E-04	2.5E-05	6.7E-03
¹⁴⁴ Ce	3.4E-09	5.6E-10	8.9E-07	2.4E-04	9.4E-06	2.5E-03
¹⁴³ Pr	2.2E-10	3.6E-11	4.6E-08	1.3E-05	5.1E-07	1.4E-04
^{144m} Pr+D (a)	5.1E-09	8.5E-10	1.5E-06	4.1E-04	2.2E-05	5.9E-03
^{144m} Pr	2.6E-09	4.3E-10	2.7E-07	7.4E-05	1.6E-06	4.3E-04
¹⁴⁴ Pr	7.8E-09	1.3E-09	2.9E-06	7.8E-04	4.2E-05	1.1E-02
¹⁴⁷ Nd+D (a)	1.1E-08	1.9E-09	3.5E-06	9.5E-04	5.4E-05	1.5E-02
¹⁴⁷ Nd	2.3E-08	3.8E-09	7.3E-06	2.0E-03	1.1E-04	3.0E-02
¹⁴⁷ Pm	1.1E-11	1.8E-12	1.2E-09	3.1E-07	8.3E-09	2.2E-06

TABLE 2.1. External Dose Rate Conversion Factors for
Exposure to Residual Radioactive Materials (contd)

Radio- nuclide	Building Surface Sources		Building Volume Sources		Soil Volume Sources	
	mrem/h per dpm/100 cm ²	μSv/h per Bq/100 cm ²	mrem/h per pCi/g	μSv/h per Bq/g	mrem/h per pCi/g	μSv/h per Bq/g
^{148m} Pm+D (a)	3.6E-07	6.0E-08	1.4E-04	3.7E-02	2.0E-03	5.4E-01
^{148m} Pm	3.8E-07	6.3E-08	1.4E-04	3.8E-02	2.2E-03	5.8E-01
¹⁴⁸ Pm	1.1E-07	1.8E-08	4.2E-05	1.1E-02	6.1E-04	1.6E-01
¹⁴⁹ Pm	2.1E-09	3.5E-10	7.0E-07	1.9E-04	9.6E-06	2.6E-03
¹⁵¹ Pm	5.9E-08	9.9E-09	2.1E-05	5.6E-03	3.1E-04	8.4E-02
¹⁴⁷ Sm	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
¹⁵¹ Sm	5.4E-12	8.9E-13	2.4E-10	6.4E-08	5.9E-10	1.6E-07
¹⁵³ Sm	1.2E-08	2.1E-09	2.9E-06	7.8E-04	2.9E-05	7.8E-03
¹⁵² Eu	2.1E-07	3.4E-08	7.8E-05	2.1E-02	1.1E-03	3.1E-01
¹⁵⁴ Eu	2.1E-07	3.6E-08	8.2E-05	2.2E-02	1.2E-03	3.2E-01
¹⁵⁶ Eu	1.0E-08	1.7E-09	2.7E-06	7.3E-04	2.7E-05	7.3E-03
¹⁵⁶ Eu	2.3E-07	3.8E-08	9.1E-05	2.5E-02	1.3E-03	3.6E-01
¹⁵³ Gd	2.0E-08	3.3E-09	4.2E-06	1.1E-03	3.9E-05	1.0E-02
¹⁶⁰ Tb	1.9E-07	3.1E-08	7.1E-05	1.9E-02	1.0E-03	2.8E-01
^{166m} Ho	2.7E-07	4.6E-08	1.0E-04	2.7E-02	1.5E-03	4.0E-01
¹⁸¹ W	6.0E-09	1.0E-09	1.1E-06	3.1E-04	8.3E-06	2.2E-03
¹⁸⁵ W	4.6E-11	7.7E-12	7.2E-09	2.0E-06	6.5E-08	1.7E-05
¹⁸⁷ W	8.4E-08	1.4E-08	3.1E-05	8.3E-03	4.7E-04	1.3E-01
¹⁸⁷ Re	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
¹⁸⁵ Os	1.3E-07	2.1E-08	4.6E-05	1.2E-02	6.8E-04	1.8E-01
¹⁹¹ Os	1.2E-08	2.0E-09	3.0E-06	8.2E-04	3.0E-05	8.0E-03
¹⁹² Ir	1.5E-07	2.5E-08	5.5E-05	1.5E-02	8.7E-04	2.4E-01
²⁰³ Hg	3.5E-08	5.8E-09	1.2E-05	3.1E-03	1.6E-04	4.2E-02
²¹⁰ Pb+D (a)	4.1E-10	6.8E-11	4.8E-08	1.3E-05	3.9E-07	1.0E-04
²¹⁰ Pb	9.5E-10	1.6E-10	7.2E-08	1.9E-05	3.1E-07	8.5E-05
²¹² Pb+D (a)	8.3E-08	1.4E-08	3.3E-05	9.0E-03	5.0E-04	1.4E-01
²¹² Pb	2.5E-08	4.2E-09	8.3E-06	2.2E-03	1.1E-04	3.0E-02
²¹⁰ Bi+D (a)	1.6E-10	2.6E-11	3.7E-08	1.0E-05	4.3E-07	1.1E-04
²¹⁰ Bi	3.2E-10	5.3E-11	7.4E-08	2.0E-05	8.6E-07	2.3E-04
²¹² Bi+I (b)	2.3E-07	3.9E-08	9.4E-05	2.5E-02	1.4E-03	3.9E-01
²¹⁰ Po	1.6E-12	2.6E-13	6.0E-10	1.6E-07	8.4E-09	2.3E-06

TABLE 2.1. External Dose Rate Conversion Factors for
Exposure to Residual Radioactive Materials (contd)

Radio- nuclide	Building Surface Sources		Building Volume Sources		Soil Volume Sources	
	mrem/h per dpm/100 cm ²	μSv/h per Bq/100 cm ²	mrem/h per pCi/g	μSv/h per Bq/g	mrem/h per pCi/g	μSv/h per Bq/g
²²³ Ra+I (b)	5.0E-08	8.4E-09	1.7E-05	4.7E-03	2.5E-04	6.8E-02
²²⁴ Ra+D (a)	4.2E-08	7.0E-09	1.7E-05	4.6E-03	2.5E-04	6.9E-02
²²⁴ Ra+I (b)	1.8E-09	3.1E-10	6.2E-07	1.7E-04	8.5E-06	2.3E-03
²²⁵ Ra+D (a)	6.2E-09	1.0E-09	2.2E-06	5.9E-04	3.4E-05	9.3E-03
²²⁵ Ra	2.8E-09	4.7E-10	3.6E-07	9.8E-05	2.2E-06	6.0E-04
²²⁶ Ra+D (a)	3.3E-08	5.5E-09	1.3E-05	3.6E-03	2.0E-04	5.3E-02
²²⁶ Ra	8.4E-10	1.4E-10	2.5E-07	6.7E-05	2.8E-06	7.5E-04
²²⁸ Ra+D (a)	4.6E-08	7.7E-09	1.8E-05	4.8E-03	2.7E-04	7.2E-02
²²⁸ Ra	5.4E-14	8.9E-15	2.3E-12	6.2E-10	3.3E-12	8.8E-10
²²⁶ Ac+I (b)	4.2E-08	7.1E-09	1.5E-05	4.1E-03	2.4E-04	6.4E-02
²²⁷ Ac+D (a)	8.4E-09	1.4E-09	2.8E-06	7.6E-04	4.0E-05	1.1E-02
²²⁷ Ac	5.4E-11	8.9E-12	8.2E-09	2.2E-06	7.8E-08	2.1E-05
²²⁸ Ac+D (a)	5.2E-08	8.6E-09	2.0E-05	5.4E-03	3.0E-04	8.1E-02
²²⁸ Ac	1.7E-07	2.8E-08	6.5E-05	1.8E-02	9.6E-04	2.6E-01
²²⁷ Th+D (a)	9.6E-09	1.6E-09	3.2E-06	8.7E-04	4.6E-05	1.2E-02
²²⁷ Th	1.9E-08	3.2E-09	6.0E-06	1.6E-03	8.3E-05	2.2E-02
²²⁸ Th+D (a)	3.6E-08	6.0E-09	1.4E-05	3.9E-03	2.2E-04	5.9E-02
²²⁸ Th	5.4E-10	9.0E-11	9.9E-08	2.7E-05	1.0E-06	2.8E-04
²²⁹ Th+D (a)	7.3E-09	1.2E-09	2.4E-06	6.5E-04	3.4E-05	9.2E-03
²²⁹ Th	1.5E-08	2.5E-09	3.9E-06	1.1E-03	4.2E-05	1.1E-02
²³⁰ Th+D (a)	3.0E-08	5.0E-09	1.2E-05	3.2E-03	1.8E-04	4.8E-02
²³⁰ Th	2.7E-10	4.5E-11	2.2E-08	5.9E-06	1.2E-07	3.3E-05
²³¹ Th+D (a)	4.1E-10	6.9E-11	5.3E-08	1.4E-05	4.3E-07	1.2E-04
²³¹ Th	4.3E-09	7.2E-10	5.4E-07	1.5E-04	4.4E-06	1.2E-03
²³² Th+D (a)	4.1E-08	6.9E-09	1.6E-05	4.3E-03	2.4E-04	6.5E-02
²³² Th-Nat (c)	4.1E-08	6.9E-09	1.6E-05	4.3E-03	2.4E-04	6.5E-02
²³² Th	2.4E-10	4.1E-11	1.5E-08	4.1E-06	6.4E-08	1.7E-05
²³⁴ Th+D (a)	2.6E-09	4.3E-10	8.0E-07	2.2E-04	1.1E-05	3.0E-03
²³⁴ Th+I (b)	4.7E-09	7.9E-10	1.5E-06	4.0E-04	2.0E-05	5.3E-03
²³¹ Pa+D (a)	8.3E-09	1.4E-09	2.7E-06	7.2E-04	3.9E-05	1.1E-02
²³¹ Pa	7.0E-09	1.2E-09	1.9E-06	5.2E-04	2.8E-05	7.6E-03
²³³ Pa	4.1E-08	6.8E-09	1.4E-05	3.8E-03	2.1E-04	5.7E-02
²³⁴ Pa	3.5E-07	5.8E-08	1.3E-04	3.6E-02	1.9E-03	5.2E-01
²³² U+D (a)	4.8E-11	8.1E-12	3.0E-09	8.1E-07	1.3E-08	3.5E-06
²³² U	3.5E-10	5.8E-11	2.2E-08	5.9E-06	9.4E-08	2.5E-05
²³³ U+D (a)	6.5E-09	1.1E-09	2.1E-06	5.8E-04	3.0E-05	8.2E-03
²³³ U	1.4E-10	2.4E-11	1.7E-08	4.6E-06	1.5E-07	3.9E-05
²³⁴ U	2.9E-10	4.9E-11	1.6E-08	4.4E-06	5.7E-08	1.5E-05
²³⁵ U+D (a)	1.2E-08	2.0E-09	3.4E-06	9.1E-04	3.8E-05	1.0E-02
²³⁵ U	2.1E-08	3.5E-09	6.3E-06	1.7E-03	7.2E-05	1.9E-02

TABLE 2.1. External Dose Rate Conversion Factors for
Exposure to Residual Radioactive Materials (contd)

Radio- nuclide	Building Surface Sources		Building Volume Sources		Soil Volume Sources	
	mrem/h per dpm/100 cm ²	μSv/h per Bq/100 cm ²	mrem/h per pCi/g	μSv/h per Bq/g	mrem/h per pCi/g	μSv/h per Bq/g
²³⁸ U	2.7E-10	4.5E-11	1.3E-08	3.6E-06	3.0E-08	8.0E-06
²³⁷ U	2.7E-08	4.5E-09	7.7E-06	2.1E-03	9.2E-05	2.5E-02
²³⁸ U+D (a)	1.8E-09	3.0E-10	5.4E-07	1.4E-04	7.5E-06	2.0E-03
²³⁸ U	2.4E-10	4.0E-11	1.2E-08	3.2E-06	2.6E-08	7.0E-06
²³⁸ U-Nat (d)	7.3E-10	1.2E-10	1.6E-07	4.2E-05	1.7E-06	4.5E-04
²⁴⁰ U+D (a)	2.2E-08	3.6E-09	8.0E-06	2.2E-03	1.2E-04	3.2E-02
²⁴⁰ U+I (b)	6.7E-08	1.1E-08	2.5E-05	6.7E-03	3.7E-04	9.9E-02
²³⁷ Np+D (a)	2.2E-08	3.7E-09	7.3E-06	2.0E-03	1.0E-04	2.8E-02
²³⁷ Np	5.4E-09	8.9E-10	9.5E-07	2.6E-04	8.9E-06	2.4E-03
²³⁸ Np+D (a)	4.7E-08	7.9E-09	1.8E-05	5.0E-03	2.7E-04	7.4E-02
²³⁸ Np	9.7E-08	1.6E-08	3.8E-05	1.0E-02	5.6E-04	1.5E-01
²³⁹ Np+D (a)	1.5E-08	2.5E-09	4.7E-06	1.3E-03	5.9E-05	1.6E-02
²³⁹ Np	3.1E-08	5.2E-09	9.7E-06	2.6E-03	1.2E-04	3.3E-02
²³⁸ Pu	3.5E-10	5.8E-11	1.6E-08	4.4E-06	2.8E-08	7.6E-06
²³⁷ Pu	1.0E-08	1.7E-09	2.7E-06	7.3E-04	2.9E-05	7.8E-03
²³⁸ Pu	3.1E-10	5.1E-11	1.4E-08	3.7E-06	1.9E-08	5.1E-06
²³⁹ Pu	1.3E-10	2.1E-11	8.3E-09	2.2E-06	4.2E-08	1.1E-05
²⁴⁰ Pu	2.9E-10	4.9E-11	1.3E-08	3.6E-06	1.9E-08	5.1E-06
²⁴¹ Pu+D (a)	2.1E-09	3.4E-10	3.1E-07	8.5E-05	2.1E-06	5.6E-04
²⁴¹ Pu	7.9E-16	1.3E-16	3.4E-14	9.1E-12	3.5E-14	9.5E-12
²⁴² Pu	2.4E-10	4.1E-11	1.1E-08	2.9E-06	1.6E-08	4.3E-06
²⁴³ Pu+D (a)	1.1E-08	1.9E-09	3.5E-06	9.3E-04	4.3E-05	1.2E-02
²⁴³ Pu	3.5E-09	5.9E-10	9.4E-07	2.5E-04	1.0E-05	2.7E-03
²⁴⁴ Pu+D (a)	1.6E-08	2.7E-09	6.0E-06	1.6E-03	8.8E-05	2.4E-02
²⁴⁴ Pu	2.1E-10	3.5E-11	9.2E-09	2.5E-06	1.1E-08	3.0E-06
²⁴¹ Am	4.2E-09	7.1E-10	6.4E-07	1.7E-04	4.3E-06	1.2E-03
^{242m} Am+D (a)	1.2E-09	2.0E-10	2.2E-07	5.9E-05	2.2E-06	5.9E-04
^{242m} Am	8.5E-10	1.4E-10	4.8E-08	1.3E-05	1.8E-07	4.8E-05
²⁴² Am+D (a)	1.3E-09	2.2E-10	2.8E-07	7.5E-05	2.9E-06	7.8E-04
²⁴² Am	3.3E-09	5.6E-10	7.9E-07	2.1E-04	8.3E-06	2.2E-03
²⁴³ Am+D (a)	1.3E-08	2.1E-09	3.7E-06	1.0E-03	4.5E-05	1.2E-02
²⁴³ Am	8.1E-09	1.4E-09	1.8E-06	4.9E-04	1.6E-05	4.3E-03
²⁴² Cm+D (a)	3.3E-10	5.4E-11	1.5E-08	4.0E-06	1.9E-08	5.2E-06
²⁴² Cm	3.1E-10	5.1E-11	1.4E-08	3.7E-06	1.8E-08	4.8E-06
²⁴³ Cm	2.3E-08	3.9E-09	7.2E-06	1.9E-03	8.9E-05	2.4E-02
²⁴⁴ Cm+D (a)	1.3E-10	2.2E-11	5.9E-09	1.6E-06	7.5E-09	2.0E-06
²⁴⁴ Cm	2.7E-10	4.6E-11	1.2E-08	3.2E-06	1.5E-08	4.1E-06
²⁴⁵ Cm+D (a)	5.6E-09	9.4E-10	1.4E-06	3.8E-04	1.4E-05	3.9E-03
²⁴⁵ Cm	1.4E-08	2.3E-09	3.7E-06	1.0E-03	4.0E-05	1.1E-02
²⁴⁶ Cm	2.4E-10	4.1E-11	1.1E-08	2.9E-06	1.3E-08	3.4E-06

TABLE 2.1. External Dose Rate Conversion Factors for
Exposure to Residual Radioactive Materials (contd)

Radio- nuclide	Building Surface Sources		Building Volume Sources		Soil Volume Sources	
	mrem/h per dpm/100 cm ²	μSv/h per Bq/100 cm ²	mrem/h per pCi/g	μSv/h per Bq/g	mrem/h per pCi/g	μSv/h per Bq/g
²⁴⁷ Cm+D ^(a)	4.4E-08	7.3E-09	1.5E-05	4.1E-03	2.4E-04	6.5E-02
²⁴⁷ Cm	6.4E-08	1.1E-08	2.4E-05	6.4E-03	4.0E-04	1.1E-01
²⁴⁸ Cm	1.9E-10	3.2E-11	8.5E-09	2.3E-06	1.1E-08	3.1E-06
²⁵² Cf	1.9E-10	3.2E-11	8.7E-09	2.3E-06	1.3E-08	3.4E-06

- (a) Where +D means "plus daughters in equilibrium" referring to explicit daughters, or daughters with half-lives greater than 10 minutes. Separate values are also included for parents and daughters so that combined factors for non-equilibrium cases can be determined. Note: in some cases +D also includes implicit daughters (i.e., uranium and thorium decay chains).
- (b) Where +I means "plus implicit daughters in equilibrium" referring to daughters with half-lives less than 10 minutes. The decay energies associated with these daughters have been assigned to the parent, and the appropriate branching ratios (described in Appendix D) have been considered.
- (c) Where Th-Nat includes an equilibrium mixture of ²³²Th plus 10 daughters in the decay chain, as discussed in Appendix D.
- (d) Where 1 Ci U-Nat equals 48.9% ²³⁸U plus 48.9% ²³⁴U plus 2.25% ²³⁵U.

2.2.2 Inhalation

The dose rate conversion factors for inhalation generated using the GENII computer program (Napier et al., Vol. 1 1988) are based on the models, metabolic data, and recommendations found in ICRP 30 (1979-1988). The general equation for estimating the committed effective dose rate equivalent by inhalation received by individuals for radionuclide i is:

$$H_{INH,i} = (V t) C_d C_{w,i} DF_{INH,i} \quad (2.2)$$

where $H_{INH,i}$ = the committed effective dose equivalent from a 1-yr intake of radionuclide i by inhalation, in mrem (μ Sv) per year of intake

V = the ventilation rate of the individual, in m^3/h (Note: For this study, a constant ventilation rate of $0.97 m^3/h$ is assumed from ICRP 1975).

t = the duration of exposure for the individual, in h/yr

C_d = concentration of respirable dust in air, in g/m^3

$C_{w,i}$ = the concentration of radionuclide i in the contaminated material, in pCi/g (Bq/g)

$DF_{INH,i}$ = the committed effective dose from inhalation of radionuclide i , in mrem/pCi (μ Sv/Bq).

The term in parentheses in Equation 2.2 is equivalent to the usage parameter defined in Equation 2.1. The values used for the parameters shown in Equation 2.2 are either scenario specific, or are based on the data requirements of the ICRP dosimetry system, as discussed in Appendix B. For the solubility class, assumptions were made by element to maximize the expected dose using the ICRP 30 lung model, as discussed in Appendix B.

Inhalation committed effective dose conversion factors are shown in Table 2.2. These factors are in units of mrem per hour of exposure per pCi/ m^3 in air and μ Sv per hour of exposure per Bq/ m^3 in air. The factors in Table 2.2 can be multiplied by the exposure duration and the estimated air concentration to obtain an estimate of the committed effective dose equivalent for inhalation.

A comparison of the inhalation committed effective dose conversion factors for selected radionuclides used in this study with those found in the literature was next conducted. The radionuclides considered included ^{90}Sr , ^{134}Cs , ^{235}U , ^{238}U and ^{239}Pu . Comparisons with the dose per unit intake factors from ICRP 30 (1979-1988) and from Federal Guidance Report No. 11 (EPA 1988) showed agreement within a few percent. This agreement verifies that the basic inhalation dose conversion factors used in this study are consistent with the ICRP methods and with other Federal guidance.

TABLE 2.2. Inhalation Committed Effective Dose Rate Conversion Factors for Exposure to Residual Radioactive Materials

<u>Radionuclide</u>	<u>mrem/h per pCi/m³</u>	<u>μSv/h per Bq/m³</u>
³ H	8.2E-08	2.2E-05
¹⁰ Be	3.4E-04	9.2E-02
¹⁴ C	1.9E-06	5.1E-04
¹⁸ F	7.7E-08	2.1E-05
²² Na	8.6E-06	2.3E-03
²⁴ Na	1.1E-06	3.0E-04
³² P	5.5E-06	1.5E-03
³³ P	5.6E-07	1.5E-04
³⁵ S	2.4E-06	6.5E-04
³⁸ Cl	1.8E-06	4.9E-04
⁴⁰ K	9.9E-06	2.7E-03
⁴¹ Ca	1.2E-06	3.2E-04
⁴⁵ Ca	6.4E-06	1.7E-03
⁴⁸ Sc	2.8E-05	7.6E-03
⁵¹ Cr	3.1E-07	8.4E-05
⁵⁴ Mn	6.1E-06	1.6E-03
⁵⁶ Mn	3.3E-07	8.9E-05
⁵⁵ Fe	1.2E-06	3.2E-04
⁵⁹ Fe	1.2E-05	3.2E-03
⁵⁷ Co	8.3E-06	2.2E-03
⁵⁸ Co	1.0E-05	2.7E-03
⁶⁰ Co	1.9E-04	5.1E-02
⁵⁹ Ni	7.9E-07	2.1E-04
⁶³ Ni	1.9E-06	5.1E-04
⁶⁵ Ni	2.3E-07	6.2E-05
⁶⁴ Cu	1.9E-07	5.1E-05
⁶⁵ Zn	1.7E-05	4.6E-03
^{69m} Zn+D (b)	4.1E-07	1.1E-04
^{69m} Zn	7.8E-07	2.1E-04

TABLE 2.2. Inhalation Committed Effective Dose Rate Conversion Factors
for Exposure to Residual Radioactive Materials (contd)

Radionuclide	mrem/h per pCi/m ³	μSv/h per Bq/m ³
⁶⁹ Zn	3.8E-08	1.0E-05
⁷⁶ As	3.8E-06	1.0E-03
⁷⁵ Se	7.6E-06	2.1E-03
⁷⁹ Se	8.8E-06	2.4E-03
⁸² Br	1.1E-06	3.0E-04
⁸³ Br+D (b)	4.5E-08	1.2E-05
⁸³ Br	8.9E-08	2.4E-05
⁸⁴ Br	9.4E-08	2.5E-05
⁸⁶ Rb	5.8E-06	1.6E-03
⁸⁸ Rb	8.3E-08	2.2E-05
⁸⁹ Rb+D (b)	2.6E-06	7.2E-04
⁸⁹ Rb	4.2E-08	1.1E-05
⁸⁵ Sr	1.4E-06	3.8E-04
⁸⁹ Sr	5.3E-06	1.4E-03
⁹⁰ Sr+D (b)	1.0E-04	2.8E-02
⁹⁰ Sr	2.0E-04	5.4E-02
⁹¹ Sr+D (b)	1.9E-05	5.0E-03
⁹¹ Sr	8.6E-07	2.3E-04
⁹² Sr+D (b)	7.0E-07	1.9E-04
⁹² Sr	5.9E-07	1.6E-04
⁹⁰ Y	8.5E-06	2.3E-03
^{91m} Y+D (b)	2.4E-05	6.3E-03
^{91m} Y	3.6E-08	9.7E-06
⁹¹ Y	4.7E-05	1.3E-02
⁹² Y	8.0E-07	2.2E-04
⁹³ Y	2.2E-06	5.9E-04
⁹³ Zr+D (b)	5.5E-05	1.5E-02
⁹³ Zr	7.9E-05	2.1E-02
⁹⁵ Zr+D (b)	1.0E-05	2.7E-03
⁹⁵ Zr	1.5E-05	4.1E-03
⁹⁷ Zr+D (b)	1.3E-06	3.6E-04
⁹⁷ Zr	3.8E-06	1.0E-03
^{93m} Nb	2.9E-05	7.8E-03
⁹⁴ Nb	3.7E-04	1.0E-01
^{95m} Nb+D (b)	3.9E-06	1.1E-03
^{95m} Nb	2.4E-06	6.5E-04
⁹⁵ Nb	5.5E-06	1.5E-03
^{97m} Nb+D (b)	4.2E-08	1.1E-05

TABLE 2.2. Inhalation Committed Effective Dose Rate Conversion Factors for Exposure to Residual Radioactive Materials (contd)

Radionuclide	mrem/h per pCi/m ³	μSv/h per Bq/m ³
^{97m} Nb	1.2E-09	3.2E-07
⁹⁷ Nb	8.3E-08	2.2E-05
⁹³ Mo+D (b)	1.5E-05	4.1E-03
⁹³ Mo	9.5E-07	2.6E-04
⁹⁹ Mo+D (b)	1.1E-06	2.9E-04
⁹⁹ Mo	1.9E-06	5.1E-04
^{99m} Tc	3.1E-08	8.4E-06
⁹⁹ Tc	8.9E-06	2.4E-03
¹⁰¹ Tc	1.5E-08	4.0E-06
¹⁰³ Ru+D (b)	4.4E-06	1.2E-03
¹⁰³ Ru	8.7E-06	2.3E-03
¹⁰⁵ Ru+D (b)	5.0E-07	1.3E-04
¹⁰⁵ Ru+I (c)	5.2E-07	1.4E-04
¹⁰⁶ Ru+I (c)	2.2E-04	6.1E-02
^{103m} Rh	4.8E-09	1.3E-06
¹⁰⁵ Rh	9.6E-07	2.6E-04
¹⁰³ Pd+D (b)	7.5E-07	2.0E-04
¹⁰³ Pd	1.5E-06	4.1E-04
¹⁰⁷ Pd	1.2E-05	3.2E-03
¹⁰⁹ Pd+I (c)	6.5E-07	1.8E-04
^{110m} Ag+I (c)	4.1E-05	1.1E-02
¹¹¹ Ag	3.3E-06	8.9E-04
¹⁰⁹ Cd	1.1E-04	3.0E-02
^{113m} Cd	1.4E-03	3.8E-01
^{115m} Cd+D (b)	3.5E-05	9.3E-03
^{115m} Cd	6.9E-05	1.9E-02
¹¹⁵ Cd	3.9E-06	1.1E-03
¹¹¹ In	5.4E-07	1.5E-04
^{114m} In+I (c)	2.2E-05	6.1E-03
^{115m} In	1.2E-07	3.2E-05
^{117m} Sn	4.2E-06	1.1E-03
^{119m} Sn	5.8E-06	1.6E-03
^{121m} Sn+D (b)	6.2E-06	1.7E-03
^{121m} Sn	1.1E-05	3.0E-03
¹²¹ Sn	4.8E-07	1.3E-04
¹²³ Sn	3.1E-05	8.4E-03
¹²⁵ Sn+D (b)	1.3E-05	3.5E-03

TABLE 2.2. Inhalation Committed Effective Dose Rate Conversion Factors
for Exposure to Residual Radioactive Materials (contd)

Radionuclide	mrem/h per pCi/m ³	μSv/h per Bq/m ³
¹²⁵ Sn	1.5E-05	4.1E-03
¹²⁶ Sn+D (b)	4.5E-05	1.2E-02
¹²⁶ Sn	9.4E-05	2.5E-02
¹²⁴ Sb	2.5E-05	6.8E-03
¹²⁵ Sb+D (b)	1.1E-05	2.9E-03
¹²⁵ Sb	1.2E-05	3.2E-03
¹²⁶ Sb+D (b)	1.5E-06	4.0E-04
¹²⁶ Sb	2.9E-08	7.8E-06
¹²⁶ Sb	1.1E-05	3.0E-03
¹²⁷ Sb+D (b)	4.4E-06	1.2E-03
¹²⁷ Sb	5.8E-06	1.6E-03
¹²³ Te	1.0E-05	2.7E-03
¹²⁵ Te	7.0E-06	1.9E-03
¹²⁷ Te+D (b)	1.1E-05	2.9E-03
¹²⁷ Te	2.1E-05	5.7E-03
¹²⁷ Te	3.2E-07	8.6E-05
¹²⁹ Te+D (b)	2.9E-04	8.0E-02
¹²⁹ Te	4.8E-04	1.3E-01
¹²⁹ Te	1.5E-07	4.1E-05
¹³¹ Te+D (b)	1.9E-05	5.1E-03
¹³¹ Te	1.2E-05	3.2E-03
¹³¹ Te+D (b)	1.5E-05	4.0E-03
¹³¹ Te	1.2E-07	3.2E-05
¹³² Te+D (b)	6.5E-06	1.8E-03
¹³² Te	1.2E-05	3.2E-03
¹³³ Te+D (b)	1.8E-06	5.0E-04
¹³³ Te	4.3E-07	1.2E-04
¹³³ Te+D (b)	1.8E-06	4.8E-04
¹³³ Te	8.7E-08	2.3E-05
¹³⁴ Te+D (b)	1.2E-07	3.2E-05
¹³⁴ Te	1.0E-07	2.7E-05
¹²⁵ I	2.2E-05	5.9E-03
¹²⁹ I	1.5E-04	4.1E-02
¹³⁰ I	2.4E-06	6.5E-04
¹³¹ I+D (b)	3.0E-05	8.0E-03
¹³¹ I	3.0E-05	8.1E-03
¹³² I	3.8E-07	1.0E-04
¹³³ I+D (b)	2.6E-06	7.1E-04
¹³³ I	5.3E-06	1.4E-03
¹³⁴ I	1.4E-07	3.8E-05
¹³⁵ I+D (b)	5.1E-07	1.4E-04
¹³⁵ I	1.1E-06	3.0E-04

TABLE 2.2. Inhalation Committed Effective Dose Rate Conversion Factors for Exposure to Residual Radioactive Materials (contd)

Radionuclide	mrem/h per pCi/m ³	μSv/h per Bq/m ³
^{134m} Cs+D (b)	1.8E-08	4.9E-06
^{134m} Cs	3.6E-08	9.7E-06
¹³⁴ Cs	4.0E-05	1.1E-02
¹³⁵ Cs	3.6E-06	9.7E-04
¹³⁶ Cs	6.4E-06	1.7E-03
¹³⁷ Cs+I (c)	1.3E-05	3.6E-03
¹³⁸ Cs	9.6E-08	2.6E-05
¹³⁹ Ba	1.7E-07	4.6E-05
¹⁴⁰ Ba+D (b)	3.2E-06	8.6E-04
¹⁴⁰ Ba	2.9E-06	7.8E-04
¹⁴¹ Ba+D (b)	3.0E-06	8.1E-04
¹⁴¹ Ba	7.8E-08	2.1E-05
¹⁴² Ba+D (b)	1.5E-07	4.1E-05
¹⁴² Ba	3.9E-08	1.1E-05
¹⁴⁰ La	3.4E-06	9.2E-04
¹⁴¹ La+D (b)	4.5E-06	1.2E-03
¹⁴¹ La	5.8E-07	1.6E-04
¹⁴² La	2.6E-07	7.0E-05
¹⁴¹ Ce	8.4E-06	2.3E-03
¹⁴³ Ce+D (b)	5.5E-06	1.5E-03
¹⁴³ Ce	3.4E-06	9.2E-04
¹⁴⁴ Ce+D (b)	1.8E-04	4.8E-02
¹⁴⁴ Ce	3.6E-04	9.7E-02
¹⁴³ Pr	7.8E-06	2.1E-03
^{144m} Pr+D (b)	3.1E-08	8.4E-06
^{144m} Pr	1.8E-08	4.9E-06
¹⁴⁴ Pr	4.3E-08	1.2E-05
¹⁴⁷ Nd+D (b)	2.2E-05	5.9E-03
¹⁴⁷ Nd	6.5E-06	1.8E-03
¹⁴⁷ Pm	3.8E-05	1.0E-02
^{148m} Pm+D (b)	2.1E-05	5.7E-03
^{148m} Pm	2.2E-05	5.9E-03
¹⁴⁸ Pm	1.1E-05	3.0E-03
¹⁴⁹ Pm	2.9E-06	7.8E-04
¹⁵¹ Pm	1.8E-06	4.9E-04
¹⁴⁷ Sm	7.3E-02	2.0E+01
¹⁵¹ Sm	2.9E-05	7.8E-03
¹⁵³ Sm	1.9E-06	5.1E-04

TABLE 2.2. Inhalation Committed Effective Dose Rate Conversion Factors
for Exposure to Residual Radioactive Materials (contd)

Radionuclide	mrem/h per pCi/m ³	μSv/h per Bq/m ³
¹⁵² Eu	2.0E-04	5.4E-02
¹⁵⁴ Eu	2.6E-04	7.0E-02
¹⁵⁵ Eu	3.9E-05	1.1E-02
¹⁵⁶ Eu	1.4E-05	3.8E-03
¹⁵³ Gd	2.3E-05	6.2E-03
¹⁶⁰ Tb	2.4E-05	6.5E-03
^{186m} Ho	7.2E-04	1.9E-01
¹⁸¹ W	1.5E-07	4.1E-05
¹⁸⁵ W	7.5E-07	2.0E-04
¹⁸⁷ W	6.5E-07	1.8E-04
¹⁸⁷ Re	5.6E-08	1.5E-05
¹⁸⁵ Os	9.2E-06	2.5E-03
¹⁹¹ Os	2.2E-06	5.9E-04
¹⁹² Ir	2.6E-05	7.0E-03
²⁰³ Hg	6.8E-06	1.8E-03
²¹⁰ Pb+D (b)	7.3E-03	2.0E+00
²¹⁰ Pb	1.3E-02	3.5E+00
²¹² Pb+D (b)	6.0E-05	1.6E-02
²¹² Pb	1.6E-04	4.3E-02
²¹⁰ Bi+D (b)	4.3E-03	1.2E+00
²¹⁰ Bi	1.9E-04	5.1E-02
²¹² Bi+I (c)	9.0E-06	2.4E-03
²¹⁰ Po	8.4E-03	2.3E+00
²²³ Ra+I (c)	1.2E-03	3.4E-01
²²⁴ Ra+D (b)	4.8E-04	1.3E-01
²²⁴ Ra+I (c)	2.7E-03	7.3E-01
²²⁵ Ra+D (b)	2.1E-03	5.8E-01
²²⁵ Ra	7.1E-03	1.9E+00
²²⁶ Ra+D (b)	3.2E-03	8.7E-01
²²⁶ Ra	7.9E-03	2.1E+00
²²⁸ Ra+D (b)	3.6E-02	9.6E+00
²²⁸ Ra	3.7E-03	1.0E+00
²²⁵ Ac+I (c)	1.3E-03	3.6E-01

TABLE 2.2. Inhalation Committed Effective Dose Rate Conversion Factors for Exposure to Residual Radioactive Materials (contd)

Radionuclide	mrem/h per pCi/m ³	μSv/h per Bq/m ³
²²⁷ Ac+D (b)	1.6E-01	4.4E+01
²²⁷ Ac	1.3E+00	3.5E+02
²²⁸ Ac+D (b)	4.0E-02	1.1E+01
²²⁸ Ac	1.1E-04	3.0E-02
²²⁷ Th+D (b)	3.3E-03	8.9E-01
²²⁷ Th	1.6E-02	4.3E+00
²²⁸ Th+D (b)	4.6E-02	1.2E+01
²²⁸ Th	3.1E-01	8.4E+01
²²⁹ Th+D (b)	2.1E-01	5.7E+01
²²⁹ Th	1.7E+00	4.6E+02
²³⁰ Th+D (b)	2.8E-02	7.6E+00
²³⁰ Th	2.5E-01	6.8E+01
²³¹ Th+D (b)	8.1E-08	2.2E-05
²³¹ Th	8.1E-07	2.2E-04
²³² Th+D (b)	1.4E-01	3.8E+01
Th-Nat (d)	1.4E-01	3.8E+01
²³² Th	1.1E+00	3.0E+02
²³⁴ Th+D (b)	1.7E-05	4.6E-03
²³⁴ Th+I (c)	3.4E-05	9.2E-03
²³¹ Pa+D (b)	2.3E-01	6.3E+01
²³¹ Pa	8.4E-01	2.3E+02
²³³ Pa	9.2E-06	2.5E-03
²³⁴ Pa	8.2E-07	2.2E-04
²³² U+D (b)	8.6E-02	2.3E+01
²³² U	6.0E-01	1.6E+02
²³³ U+D (b)	2.0E-01	5.4E+01
²³³ U	1.3E-01	3.5E+01
²³⁴ U	1.3E-01	3.5E+01
²³⁵ U+D (b)	6.0E-02	1.6E+01
²³⁵ U	1.2E-01	3.2E+01
²³⁶ U	1.2E-01	3.2E+01
²³⁷ U	3.5E-06	9.5E-04
²³⁸ U+D (b)	3.7E-02	9.9E+00
²³⁸ U	1.1E-01	3.0E+01
U-Nat (e)	1.2E-01	3.2E+01
²⁴⁰ U+D (b)	7.3E-07	2.0E-04
²⁴⁰ U+I (c)	2.2E-06	5.9E-04
²³⁷ Np+D (b)	3.1E-01	8.2E+01
²³⁷ Np	6.1E-01	1.6E+02
²³⁸ Np+D (b)	1.4E-01	3.8E+01
²³⁸ Np	4.0E-05	1.1E-02
²³⁹ Np+D (b)	1.2E-06	3.2E-04

TABLE 2.2. Inhalation Committed Effective Dose Rate Conversion Factors for Exposure to Residual Radioactive Materials (contd)

Radionuclide	mrem/h per pCi/m ³	μSv/h per Bq/m ³
²³⁹ Np	2.4E-06	6.5E-04
²³⁸ Pu	7.2E-02	1.9E+01
²³⁷ Pu	1.8E-06	4.9E-04
²³⁸ Pu	2.8E-01	7.6E+01
²³⁹ Pu	2.9E-01	7.8E+01
²⁴⁰ Pu	2.9E-01	7.8E+01
²⁴¹ Pu+D (b)	2.1E-01	5.8E+01
²⁴¹ Pu	4.7E-03	1.3E+00
²⁴² Pu	2.7E-01	7.3E+01
²⁴³ Pu+D (b)	7.0E-08	1.9E-05
²⁴³ Pu	1.4E-07	3.8E-05
²⁴⁴ Pu+D (b)	6.5E-02	1.8E+01
²⁴⁴ Pu	2.6E-01	7.0E+01
²⁴¹ Am	4.3E-01	1.2E+02
^{242m} Am+D (b)	1.6E-01	4.4E+01
^{242m} Am	3.9E-01	1.1E+02
²⁴² Am+D (b)	8.5E-02	2.3E+01
²⁴² Am	5.2E-05	1.4E-02
²⁴³ Am+D (b)	1.4E-01	3.7E+01
²⁴³ Am	4.1E-01	1.1E+02
²⁴² Cm+D (b)	1.6E-01	4.3E+01
²⁴² Cm	1.5E-02	4.0E+00
²⁴³ Cm	5.8E-01	1.6E+02
²⁴⁴ Cm+D (b)	1.2E-01	3.1E+01
²⁴⁴ Cm	2.3E-01	6.2E+01
²⁴⁵ Cm+D (b)	2.8E-01	7.7E+01
²⁴⁵ Cm	4.2E-01	1.1E+02
²⁴⁶ Cm	4.2E-01	1.1E+02
²⁴⁷ Cm+D (b)	2.0E-01	5.3E+01
²⁴⁷ Cm	3.9E-01	1.1E+02
²⁴⁸ Cm	1.5E+00	4.0E+02
²⁵² Cf	1.3E-01	3.5E+01

(a) Includes a 50% contribution from skin absorption, as recommended by the ICRP (1979-1988).

(b) Where +D means "plus daughters in equilibrium" referring to explicit daughters, or daughters with half-lives greater than 10 minutes. Separate values are also included for parents and daughters so that combined factors for non-equilibrium cases can be determined. Note: in some cases +D also includes implicit daughters (i.e., uranium and thorium decay chains).

TABLE 2.2. Inhalation Committed Effective Dose Rate Conversion
Factors for Exposure to Residual Radioactive Materials
(contd)

- (c) Where +I means "plus implicit daughters in equilibrium" referring to daughters with half-lives less than 10 minutes. The decay energies associated with these daughters have been assigned to the parent, and the appropriate branching ratios (described in Appendix D) have been considered.
- (d) Where Th-Nat includes an equilibrium mixture of ^{232}Th plus 10 daughters in the decay chain, as discussed in Appendix D.
- (e) Where 1 Ci U-Nat equals 48.9% ^{238}U plus 48.9% ^{234}U plus 2.25% ^{235}U .

2.2.3 Secondary Ingestion

Ingestion of removable radioactive contamination found on facility surfaces can occur when the contamination is transferred from a surface to hands, foodstuffs, cigarettes, or other items that enter the mouth. These pathways of potential ingestion are referred to as secondary ingestion pathways.

The general equation for estimating the committed dose rate by secondary ingestion received by the individuals defined in the exposure scenarios for radionuclide i is:

$$H_{\text{ING},i} = (I \ t) \ C_{\text{ING},i} \ DF_{\text{ING},i} \quad (2.3)$$

where $H_{\text{ING},i}$ = the committed effective dose equivalent from a 1-yr intake of radionuclide i by ingestion, in mrem (μSv) per year of exposure

I = the rate of secondary ingestion of removable surface contamination, in g/h

t = the duration of exposure for the individual, in h/yr

$C_{\text{ING},i}$ = the concentration of radionuclide i in the removable dust, in pCi/g (Bq/g)

$DF_{\text{ING},i}$ = the committed effective dose equivalent rate from ingestion of radionuclide i , in mrem/pCi ($\mu\text{Sv/Bq}$).

The term in parentheses in Equation 2.3 is equivalent to the usage parameter defined in Equation 2.1. Potential values for the ingestion rate, I , from literature sources are discussed in Appendix B. Ingestion committed effective dose conversion factors are shown in Table 2.3. These factors apply to both secondary ingestion and ingestion of drinking water and are in units of mrem per pCi ingested and μSv per Bq ingested. These factors can be multiplied by the exposure duration (h) and secondary ingestion rate in pCi/h or Bq/h to obtain scenario-specific estimates of the committed effective dose equivalent rate from the secondary ingestion pathway.

A comparison of the ingestion committed effective dose conversion factors for selected radionuclides used in this study with those found in the literature was next conducted. The radionuclides considered included ^{90}Sr , ^{134}Cs , ^{235}U , ^{238}U and ^{239}Pu . Comparisons with the dose per unit intake factors from ICRP 30 (1979-1988) and from Federal Guidance Report No. 11 (EPA 1988) showed agreement within a few percent. This agreement verifies that the basic ingestion dose conversion factors used in this study are consistent with the ICRP methods and with other Federal guidance.

TABLE 2.3. Ingestion Committed Effective Dose Rate Conversion Factors for Exposure to Residual Radioactive Materials

<u>Radionuclide</u>	<u>mrem/pCi</u>	<u>μSv/Bq</u>
³ H	5.7E-08	1.5E-05
¹⁰ Be	4.6E-06	1.2E-03
¹⁴ C	1.9E-06	5.1E-04
¹⁸ F	1.1E-07	3.0E-05
²² Na	1.4E-05	3.8E-03
²⁴ Na	1.4E-06	3.8E-04
³² P	8.5E-06	2.3E-03
³³ P	8.7E-07	2.3E-04
³⁵ S	4.0E-07	1.1E-04
³⁸ Cl	2.8E-06	7.6E-04
⁴⁰ K	1.7E-05	4.6E-03
⁴¹ Ca	1.2E-06	3.2E-04
⁴⁵ Ca	3.1E-06	8.4E-04
⁴⁸ Sc	6.2E-06	1.7E-03
⁵¹ Cr	1.4E-07	3.8E-05
⁵⁴ Mn	2.8E-06	7.6E-04
⁵⁶ Mn	1.0E-06	2.7E-04
⁵⁵ Fe	5.8E-07	1.6E-04
⁵⁹ Fe	6.5E-06	1.8E-03
⁵⁷ Co	7.5E-07	2.0E-04
⁵⁸ Co	2.9E-06	7.8E-04
⁶⁰ Co	1.0E-05	2.7E-03
⁵⁹ Ni	1.9E-07	5.1E-05
⁶³ Ni	5.1E-07	1.4E-04
⁶⁵ Ni	6.5E-07	1.8E-04
⁶⁴ Cu	4.8E-07	1.3E-04
⁶⁵ Zn	1.3E-05	3.5E-03
^{69m} Zn+D (a)	7.0E-07	1.9E-04
^{69m} Zn	1.3E-06	3.5E-04
⁶⁹ Zn	8.9E-08	2.4E-05

TABLE 2.3. Ingestion Committed Effective Dose Rate Conversion Factors for Exposure to Residual Radioactive Materials (contd)

<u>Radionuclide</u>	<u>mrem/pCi</u>	<u>μSv/Bq</u>
⁷⁶ As	5.3E-06	1.4E-03
⁷⁵ Se	8.9E-06	2.4E-03
⁷⁹ Se	8.0E-06	2.2E-03
⁸² Br	1.6E-06	4.3E-04
⁸³ Br+D (a)	4.7E-08	1.3E-05
⁸³ Br	9.4E-08	2.5E-05
⁸⁴ Br	1.8E-07	4.9E-05
⁸⁶ Rb	9.1E-06	2.5E-03
⁸⁸ Rb	1.8E-07	4.9E-05
⁸⁹ Rb+D (a)	4.4E-06	1.2E-03
⁸⁹ Rb	9.5E-08	2.6E-05
⁸⁵ Sr	1.7E-06	4.6E-04
⁸⁹ Sr	8.7E-06	2.3E-03
⁹⁰ Sr+D (a)	6.5E-05	1.8E-02
⁹⁰ Sr	1.2E-04	3.2E-02
⁹¹ Sr+D (a)	4.7E-06	1.3E-03
⁹¹ Sr	2.4E-06	6.5E-04
⁹² Sr+D (a)	1.8E-06	4.9E-04
⁹² Sr	1.6E-06	4.3E-04
⁹⁰ Y	1.1E-05	3.0E-03
^{91m} Y+D (a)	4.7E-06	1.3E-03
^{91m} Y	4.1E-08	1.1E-05
⁹¹ Y	9.4E-06	2.5E-03
⁹² Y	2.0E-06	5.4E-04
⁹³ Y	4.8E-06	1.3E-03
⁹³ Zr+D (a)	1.0E-06	2.8E-04
⁹³ Zr	1.6E-06	4.3E-04
⁹⁵ Zr+D (a)	3.1E-06	8.5E-04
⁹⁵ Zr	3.7E-06	1.0E-03
⁹⁷ Zr+D (a)	2.9E-06	7.9E-04
⁹⁷ Zr	8.4E-06	2.3E-03
^{93m} Nb	5.0E-07	1.3E-04
⁹⁴ Nb	7.2E-06	1.9E-03
^{95m} Nb+D (a)	2.4E-06	6.5E-04
^{95m} Nb	2.3E-06	6.2E-04
⁹⁵ Nb	2.5E-06	6.7E-04
^{97m} Nb+D (a)	1.2E-07	3.2E-05
^{97m} Nb	3.9E-09	1.1E-06
⁹⁷ Nb	2.4E-07	6.5E-05

TABLE 2.3. Ingestion Committed Effective Dose Rate Conversion Factors
for Exposure to Residual Radioactive Materials (contd)

Radionuclide	mrem/pCi	μ Sv/Bq
$^{93}\text{Mo}+\text{D}$ (a)	9.0E-07	2.4E-04
^{93}Mo	1.4E-06	3.8E-04
$^{99}\text{Mo}+\text{D}$ (a)	1.6E-06	4.4E-04
^{99}Mo	3.1E-06	8.4E-04
$^{99\text{m}}\text{Tc}$	8.3E-08	2.2E-05
^{99}Tc	3.1E-06	8.4E-04
^{101}Tc	7.5E-08	2.0E-05
$^{103}\text{Ru}+\text{D}$ (a)	1.5E-06	4.1E-04
^{103}Ru	3.0E-06	8.1E-04
$^{105}\text{Ru}+\text{D}$ (a)	9.0E-07	2.4E-04
$^{105}\text{Ru}+\text{I}$ (b)	1.3E-06	3.5E-04
$^{106}\text{Ru}+\text{I}$ (b)	1.3E-05	3.5E-03
$^{103\text{m}}\text{Rh}$	1.2E-08	3.2E-06
^{105}Rh	1.5E-06	4.1E-04
$^{103}\text{Pd}+\text{D}$ (a)	4.0E-07	1.1E-04
^{103}Pd	7.8E-07	2.1E-04
^{107}Pd	1.5E-07	4.1E-05
$^{109}\text{Pd}+\text{I}$ (b)	1.3E-06	3.5E-04
$^{110\text{m}}\text{Ag}+\text{I}$ (b)	1.7E-05	4.5E-03
^{111}Ag	5.1E-06	1.4E-03
^{109}Cd	1.3E-05	3.5E-03
$^{113\text{m}}\text{Cd}$	1.6E-04	4.3E-02
$^{115\text{m}}\text{Cd}+\text{D}$ (a)	8.0E-06	2.2E-03
$^{115\text{m}}\text{Cd}$	1.6E-05	4.3E-03
^{115}Cd	6.1E-06	1.6E-03
^{111}In	1.3E-06	3.5E-04
$^{114\text{m}}\text{In}+\text{I}$ (b)	7.7E-06	2.1E-03
$^{115\text{m}}\text{In}$	3.5E-07	9.4E-05
$^{117\text{m}}\text{Sn}$	2.9E-06	7.8E-04
$^{119\text{m}}\text{Sn}$	1.4E-06	3.8E-04
$^{121\text{m}}\text{Sn}+\text{D}$ (a)	1.2E-06	3.3E-04
$^{121\text{m}}\text{Sn}$	1.5E-06	4.1E-04
^{121}Sn	9.1E-07	2.5E-04
^{123}Sn	8.4E-06	2.3E-03
$^{125}\text{Sn}+\text{D}$ (a)	7.2E-06	1.9E-03
^{125}Sn	1.2E-05	3.2E-03
$^{126}\text{Sn}+\text{D}$ (a)	9.8E-06	2.6E-03
^{126}Sn	1.9E-05	5.1E-03

TABLE 2.3. Ingestion Committed Effective Dose Rate Conversion Factors
for Exposure to Residual Radioactive Materials (contd)

<u>Radionuclide</u>	<u>mrem/pCi</u>	<u>μSv/Bq</u>
¹²⁴ Sb	9.9E-06	2.7E-03
¹²⁵ Sb+D (a)	2.9E-06	7.9E-04
¹²⁵ Sb	2.8E-06	7.6E-04
^{126m} Sb+D (a)	1.3E-06	3.6E-04
^{126m} Sb	9.1E-08	2.5E-05
¹²⁶ Sb	1.0E-05	2.7E-03
¹²⁷ Sb+D (a)	4.3E-06	1.2E-03
¹²⁷ Sb	7.2E-06	1.9E-03
^{123m} Te	5.7E-06	1.5E-03
^{125m} Te	3.7E-06	1.0E-03
^{127m} Te+D (a)	4.5E-06	1.2E-03
^{127m} Te	8.2E-06	2.2E-03
¹²⁷ Te	7.1E-07	1.9E-04
^{129m} Te+D (a)	3.3E-04	9.0E-02
^{129m} Te	5.4E-04	1.5E-01
¹²⁹ Te	2.6E-07	7.0E-05
^{131m} Te+D (a)	3.0E-05	8.1E-03
^{131m} Te	1.7E-05	4.6E-03
¹³¹ Te+D (a)	2.5E-05	6.7E-03
¹³¹ Te	2.1E-07	5.7E-05
¹³² Te+D (a)	7.5E-06	2.0E-03
¹³² Te	1.5E-05	4.1E-03
^{133m} Te+D (a)	3.5E-06	9.4E-04
^{133m} Te	7.8E-07	2.1E-04
¹³³ Te+D (a)	3.3E-06	8.8E-04
¹³³ Te	1.6E-07	4.3E-05
¹³⁴ Te+D (a)	2.3E-07	6.1E-05
¹³⁴ Te	1.9E-07	5.1E-05
¹²⁵ I	3.6E-05	9.7E-03
¹²⁹ I	2.5E-04	6.8E-02
¹³⁰ I	4.4E-06	1.2E-03
¹³¹ I+D (a)	4.9E-05	1.3E-02
¹³¹ I	5.0E-05	1.4E-02
¹³² I	6.9E-07	1.9E-04
¹³³ I+D (a)	4.8E-06	1.3E-03
¹³³ I	9.7E-06	2.6E-03
¹³⁴ I	2.6E-07	7.0E-05
¹³⁵ I+D (a)	9.7E-07	2.6E-04
¹³⁵ I	2.1E-06	5.7E-04
^{134m} Cs+D (a)	1.8E-08	4.9E-06
^{134m} Cs	3.6E-08	9.7E-06
¹³⁴ Cs	6.7E-05	1.8E-02
¹³⁵ Cs	6.4E-06	1.7E-03
¹³⁶ Cs	1.0E-05	2.7E-03

TABLE 2.3. Ingestion Committed Effective Dose Rate Conversion Factors
for Exposure to Residual Radioactive Materials (contd)

<u>Radionuclide</u>	<u>mrem/pCi</u>	<u>μSv/Bq</u>
¹³⁷ Cs+I (b)	2.4E-05	6.4E-03
¹³⁸ Cs	1.9E-07	5.1E-05
¹³⁹ Ba	4.1E-07	1.1E-04
¹⁴⁰ Ba+D (a)	8.5E-06	2.3E-03
¹⁴⁰ Ba	9.1E-06	2.5E-03
¹⁴¹ Ba+D (a)	1.5E-06	4.1E-04
¹⁴¹ Ba	2.1E-07	5.7E-05
¹⁴² Ba+D (a)	4.1E-07	1.1E-04
¹⁴² Ba	1.1E-07	3.0E-05
¹⁴⁰ La	8.3E-06	2.2E-03
¹⁴¹ La+D (a)	2.2E-06	5.9E-04
¹⁴¹ La	1.5E-06	4.1E-04
¹⁴² La	7.0E-07	1.9E-04
¹⁴¹ Ce	2.9E-06	7.8E-04
¹⁴³ Ce+D (a)	4.6E-06	1.3E-03
¹⁴³ Ce	4.6E-06	1.2E-03
¹⁴⁴ Ce+D (a)	1.0E-05	2.8E-03
¹⁴⁴ Ce	2.1E-05	5.7E-03
¹⁴³ Pr	4.7E-06	1.3E-03
¹⁴⁴ Pr+D (a)	8.5E-08	2.3E-05
¹⁴⁴ Pr	4.8E-08	1.3E-05
¹⁴⁴ Pr	1.2E-07	3.2E-05
¹⁴⁷ Nd+D (a)	2.6E-06	7.0E-04
¹⁴⁷ Nd	4.2E-06	1.1E-03
¹⁴⁷ Pm	1.0E-06	2.7E-04
¹⁴⁸ Pm+D (a)	7.8E-06	2.1E-03
¹⁴⁸ Pm	7.6E-06	2.1E-03
¹⁴⁸ Pm	1.1E-05	3.0E-03
¹⁴⁹ Pm	4.1E-06	1.1E-03
¹⁵¹ Pm	3.0E-06	8.1E-04
¹⁴⁷ Sm	1.9E-04	5.1E-02
¹⁵¹ Sm	3.8E-07	1.0E-04
¹⁵³ Sm	3.0E-06	8.1E-04
¹⁵² Eu	6.3E-06	1.7E-03
¹⁵⁴ Eu	9.2E-06	2.5E-03
¹⁵⁵ Eu	1.5E-06	4.1E-04
¹⁵⁶ Eu	9.1E-06	2.5E-03
¹⁵³ Gd	1.2E-06	3.2E-04

TABLE 2.3. Ingestion Committed Effective Dose Rate Conversion Factors
for Exposure to Residual Radioactive Materials (contd)

<u>Radionuclide</u>	<u>mrem/pCi</u>	<u>μSv/Bq</u>
¹⁶⁰ Tb	6.6E-06	1.8E-03
^{166m} Ho	7.7E-06	2.1E-03
¹⁸¹ W	2.9E-07	7.8E-05
¹⁸⁵ W	1.6E-06	4.3E-04
¹⁸⁷ W	2.1E-06	5.7E-04
¹⁸⁷ Re	1.4E-08	3.8E-06
¹⁸⁵ Os	2.2E-06	5.9E-04
¹⁹¹ Os	2.3E-06	6.2E-04
¹⁹² Ir	5.7E-06	1.5E-03
²⁰³ Hg	1.1E-05	3.0E-03
²¹⁰ Pb+D (a)	2.4E-03	6.6E-01
²¹⁰ Pb	5.4E-03	1.5E+00
²¹² Pb+D (a)	1.7E-05	4.5E-03
²¹² Pb	4.9E-05	1.3E-02
²¹⁰ Bi+D (a)	9.5E-04	2.6E-01
²¹⁰ Bi	6.3E-06	1.7E-03
²¹² Bi+I (b)	5.5E-07	1.5E-04
²¹⁰ Po	1.9E-03	5.1E-01
²²³ Ra+I (b)	4.5E-05	1.2E-02
²²⁴ Ra+D (a)	3.0E-05	8.1E-03
²²⁴ Ra+I (b)	1.3E-04	3.5E-02
²²⁵ Ra+D (a)	4.7E-05	1.3E-02
²²⁵ Ra	2.2E-04	5.9E-02
²²⁶ Ra+D (a)	9.1E-04	2.5E-01
²²⁶ Ra	9.5E-04	2.6E-01
²²⁸ Ra+D (a)	1.6E-04	4.2E-02
²²⁸ Ra	8.4E-04	2.3E-01
²²⁵ Ac+I (b)	1.8E-05	4.9E-03
²²⁷ Ac+D (a)	1.8E-03	4.7E-01
²²⁷ Ac	1.4E-02	3.8E+00
²²⁸ Ac+D (a)	7.2E-05	2.0E-02
²²⁸ Ac	2.1E-06	5.7E-04
²²⁷ Th+D (a)	4.4E-05	1.2E-02
²²⁷ Th	3.8E-05	1.0E-02
²²⁸ Th+D (a)	8.1E-05	2.2E-02

TABLE 2.3. Ingestion Committed Effective Dose Rate Conversion Factors for Exposure to Residual Radioactive Materials (contd)

Radionuclide	mrem/pCi	μ Sv/Bq
²²⁸ Th	4.0E-04	1.1E-01
²²⁹ Th+D (a)	4.8E-04	1.3E-01
²²⁹ Th	3.5E-03	9.5E-01
²³⁰ Th+D (a)	8.8E-04	2.4E-01
²³⁰ Th	5.4E-04	1.5E-01
²³¹ Th+D (a)	1.3E-07	3.5E-05
²³¹ Th	1.3E-06	3.5E-04
²³² Th+D (a)	4.2E-04	1.1E-01
²³² Th-Nat (c)	4.2E-04	1.1E-01
²³² Th	2.8E-03	7.6E-01
²³⁴ Th+D (a)	6.5E-06	1.8E-03
²³⁴ Th+I (b)	1.3E-05	3.5E-03
²³¹ Pa+D (a)	2.8E-03	7.5E-01
²³¹ Pa	1.1E-02	3.0E+00
²³³ Pa	3.6E-06	9.7E-04
²³⁴ Pa	2.2E-06	5.9E-04
²³² U+D (a)	9.7E-06	2.6E-03
²³² U	6.8E-05	1.8E-02
²³³ U+D (a)	4.3E-04	1.2E-01
²³³ U	2.6E-05	7.0E-03
²³⁴ U	2.6E-05	7.0E-03
²³⁵ U+D (a)	1.4E-05	3.8E-03
²³⁵ U	2.6E-05	7.0E-03
²³⁶ U	2.4E-05	6.5E-03
²³⁷ U	3.2E-06	8.6E-04
²³⁸ U+D (a)	1.2E-05	3.3E-03
²³⁸ U	2.4E-05	6.5E-03
²³⁸ U-Nat (d)	2.5E-05	6.8E-03
²⁴⁰ U+D (a)	1.6E-06	4.2E-04
²⁴⁰ U+I (b)	4.7E-06	1.3E-03
²³⁷ Np+D (a)	2.6E-03	7.0E-01
²³⁷ Np	5.2E-03	1.4E+00
²³⁸ Np+D (a)	1.7E-04	4.6E-02
²³⁸ Np	4.0E-06	1.1E-03
²³⁹ Np+D (a)	1.7E-06	4.5E-04
²³⁹ Np	3.3E-06	8.9E-04
²³⁸ Pu	6.3E-05	1.7E-02
²³⁷ Pu	4.3E-07	1.2E-04
²³⁸ Pu	3.4E-04	9.2E-02
²³⁹ Pu	3.7E-04	1.0E-01
²⁴⁰ Pu	3.7E-04	1.0E-01
²⁴¹ Pu+D (a)	1.8E-03	4.9E-01
²⁴¹ Pu	6.8E-06	1.8E-03

TABLE 2.3. Ingestion Committed Effective Dose Rate Conversion Factors
for Exposure to Residual Radioactive Materials (contd)

Radionuclide	mrem/pCi	μ Sv/Bq
²⁴² Pu	3.4E-04	9.2E-02
²⁴³ Pu+D (a)	1.6E-07	4.3E-05
²⁴³ Pu	3.2E-07	8.6E-05
²⁴⁴ Pu+D (a)	9.0E-05	2.4E-02
²⁴⁴ Pu	3.5E-04	9.4E-02
²⁴¹ Am	3.6E-03	9.7E-01
^{242m} Am+D (a)	9.9E-04	2.7E-01
^{242m} Am	3.5E-03	9.5E-01
²⁴² Am+D (a)	1.3E-04	3.5E-02
²⁴² Am	1.4E-06	3.8E-04
²⁴³ Am+D (a)	1.2E-03	3.2E-01
²⁴³ Am	3.6E-03	9.7E-01
²⁴² Cm+D (a)	2.5E-04	6.7E-02
²⁴² Cm	1.1E-04	3.0E-02
²⁴³ Cm	2.9E-03	7.8E-01
²⁴⁴ Cm+D (a)	1.0E-03	2.7E-01
²⁴⁴ Cm	2.0E-03	5.4E-01
²⁴⁵ Cm+D (a)	2.4E-03	6.6E-01
²⁴⁵ Cm	3.7E-03	1.0E+00
²⁴⁶ Cm	3.7E-03	1.0E+00
²⁴⁷ Cm+D (a)	1.7E-03	4.6E-01
²⁴⁷ Cm	3.4E-03	9.2E-01
²⁴⁸ Cm	1.3E-02	3.5E+00
²⁵² Cf	1.1E-03	3.0E-01

- (a) Where +D means "plus daughters in equilibrium" referring to explicit daughters, or daughters with half-lives greater than 10 minutes. Separate values are also included for parents and daughters so that combined factors for non-equilibrium cases can be determined. Note: in some cases +D also includes implicit daughters (i.e., uranium and thorium decay chains).
- (b) Where +I means "plus implicit daughters in equilibrium" referring to daughters with half-lives less than 10 minutes. The decay energies associated with these daughters have been assigned to the parent, and the appropriate branching ratios (described in Appendix D) have been considered.
- (c) Where Th-Nat includes an equilibrium mixture of ²³²Th plus 10 daughters in the decay chain, as discussed in Appendix D.
- (d) Where 1 Ci U-Nat equals 48.9% ²³⁸U plus 48.9% ²³⁴U plus 2.25% ²³⁵U.

2.2.4 Drinking Water Ingestion

For sites contaminated with residual radioactivity in soils, the potential exists for contamination of ground-water sources. Appendix B contains a brief discussion of models that could apply to generic drinking-water contamination situations. These models can be used to estimate the concentration of radionuclides in a ground-water source that could provide drinking water through a well. The concentration is calculated based on the entire inventory (pCi or Bq) in soils or in buildings that could be demolished as left as buried rubble, not the concentration (pCi/g or Bq/g) in the soil or building materials. The general equation for estimating the committed dose rate by ingestion of drinking water containing radionuclide i is:

$$H_{DW,i} = Q_{DW} C_{DW,i} D_{FING,i} \quad (2.4)$$

where $H_{DW,i}$ = the committed effective dose equivalent from a 1-yr intake of radionuclide i by ingestion of drinking water, in mrem (μ Sv) per year of intake

Q_{DW} = the quantity of drinking water ingested during a year, in L

$C_{DW,i}$ = the concentration of radionuclide i in the drinking water, in pCi/L (Bq/L)

$D_{FING,i}$ = the committed effective dose equivalent factor from ingestion of radionuclide i , in mrem/pCi (μ Sv/Bq) per year of intake.

Parameter values for the quantity of drinking water ingested during a year and the concentration of radionuclides in the drinking water are scenario specific, as discussed in Appendix B. Committed effective dose conversion factors for ingestion are shown in Table 2.3. These factors apply to both secondary ingestion and drinking water and are in units of mrem/pCi and μ Sv/Bq ingested. Scenario-specific estimates of the committed effective dose equivalent from ingestion of drinking water can be obtained by multiplying the factors shown in Table 2.3 by the quantity of drinking water consumed during a year (L) and the concentration of radionuclides in that water source (pCi/L or Bq/L). For comparison with U.S. Environmental Protection Agency (EPA) drinking water standards, expressed in terms of organ dose limits, maximum organ doses by radionuclide are needed. Table 2.4 lists the maximum organ dose per unit of intake (mrem/pCi and μ Sv/Bq) and the limiting organ for each radionuclide. It should be noted that the maximum organ doses shown in Table 2.4 are based on the dosimetry models, metabolic data, and recommendations of the ICRP in Publication 30 (1977-1988).

TABLE 2.4. Maximum Organ Dose Rate Conversion Factors
for Ingestion of Drinking Water

<u>Radionuclide</u>	<u>mrem/pCi</u>	<u>μSv/Bq</u>	<u>Limiting Organ(a)</u>
³ H	6.7E-08	1.8E-05	SI Wall
¹⁰ Be	4.8E-05	1.3E-02	LLI Wall
¹⁴ C	2.3E-06	6.2E-04	LLI Wall
¹⁸ F	1.1E-06	3.0E-04	Stomach Wall
²² Na	2.3E-05	6.2E-03	Bone Surface
²⁴ Na	4.4E-06	1.2E-03	Stomach Wall
³² P	3.1E-05	8.4E-03	Red Marrow
³³ P	4.8E-06	1.3E-03	Bone Surface
³⁵ S	2.0E-06	5.4E-04	LLI Wall
³⁶ Cl	3.2E-06	8.6E-04	SI Wall
⁴⁰ K	2.0E-05	5.4E-03	SI Wall
⁴¹ Ca	1.5E-05	4.1E-03	Bone Surface
⁴⁵ Ca	1.9E-05	5.1E-03	Bone Surface
⁴⁸ Sc	3.7E-05	1.0E-02	LLI Wall
⁵¹ Cr	9.2E-07	2.5E-04	LLI Wall
⁵⁴ Mn	8.5E-06	2.3E-03	LLI Wall
⁵⁶ Mn	5.2E-06	1.4E-03	ULI Wall
⁵⁵ Fe	2.1E-06	5.7E-04	Spleen
⁵⁹ Fe	3.1E-05	8.4E-03	LLI Wall
⁵⁷ Co	4.8E-06	1.3E-03	LLI Wall
⁵⁸ Co	1.4E-05	3.8E-03	LLI Wall
⁶⁰ Co	4.3E-05	1.2E-02	LLI Wall
⁵⁹ Ni	9.7E-07	2.6E-04	LLI Wall
⁶³ Ni	3.2E-06	8.6E-04	LLI Wall
⁶⁵ Ni	3.6E-06	9.7E-04	ULI Wall
⁶⁴ Cu	2.9E-06	7.8E-04	LLI Wall
⁶⁵ Zn	1.7E-05	4.6E-03	LLI Wall
^{69m} Zn+D ^(b)	4.4E-06	1.2E-03	LLI Wall
^{69m} Zn	8.9E-06	2.4E-03	LLI Wall
⁶⁹ Zn	7.8E-07	2.1E-04	Stomach Wall

TABLE 2.4. Maximum Organ Dose Rate Conversion Factors
for Ingestion of Drinking Water (contd)

<u>Radionuclide</u>	<u>mrem/pCi</u>	<u>μSv/Bq</u>	<u>Limiting Organ(a)</u>
⁷⁶ As	4.4E-05	1.2E-02	LLI Wall
⁷⁵ Se	2.6E-05	7.0E-03	Kidneys
⁷⁹ Se	4.8E-05	1.3E-02	Kidneys
⁸² Br	3.0E-06	8.1E-04	Stomach Wall
⁸³ Br+D (b)	5.5E-07	1.5E-04	Stomach Wall
⁸³ Br	1.1E-06	3.0E-04	Stomach Wall
⁸⁴ Br	2.6E-06	7.0E-04	Stomach Wall
⁸⁶ Rb	2.7E-05	7.3E-03	Bone Surface
⁸⁸ Rb	2.8E-06	7.6E-04	Stomach Wall
⁸⁹ Rb+D (b)	3.9E-05	1.1E-02	LLI Wall
⁸⁹ Rb	1.4E-06	3.8E-04	Stomach Wall
⁸⁵ Sr	5.2E-06	1.4E-03	LLI Wall
⁸⁹ Sr	7.8E-05	2.1E-02	LLI Wall
⁹⁰ Sr+D (b)	7.0E-04	1.9E-01	Bone Surface
⁹⁰ Sr	1.4E-03	3.8E-01	Bone Surface
⁹¹ Sr+D (b)	5.1E-05	1.4E-02	LLI Wall
⁹¹ Sr	1.4E-05	3.8E-03	LLI Wall
⁹² Sr+D (b)	1.2E-05	3.2E-03	ULI Wall
⁹² Sr	1.1E-05	3.0E-03	ULI Wall
⁹⁰ Y	1.2E-04	3.2E-02	LLI Wall
^{91m} Y+D (b)	5.5E-05	1.5E-02	LLI Wall
^{91m} Y	1.9E-07	5.1E-05	Stomach Wall
⁹¹ Y	1.1E-04	3.0E-02	LLI Wall
⁹² Y	1.3E-05	3.5E-03	ULI Wall
⁹³ Y	3.5E-05	9.5E-03	LLI Wall
⁹³ Zr+D (b)	1.7E-05	4.5E-03	Bone Surface
⁹³ Zr	3.3E-05	8.9E-03	Bone Surface
⁹⁵ Zr+D (b)	2.2E-05	5.9E-03	LLI Wall
⁹⁵ Zr	2.9E-05	7.8E-03	LLI Wall
⁹⁷ Zr+D (b)	2.3E-05	6.1E-03	LLI Wall
⁹⁷ Zr	6.7E-05	1.8E-02	LLI Wall
^{93m} Nb	5.6E-06	1.5E-03	LLI Wall
⁹⁴ Nb	4.8E-05	1.3E-02	LLI Wall
^{95m} Nb+D (b)	2.0E-05	5.3E-03	LLI Wall
^{95m} Nb	2.4E-05	6.5E-03	LLI Wall
⁹⁵ Nb	1.5E-05	4.1E-03	LLI Wall
^{97m} Nb+D (b)	7.0E-07	1.9E-04	Stomach Wall
^{97m} Nb	2.7E-08	7.3E-06	Stomach Wall
⁹⁷ Nb	1.4E-06	3.8E-04	Stomach Wall

TABLE 2.4. Maximum Organ Dose Rate Conversion Factors
for Ingestion of Drinking Water (contd)

<u>Radionuclide</u>	<u>mrem/pCi</u>	<u>μSv/Bq</u>	<u>Limiting Organ(a)</u>
⁹³ Mo+D (b)	3.4E-06	9.0E-04	Liver
⁹³ Mo	6.7E-06	1.8E-03	Liver
⁹⁹ Mo+D (b)	6.4E-06	1.7E-03	LLI Wall
⁹⁹ Mo	1.1E-05	3.0E-03	LLI Wall
^{99m} Tc	4.1E-07	1.1E-04	ULI Wall
⁹⁹ Tc	2.7E-05	7.3E-03	Thyroid
¹⁰¹ Tc	5.7E-07	1.5E-04	ULI Wall
¹⁰³ Ru+D (b)	1.2E-05	3.2E-03	LLI Wall
¹⁰³ Ru	2.4E-05	6.5E-03	LLI Wall
¹⁰⁵ Ru+D (b)	6.7E-06	1.8E-03	LLI Wall
¹⁰⁵ Ru+I (c)	7.0E-06	1.9E-03	ULI Wall
¹⁰⁶ Ru+I (c)	1.3E-04	3.5E-02	LLI Wall
^{103m} Rh	9.6E-08	2.6E-05	Stomach Wall
¹⁰⁵ Rh	1.4E-05	3.8E-03	LLI Wall
¹⁰³ Pd+D (b)	4.3E-06	1.1E-03	LLI Wall
¹⁰³ Pd	8.5E-06	2.3E-03	LLI Wall
¹⁰⁷ Pd	1.7E-06	4.6E-04	LLI Wall
¹⁰⁹ Pd+I (c)	1.0E-05	2.8E-03	LLI Wall
^{110m} Ag+I (c)	1.3E-04	3.4E-02	LLI Wall
¹¹¹ Ag	5.5E-05	1.5E-02	LLI Wall
¹⁰⁹ Cd	1.5E-04	4.1E-02	Kidneys
^{113m} Cd	2.1E-03	5.7E-01	Kidneys
^{115m} Cd+D (b)	5.0E-05	1.4E-02	LLI Wall
^{115m} Cd	1.0E-04	2.7E-02	LLI Wall
¹¹⁵ Cd	5.7E-05	1.5E-02	LLI Wall
¹¹¹ In	7.4E-06	2.0E-03	LLI Wall
^{114m} In+I (c)	8.2E-05	2.2E-02	LLI Wall
^{115m} In	2.1E-06	5.7E-04	ULI Wall
^{117m} Sn	3.0E-05	8.1E-03	LLI Wall
^{119m} Sn	1.5E-05	4.1E-03	LLI Wall
^{121m} Sn+D (b)	1.3E-05	3.5E-03	LLI Wall
^{121m} Sn	1.6E-05	4.3E-03	LLI Wall
¹²¹ Sn	8.9E-06	2.4E-03	LLI Wall
¹²³ Sn	9.6E-05	2.6E-02	LLI Wall
¹²⁵ Sn+D (b)	7.2E-05	1.9E-02	LLI Wall
¹²⁵ Sn	1.3E-04	3.5E-02	LLI Wall
¹²⁶ Sn+D (b)	7.9E-05	2.1E-02	LLI Wall
¹²⁶ Sn	1.6E-04	4.3E-02	LLI Wall

TABLE 2.4. Maximum Organ Dose Rate Conversion Factors
for Ingestion of Drinking Water (contd)

Radionuclide	mrem/pCi	μ Sv/Bq	Limiting Organ(a)
¹²⁴ Sb	8.5E-05	2.3E-02	LLI Wall
¹²⁵ Sb+D (b)	2.3E-05	6.1E-03	LLI Wall
¹²⁵ Sb	2.4E-05	6.5E-03	LLI Wall
^{126m} Sb+D (b)	8.7E-06	2.3E-03	LLI Wall
^{126m} Sb	9.6E-07	2.6E-04	Stomach Wall
¹²⁶ Sb	7.0E-05	1.9E-02	LLI Wall
¹²⁷ Sb+D (b)	4.0E-05	1.1E-02	LLI Wall
¹²⁷ Sb	7.4E-05	2.0E-02	LLI Wall
^{123m} Te	9.2E-05	2.5E-02	Bone Surface
^{125m} Te	4.9E-05	1.3E-02	Bone Surface
^{127m} Te+D (b)	3.9E-05	1.1E-02	Bone Surface
^{127m} Te	7.8E-05	2.1E-02	Bone Surface
¹²⁷ Te	4.8E-06	1.3E-03	LLI Wall
^{129m} Te+D (b)	1.3E-03	3.5E-01	Testes
^{129m} Te	2.1E-03	5.7E-01	Testes
¹²⁹ Te	1.5E-06	4.1E-04	Stomach Wall
^{131m} Te+D (b)	8.1E-04	2.2E-01	Thyroid
^{131m} Te	1.4E-04	3.8E-02	Thyroid
¹³¹ Te+D (b)	8.0E-04	2.1E-01	Thyroid
¹³¹ Te	3.3E-06	8.9E-04	Thyroid
¹³² Te+D (b)	8.0E-05	2.2E-02	Thyroid
¹³² Te	1.5E-04	4.1E-02	Thyroid
^{133m} Te+D (b)	9.8E-05	2.6E-02	Thyroid
^{133m} Te	1.3E-05	3.5E-03	Thyroid
¹³³ Te+D (b)	9.9E-05	2.7E-02	Thyroid
¹³³ Te	3.0E-06	8.1E-04	Thyroid
¹³⁴ Te+D (b)	1.9E-06	5.1E-04	Thyroid
¹³⁴ Te	2.1E-06	5.7E-04	Thyroid
¹²⁵ I	1.2E-03	3.2E-01	Thyroid
¹²⁹ I	8.3E-03	2.2E+00	Thyroid
¹³⁰ I	1.2E-04	3.2E-02	Thyroid
¹³¹ I+D (b)	1.6E-03	4.3E-01	Thyroid
¹³¹ I	1.6E-03	4.3E-01	Thyroid
¹³² I	1.0E-05	2.7E-03	Thyroid
¹³³ I+D (b)	1.5E-04	4.0E-02	Thyroid
¹³³ I	3.0E-04	8.1E-02	Thyroid
¹³⁴ I	2.1E-06	5.7E-04	Stomach Wall
¹³⁵ I+D (b)	2.4E-05	6.5E-03	Thyroid
¹³⁵ I	5.2E-05	1.4E-02	Thyroid
^{134m} Cs+D (b)	2.1E-07	5.5E-05	Stomach Wall
^{134m} Cs	4.1E-07	1.1E-04	Stomach Wall
¹³⁴ Cs	8.8E-05	2.4E-02	SI Wall
¹³⁵ Cs	7.8E-06	2.1E-03	SI Wall
¹³⁶ Cs	1.4E-05	3.8E-03	SI Wall

TABLE 2.4. Maximum Organ Dose Rate Conversion Factors
for Ingestion of Drinking Water (contd)

Radionuclide	mrem/pCi	$\mu\text{Sv/Bq}$	Limiting Organ(a)
¹³⁷ Cs+I (c)	2.9E-05	7.9E-03	SI Wall
¹³⁸ Cs	2.7E-06	7.3E-04	Stomach Wall
¹³⁹ Ba	2.6E-06	7.0E-04	Stomach Wall
¹⁴⁰ Ba+D (b)	8.0E-05	2.2E-02	LLI Wall
¹⁴⁰ Ba	9.6E-05	2.6E-02	LLI Wall
¹⁴¹ Ba+D (b)	1.3E-05	3.5E-03	LLI Wall
¹⁴¹ Ba	1.4E-06	3.8E-04	Stomach Wall
¹⁴² Ba+D (b)	2.0E-06	5.4E-04	Stomach Wall
¹⁴² Ba	7.4E-07	2.0E-04	Stomach Wall
¹⁴⁰ La	6.3E-05	1.7E-02	LLI Wall
¹⁴¹ La+D (b)	1.9E-05	5.1E-03	LLI Wall
¹⁴¹ La	9.6E-06	2.6E-03	ULI Wall
¹⁴² La	3.3E-06	8.9E-04	Stomach Wall
¹⁴¹ Ce	3.2E-05	8.6E-03	LLI Wall
¹⁴³ Ce+D (b)	5.0E-05	1.4E-02	LLI Wall
¹⁴³ Ce	4.4E-05	1.2E-02	LLI Wall
¹⁴⁴ Ce+D (b)	1.2E-04	3.4E-02	LLI Wall
¹⁴⁴ Ce	2.5E-04	6.8E-02	LLI Wall
¹⁴³ Pr	5.5E-05	1.5E-02	LLI Wall
^{144m} Pr+D (b)	1.0E-06	2.8E-04	Stomach Wall
^{144m} Pr	5.5E-07	1.5E-04	Stomach Wall
¹⁴⁴ Pr	1.6E-06	4.3E-04	Stomach Wall
¹⁴⁷ Nd+D (b)	2.8E-05	7.6E-03	LLI Wall
¹⁴⁷ Nd	4.4E-05	1.2E-02	LLI Wall
¹⁴⁷ Pm	1.2E-05	3.2E-03	LLI Wall
^{148m} Pm+D (b)	5.5E-05	1.5E-02	LLI Wall
^{148m} Pm	5.2E-05	1.4E-02	LLI Wall
¹⁴⁸ Pm	1.2E-04	3.2E-02	LLI Wall
¹⁴⁹ Pm	4.4E-05	1.2E-02	LLI Wall
¹⁵¹ Pm	2.7E-05	7.3E-03	LLI Wall
¹⁴⁷ Sm	3.2E-03	8.6E-01	Bone Surface
¹⁵¹ Sm	3.7E-06	1.0E-03	LLI Wall
¹⁵³ Sm	3.0E-05	8.1E-03	LLI Wall
¹⁵² Eu	3.7E-05	1.0E-02	LLI Wall
¹⁵⁴ Eu	6.7E-05	1.8E-02	LLI Wall
¹⁵⁵ Eu	1.3E-05	3.5E-03	LLI Wall
¹⁵⁶ Eu	8.5E-05	2.3E-02	LLI Wall
¹⁵³ Gd	1.0E-05	2.7E-03	LLI Wall

TABLE 2.4. Maximum Organ Dose Rate Conversion Factors
for Ingestion of Drinking Water (contd)

Radionuclide	mrem/pCi	μ Sv/Bq	Limiting Organ(a)
^{180}Tb	5.5E-05	1.5E-02	LLI Wall
^{186}Ho	4.1E-05	1.1E-02	LLI Wall
^{181}W	1.9E-06	5.1E-04	LLI Wall
^{185}W	1.7E-05	4.6E-03	LLI Wall
^{187}W	1.7E-05	4.6E-03	LLI Wall
^{187}Re	9.0E-08	2.4E-05	ULI Wall
^{185}Os	1.0E-05	2.7E-03	LLI Wall
^{191}Os	2.4E-05	6.5E-03	LLI Wall
^{192}Ir	4.8E-05	1.3E-02	LLI Wall
^{203}Hg	7.0E-05	1.9E-02	Kidneys
$^{210}\text{Pb+D}$ (b)	2.7E-02	7.2E+00	Bone Surface
^{210}Pb	8.0E-02	2.2E+01	Bone Surface
$^{212}\text{Pb+D}$ (b)	2.2E-04	6.0E-02	Bone Surface
^{212}Pb	6.7E-04	1.8E-01	Bone Surface
$^{210}\text{Bi+D}$ (b)	8.0E-03	2.2E+00	Spleen
^{210}Bi	5.5E-05	1.5E-02	LLI Wall
$^{212}\text{Bi+I}$ (c)	2.9E-06	8.0E-04	Stomach Wall
^{210}Po	1.6E-02	4.3E+00	Spleen
$^{223}\text{Ra+I}$ (c)	6.8E-04	1.8E-01	Bone Surface
$^{224}\text{Ra+D}$ (b)	3.2E-04	8.6E-02	Bone Surface
$^{224}\text{Ra+I}$ (c)	1.2E-03	3.2E-01	Bone Surface
$^{226}\text{Ra+D}$ (b)	8.4E-04	2.3E-01	Bone Surface
^{226}Ra	5.6E-03	1.5E+00	Bone Surface
$^{228}\text{Ra+D}$ (b)	1.1E-02	3.0E+00	Bone Surface
^{228}Ra	2.3E-02	6.2E+00	Bone Surface
$^{228}\text{Ra+D}$ (b)	3.3E-03	9.0E-01	Bone Surface
^{228}Ra	2.0E-02	5.4E+00	Bone Surface
$^{225}\text{Ac+I}$ (c)	1.7E-04	4.5E-02	LLI Wall
$^{227}\text{Ac+D}$ (b)	3.1E-02	8.4E+00	Bone Surface
^{227}Ac	2.5E-01	6.8E+01	Bone Surface
$^{228}\text{Ac+D}$ (b)	1.4E-03	3.7E-01	Bone Surface
^{228}Ac	1.1E-05	3.0E-03	Bone Surface
$^{227}\text{Th+D}$ (b)	6.1E-04	1.7E-01	Bone Surface
^{227}Th	3.4E-04	9.2E-02	LLI Wall
$^{228}\text{Th+D}$ (b)	1.6E-03	4.2E-01	Bone Surface

**TABLE 2.4. Maximum Organ Dose Rate Conversion Factors
for Ingestion of Drinking Water (contd)**

<u>Radionuclide</u>	<u>mrem/pCi</u>	<u>μSv/Bq</u>	<u>Limiting Organ(a)</u>
²²⁸ Th	8.9E-03	2.4E+00	Bone Surface
²²⁹ Th+D (b)	1.2E-02	3.2E+00	Bone Surface
²²⁹ Th	8.8E-02	2.4E+01	Bone Surface
²³⁰ Th+D (b)	1.2E-02	3.2E+00	Bone Surface
²³⁰ Th	1.3E-02	3.5E+00	Bone Surface
²³¹ Th+D (b)	1.3E-06	3.5E-04	LLI Wall
²³¹ Th	1.3E-05	3.5E-03	LLI Wall
²³² Th+D (b)	9.9E-03	2.7E+00	Bone Surface
Th-Nat (d)	9.9E-03	2.7E+00	Bone Surface
²³² Th	6.9E-02	1.9E+01	Bone Surface
²³⁴ Th+D (b)	8.0E-05	2.2E-02	LLI Wall
²³⁴ Th+I (c)	1.6E-04	4.3E-02	LLI Wall
²³¹ Pa+D (b)	5.8E-02	1.6E+01	Bone Surface
²³¹ Pa	2.7E-01	7.3E+01	Bone Surface
²³³ Pa	3.7E-05	1.0E-02	LLI Wall
²³⁴ Pa	1.2E-05	3.2E-03	ULI Wall
²³² U+D (b)	1.4E-04	3.7E-02	Bone Surface
²³² U	9.7E-04	2.6E-01	Bone Surface
²³³ U+D (b)	1.0E-02	2.8E+00	Bone Surface
²³³ U	1.9E-04	5.1E-02	LLI Wall
²³⁴ U	1.9E-04	5.1E-02	LLI Wall
²³⁵ U+D (b)	1.0E-04	2.8E-02	LLI Wall
²³⁵ U	2.0E-04	5.4E-02	LLI Wall
²³⁶ U	1.7E-04	4.6E-02	LLI Wall
²³⁷ U	3.3E-05	8.9E-03	LLI Wall
²³⁸ U+D (b)	1.1E-04	3.0E-02	LLI Wall
²³⁸ U	1.7E-04	4.6E-02	LLI Wall
U-Nat (e)	1.8E-04	4.9E-02	LLI Wall
²⁴⁰ U+D (b)	1.2E-05	3.3E-03	LLI Wall
²⁴⁰ U+I (c)	3.7E-05	1.0E-02	LLI Wall
²³⁷ Np+D (b)	6.0E-02	1.6E+01	Bone Surface
²³⁷ Np	1.2E-01	3.2E+01	Bone Surface
²³⁸ Np+D (b)	2.9E-03	8.0E-01	Bone Surface
²³⁸ Np	3.4E-05	9.2E-03	LLI Wall
²³⁹ Np+D (b)	1.7E-05	4.5E-03	LLI Wall
²³⁹ Np	3.3E-05	8.9E-03	LLI Wall
²³⁶ Pu	7.8E-04	2.1E-01	Bone Surface
²³⁷ Pu	3.7E-06	1.0E-03	LLI Wall
²³⁸ Pu	5.9E-03	1.6E+00	Bone Surface
²³⁹ Pu	6.7E-03	1.8E+00	Bone Surface
²⁴⁰ Pu	6.7E-03	1.8E+00	Bone Surface
²⁴¹ Pu+D (b)	3.4E-02	9.2E+00	Bone Surface
²⁴¹ Pu	1.3E-04	3.5E-02	Bone Surface

TABLE 2.4. Maximum Organ Dose Rate Conversion Factors
for Ingestion of Drinking Water (contd)

<u>Radionuclide</u>	<u>mrem/pCi</u>	<u>μSv/Bq</u>	<u>Limiting Organ(a)</u>
²⁴² Pu	6.1E-03	1.6E+00	Bone Surface
²⁴³ Pu+D (b)	1.0E-06	2.8E-04	ULI Wall
²⁴³ Pu	2.1E-06	5.7E-04	ULI Wall
²⁴⁴ Pu+D (b)	1.5E-03	4.1E-01	Bone Surface
²⁴⁴ Pu	6.1E-03	1.6E+00	Bone Surface
²⁴¹ Am	6.7E-02	1.8E+01	Bone Surface
^{242m} Am+D (b)	1.9E-02	5.0E+00	Bone Surface
^{242m} Am	6.4E-02	1.7E+01	Bone Surface
²⁴² Am+D (b)	2.2E-03	6.0E-01	Bone Surface
²⁴² Am	9.6E-06	2.6E-03	LLI Wall
²⁴³ Am+D (b)	2.2E-02	6.0E+00	Bone Surface
²⁴³ Am	6.7E-02	1.8E+01	Bone Surface
²⁴² Cm+D (b)	4.1E-03	1.1E+00	Bone Surface
²⁴² Cm	1.6E-03	4.3E-01	Bone Surface
²⁴³ Cm	5.2E-02	1.4E+01	Bone Surface
²⁴⁴ Cm+D (b)	1.8E-02	4.9E+00	Bone Surface
²⁴⁴ Cm	3.6E-02	9.7E+00	Bone Surface
²⁴⁵ Cm+D (b)	4.7E-02	1.3E+01	Bone Surface
²⁴⁵ Cm	6.8E-02	1.8E+01	Bone Surface
²⁴⁶ Cm	7.0E-02	1.9E+01	Bone Surface
²⁴⁷ Cm+D (b)	3.2E-02	8.6E+00	Bone Surface
²⁴⁷ Cm	6.4E-02	1.7E+01	Bone Surface
²⁴⁸ Cm	2.5E-01	6.8E+01	Bone Surface
²⁵² Cf	2.2E-02	5.9E+00	Bone Surface

- (a) Where Si is Small Intestine, LLI is Lower Large Intestine, and ULI is Upper Large Intestine.
- (b) Where +D means "plus daughters in equilibrium" referring to explicit daughters, or daughters with half-lives greater than 10 minutes. Separate values are also included for parents and daughters so that combined factors for non-equilibrium cases can be determined. Note: in some cases +D also includes implicit daughters (i.e., uranium and thorium decay chains).
- (c) Where +I means "plus implicit daughters in equilibrium" referring to daughters with half-lives less than 10 minutes. The decay energies associated with these daughters have been assigned to the parent, and the appropriate branching ratios (described in Appendix D) have been considered.
- (d) Where Th-Nat includes an equilibrium mixture of ²³²Th plus 10 daughters in the decay chain, as discussed in Appendix D.
- (e) Where 1 Ci U-Nat equals 48.9% ²³⁸U plus 48.9% ²³⁴U plus 2.25% ²³⁵U.

2.2.5 Agricultural Pathways

Food crops may become contaminated by radionuclides deposited directly on plant surfaces from the air or from irrigation water, or by radionuclides taken up from soil previously contaminated via air or water. Many factors must be considered when calculating doses or dose rates from ingestion of these foods. These factors account for the movement of radionuclides from soil to the receptor in a complex sequence (Soldat and Harr 1971; Baker et al. 1976).

Equations used to calculate concentrations in various plant food products (i.e., the C_{ip} terms in Equation 2.1) are given in two parts: the first part accounts for direct deposition onto leaves and translocation to the edible parts of the plant, and the second accounts for long-term accumulation in the soil and consequent root uptake. The equations do not account for the rainsplash of soil onto plant surfaces or washing plant materials before ingestion. The concentration of radioactive material in vegetation resulting from direct deposition onto plant foliage and uptake of radionuclides previously deposited in the soil is determined by:

$$C_{iv} = \left\{ \frac{\left[d_i^a + d_i^I \right] r T_v \left[1 - \exp \left[-\lambda_{Ei} t \right] \right]}{\gamma_v \lambda_{Ei}} + \frac{\left[d_i^a + d_i^I \right] f_{t iv} B_{i b} \left[1 - \exp \left[-\lambda_{i b} t \right] \right]}{p \lambda_i} \right. \\ \left. + \frac{0.15 f_{t is} C_{is} B_{iv}}{p} + \frac{f_{w it} C_{w} B_{iv}}{\rho} \right\} \exp \left[-\lambda_i t_h \right] \quad (2.5)$$

where C_{iv} = concentration of radionuclide i in the edible portion of the vegetation, in pCi/kg (Bq/kg)

d_i^a = deposition rate of radionuclide i , in pCi/m²-day (Bq/m²-day):

$$d_i^a = 86,400 \chi_i V_{di} \quad (2.5a)$$

where 86,400 = dimensional conversion factor, in sec/day
 χ_i = average air concentration of radionuclide i,
in pCi/m³ (Bq/m³)

V_{di} = deposition velocity of radionuclide i, in m/sec

d_i^I = deposition rate or flux of radionuclides applied with irrigation
water, in pCi/m²-day (Bq/m²-day):

$$d_i^I = C_{iw} I \quad (2.5b)$$

where C_{iw} = the concentration of radionuclide i in the water used
for irrigation, in pCi/L (Bq/L), and I is the irrigation rate
(the amount of water sprinkled on a unit area of field in 1
day), in L/m² day

r = fraction of initially deposited material retained on the
vegetation (dimensionless)

T_v = factor for translocation of externally deposited radionuclides
to the edible parts of the vegetation (dimensionless). For
simplicity, this parameter is assumed to be independent of the
radionuclide and is assigned values of 1 for leafy vegetables
and fresh forage, and 0.1 for all other produce, including
grain.

λ_{Ei} = the effective removal constant for radionuclide i, in days⁻¹:
 $\lambda_{Ei} = \lambda_i + \lambda_w$ (2.5c)

where λ_i = the radiological decay constant for radionuclide i, in days⁻¹,
and λ_w is the weathering removal constant for vegetation,
days⁻¹, taken to be (0.693/14) days⁻¹ (i.e., a weathering half-
time of 14 d)

t_e = time of above-ground vegetation exposure to contamination during
growing season, in days

Y_v = vegetation yield, in kg/m²

f_t = fraction of the roots in the plow layer of soil (dimensionless)

B_{iv} = concentration factor for uptake of radionuclide i from the soil
in vegetation v, in pCi/kg (Bq/kg) wet weight per pCi/kg (Bq/kg)
dry soil

t_b = time for buildup of radionuclides in the soil, in days

p = soil "surface density," in kg dry soil/m². A value of 224 kg/m² is used, assuming the contaminated ground is plowed to a depth of 15 cm.

0.15 = thickness of plow layer

C_{is} = concentration of radionuclide i in soil available for plant uptake from residual contamination in the soil plow layer (top 15 cm of soil), in pCi/m² (Bq/m²)

f_w = fraction of the roots that penetrate the residual contamination (dimensionless)

C_{it} = concentration of radionuclide i available for plant uptake from subsurface contamination, in pCi/m³ (Bq/m³)

ρ = bulk density of subsurface soil, in kg/m³ (taken to be 1600 kg/m³)

t_h = holdup time between harvest and food consumption, in days.

The first term inside the brackets of Equation 2.5 relates to the concentration resulting from direct deposition of airborne and irrigation-borne material on foliage during the growing season. The second term relates to plant uptake from the soil of material previously deposited. The third and fourth terms account for uptake of radionuclides contained in the top 0.15 m of soil and below this layer, respectively. Specific values used for the parameters in Equation 2.5 are published in NRC (1977), Oztunali et. al. (1981), and Napier et al. (Vol. 1, 1988), and are discussed in Appendix B. These concentrations and intake rates by type of plant crop are used with ingestion dose conversion factors to perform ingestion dose calculations using equations similar to Equations 2.1 and 2.4 to obtain the committed effective dose equivalent.

The radionuclide concentration in animal products such as meat, milk, and eggs depends on the amount of contaminated forage or feed eaten by the animal. This concentration is described by:

$$C_{ia} = S_{ia} [C_{if} Q_f + C_{iaw} Q_{aw}] \quad (2.6)$$

where C_{ia} = concentration of radionuclide i in the animal product, in pCi/kg (Bq/kg) or pCi/L (Bq/L)

S_{ia} = equilibrium transfer coefficient of radionuclide i from daily intake of the animal to the edible portion of the animal product, in pCi/L (Bq/L) milk, or pCi/kg (Bq/kg) meat or eggs, per pCi/d (Bq/d) intake by animal

C_{if} = concentration of radionuclide i in feed or forage, in pCi/kg (Bq/kg)

Q_f = animal consumption rate of contaminated feed or forage, in kg/day

C_{iaw} = concentration of radionuclide i in the water consumed by animals, in pCi/L (Bq/L). Assumed to be the same as the irrigation water, C_{iw} , used in Equation 2.5

Q_{aw} = consumption rate of contaminated water by the animal, in L/day.

Specific values of the parameters used in Equation 2.6 are described in Napier et al. (Vol. 1, 1988) and obtained from Oztunali et al. (1981) and NRC (1977), as discussed in Appendix B. Committed effective dose conversion factors for the ingestion of agricultural food products are shown for over 200 radionuclides in Table 2.5. These factors account for both deposition of resuspended contaminated soil on leaves and root uptake from soil and do not account for rainsplash of soil onto plant surfaces. They are in units of mrem per year of exposure per pCi/g in soil and μ Sv per year of exposure per Bq/g in soil. They are for ingestion of agricultural foods only and do not include other pathways such as external or inhalation exposure. The factors are based on ingestion of the total diet (NRC 1977) grown in contaminated soil, including vegetable produce and animal products. Scenario-specific estimates of the committed effective dose equivalent from ingestion of agricultural products can be obtained by multiplying the factors shown in Table 2.5 by the fraction of the total diet assumed to be grown on a site and the site-specific soil concentration of radionuclides.

TABLE 2.5. Agricultural Food Product Ingestion Committed Effective Dose Rate Conversion Factors for Exposure to Residual Radioactive Materials (Air and Soil Contributions)

Radionuclide	Air Deposition		Soil Uptake	
	mrem per pCi/m ³	μSv per Bq/m ³	mrem per pCi/g	μSv per Bq/g
³ H	2.3E-03	6.2E-01	0.0E+00	0.0E+00
¹⁰ Be	5.7E-02	1.5E+01	3.7E-04	1.0E-01
¹⁴ C	7.2E-01	1.9E+02	0.0E+00	0.0E+00
¹⁸ F	7.8E-06	2.1E-03	8.9E-05	2.4E-02
²² Na	1.7E+00	4.6E+02	5.7E-01	1.5E+02
²⁴ Na	1.6E-03	4.3E-01	1.7E-02	4.6E+00
³² P	3.5E-01	9.5E+01	4.3E+00	1.2E+03
³³ P	4.6E-02	1.2E+01	4.6E-01	1.2E+02
³⁵ S	2.6E-02	7.0E+00	1.0E-01	2.7E+01
³⁶ Cl	2.1E-01	5.7E+01	1.1E+01	3.0E+03
⁴⁰ K	5.9E-01	1.6E+02	3.2E+00	8.6E+02
⁴¹ Ca	6.1E-02	1.6E+01	2.3E-02	6.2E+00
⁴⁵ Ca	1.4E-01	3.8E+01	5.0E-02	1.3E+01
⁴⁶ Sc	6.9E-02	1.9E+01	2.5E-03	6.8E-01
⁵¹ Cr	1.8E-03	4.9E-01	7.6E-06	2.1E-03
⁵⁴ Mn	3.5E-02	9.4E+00	1.6E-02	4.3E+00
⁵⁶ Mn	9.7E-05	2.6E-02	5.5E-03	1.5E+00
⁵⁵ Fe	1.3E-02	3.5E+00	1.4E-04	3.8E-02
⁵⁹ Fe	7.3E-02	2.0E+01	9.5E-04	2.6E-01
⁵⁷ Co	1.2E-02	3.2E+00	1.7E-03	4.6E-01
⁵⁸ Co	3.9E-02	1.1E+01	5.9E-03	1.6E+00
⁶⁰ Co	1.8E-01	4.9E+01	2.4E-02	6.5E+00
⁵⁹ Ni	8.1E-03	2.2E+00	1.9E-03	5.1E-01
⁶³ Ni	2.2E-02	5.9E+00	5.1E-03	1.4E+00
⁶⁵ Ni	6.2E-05	1.7E-02	2.3E-03	6.2E-01
⁶⁴ Cu	2.8E-04	7.6E-02	1.2E-02	3.2E+00
⁶⁵ Zn	1.4E+00	3.8E+02	3.8E+00	1.0E+03

TABLE 2.5. Agricultural Food Product Ingestion Committed Effective Dose Rate Conversion Factors for Exposure to Residual Radioactive Materials (Air and Soil Contributions) (contd)

Radionuclide	Air Deposition		Soil Uptake	
	mrem per pCi/m ³	μSv per Bq/m ³	mrem per pCi/g	μSv per Bq/g
^{69m} Zn+D (a)	6.5E-04	1.8E-01	6.5E-02	1.8E+01
^{69m} Zn	1.2E-03	3.2E-01	1.2E-01	3.2E+01
⁶⁹ Zn	3.2E-06	8.6E-04	6.6E-03	1.8E+00
⁷⁶ As	5.0E-03	1.4E+00	2.1E-03	5.7E-01
⁷⁶ Se	1.7E+00	4.6E+02	4.6E-01	1.2E+02
⁷⁹ Se	2.7E+00	7.3E+02	5.7E-01	1.5E+02
⁸² Br	5.9E-03	1.6E+00	6.0E-02	1.6E+01
⁸³ Br+D (a)	4.3E-06	1.1E-03	1.4E-03	3.8E-01
⁸³ Br	8.5E-06	2.3E-03	2.8E-03	7.6E-01
⁸⁴ Br	3.6E-06	9.7E-04	5.2E-03	1.4E+00
⁸⁶ Rb	5.0E-01	1.3E+02	6.2E-01	1.7E+02
⁸⁸ Rb	2.0E-06	5.4E-04	4.3E-03	1.2E+00
⁸⁹ Rb+D (a)	6.5E-02	1.8E+01	2.8E-01	7.4E+01
⁸⁹ Rb	9.3E-07	2.5E-04	2.3E-03	6.2E-01
⁸⁵ Sr	2.7E-02	7.3E+00	1.1E-01	3.0E+01
⁸⁹ Sr	1.3E-01	3.5E+01	5.5E-01	1.5E+02
⁹⁰ Sr+D (a)	1.2E+00	3.2E+02	3.8E+00	1.0E+03
⁹⁰ Sr	2.2E+00	5.9E+02	7.7E+00	2.1E+03
⁹¹ Sr+D (a)	3.8E-02	1.0E+01	5.4E-02	1.5E+01
⁹¹ Sr	8.9E-04	2.4E-01	1.3E-01	3.5E+01
⁹² Sr+D (a)	3.1E-04	8.5E-02	4.5E-02	1.2E+01
⁹² Sr	1.6E-04	4.3E-02	8.8E-02	2.4E+01
⁹⁰ Y	2.2E-02	5.9E+00	5.0E-03	1.4E+00
^{91m} Y+D (a)	4.9E-02	1.3E+01	2.3E-03	6.1E-01
^{91m} Y	1.3E-06	3.5E-04	1.9E-05	5.1E-03
⁹¹ Y	9.8E-02	2.6E+01	4.5E-03	1.2E+00
⁹² Y	2.6E-04	7.0E-02	9.2E-04	2.5E-01
⁹³ Y	1.8E-03	4.9E-01	2.2E-03	5.9E-01
⁹³ Zr+D (a)	4.1E-02	1.1E+01	3.6E-03	9.6E-01
⁹³ Zr	3.5E-02	9.4E+00	9.5E-05	2.6E-02
⁹⁵ Zr+D (a)	8.0E-02	2.2E+01	4.5E-03	1.2E+00
⁹⁵ Zr	4.6E-02	1.2E+01	1.5E-04	4.1E-02
⁹⁷ Zr+D (a)	1.8E-03	4.8E-01	2.3E-04	6.3E-02
⁹⁷ Zr	5.0E-03	1.4E+00	2.6E-04	7.0E-02
^{93m} Nb	4.6E-02	1.2E+01	7.0E-03	1.9E+00
⁹⁴ Nb	6.8E-01	1.8E+02	1.0E-01	2.7E+01

TABLE 2.5. Agricultural Food Product Ingestion Committed Effective Dose Rate Conversion Factors for Exposure to Residual Radioactive Materials (Air and Soil Contributions) (contd)

Radionuclide	Air Deposition		Soil Uptake	
	mrem per pCi/m ³	μSv per Bq/m ³	mrem per pCi/g	μSv per Bq/g
^{95m} Nb+D (a)	3.1E-02	8.5E+00	6.7E-03	1.8E+00
^{95m} Nb	8.7E-03	2.3E+00	4.5E-03	1.2E+00
⁹⁵ Nb	5.1E-02	1.4E+01	8.7E-03	2.3E+00
^{97m} Nb+D (a)	5.5E-06	1.5E-03	2.2E-04	5.8E-02
^{97m} Nb	2.5E-09	6.8E-07	6.9E-06	1.9E-03
⁹⁷ Nb	1.1E-05	3.0E-03	4.2E-04	1.1E-01
⁹³ Mo+D (a)	3.5E-02	9.4E+00	2.4E-02	6.5E+00
⁹³ Mo	2.4E-02	6.5E+00	4.0E-02	1.1E+01
⁹⁹ Mo+D (a)	4.2E-03	1.1E+00	4.7E-02	1.3E+01
⁹⁹ Mo	7.8E-03	2.1E+00	7.4E-02	2.0E+01
^{99m} Tc	1.9E-05	5.1E-03	1.7E-02	4.6E+00
⁹⁹ Tc	1.2E-01	3.2E+01	1.2E+00	3.2E+02
¹⁰¹ Tc	6.8E-07	1.8E-04	1.6E-02	4.3E+00
¹⁰³ Ru+D (a)	3.2E-02	8.5E+00	3.5E-02	9.5E+00
¹⁰³ Ru	6.3E-02	1.7E+01	6.9E-02	1.9E+01
¹⁰⁵ Ru+D (a)	8.3E-04	2.2E-01	2.8E-02	7.5E+00
¹⁰⁵ Ru+I (b)	2.1E-04	5.7E-02	1.2E-02	3.2E+00
¹⁰⁶ Ru+I (b)	1.3E+00	3.5E+02	1.1E+00	3.1E+02
^{103m} Rh	4.3E-07	1.2E-04	5.6E-04	1.5E-01
¹⁰⁵ Rh	2.1E-03	5.7E-01	7.2E-02	1.9E+01
¹⁰³ Pd+D (a)	5.5E-03	1.5E+00	4.7E-03	1.3E+00
¹⁰³ Pd	1.1E-02	3.0E+00	8.8E-03	2.4E+00
¹⁰⁷ Pd	3.8E-03	1.0E+00	1.7E-03	4.6E-01
¹⁰⁹ Pd+I (b)	7.0E-04	1.9E-01	1.3E-02	3.5E+00
^{110m} Ag+I (b)	2.3E+00	6.1E+02	2.1E+00	5.7E+02
¹¹¹ Ag	2.6E-01	7.0E+01	5.2E-01	1.4E+02
¹⁰⁹ Cd	1.6E-01	4.3E+01	8.7E-01	2.3E+02
^{113m} Cd	2.0E+00	5.4E+02	1.1E+01	3.0E+03
^{115m} Cd+D (a)	8.0E-02	2.2E+01	5.5E-01	1.5E+02
^{115m} Cd	1.6E-01	4.3E+01	1.1E+00	3.0E+02
¹¹⁵ Cd	1.1E-02	3.0E+00	3.8E-01	1.0E+02
¹¹¹ In	2.9E-03	7.8E-01	4.1E-04	1.1E-01
^{114m} In+I (b)	8.2E-02	2.2E+01	2.5E-03	6.6E-01
^{115m} In	5.7E-05	1.5E-02	1.1E-04	3.0E-02
^{117m} Sn	2.3E-02	6.2E+00	9.5E-03	2.6E+00

TABLE 2.5. Agricultural Food Product Ingestion Committed Effective Dose Rate Conversion Factors for Exposure to Residual Radioactive Materials (Air and Soil Contributions) (contd)

Radionuclide	Air Deposition		Soil Uptake	
	mrem per pCi/m ³	μSv per Bq/m ³	mrem per pCi/g	μSv per Bq/g
^{119m} Sn	2.2E-02	5.9E+00	4.6E-03	1.2E+00
^{121m} Sn+D (a)	2.1E-02	5.8E+00	4.1E-03	1.1E+00
^{121m} Sn	2.5E-02	6.7E+00	4.9E-03	1.3E+00
¹²¹ Sn	9.3E-04	2.5E-01	2.9E-03	7.8E-01
¹²³ Sn	1.2E-01	3.2E+01	2.8E-02	7.6E+00
¹²⁵ Sn+D (a)	6.3E-02	1.7E+01	1.7E-01	4.6E+01
¹²⁵ Sn	7.6E-02	2.1E+01	3.9E-02	1.1E+01
¹²⁶ Sn+D (a)	1.7E-01	4.5E+01	3.1E-02	8.5E+00
¹²⁶ Sn	3.3E-01	8.9E+01	6.4E-02	1.7E+01
¹²⁴ Sb	1.2E-01	3.2E+01	2.0E-02	5.4E+00
¹²⁵ Sb+D (a)	5.3E-02	1.4E+01	2.8E-01	7.7E+01
¹²⁵ Sb	3.9E-02	1.1E+01	5.6E-03	1.5E+00
^{126m} Sb+D (a)	8.8E-03	2.4E+00	2.7E-03	7.3E-01
^{126m} Sb	1.1E-06	3.0E-04	1.8E-04	4.9E-02
¹²⁶ Sb	7.2E-02	1.9E+01	2.0E-02	5.4E+00
¹²⁷ Sb+D (a)	2.7E-02	7.4E+00	4.2E-01	1.1E+02
¹²⁷ Sb	2.2E-02	5.9E+00	1.4E-02	3.8E+00
^{123m} Te	1.3E-01	3.5E+01	2.9E+00	7.8E+02
^{125m} Te	6.3E-02	1.7E+01	1.4E+00	3.8E+02
^{127m} Te+D (a)	1.0E-01	2.7E+01	2.2E+00	6.0E+02
^{127m} Te	1.9E-01	5.1E+01	4.0E+00	1.1E+03
¹²⁷ Te	2.4E-04	6.5E-02	1.7E-01	4.6E+01
^{129m} Te+D (a)	4.1E+00	1.1E+03	1.0E+02	2.8E+04
^{129m} Te	6.7E+00	1.8E+03	1.7E+02	4.6E+04
¹²⁹ Te	1.1E-05	3.0E-03	6.3E-02	1.7E+01
^{131m} Te+D (a)	4.0E+00	1.1E+03	2.3E+00	6.3E+02
^{131m} Te	2.0E-02	5.4E+00	4.3E+00	1.2E+03
¹³¹ Te+D (a)	4.4E+00	1.2E+03	4.2E-01	1.1E+02
¹³¹ Te	3.4E-06	9.2E-04	5.3E-02	1.4E+01
¹³² Te+D (a)	2.2E-02	5.9E+00	1.9E+00	5.1E+02
¹³² Te	4.2E-02	1.1E+01	3.8E+00	1.0E+03
^{133m} Te+D (a)	4.4E-02	1.2E+01	9.8E-02	2.6E+01
^{133m} Te	2.8E-05	7.6E-03	1.9E-01	5.1E+01
¹³³ Te+D (a)	4.6E-02	1.2E+01	5.0E-02	1.3E+01
¹³³ Te	1.3E-06	3.5E-04	4.0E-02	1.1E+01
¹³⁴ Te+D (a)	6.0E-05	1.6E-02	2.4E-02	6.5E+00
¹³⁴ Te	4.9E-06	1.3E-03	4.6E-02	1.2E+01
¹²⁵ I	1.4E+01	3.8E+03	6.2E-01	1.7E+02
¹²⁹ I	1.2E+02	3.2E+04	4.7E+00	1.3E+03
¹³⁰ I	2.9E-02	7.8E+00	4.8E-02	1.3E+01
¹³¹ I+D (a)	8.8E+00	2.4E+03	7.8E-01	2.1E+02

TABLE 2.5. Agricultural Food Product Ingestion Committed Effective Dose Rate Conversion Factors for Exposure to Residual Radioactive Materials (Air and Soil Contributions) (contd)

Radionuclide	Air Deposition		Soil Uptake	
	mrem per pCi/m ³	μSv per Bq/m ³	mrem per pCi/g	μSv per Bq/g
¹³¹ I	8.9E+00	2.4E+03	7.9E-01	2.1E+02
¹³² I	7.5E-04	2.0E-01	7.1E-03	1.9E+00
¹³³ I+D (a)	6.9E-02	1.9E+01	5.4E-02	1.5E+01
¹³³ I	1.4E-01	3.8E+01	1.1E-01	3.0E+01
¹³⁴ I	1.1E-04	3.0E-02	2.7E-03	7.3E-01
¹³⁵ I+D (a)	3.0E-03	8.2E-01	1.0E-02	2.7E+00
¹³⁵ I	6.6E-03	1.8E+00	2.2E-02	5.9E+00
^{134m} Cs+D (a)	2.0E-06	5.4E-04	3.1E-05	8.5E-03
^{134m} Cs	4.0E-06	1.1E-03	6.3E-05	1.7E-02
¹³⁴ Cs	2.0E+00	5.4E+02	2.0E-01	5.4E+01
¹³⁵ Cs	1.9E-01	5.1E+01	1.9E-02	5.1E+00
¹³⁶ Cs	1.4E-01	3.8E+01	2.4E-02	6.5E+00
¹³⁷ Cs+I (b)	7.2E-01	1.9E+02	1.2E-02	3.3E+00
¹³⁸ Cs	3.8E-06	1.0E-03	3.2E-04	8.6E-02
¹³⁹ Ba	2.1E-05	5.7E-03	3.9E-04	1.1E-01
¹⁴⁰ Ba+D (a)	6.0E-02	1.6E+01	6.5E-03	1.8E+00
¹⁴⁰ Ba	5.9E-02	1.6E+01	8.7E-03	2.3E+00
¹⁴¹ Ba+D (a)	9.0E-03	2.4E+00	7.3E-04	2.0E-01
¹⁴¹ Ba	2.4E-06	6.5E-04	2.0E-04	5.4E-02
¹⁴² Ba+D (a)	2.4E-05	6.5E-03	2.2E-04	5.8E-02
¹⁴² Ba	7.4E-07	2.0E-04	1.0E-04	2.7E-02
¹⁴⁰ La	1.1E-02	3.0E+00	3.8E-03	1.0E+00
¹⁴¹ La+D (a)	1.4E-02	3.6E+00	1.0E-03	2.7E-01
¹⁴¹ La	2.2E-04	5.9E-02	6.8E-04	1.8E-01
¹⁴² La	4.2E-05	1.1E-02	3.3E-04	8.9E-02
¹⁴¹ Ce	2.6E-02	7.0E+00	1.4E-03	3.8E-01
¹⁴³ Ce+D (a)	1.9E-02	5.1E+00	2.2E-03	5.8E-01
¹⁴³ Ce	5.3E-03	1.4E+00	2.1E-03	5.7E-01
¹⁴⁴ Ce+D (a)	1.2E-01	3.4E+01	5.0E-03	1.3E+00
¹⁴⁴ Ce	2.5E-01	6.8E+01	1.0E-02	2.7E+00
¹⁴³ Pr	3.0E-02	8.1E+00	2.2E-03	5.9E-01
^{144m} Pr+D (a)	1.0E-06	2.8E-04	3.9E-05	1.1E-02
^{144m} Pr	2.2E-07	5.9E-05	2.2E-05	5.9E-03
¹⁴⁴ Pr	1.3E-06	3.5E-04	5.6E-05	1.5E-02
¹⁴⁷ Nd+D (a)	1.9E-02	5.0E+00	1.1E-03	3.0E-01
¹⁴⁷ Nd	2.3E-02	6.2E+00	1.9E-03	5.1E-01
¹⁴⁷ Pm	1.4E-02	3.8E+00	3.3E-04	8.9E-02

TABLE 2.5. Agricultural Food Product Ingestion Committed Effective Dose Rate Conversion Factors for Exposure to Residual Radioactive Materials (Air and Soil Contributions) (contd)

Radionuclide	Air Deposition		Soil Uptake	
	mrem per pCi/m ³	μSv per Bq/m ³	mrem per pCi/g	μSv per Bq/g
^{148m} Pm+D (a)	7.4E-02	2.0E+01	2.4E-03	6.5E-01
^{148m} Pm	7.2E-02	1.9E+01	2.4E-03	6.5E-01
¹⁴⁸ Pm	3.9E-02	1.1E+01	3.5E-03	9.5E-01
¹⁴⁹ Pm	7.2E-03	1.9E+00	1.3E-03	3.5E-01
¹⁵¹ Pm	3.0E-03	8.1E-01	9.5E-04	2.6E-01
¹⁴⁷ Sm	2.5E+00	6.7E+02	8.0E-02	2.2E+01
¹⁵¹ Sm	5.1E-03	1.4E+00	1.6E-04	4.3E-02
¹⁵³ Sm	4.7E-03	1.3E+00	1.2E-03	3.2E-01
¹⁵² Eu	8.4E-02	2.3E+01	3.3E-03	8.9E-01
¹⁵⁴ Eu	1.2E-01	3.2E+01	4.8E-03	1.3E+00
¹⁵⁵ Eu	2.0E-02	5.4E+00	7.8E-04	2.1E-01
¹⁵⁶ Eu	6.1E-02	1.6E+01	4.2E-03	1.1E+00
¹⁵³ Gd	1.4E-02	3.8E+00	1.8E-03	4.9E-01
¹⁶⁰ Tb	7.1E-02	1.9E+01	6.9E-04	1.9E-01
^{166m} Ho	1.0E-01	2.7E+01	4.4E-03	1.2E+00
¹⁸¹ W	3.6E-03	9.7E-01	1.0E-03	2.7E-01
¹⁸⁵ W	1.9E-02	5.1E+00	5.6E-03	1.5E+00
¹⁸⁷ W	1.8E-03	4.9E-01	7.2E-03	1.9E+00
¹⁸⁷ Re	2.1E-04	5.7E-02	5.8E-07	1.6E-04
¹⁸⁵ Os	0.0E+00	0.0E+00	0.0E+00	0.0E+00
¹⁹¹ Os	0.0E+00	0.0E+00	0.0E+00	0.0E+00
¹⁹² Ir	6.1E-02	1.6E+01	1.8E-02	4.9E+00
²⁰³ Hg	1.7E-01	4.6E+01	3.8E-01	1.0E+02
²¹⁰ Pb+D (a)	3.1E+01	8.4E+03	1.7E+00	4.5E+02
²¹⁰ Pb	6.7E+01	1.8E+04	4.1E+00	1.1E+03
²¹² Pb+D (a)	6.3E-03	1.7E+00	2.1E-02	5.7E+00
²¹² Pb	1.9E-02	5.1E+00	3.6E-02	9.7E+00
²¹⁰ Bi+D (a)	1.2E+01	3.2E+03	4.6E-01	1.2E+02
²¹⁰ Bi	2.3E-02	6.2E+00	1.8E-01	4.9E+01
²¹² Bi+I (b)	2.1E-05	5.7E-03	1.5E-02	4.0E+00
²¹⁰ Po	2.3E+01	6.2E+03	6.1E-01	1.6E+02

TABLE 2.5. Agricultural Food Product Ingestion Committed Effective Dose Rate Conversion Factors for Exposure to Residual Radioactive Materials (Air and Soil Contributions) (contd)

Radionuclide	Air Deposition		Soil Uptake	
	mrem per pCi/m ³	μSv per Bq/m ³	mrem per pCi/g	μSv per Bq/g
²²³ Ra+I (b)	2.8E-01	7.7E+01	1.2E-01	3.3E+01
²²⁴ Ra+D (a)	8.8E-02	2.4E+01	7.0E-02	1.9E+01
²²⁴ Ra+I (b)	3.8E-01	1.0E+02	3.6E-01	9.7E+01
²²⁵ Ra+D (a)	3.9E-01	1.0E+02	9.1E-02	2.5E+01
²²⁵ Ra	1.6E+00	4.3E+02	6.1E-01	1.6E+02
²²⁶ Ra+D (a)	1.2E+01	3.3E+03	8.6E-01	2.3E+02
²²⁶ Ra	1.3E+01	3.5E+03	2.7E+00	7.3E+02
²²⁸ Ra+D (a)	2.1E+00	5.7E+02	3.4E-01	9.3E+01
²²⁸ Ra	1.1E+01	3.0E+03	2.3E+00	6.2E+02
²²⁵ Ac+I (b)	1.0E-01	2.7E+01	4.7E-03	1.3E+00
²²⁷ Ac+D (a)	2.1E+01	5.7E+03	5.4E-01	1.5E+02
²²⁷ Ac	1.7E+02	4.6E+04	3.6E+00	9.7E+02
²²⁸ Ac+D (a)	8.9E-01	2.4E+02	9.1E-02	2.5E+01
²²⁸ Ac	4.9E-04	1.3E-01	5.4E-04	1.5E-01
²²⁷ Th+D (a)	4.6E-01	1.2E+02	1.1E-01	2.9E+01
²²⁷ Th	2.8E-01	7.6E+01	3.0E-02	8.1E+00
²²⁸ Th+D (a)	1.0E+00	2.7E+02	1.0E-01	2.8E+01
²²⁸ Th	4.8E+00	1.3E+03	3.1E-01	8.4E+01
²²⁹ Th+D (a)	5.9E+00	1.6E+03	4.3E-01	1.1E+02
²²⁹ Th	4.3E+01	1.2E+04	2.8E+00	7.6E+02
²³⁰ Th+D (a)	1.1E+01	3.0E+03	8.1E-01	2.2E+02
²³⁰ Th	6.5E+00	1.8E+03	4.2E-01	1.1E+02
²³¹ Th+D (a)	1.2E-04	3.2E-02	1.0E-04	2.7E-02
²³¹ Th	1.2E-03	3.2E-01	1.0E-03	2.7E-01
²³² Th+D (a)	5.2E+00	1.4E+03	5.2E-01	1.4E+02
Th-Nat (c)	5.2E+00	1.4E+03	5.2E-01	1.4E+02
²³² Th	3.3E+01	8.9E+03	2.2E+00	5.9E+02
²³⁴ Th+D (a)	5.5E-02	1.5E+01	5.5E-03	1.5E+00
²³⁴ Th+I (b)	1.1E-01	3.0E+01	1.1E-02	3.0E+00
²³¹ Pa+D (a)	3.6E+01	9.6E+03	2.6E+00	6.9E+02
²³¹ Pa	1.4E+02	3.8E+04	1.9E+01	5.1E+03
²³³ Pa	3.0E-02	8.1E+00	6.0E-03	1.6E+00
²³⁴ Pa	5.5E-04	1.5E-01	3.7E-03	1.0E+00
²³² U+D (a)	1.3E-01	3.6E+01	4.7E-03	1.3E+00
²³² U	9.3E-01	2.5E+02	3.3E-02	8.9E+00
²³³ U+D (a)	5.2E+00	1.4E+03	3.8E-01	1.0E+02
²³³ U	3.6E-01	9.7E+01	1.3E-02	3.5E+00
²³⁴ U	3.5E-01	9.5E+01	1.3E-02	3.5E+00
²³⁵ U+D (a)	1.9E-01	5.1E+01	7.0E-03	1.9E+00
²³⁵ U	3.6E-01	9.7E+01	1.3E-02	3.5E+00

TABLE 2.5. Agricultural Food Product Ingestion Committed Effective Dose Rate Conversion Factors for Exposure to Residual Radioactive Materials (Air and Soil Contributions) (contd)

Radionuclide	Air Deposition		Soil Uptake	
	mrem per pCi/m ³	μSv per Bq/m ³	mrem per pCi/g	μSv per Bq/g
²³⁸ U	3.3E-01	8.9E+01	1.2E-02	3.2E+00
²³⁷ U	1.5E-02	4.0E+00	1.5E-03	4.1E-01
²³⁸ U+D (a)	1.6E-01	4.4E+01	7.3E-03	2.0E+00
²³⁸ U	3.2E-01	8.6E+01	1.1E-02	3.0E+00
U-Nat (d)	3.4E-01	9.1E+01	1.2E-02	3.2E+00
²⁴⁰ U+D (a)	8.0E-04	2.2E-01	7.3E-04	2.0E-01
²⁴⁰ U+I (b)	2.4E-03	6.5E-01	2.2E-03	5.9E-01
²³⁷ Np+D (a)	3.2E+01	8.6E+03	1.2E+00	3.2E+02
²³⁷ Np	6.4E+01	1.7E+04	2.4E+00	6.5E+02
²³⁸ Np+D (a)	2.0E+00	5.5E+02	1.9E-02	5.0E+00
²³⁸ Np	6.8E-03	1.8E+00	1.9E-03	5.1E-01
²³⁹ Np+D (a)	3.0E-03	8.2E-01	7.5E-04	2.0E-01
²³⁹ Np	6.1E-03	1.6E+00	1.5E-03	4.1E-01
²³⁸ Pu	7.6E-01	2.1E+02	6.6E-03	1.8E+00
²³⁷ Pu	4.1E-03	1.1E+00	4.4E-05	1.2E-02
²³⁸ Pu	4.1E+00	1.1E+03	3.5E-02	9.4E+00
²³⁹ Pu	4.5E+00	1.2E+03	3.9E-02	1.1E+01
²⁴⁰ Pu	4.5E+00	1.2E+03	3.8E-02	1.0E+01
²⁴¹ Pu+D (a)	2.4E+01	6.3E+03	2.0E+00	5.5E+02
²⁴¹ Pu	8.3E-02	2.2E+01	7.1E-04	1.9E-01
²⁴² Pu	4.2E+00	1.1E+03	3.6E-02	9.7E+00
²⁴³ Pu+D (a)	2.8E-05	7.6E-03	1.7E-05	4.5E-03
²⁴³ Pu	5.6E-05	1.5E-02	3.3E-05	8.9E-03
²⁴⁴ Pu+D (a)	1.1E+00	3.0E+02	9.8E-03	2.6E+00
²⁴⁴ Pu	4.3E+00	1.2E+03	3.7E-02	1.0E+01
²⁴¹ Am	4.7E+01	1.3E+04	4.1E+00	1.1E+03
^{242m} Am+D (a)	1.3E+01	3.5E+03	1.0E+00	2.8E+02
^{242m} Am	4.5E+01	1.2E+04	3.9E+00	1.1E+03
²⁴² Am+D (a)	1.6E+00	4.3E+02	2.7E-02	7.3E+00
²⁴² Am	8.2E-04	2.2E-01	1.4E-03	3.8E-01
²⁴³ Am+D (a)	1.6E+01	4.2E+03	1.4E+00	3.7E+02
²⁴³ Am	4.7E+01	1.3E+04	4.1E+00	1.1E+03
²⁴² Cm+D (a)	3.0E+00	8.0E+02	4.7E-02	1.3E+01
²⁴² Cm	1.3E+00	3.5E+02	5.1E-02	1.4E+01
²⁴³ Cm	3.5E+01	9.4E+03	1.2E+00	3.2E+02
²⁴⁴ Cm+D (a)	1.2E+01	3.2E+03	4.7E-01	1.3E+02
²⁴⁴ Cm	2.4E+01	6.5E+03	9.3E-01	2.5E+02
²⁴⁵ Cm+D (a)	3.1E+01	8.3E+03	1.9E+00	5.2E+02
²⁴⁵ Cm	4.5E+01	1.2E+04	1.7E+00	4.6E+02
²⁴⁸ Cm	4.5E+01	1.2E+04	1.7E+00	4.6E+02

TABLE 2.5. Agricultural Food Product Ingestion Committed Effective Dose Rate Conversion Factors for Exposure to Residual Radioactive Materials (Air and Soil Contributions) (contd)

Radionuclide	Air Deposition		Soil Uptake	
	mrem per pCi/m ³	μSv per Bq/m ³	mrem per pCi/g	μSv per Bq/g
²⁴⁷ Cm+D (a)	2.1E+01	5.7E+03	8.0E-01	2.2E+02
²⁴⁷ Cm	4.2E+01	1.1E+04	1.6E+00	4.3E+02
²⁴⁸ Cm	1.6E+02	4.3E+04	6.2E+00	1.7E+03
²⁵² Cf	1.4E+01	3.8E+03	1.1E-01	3.0E+01

- (a) Where +D means "plus daughters in equilibrium" referring to explicit daughters, or daughters with half-lives greater than 10 minutes. Separate values are also included for parents and daughters so that combined factors for non-equilibrium cases can be determined. Note: in some cases +D also includes implicit daughters (i.e., uranium and thorium decay chains).
- (b) Where +I means "plus implicit daughters in equilibrium" referring to daughters with half-lives less than 10 minutes. The decay energies associated with these daughters have been assigned to the parent, and the appropriate branching ratios (described in Appendix D) have been considered.
- (c) Where Th-Nat includes an equilibrium mixture of ²³²Th plus 10 daughters in the decay chain, as discussed in Appendix D.
- (d) Where 1 Ci U-Nat equals 48.9% ²³⁸U plus 48.9% ²³⁴U plus 2.25% ²³⁵U.

3.0 SCENARIO ANALYSIS FOR RESIDUAL RADIOACTIVE MATERIALS

Radiation exposure scenarios represent a combination of radiation exposure pathways in an effort to conceptually model the potential conditions, events, and processes that result in radiation exposure to individuals or groups of people. Residual contamination can exist in buildings as volume or surface sources and as volume sources in soils. To adequately model these conditions, a series of scenarios for volume and surface source relationships were developed. The scenarios combine the pathway dose rate conversion factors and committed effective dose rate conversion factors described in Section 2.0 with scenario-specific assumptions to produce annual TEDE factors. The scenario-specific assumptions include the exposure durations, quantities inhaled or ingested, and media concentrations (i.e., surface, air, food product, or drinking water concentrations). Listings of the annual TEDE are provided for each scenario considered for over 200 radionuclides or parent-daughter mixtures. For this study, daughters with half-lives less than 10 minutes are always assumed to be in equilibrium with their parent and are referred to as implicit daughters. It is important to note that the unit activity shown in the TEDE tables includes contributions from both the parent and daughters. To accomplish this, a +I notation has been included in the TEDE listings with an appropriate footnote describing the meaning. Daughters with half-lives greater than 10 minutes that may not be in equilibrium with their parents are referred to as explicit daughters. These are shown in equilibrium conditions with the parent by a +D listing in the TEDE tables. Separate values are also included for parents and daughters so that values for non-equilibrium cases can be determined. For cases where there is a short-lived parent with a long-lived daughter, no attempt is made to combine the parent and daughter. Instead, separate listings for parent and daughter are included so that any equilibrium condition may be evaluated. Finally, for decay chains, the listing include parents alone, parents with +D and +I notations (to include both implicit and explicit daughters) and daughters alone so that equilibrium and non-equilibrium cases can be considered. A further description of the parent-daughter and chain decay relationships used in this study is included in Appendix D. The following sections describe the scenarios for residual radioactive materials in buildings and in soils, and the resulting annual TEDE factors for volume and surface activity.

3.1 SCENARIO DESCRIPTIONS FOR THE RELEASE OF BUILDINGS

Two scenarios are defined for facilities to account for 1) building renovation (sub-surface or volume sources), and 2) normal building occupancy (thin-layer and removable surface sources). The building renovation scenario accounts for an average volumetric concentration of material in building surfaces. The building occupancy scenario accounts for contamination located in a thin surface layer, with a small fraction that is removable. This approach is needed to permit the calculation of unit concentration annual TEDE factors for residual radioactivity in structures. The resulting generically derived unit concentration annual TEDE factors should serve as a basis for developing screening levels for simple situations and should help

determine when more detailed site-specific data, models, and assessments are required. For this study, it is assumed that the facility is used as a commercial building after license termination. Sections 3.1.1 and 3.1.2 describe the scenarios, parameters, and calculations developed to model the unrestricted release of buildings. The results of the dose calculations are provided in terms of unit concentration annual TEDE factors for each scenario. Additional information regarding potential modifications to the calculations to account for site-specific conditions and a further discussion of the selection of parameter values are found in Appendix B.

3.1.1 Building Renovation (Volume Activity) Scenario

Decontamination operations are designed to reduce or eliminate the surface inventory through process including surface washing, sandblasting, or concrete spalling. For the building renovation scenario, it is assumed that the residual contamination in a building is associated with volume sources; that is, radionuclides are assumed to be distributed within an effective volume of material and are not confined to a thin surface layer. This assumption also anticipates that there could be subsurface sources or volume sources, for example, around floor drains or cracks that could contain significant quantities of radioactive material. It also anticipates the variability among types of surfaces and materials that may be encountered. To permit the derivation of unit concentration annual TEDE factors for volume sources in buildings, the building renovation scenario was defined accounting for exposures to individuals in a facility by external penetrating radiation, inhalation, and secondary ingestion. Typical licensed facilities are likely to continue to be used as commercial buildings. To do so, it is anticipated that they will require some renovation after unrestricted release with disturbance of volume sources associated with floors and walls. For this scenario, it is assumed that there are no significant removable contamination sources at the time of license termination (i.e., only a small amount of loose material is present after decontamination efforts). However, volume contamination sources are assumed to be disturbed during building renovation resulting in loose contamination available for resuspension and secondary ingestion. After renovation, the loose contamination is assumed to be removed and the surfaces stabilized through the application of fresh paint, new floor surfaces, and other methods. For completeness, long-term chronic exposure to low levels of loose surface contamination is considered in the building occupancy scenario discussed in Section 3.1.2.

For this analysis, the residual contamination is assumed to be homogeneously distributed in the top 1 cm of building surfaces. Building renovation operations are also assumed to uniformly mix materials within the top 1 cm of building surface as they are removed. Building renovation is assumed to last for 500 h (about 3 work-months) and produce an average air concentration of dust of 10^{-4} g/m³ in air. For secondary ingestion, the individual is assumed to ingest 0.01 g/h during 500 h of exposure. These parameters and their expected ranges are summarized in Section 3.3 and are more fully discussed in Appendix B.

To develop a renovation scenario with a balanced set of exposure pathways, it is assumed that the same individual is exposed by all three pathways: external, inhalation, and secondary ingestion. This scenario does not include consideration of indoor radon from residual uranium in building materials. Building renovation is assumed to occur immediately after release of the building, before significant radioactive decay occurs, in an attempt to maximize the potential impact of renovation. The results of unit concentration dose rate calculations for this scenario (mrem per pCi/g and μ Sv per Bq/g), accounting for volume sources in the facility, are shown in Table 3.1. This table contains the annual TEDE factors for the building renovation scenario and lists the contribution by exposure pathway for about 200 radionuclides, including key parent-daughter decay chains. Again, the +I (implicit daughter) and +D (explicit daughter) notation has been used to provide maximum flexibility for consideration of all parent-daughter and decay chain situations. Further description of the parent-daughter and chain decay relationships used in this study is provided in Appendix D.

Hand calculations were performed to verify the computer calculations for selected radionuclides using the pathway factors from Section 2.0 and the Building renovation scenario assumptions for the external exposure, inhalation, and secondary ingestion pathways. The results for ^{60}Co , ^{90}Sr , ^{137}Cs , ^{235}U , and ^{239}Pu indicated that the values in Table 3.1 were calculated correctly.

TABLE 3.1. Annual Total Effective Dose Equivalent Factors for the Building Renovation (Volume Activity) Scenario(a)

Radionuclide	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
³ H	5.1E-12	4.1E-09	2.8E-07	2.9E-07	7.8E-05
¹⁰ Be	7.0E-06	1.7E-05	2.3E-05	4.7E-05	1.3E-02
¹⁴ C	2.1E-07	9.5E-08	9.5E-06	9.8E-06	2.6E-03
¹⁸ F	3.0E-02	3.8E-09	5.5E-07	3.0E-02	8.1E+00
²² Na	6.9E-02	4.3E-07	7.0E-05	6.9E-02	1.9E+01
²⁴ Na	1.4E-01	5.5E-08	7.0E-06	1.4E-01	3.7E+01
³² P	1.1E-04	2.7E-07	4.2E-05	1.6E-04	4.2E-02
³³ P	7.7E-07	2.8E-08	4.3E-06	5.1E-06	1.4E-03
³⁵ S	2.4E-07	1.2E-07	2.0E-06	2.4E-06	6.4E-04
³⁶ Cl	1.3E-05	9.0E-08	1.4E-05	2.7E-05	7.2E-03
⁴⁰ K	5.4E-03	4.9E-07	8.5E-05	5.5E-03	1.5E+00
⁴¹ Ca	6.9E-06	6.0E-08	6.0E-06	1.3E-05	3.5E-03
⁴⁵ Ca	8.1E-07	3.2E-07	1.5E-05	1.7E-05	4.5E-03
⁴⁶ Sc	7.0E-02	1.4E-06	3.1E-05	7.0E-02	1.9E+01
⁵¹ Cr	1.1E-03	1.5E-08	7.0E-07	1.1E-03	3.0E-01
⁵⁴ Mn	2.8E-02	3.0E-07	1.4E-05	2.8E-02	7.6E+00
⁵⁶ Mn	5.8E-02	1.6E-08	5.0E-06	5.8E-02	1.6E+01
⁵⁵ Fe	1.6E-05	6.0E-08	2.9E-06	1.9E-05	5.0E-03
⁵⁹ Fe	3.8E-02	6.0E-07	3.3E-05	3.8E-02	1.0E+01
⁵⁷ Co	3.4E-03	4.1E-07	3.8E-06	3.4E-03	9.2E-01
⁵⁸ Co	3.3E-02	5.0E-07	1.4E-05	3.3E-02	8.9E+00
⁶⁰ Co	8.3E-02	9.5E-06	5.0E-05	8.3E-02	2.3E+01
⁵⁹ Ni	1.9E-05	3.9E-08	9.5E-07	2.0E-05	5.5E-03
⁶³ Ni	9.9E-09	9.5E-08	2.5E-06	2.7E-06	7.2E-04
⁶⁵ Ni	1.9E-02	1.2E-08	3.2E-06	1.9E-02	5.2E+00
⁶⁴ Cu	5.7E-03	9.5E-09	2.4E-06	5.7E-03	1.5E+00
⁶⁵ Zn	2.2E-02	8.5E-07	6.5E-05	2.2E-02	5.8E+00
^{69m} Zn+D(b)	7.2E-03	2.0E-08	3.5E-06	7.2E-03	2.0E+00

TABLE 3.1. Annual Total Effective Dose Equivalent Factors for the Building Renovation (Volume Activity) Scenario(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
^{69m} Zn	1.5E-02	3.9E-08	6.5E-06	1.5E-02	4.0E+00
⁶⁹ Zn	2.3E-05	1.9E-09	4.5E-07	2.4E-05	6.4E-03
⁷⁶ As	1.6E-02	1.9E-07	2.6E-05	1.6E-02	4.4E+00
⁷⁵ Se	1.1E-02	3.8E-07	4.4E-05	1.1E-02	2.9E+00
⁷⁹ Se	1.5E-07	4.4E-07	4.0E-05	4.1E-05	1.1E-02
⁸² Br	9.3E-02	5.5E-08	8.0E-06	9.3E-02	2.5E+01
⁸³ Br+D (b)	1.2E-04	2.2E-09	2.4E-07	1.2E-04	3.4E-02
⁸³ Br	2.4E-04	4.4E-09	4.7E-07	2.4E-04	6.5E-02
⁸⁴ Br	5.7E-02	4.7E-09	9.0E-07	5.7E-02	1.5E+01
⁸⁶ Rb	3.1E-03	2.9E-07	4.6E-05	3.2E-03	8.6E-01
⁸⁸ Rb	2.3E-02	4.1E-09	9.0E-07	2.3E-02	6.2E+00
⁸⁹ Rb+D (b)	3.4E-02	1.3E-07	2.2E-05	3.4E-02	9.1E+00
⁸⁹ Rb	6.9E-02	2.1E-09	4.8E-07	6.9E-02	1.9E+01
⁸⁵ Sr	1.5E-02	7.0E-08	8.5E-06	1.5E-02	4.1E+00
⁸⁹ Sr	8.5E-05	2.6E-07	4.3E-05	1.3E-04	3.5E-02
⁹⁰ Sr+D (b)	1.1E-04	5.2E-06	3.3E-04	4.4E-04	1.2E-01
⁹⁰ Sr	5.8E-06	1.0E-05	6.0E-04	6.2E-04	1.7E-01
⁹¹ Sr+D (b)	1.3E-02	9.3E-07	2.3E-05	1.3E-02	3.6E+00
⁹¹ Sr	2.3E-02	4.3E-08	1.2E-05	2.3E-02	6.1E+00
⁹² Sr+D (b)	2.9E-02	3.5E-08	9.0E-06	2.9E-02	7.7E+00
⁹² Sr	4.8E-02	3.0E-08	8.0E-06	4.8E-02	1.3E+01
⁹⁰ Y	2.3E-04	4.2E-07	5.5E-05	2.8E-04	7.7E-02
^{91m} Y+D (b)	1.0E-02	1.2E-06	2.4E-05	1.0E-02	2.8E+00
^{91m} Y	2.1E-02	1.8E-09	2.0E-07	2.1E-02	5.7E+00
⁹¹ Y	2.1E-04	2.3E-06	4.7E-05	2.6E-04	7.0E-02
⁹² Y	9.7E-03	4.0E-08	1.0E-05	9.7E-03	2.6E+00
⁹³ Y	3.3E-03	1.1E-07	2.4E-05	3.3E-03	9.0E-01
⁹³ Zr+D (b)	3.7E-06	2.8E-06	5.2E-06	1.2E-05	3.2E-03
⁹³ Zr	7.6E-09	4.0E-06	8.0E-06	1.2E-05	3.2E-03
⁹⁵ Zr+D (b)	2.6E-02	5.0E-07	1.6E-05	2.6E-02	7.0E+00
⁹⁵ Zr	2.5E-02	7.5E-07	1.8E-05	2.5E-02	6.8E+00
⁹⁷ Zr+D (b)	1.6E-02	6.6E-08	1.5E-05	1.6E-02	4.4E+00
⁹⁷ Zr	6.2E-03	1.9E-07	4.2E-05	6.3E-03	1.7E+00
^{93m} Nb	7.6E-06	1.5E-06	2.5E-06	1.2E-05	3.1E-03
⁹⁴ Nb	5.0E-02	1.9E-05	3.6E-05	5.0E-02	1.4E+01
^{95m} Nb+D (b)	1.4E-02	2.0E-07	1.2E-05	1.4E-02	3.9E+00
^{95m} Nb	1.8E-03	1.2E-07	1.1E-05	1.9E-03	5.0E-01

TABLE 3.1. Annual Total Effective Dose Equivalent Factors for the Building Renovation (Volume Activity) Scenario(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
⁹⁵ Nb	2.8E-02	2.7E-07	1.2E-05	2.8E-02	7.6E+00
^{97m} Nb+D (b)	2.2E-02	2.1E-09	6.0E-07	2.2E-02	5.9E+00
^{97m} Nb	2.2E-02	6.0E-11	2.0E-08	2.2E-02	5.8E+00
⁹⁷ Nb	2.2E-02	4.1E-09	1.2E-06	2.2E-02	6.0E+00
⁹³ Mo+D (b)	2.2E-05	7.5E-07	4.5E-06	2.7E-05	7.3E-03
⁹³ Mo	3.7E-05	4.7E-08	7.0E-06	4.4E-05	1.2E-02
⁹⁹ Mo+D (b)	3.9E-03	5.3E-08	8.2E-06	3.9E-03	1.1E+00
⁹⁹ Mo	4.7E-03	9.5E-08	1.5E-05	4.7E-03	1.3E+00
^{99m} Tc	3.1E-03	1.6E-09	4.2E-07	3.1E-03	8.4E-01
⁹⁹ Tc	1.1E-06	4.4E-07	1.5E-05	1.7E-05	4.6E-03
¹⁰¹ Tc	1.2E-02	7.5E-10	3.8E-07	1.2E-02	3.2E+00
¹⁰³ Ru+D (b)	7.6E-03	2.2E-07	7.5E-06	7.7E-03	2.1E+00
¹⁰³ Ru	1.5E-02	4.3E-07	1.5E-05	1.5E-02	4.1E+00
¹⁰⁵ Ru+D (b)	9.4E-03	2.5E-08	4.5E-06	9.4E-03	2.5E+00
¹⁰⁵ Ru+I (c)	2.6E-02	2.6E-08	6.5E-06	2.6E-02	6.9E+00
¹⁰⁶ Ru+I (c)	7.3E-03	1.1E-05	6.5E-05	7.4E-03	2.0E+00
^{103m} Rh	1.4E-05	2.4E-10	6.0E-08	1.4E-05	3.7E-03
¹⁰⁶ Rh	2.7E-03	4.8E-08	7.5E-06	2.8E-03	7.4E-01
¹⁰³ Pd+D (b)	6.0E-05	3.8E-08	2.0E-06	6.2E-05	1.7E-02
¹⁰³ Pd	1.1E-04	7.5E-08	3.9E-06	1.1E-04	3.0E-02
¹⁰⁷ Pd	5.2E-10	6.0E-07	7.5E-07	1.4E-06	3.6E-04
¹⁰⁹ Pd+I (c)	1.6E-04	3.3E-08	6.5E-06	1.7E-04	4.6E-02
^{110m} Ag+I (c)	9.4E-02	2.0E-06	8.3E-05	9.4E-02	2.5E+01
¹¹¹ Ag	8.8E-04	1.7E-07	2.5E-05	9.1E-04	2.4E-01
¹⁰⁹ Cd	9.8E-05	5.5E-06	6.5E-05	1.7E-04	4.5E-02
^{113m} Cd	6.9E-06	7.0E-05	8.0E-04	8.8E-04	2.4E-01
^{115m} Cd+D (b)	4.0E-04	1.7E-06	4.0E-05	4.4E-04	1.2E-01
^{115m} Cd	8.6E-04	3.4E-06	8.0E-05	9.4E-04	2.5E-01
¹¹⁵ Cd	6.1E-03	1.9E-07	3.0E-05	6.1E-03	1.6E+00
¹¹¹ In	1.0E-02	2.7E-08	6.5E-06	1.0E-02	2.7E+00
^{114m} In+I (c)	3.9E-03	1.1E-06	3.8E-05	3.9E-03	1.1E+00
^{115m} In	5.3E-03	6.0E-09	1.7E-06	5.3E-03	1.4E+00
^{117m} Sn	3.2E-03	2.1E-07	1.4E-05	3.2E-03	8.6E-01
^{119m} Sn	7.0E-05	2.9E-07	7.0E-06	7.8E-05	2.1E-02
^{121m} Sn+D (b)	0.0E+00	3.1E-07	6.2E-06	6.5E-06	1.8E-03
^{121m} Sn	0.0E+00	5.5E-07	7.5E-06	8.1E-06	2.2E-03

TABLE 3.1. Annual Total Effective Dose Equivalent Factors for the Building Renovation (Volume Activity) Scenario(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
¹²¹ Sn	0.0E+00	2.4E-08	4.6E-06	4.6E-06	1.2E-03
¹²³ Sn	2.8E-04	1.5E-06	4.2E-05	3.3E-04	8.9E-02
¹²⁵ Sn+D (b)	1.1E-02	6.5E-07	3.6E-05	1.1E-02	3.0E+00
¹²⁵ Sn	1.0E-02	7.5E-07	6.0E-05	1.0E-02	2.8E+00
¹²⁶ Sn+D (b)	3.0E-02	2.2E-06	4.9E-05	3.0E-02	8.2E+00
¹²⁶ Sn	8.7E-04	4.7E-06	9.5E-05	9.6E-04	2.6E-01
¹²⁴ Sb	6.5E-02	1.3E-06	4.9E-05	6.5E-02	1.8E+01
¹²⁵ Sb+D (b)	1.2E-02	5.3E-07	1.5E-05	1.2E-02	3.2E+00
¹²⁵ Sb	1.5E-02	6.0E-07	1.4E-05	1.5E-02	4.0E+00
^{126m} Sb+D (b)	5.6E-02	7.5E-08	6.6E-06	5.6E-02	1.5E+01
^{126m} Sb	5.3E-02	1.5E-09	4.5E-07	5.3E-02	1.4E+01
¹²⁶ Sb	9.1E-02	5.5E-07	5.0E-05	9.1E-02	2.5E+01
¹²⁷ Sb+D (b)	1.0E-02	2.2E-07	2.1E-05	1.0E-02	2.7E+00
¹²⁷ Sb	2.2E-02	2.9E-07	3.6E-05	2.2E-02	5.9E+00
^{123m} Te	3.0E-03	5.0E-07	2.9E-05	3.1E-03	8.2E-01
^{125m} Te	2.6E-04	3.5E-07	1.8E-05	2.8E-04	7.5E-02
^{127m} Te+D (b)	1.3E-04	5.3E-07	2.2E-05	1.5E-04	4.1E-02
^{127m} Te	8.3E-05	1.0E-06	4.1E-05	1.3E-04	3.4E-02
¹²⁷ Te	1.8E-04	1.6E-08	3.5E-06	1.9E-04	5.0E-02
^{129m} Te+D (b)	1.4E-03	1.5E-05	1.7E-03	3.1E-03	8.2E-01
^{129m} Te	1.1E-03	2.4E-05	2.7E-03	3.8E-03	1.0E+00
¹²⁹ Te	1.8E-03	7.5E-09	1.3E-06	1.8E-03	5.0E-01
^{131m} Te+D (b)	2.8E-02	9.4E-07	1.5E-04	2.8E-02	7.6E+00
^{131m} Te	5.0E-02	6.0E-07	8.5E-05	5.0E-02	1.3E+01
¹³¹ Te+D (b)	1.2E-02	7.5E-07	1.2E-04	1.3E-02	3.4E+00
¹³¹ Te	1.3E-02	6.0E-09	1.1E-06	1.3E-02	3.6E+00
¹³² Te+D (b)	4.0E-02	3.3E-07	3.7E-05	4.0E-02	1.1E+01
¹³² Te	6.7E-03	6.0E-07	7.5E-05	6.8E-03	1.8E+00
^{133m} Te+D (b)	3.1E-02	9.2E-08	1.7E-05	3.1E-02	8.2E+00
^{133m} Te	7.8E-02	2.2E-08	3.9E-06	7.8E-02	2.1E+01
¹³³ Te+D (b)	1.6E-02	8.9E-08	1.6E-05	1.6E-02	4.4E+00
¹³³ Te	3.2E-02	4.3E-09	8.0E-07	3.2E-02	8.7E+00
¹³⁴ Te+D (b)	5.6E-02	6.0E-09	1.1E-06	5.6E-02	1.5E+01
¹³⁴ Te	2.9E-02	5.0E-09	9.5E-07	2.9E-02	7.8E+00
¹²⁵ I	3.0E-04	1.1E-06	1.8E-04	4.8E-04	1.3E-01
¹²⁹ I	1.7E-04	7.5E-06	1.3E-03	1.4E-03	3.8E-01
¹³⁰ I	6.7E-02	1.2E-07	2.2E-05	6.7E-02	1.8E+01
¹³¹ I+D (b)	1.1E-02	1.5E-06	2.5E-04	1.1E-02	3.1E+00
¹³¹ I	1.2E-02	1.5E-06	2.5E-04	1.2E-02	3.2E+00
¹³² I	7.9E-02	1.9E-08	3.4E-06	7.9E-02	2.1E+01
¹³³ I+D (b)	9.1E-03	1.3E-07	2.4E-05	9.1E-03	2.5E+00
¹³³ I	1.8E-02	2.6E-07	4.8E-05	1.8E-02	4.9E+00

TABLE 3.1. Annual Total Effective Dose Equivalent Factors for the Building Renovation (Volume Activity) Scenario(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
¹³⁴ I	8.8E-02	7.0E-09	1.3E-06	8.8E-02	2.4E+01
¹³⁵ I+D (b)	2.9E-02	2.5E-08	4.8E-06	2.9E-02	7.7E+00
¹³⁵ I	5.4E-02	5.5E-08	1.0E-05	5.4E-02	1.5E+01
^{134m} Cs+D (b)	2.9E-04	9.0E-10	9.0E-08	2.9E-04	7.7E-02
^{134m} Cs	5.8E-04	1.8E-09	1.8E-07	5.8E-04	1.6E-01
¹³⁴ Cs	5.6E-02	2.0E-06	3.3E-04	5.6E-02	1.5E+01
¹³⁵ Cs	3.5E-07	1.8E-07	3.2E-05	3.3E-05	8.8E-03
¹³⁶ Cs	7.2E-02	3.2E-07	5.0E-05	7.2E-02	1.9E+01
¹³⁷ Cs+I (c)	1.9E-02	6.7E-07	1.2E-04	1.9E-02	5.1E+00
¹³⁸ Cs	8.1E-02	4.8E-09	9.5E-07	8.1E-02	2.2E+01
¹³⁹ Ba	1.0E-03	8.5E-09	2.0E-06	1.0E-03	2.7E-01
¹⁴⁰ Ba+D (b)	3.9E-02	1.6E-07	4.2E-05	3.9E-02	1.1E+01
¹⁴⁰ Ba	5.6E-03	1.5E-07	4.6E-05	5.6E-03	1.5E+00
¹⁴¹ Ba+D (b)	1.0E-02	1.5E-07	7.7E-06	1.0E-02	2.8E+00
¹⁴¹ Ba	2.8E-02	3.9E-09	1.1E-06	2.8E-02	7.6E+00
¹⁴² Ba+D (b)	6.0E-02	7.5E-09	2.0E-06	6.0E-02	1.6E+01
¹⁴² Ba	3.0E-02	1.9E-09	5.5E-07	3.0E-02	8.2E+00
¹⁴⁰ La	7.5E-02	1.7E-07	4.1E-05	7.5E-02	2.0E+01
¹⁴¹ La+D (b)	1.8E-03	2.2E-07	1.1E-05	1.8E-03	4.8E-01
¹⁴¹ La	1.8E-03	2.9E-08	7.5E-06	1.8E-03	4.9E-01
¹⁴² La	8.9E-02	1.3E-08	3.5E-06	8.9E-02	2.4E+01
¹⁴¹ Ce	1.8E-03	4.2E-07	1.4E-05	1.8E-03	4.8E-01
¹⁴³ Ce+D (b)	3.6E-03	2.7E-07	2.3E-05	3.6E-03	9.8E-01
¹⁴³ Ce	7.3E-03	1.7E-07	2.3E-05	7.3E-03	2.0E+00
¹⁴⁴ Ce+D (b)	9.2E-04	8.9E-06	5.2E-05	9.8E-04	2.6E-01
¹⁴⁴ Ce	4.4E-04	1.8E-05	1.0E-04	5.7E-04	1.5E-01
¹⁴³ Pr	2.3E-05	3.9E-07	2.3E-05	4.7E-05	1.3E-02
^{144m} Pr+D (b)	7.6E-04	1.6E-09	4.2E-07	7.6E-04	2.1E-01
^{144m} Pr	1.4E-04	9.0E-10	2.4E-07	1.4E-04	3.7E-02
¹⁴⁴ Pr	1.4E-03	2.1E-09	6.0E-07	1.4E-03	3.9E-01
¹⁴⁷ Nd+D (b)	1.8E-03	1.1E-06	1.3E-05	1.8E-03	4.8E-01
¹⁴⁷ Nd	3.6E-03	3.3E-07	2.1E-05	3.7E-03	9.9E-01
¹⁴⁷ Pm	5.8E-07	1.9E-06	5.0E-06	7.5E-06	2.0E-03
^{148m} Pm+D (b)	6.8E-02	1.1E-06	3.9E-05	6.8E-02	1.8E+01
^{148m} Pm	7.1E-02	1.1E-06	3.8E-05	7.1E-02	1.9E+01
¹⁴⁸ Pm	2.1E-02	5.5E-07	5.5E-05	2.1E-02	5.7E+00
¹⁴⁹ Pm	3.5E-04	1.5E-07	2.0E-05	3.7E-04	1.0E-01
¹⁵¹ Pm	1.0E-02	9.0E-08	1.5E-05	1.0E-02	2.8E+00

TABLE 3.1. Annual Total Effective Dose Equivalent Factors for the Building Renovation (Volume Activity) Scenario(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
¹⁴⁷ Sm	0.0E+00	3.7E-03	9.5E-04	4.6E-03	1.2E+00
¹⁵¹ Sm	1.2E-07	1.5E-06	1.9E-06	3.5E-06	9.4E-04
¹⁵³ Sm	1.5E-03	9.5E-08	1.5E-05	1.5E-03	4.0E-01
¹⁵² Eu	3.9E-02	1.0E-05	3.1E-05	3.9E-02	1.1E+01
¹⁵⁴ Eu	4.1E-02	1.3E-05	4.6E-05	4.1E-02	1.1E+01
¹⁵⁶ Eu	1.3E-03	1.9E-06	7.5E-06	1.4E-03	3.7E-01
¹⁵⁸ Eu	4.5E-02	7.0E-07	4.6E-05	4.6E-02	1.2E+01
¹⁵³ Gd	2.1E-03	1.2E-06	6.0E-06	2.1E-03	5.7E-01
¹⁸⁰ Tb	3.6E-02	1.2E-06	3.3E-05	3.6E-02	9.6E+00
^{186m} Ho	5.1E-02	3.6E-05	3.8E-05	5.1E-02	1.4E+01
¹⁸¹ W	5.7E-04	7.5E-09	1.5E-06	5.7E-04	1.5E-01
¹⁸⁵ W	3.6E-06	3.8E-08	8.0E-06	1.2E-05	3.1E-03
¹⁸⁷ W	1.5E-02	3.3E-08	1.0E-05	1.5E-02	4.2E+00
¹⁸⁷ Re	0.0E+00	2.8E-09	7.0E-08	7.3E-08	2.0E-05
¹⁸⁵ Os	2.3E-02	4.6E-07	1.1E-05	2.3E-02	6.2E+00
¹⁹¹ Os	1.5E-03	1.1E-07	1.1E-05	1.5E-03	4.1E-01
¹⁹² Ir	2.7E-02	1.3E-06	2.9E-05	2.8E-02	7.4E+00
²⁰³ Hg	5.8E-03	3.4E-07	5.5E-05	5.9E-03	1.6E+00
²¹⁰ Pb+D (b)	2.4E-05	3.7E-04	1.2E-02	1.3E-02	3.4E+00
²¹⁰ Pb	3.6E-05	6.5E-04	2.7E-02	2.8E-02	7.5E+00
²¹² Pb+D (b)	1.7E-02	3.0E-06	8.3E-05	1.7E-02	4.5E+00
²¹² Pb	4.1E-03	8.0E-06	2.5E-04	4.4E-03	1.2E+00
²¹⁰ Bi+D (b)	1.8E-05	2.2E-04	4.7E-03	5.0E-03	1.3E+00
²¹⁰ Bi	3.7E-05	9.5E-06	3.1E-05	7.8E-05	2.1E-02
²¹² Bi+I (c)	4.7E-02	4.5E-07	2.7E-06	4.7E-02	1.3E+01
²¹⁰ Po	3.0E-07	4.2E-04	9.5E-03	9.9E-03	2.7E+00
²²³ Ra+I (c)	8.6E-03	6.2E-05	2.2E-04	8.9E-03	2.4E+00
²²⁴ Ra+D (b)	8.4E-03	2.4E-05	1.5E-04	8.6E-03	2.3E+00
²²⁴ Ra+I (c)	3.1E-04	1.3E-04	6.5E-04	1.1E-03	3.0E-01
²²⁵ Ra+D (b)	1.1E-03	1.1E-04	2.4E-04	1.4E-03	3.9E-01
²²⁵ Ra	1.8E-04	3.5E-04	1.1E-03	1.6E-03	4.4E-01
²²⁶ Ra+D (b)	6.6E-03	1.6E-04	4.6E-03	1.1E-02	3.1E+00

TABLE 3.1. Annual Total Effective Dose Equivalent Factors for the Building Renovation (Volume Activity) Scenario(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
^{226}Ra	1.2E-04	4.0E-04	4.7E-03	5.3E-03	1.4E+00
$^{226}\text{Ra}+\text{D}$ (b)	8.9E-03	1.8E-03	7.8E-04	1.1E-02	3.1E+00
^{228}Ra	1.1E-09	1.8E-04	4.2E-03	4.4E-03	1.2E+00
$^{225}\text{Ac}+\text{I}$ (c)	7.6E-03	6.6E-05	9.2E-05	7.8E-03	2.1E+00
$^{227}\text{Ac}+\text{D}$ (b)	1.4E-03	8.1E-03	8.8E-03	1.8E-02	4.9E+00
^{227}Ac	4.1E-06	6.5E-02	7.0E-02	1.4E-01	3.6E+01
$^{228}\text{Ac}+\text{D}$ (b)	1.0E-02	2.0E-03	3.6E-04	1.2E-02	3.3E+00
^{228}Ac	3.3E-02	5.5E-06	1.0E-05	3.3E-02	8.8E+00
$^{227}\text{Th}+\text{D}$ (b)	1.6E-03	1.6E-04	2.2E-04	2.0E-03	5.4E-01
^{227}Th	3.0E-03	8.0E-04	1.9E-04	4.0E-03	1.1E+00
$^{228}\text{Th}+\text{D}$ (b)	7.2E-03	2.3E-03	4.1E-04	9.9E-03	2.7E+00
^{228}Th	5.0E-05	1.5E-02	2.0E-03	1.8E-02	4.7E+00
$^{229}\text{Th}+\text{D}$ (b)	1.2E-03	1.1E-02	2.4E-03	1.4E-02	3.8E+00
^{229}Th	2.0E-03	8.5E-02	1.8E-02	1.0E-01	2.8E+01
$^{230}\text{Th}+\text{D}$ (b)	5.9E-03	1.4E-03	4.4E-03	1.2E-02	3.2E+00
^{230}Th	1.1E-05	1.2E-02	2.7E-03	1.5E-02	4.1E+00
$^{231}\text{Th}+\text{D}$ (b)	2.7E-05	4.0E-09	6.5E-07	2.7E-05	7.3E-03
^{231}Th	2.7E-04	4.1E-08	6.5E-06	2.8E-04	7.5E-02
$^{232}\text{Th}+\text{D}$ (b)	8.0E-03	7.0E-03	2.1E-03	1.7E-02	4.6E+00
Th-Nat (d)	8.0E-03	7.0E-03	2.1E-03	1.7E-02	4.6E+00
^{232}Th	7.7E-06	5.5E-02	1.4E-02	6.9E-02	1.9E+01
$^{234}\text{Th}+\text{D}$ (b)	4.0E-04	8.5E-07	3.3E-05	4.4E-04	1.2E-01
$^{234}\text{Th}+\text{I}$ (c)	7.5E-04	1.7E-06	6.5E-05	8.1E-04	2.2E-01
$^{231}\text{Pa}+\text{D}$ (b)	1.3E-03	1.2E-02	1.4E-02	2.7E-02	7.3E+00
^{231}Pa	9.7E-04	4.2E-02	5.5E-02	9.8E-02	2.6E+01
^{233}Pa	7.0E-03	4.6E-07	1.8E-05	7.0E-03	1.9E+00
^{234}Pa	6.6E-02	4.1E-08	1.1E-05	6.6E-02	1.8E+01
$^{232}\text{U}+\text{D}$ (b)	1.5E-06	4.3E-03	4.9E-05	4.3E-03	1.2E+00
^{232}U	1.1E-05	3.0E-02	3.4E-04	3.0E-02	8.2E+00
$^{233}\text{U}+\text{D}$ (b)	1.1E-03	1.0E-02	2.2E-03	1.3E-02	3.6E+00
^{233}U	8.5E-06	6.5E-03	1.3E-04	6.6E-03	1.8E+00
^{234}U	8.2E-06	6.5E-03	1.3E-04	6.6E-03	1.8E+00
$^{235}\text{U}+\text{D}$ (b)	1.7E-03	3.0E-03	7.0E-05	4.8E-03	1.3E+00
^{235}U	3.2E-03	6.0E-03	1.3E-04	9.3E-03	2.5E+00
^{238}U	6.7E-06	6.0E-03	1.2E-04	6.1E-03	1.7E+00
^{237}U	3.9E-03	1.7E-07	1.6E-05	3.9E-03	1.0E+00
$^{238}\text{U}+\text{D}$ (b)	2.7E-04	1.8E-03	6.2E-05	2.2E-03	5.8E-01
^{238}U	7.8E-05	6.0E-03	1.3E-04	6.2E-03	1.7E+00
U-Nat (e)	1.1E-04	6.2E-03	1.3E-04	6.5E-03	1.8E+00
$^{240}\text{U}+\text{D}$ (b)	4.0E-03	3.7E-08	7.8E-06	4.0E-03	1.1E+00
$^{240}\text{U}+\text{I}$ (c)	1.2E-02	1.1E-07	2.3E-05	1.2E-02	3.3E+00

TABLE 3.1. Annual Total Effective Dose Equivalent Factors for the Building Renovation (Volume Activity) Scenario(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
²³⁷ Np+D (b)	3.7E-03	1.5E-02	1.3E-02	3.2E-02	8.6E+00
²³⁷ Np	4.7E-04	3.1E-02	2.6E-02	5.7E-02	1.5E+01
²³⁸ Np+D (b)	9.2E-03	7.0E-03	8.5E-04	1.7E-02	4.6E+00
²³⁸ Np	1.9E-02	2.0E-06	2.0E-05	1.9E-02	5.1E+00
²³⁹ Np+D (b)	2.4E-03	6.0E-08	8.3E-06	2.4E-03	6.4E-01
²³⁹ Np	4.9E-03	1.2E-07	1.7E-05	4.9E-03	1.3E+00
²³⁸ Pu	8.1E-06	3.6E-03	3.1E-04	3.9E-03	1.1E+00
²³⁷ Pu	1.3E-03	9.0E-08	2.2E-06	1.3E-03	3.6E-01
²³⁸ Pu	6.9E-06	1.4E-02	1.7E-03	1.6E-02	4.2E+00
²³⁹ Pu	4.1E-06	1.4E-02	1.9E-03	1.6E-02	4.4E+00
²⁴⁰ Pu	6.6E-06	1.4E-02	1.9E-03	1.6E-02	4.4E+00
²⁴¹ Pu+D (b)	1.6E-04	1.1E-02	9.0E-03	2.0E-02	5.4E+00
²⁴¹ Pu	1.7E-11	2.3E-04	3.4E-05	2.7E-04	7.3E-02
²⁴² Pu	5.5E-06	1.3E-02	1.7E-03	1.5E-02	4.1E+00
²⁴³ Pu+D (b)	1.7E-03	3.5E-09	8.0E-07	1.7E-03	4.7E-01
²⁴³ Pu	4.7E-04	7.0E-09	1.6E-06	4.7E-04	1.3E-01
²⁴⁴ Pu+D (b)	3.0E-03	3.3E-03	4.5E-04	6.7E-03	1.8E+00
²⁴⁴ Pu	4.6E-06	1.3E-02	1.7E-03	1.5E-02	4.0E+00
²⁴¹ Am	3.2E-04	2.1E-02	1.8E-02	4.0E-02	1.1E+01
^{242m} Am+D (b)	1.1E-04	8.2E-03	5.0E-03	1.3E-02	3.6E+00
^{242m} Am	2.4E-05	2.0E-02	1.8E-02	3.7E-02	1.0E+01
²⁴² Am+D (b)	1.4E-04	4.2E-03	6.5E-04	5.0E-03	1.4E+00
²⁴² Am	3.9E-04	2.6E-06	7.0E-06	4.0E-04	1.1E-01
²⁴³ Am+D (b)	1.9E-03	6.8E-03	6.0E-03	1.5E-02	4.0E+00
²⁴³ Am	9.1E-04	2.0E-02	1.8E-02	3.9E-02	1.1E+01
²⁴² Cm+D (b)	7.5E-06	7.9E-03	1.2E-03	9.2E-03	2.5E+00
²⁴² Cm	6.8E-06	7.5E-04	5.5E-04	1.3E-03	3.5E-01
²⁴³ Cm	3.6E-03	2.9E-02	1.4E-02	4.7E-02	1.3E+01
²⁴⁴ Cm+D (b)	2.9E-06	5.8E-03	5.0E-03	1.1E-02	2.9E+00
²⁴⁴ Cm	6.0E-06	1.2E-02	1.0E-02	2.2E-02	5.8E+00
²⁴⁵ Cm+D (b)	7.0E-04	1.4E-02	1.2E-02	2.7E-02	7.3E+00
²⁴⁵ Cm	1.8E-03	2.1E-02	1.9E-02	4.1E-02	1.1E+01
²⁴⁶ Cm	5.3E-06	2.1E-02	1.9E-02	4.0E-02	1.1E+01
²⁴⁷ Cm+D (b)	7.6E-03	9.8E-03	8.5E-03	2.6E-02	7.0E+00
²⁴⁷ Cm	1.2E-02	2.0E-02	1.7E-02	4.8E-02	1.3E+01
²⁴⁸ Cm	4.3E-06	7.5E-02	6.5E-02	1.4E-01	3.8E+01
²⁵² Cf	4.3E-06	6.5E-03	5.5E-03	1.2E-02	3.2E+00

(a) Based on 500 h of exposure during building renovation with a contamination level of 1 pCi/g (1 Bq/g).

TABLE 3.1. Annual Total Effective Dose Equivalent Factors for the Building Renovation (Volume Activity) Scenario(a) (contd)

- (b) Where +D means "plus daughters in equilibrium" referring to explicit daughters, or daughters with half-lives greater than 10 minutes. Separate values are also included for parents and daughters so that combined factors for non-equilibrium cases can be determined. Note: in some cases +D also includes implicit daughters (i.e., uranium and thorium decay chains).
- (c) Where +I means "plus implicit daughters in equilibrium" referring to daughters with half-lives less than 10 minutes. The decay energies associated with these daughters have been assigned to the parent, and the appropriate branching ratios (described in Appendix D) have been considered.
- (d) Where Th-Nat includes an equilibrium mixture of ^{232}Th plus 10 daughters in the decay chain, as discussed in Appendix D.
- (e) Where 1 Ci U-Nat equals 48.9% ^{238}U plus 48.9% ^{234}U plus 2.25% ^{235}U .

3.1.2 Building Occupancy (Surface Activity) Scenario

At many facilities, most of the residual radioactive inventory may be associated with surface or thin-layer surface sources. Because surface decontamination operations may not remove all of the surface sources, a scenario describing surface activity must be considered. For this analysis, the building occupancy scenario is defined to account for potential exposure to both fixed and removable thin layer or surface contamination sources. This scenario is used to derive surface activity annual TEDE factors.

This scenario considers chronic exposure to an individual for 2000 h/yr, which represents occupancy during a full work year (i.e., 50 weeks at 8 h/d) in a commercial facility. The exposure pathways considered include direct external exposure from surface sources, inhalation of resuspended removable contamination, and secondary ingestion of removable contamination. This scenario does not include consideration of indoor radon gas that may evolve from residual ^{226}Ra in the building. The air concentration and secondary ingestion rates are assumed to be 10% of those encountered during building renovation, or 10^{-5} g/m^3 and 0.001 g/h , respectively. These parameter values and their expected ranges are summarized in Section 3.3 and are more fully discussed in Appendix B. These assumptions and parameter values are used to modify the pathway dose rate conversion and committed effective dose rate conversion factors listed in Section 2.0 to obtain the scenario-specific annual TEDE factors (shown in Table 3.2), in units of mrem per dpm/100 cm^2 (and μSv per Bq/100 cm^2). Table 3.2 lists the contribution by exposure pathway for about 200 radionuclides including key parent-daughter relationships. Again, the +I (implicit daughter) and +D (explicit daughter) notation has been used to provide maximum flexibility for consideration of all parent-daughter and decay chain situations. Further description of the parent-daughter and chain decay relationships used in this study is provided in Appendix D.

Hand calculations were performed to verify the computer calculations for selected radionuclides using the pathway factors from Section 2.0 and the building occupancy scenario assumptions for the external exposure, inhalation, and secondary ingestion pathways. The results for ^{60}Co , ^{90}Sr , ^{137}Cs , ^{235}U , and ^{239}Pu indicated that the values in Table 3.2 were calculated correctly.

TABLE 3.2. Annual Total Effective Dose Equivalent Factors for the Building Occupancy (Surface Activity) Scenario(a)

Radionuclide	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
³ H	4.8E-13	1.6E-09	1.1E-07	1.2E-07	3.1E-05
¹⁰ Be	1.7E-07	6.8E-06	9.2E-06	1.6E-05	4.4E-03
¹⁴ C	1.0E-08	3.8E-08	3.8E-06	3.8E-06	1.0E-03
¹⁸ F	3.2E-04	1.5E-09	2.2E-07	3.2E-04	1.9E-01
²² Na	7.2E-04	1.7E-07	2.8E-05	7.5E-04	4.4E-01
²⁴ Na	1.3E-03	2.2E-08	2.8E-06	1.3E-03	8.0E-01
³² P	1.5E-06	1.1E-07	1.7E-05	1.9E-05	5.5E-03
³³ P	3.0E-08	1.1E-08	1.7E-06	1.8E-06	4.9E-04
³⁵ S	1.1E-08	4.8E-08	8.0E-07	8.6E-07	2.4E-04
³⁶ Cl	2.6E-07	3.6E-08	5.6E-06	5.9E-06	1.7E-03
⁴⁰ K	5.4E-05	2.0E-07	3.4E-05	8.8E-05	4.2E-02
⁴¹ Ca	6.5E-07	2.4E-08	2.4E-06	3.1E-06	1.0E-03
⁴⁵ Ca	3.1E-08	1.3E-07	6.2E-06	6.4E-06	1.7E-03
⁴⁶ Sc	7.1E-04	5.6E-07	1.2E-05	7.3E-04	4.3E-01
⁵¹ Cr	1.3E-05	6.2E-09	2.8E-07	1.4E-05	8.1E-03
⁵⁴ Mn	2.9E-04	1.2E-07	5.6E-06	3.0E-04	1.8E-01
⁵⁶ Mn	5.8E-04	6.6E-09	2.0E-06	5.9E-04	3.5E-01
⁵⁵ Fe	1.5E-06	2.4E-08	1.2E-06	2.7E-06	1.2E-03
⁵⁹ Fe	3.8E-04	2.4E-07	1.3E-05	3.9E-04	2.3E-01
⁵⁷ Co	4.7E-05	1.7E-07	1.5E-06	4.9E-05	2.9E-02
⁵⁸ Co	3.5E-04	2.0E-07	5.8E-06	3.5E-04	2.1E-01
⁶⁰ Co	8.4E-04	3.8E-06	2.0E-05	8.6E-04	5.1E-01
⁵⁹ Ni	1.8E-06	1.6E-08	3.8E-07	2.2E-06	1.2E-03
⁶³ Ni	8.0E-10	3.8E-08	1.0E-06	1.1E-06	2.9E-04
⁶⁵ Ni	1.9E-04	4.6E-09	1.3E-06	1.9E-04	1.2E-01
⁶⁴ Cu	6.2E-05	3.8E-09	9.6E-07	6.3E-05	3.8E-02
⁶⁵ Zn	2.2E-04	3.4E-07	2.6E-05	2.5E-04	1.4E-01
^{69m} Zn+D(b)	7.4E-05	8.2E-09	1.4E-06	7.6E-05	4.5E-02

TABLE 3.2. Annual Total Effective Dose Equivalent Factors for the Building Occupancy (Surface Activity) Scenario(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
^{69m} Zn	1.6E-04	1.6E-08	2.6E-06	1.6E-04	9.5E-02
⁶⁹ Zn	4.3E-07	7.6E-10	1.8E-07	6.1E-07	3.1E-04
⁷⁶ As	1.7E-04	7.6E-08	1.1E-05	1.8E-04	1.1E-01
⁷⁶ Se	1.3E-04	1.5E-07	1.8E-05	1.5E-04	8.4E-02
⁷⁹ Se	7.8E-09	1.8E-07	1.6E-05	1.6E-05	4.4E-03
⁸² Br	9.6E-04	2.2E-08	3.2E-06	9.7E-04	5.8E-01
⁸³ Br+D (b)	2.0E-06	8.9E-10	9.4E-08	2.1E-06	1.2E-03
⁸³ Br	2.8E-06	1.8E-09	1.9E-07	3.0E-06	1.7E-03
⁸⁴ Br	5.6E-04	1.9E-09	3.6E-07	5.6E-04	3.4E-01
⁸⁶ Rb	3.2E-05	1.2E-07	1.8E-05	5.1E-05	2.4E-02
⁸⁸ Rb	2.3E-04	1.7E-09	3.6E-07	2.3E-04	1.4E-01
⁸⁹ Rb+D (b)	3.3E-04	5.3E-08	8.8E-06	3.4E-04	2.0E-01
⁸⁹ Rb	6.9E-04	8.4E-10	1.9E-07	6.9E-04	4.1E-01
⁸⁵ Sr	1.7E-04	2.8E-08	3.4E-06	1.7E-04	1.0E-01
⁸⁹ Sr	1.3E-06	1.1E-07	1.7E-05	1.9E-05	5.5E-03
⁹⁰ Sr+D (b)	1.6E-06	2.1E-06	1.3E-04	1.3E-04	3.7E-02
⁹⁰ Sr	1.4E-07	4.0E-06	2.4E-04	2.4E-04	6.6E-02
⁹¹ Sr+D (b)	1.4E-04	3.7E-07	9.3E-06	1.5E-04	8.5E-02
⁹¹ Sr	2.3E-04	1.7E-08	4.8E-06	2.4E-04	1.4E-01
⁹² Sr+D (b)	2.8E-04	1.4E-08	3.6E-06	2.9E-04	1.7E-01
⁹² Sr	4.8E-04	1.2E-08	3.2E-06	4.9E-04	2.9E-01
⁹⁰ Y	3.1E-06	1.7E-07	2.2E-05	2.5E-05	7.9E-03
^{91m} Y+D (b)	1.1E-04	4.7E-07	9.5E-06	1.2E-04	6.8E-02
^{91m} Y	2.2E-04	7.2E-10	8.2E-08	2.2E-04	1.3E-01
⁹¹ Y	2.6E-06	9.4E-07	1.9E-05	2.2E-05	6.9E-03
⁹² Y	1.0E-04	1.6E-08	4.0E-06	1.0E-04	6.1E-02
⁹³ Y	3.5E-05	4.4E-08	9.6E-06	4.5E-05	2.4E-02
⁹³ Zr+D (b)	3.4E-07	1.1E-06	2.1E-06	3.5E-06	1.1E-03
⁹³ Zr	6.4E-10	1.6E-06	3.2E-06	4.8E-06	1.3E-03
⁹⁵ Zr+D (b)	2.7E-04	2.0E-07	6.3E-06	2.8E-04	1.6E-01
⁹⁵ Zr	2.7E-04	3.0E-07	7.4E-06	2.7E-04	1.6E-01
⁹⁷ Zr+D (b)	1.7E-04	2.6E-08	5.8E-06	1.8E-04	1.1E-01
⁹⁷ Zr	6.5E-05	7.6E-08	1.7E-05	8.1E-05	4.3E-02
^{93m} Nb	7.2E-07	5.8E-07	1.0E-06	2.3E-06	8.6E-04
⁹⁴ Nb	5.3E-04	7.4E-06	1.4E-05	5.5E-04	3.2E-01
^{95m} Nb+D (b)	1.6E-04	7.8E-08	4.8E-06	1.6E-04	9.7E-02
^{95m} Nb	2.4E-05	4.8E-08	4.6E-06	2.8E-05	1.5E-02

TABLE 3.2. Annual Total Effective Dose Equivalent Factors for the Building Occupancy (Surface Activity) Scenario(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
⁹⁵ Nb	2.9E-04	1.1E-07	5.0E-06	3.0E-04	1.8E-01
^{97m} Nb+D (b)	2.3E-04	8.4E-10	2.4E-07	2.3E-04	1.4E-01
^{97m} Nb	2.3E-04	2.4E-11	7.8E-09	2.3E-04	1.4E-01
⁹⁷ Nb	2.4E-04	1.7E-09	4.8E-07	2.4E-04	1.4E-01
⁹³ Mo+D (b)	2.0E-06	3.0E-07	1.8E-06	4.1E-06	1.8E-03
⁹³ Mo	3.5E-06	1.9E-08	2.8E-06	6.3E-06	2.8E-03
⁹⁹ Mo+D (b)	4.5E-05	2.1E-08	3.3E-06	4.8E-05	2.8E-02
⁹⁹ Mo	5.1E-05	3.8E-08	6.2E-06	5.8E-05	3.3E-02
^{99m} Tc	4.1E-05	6.2E-10	1.7E-07	4.1E-05	2.4E-02
⁹⁹ Tc	3.8E-08	1.8E-07	6.2E-06	6.4E-06	1.7E-03
¹⁰¹ Tc	1.3E-04	3.0E-10	1.5E-07	1.3E-04	7.9E-02
¹⁰³ Ru+D (b)	8.1E-05	8.7E-08	3.0E-06	8.4E-05	5.0E-02
¹⁰³ Ru	1.6E-04	1.7E-07	6.0E-06	1.7E-04	1.0E-01
¹⁰⁵ Ru+D (b)	9.9E-05	1.0E-08	1.8E-06	1.0E-04	6.0E-02
¹⁰⁵ Ru+I (c)	2.8E-04	1.0E-08	2.6E-06	2.8E-04	1.7E-01
¹⁰⁶ Ru+I (c)	7.8E-05	4.5E-06	2.6E-05	1.1E-04	5.5E-02
^{103m} Rh	1.2E-06	9.6E-11	2.4E-08	1.2E-06	7.4E-04
¹⁰⁵ Rh	3.0E-05	1.9E-08	3.0E-06	3.3E-05	1.9E-02
¹⁰³ Pd+D (b)	5.1E-06	1.5E-08	7.9E-07	5.9E-06	3.3E-03
¹⁰³ Pd	9.4E-06	3.0E-08	1.6E-06	1.1E-05	6.0E-03
¹⁰⁷ Pd	4.9E-11	2.4E-07	3.0E-07	5.4E-07	1.5E-04
¹⁰⁹ Pd+I (c)	6.4E-06	1.3E-08	2.6E-06	9.0E-06	4.5E-03
^{110m} Ag+I (c)	9.7E-04	8.2E-07	3.3E-05	1.0E-03	5.9E-01
¹¹¹ Ag	1.0E-05	6.6E-08	1.0E-05	2.0E-05	8.8E-03
¹⁰⁹ Cd	8.8E-06	2.2E-06	2.6E-05	3.7E-05	1.3E-02
^{113m} Cd	1.6E-07	2.8E-05	3.2E-04	3.5E-04	9.4E-02
^{115m} Cd+D (b)	4.5E-06	6.9E-07	1.6E-05	2.1E-05	7.2E-03
^{115m} Cd	9.2E-06	1.4E-06	3.2E-05	4.3E-05	1.5E-02
¹¹⁵ Cd	6.6E-05	7.8E-08	1.2E-05	7.8E-05	4.3E-02
¹¹¹ In	1.3E-04	1.1E-08	2.6E-06	1.3E-04	8.0E-02
^{114m} In+I (c)	4.8E-05	4.5E-07	1.5E-05	6.3E-05	3.3E-02
^{115m} In	6.2E-05	2.4E-09	7.0E-07	6.3E-05	3.7E-02
^{117m} Sn	4.9E-05	8.4E-08	5.8E-06	5.5E-05	3.1E-02
^{119m} Sn	6.3E-06	1.2E-07	2.8E-06	9.3E-06	4.6E-03
^{121m} Sn+D (b)	0.0E+00	1.2E-07	2.5E-06	2.6E-06	7.0E-04
^{121m} Sn	0.0E+00	2.2E-07	3.0E-06	3.2E-06	8.7E-04

TABLE 3.2. Annual Total Effective Dose Equivalent Factors for the Building Occupancy (Surface Activity) Scenario(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
¹²¹ Sn	0.0E+00	9.6E-09	1.8E-06	1.8E-06	4.9E-04
¹²³ Sn	3.3E-06	6.2E-07	1.7E-05	2.1E-05	6.7E-03
¹²⁵ Sn+D (b)	1.2E-04	2.6E-07	1.4E-05	1.4E-04	7.7E-02
¹²⁵ Sn	1.1E-04	3.0E-07	2.4E-05	1.3E-04	7.0E-02
¹²⁶ Sn+D (b)	3.3E-04	9.0E-07	2.0E-05	3.5E-04	2.0E-01
¹²⁶ Sn	1.7E-05	1.9E-06	3.8E-05	5.7E-05	2.1E-02
¹²⁴ Sb	6.7E-04	5.0E-07	2.0E-05	6.9E-04	4.1E-01
¹²⁵ Sb+D (b)	1.3E-04	2.1E-07	5.8E-06	1.4E-04	8.1E-02
¹²⁵ Sb	1.6E-04	2.4E-07	5.6E-06	1.7E-04	1.0E-01
^{126m} Sb+D (b)	5.9E-04	3.0E-08	2.6E-06	6.0E-04	3.6E-01
^{126m} Sb	5.7E-04	5.8E-10	1.8E-07	5.7E-04	3.4E-01
¹²⁶ Sb	9.6E-04	2.2E-07	2.0E-05	9.8E-04	5.8E-01
¹²⁷ Sb+D (b)	1.1E-04	8.9E-08	8.6E-06	1.1E-04	6.6E-02
¹²⁷ Sb	2.3E-04	1.2E-07	1.4E-05	2.5E-04	1.4E-01
^{123m} Te	4.5E-05	2.0E-07	1.1E-05	5.7E-05	3.0E-02
^{125m} Te	1.7E-05	1.4E-07	7.4E-06	2.5E-05	1.2E-02
^{127m} Te+D (b)	3.8E-06	2.1E-07	9.0E-06	1.3E-05	4.7E-03
^{127m} Te	5.5E-06	4.2E-07	1.6E-05	2.2E-05	7.9E-03
¹²⁷ Te	2.1E-06	6.4E-09	1.4E-06	3.5E-06	1.6E-03
^{129m} Te+D (b)	1.7E-05	5.9E-06	6.6E-04	6.9E-04	1.9E-01
^{129m} Te	1.5E-05	9.6E-06	1.1E-03	1.1E-03	3.0E-01
¹²⁹ Te	2.2E-05	3.0E-09	5.2E-07	2.3E-05	1.3E-02
^{131m} Te+D (b)	3.0E-04	3.8E-07	6.0E-05	3.6E-04	1.9E-01
^{131m} Te	5.2E-04	2.4E-07	3.4E-05	5.5E-04	3.2E-01
¹³¹ Te+D (b)	1.3E-04	3.0E-07	5.0E-05	1.8E-04	9.4E-02
¹³¹ Te	1.5E-04	2.4E-09	4.2E-07	1.5E-04	8.9E-02
¹³² Te+D (b)	4.4E-04	1.3E-07	1.5E-05	4.5E-04	2.7E-01
¹³² Te	8.7E-05	2.4E-07	3.0E-05	1.2E-04	6.0E-02
^{133m} Te+D (b)	3.3E-04	3.7E-08	7.0E-06	3.3E-04	2.0E-01
^{133m} Te	8.0E-04	8.6E-09	1.6E-06	8.0E-04	4.8E-01
¹³³ Te+D (b)	1.7E-04	3.6E-08	6.5E-06	1.8E-04	1.1E-01
¹³³ Te	3.4E-04	1.7E-09	3.2E-07	3.4E-04	2.0E-01
¹³⁴ Te+D (b)	5.9E-04	2.4E-09	4.5E-07	6.0E-04	3.6E-01
¹³⁴ Te	3.2E-04	2.0E-09	3.8E-07	3.2E-04	1.9E-01
¹²⁵ I	2.0E-05	4.4E-07	7.2E-05	9.3E-05	3.2E-02
¹²⁹ I	1.1E-05	3.0E-06	5.0E-04	5.1E-04	1.4E-01
¹³⁰ I	7.2E-04	4.8E-08	8.8E-06	7.3E-04	4.3E-01
¹³¹ I+D (b)	1.2E-04	5.9E-07	9.9E-05	2.2E-04	1.0E-01
¹³¹ I	1.3E-04	6.0E-07	1.0E-04	2.3E-04	1.0E-01
¹³² I	8.2E-04	7.6E-09	1.4E-06	8.2E-04	4.9E-01
¹³³ I+D (b)	1.0E-04	5.2E-08	9.6E-06	1.1E-04	6.3E-02
¹³³ I	1.9E-04	1.1E-07	1.9E-05	2.1E-04	1.2E-01

TABLE 3.2. Annual Total Effective Dose Equivalent Factors for the Building Occupancy (Surface Activity) Scenario^(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
¹³⁴ I	9.1E-04	2.8E-09	5.2E-07	9.1E-04	5.5E-01
¹³⁵ I+D (b)	2.9E-04	1.0E-08	1.9E-06	2.9E-04	1.7E-01
¹³⁵ I	5.4E-04	2.2E-08	4.2E-06	5.5E-04	3.3E-01
^{134m} Cs+D (b)	5.5E-06	3.6E-10	3.6E-08	5.5E-06	3.3E-03
^{134m} Cs	1.1E-05	7.2E-10	7.2E-08	1.1E-05	6.8E-03
¹³⁴ Cs	5.9E-04	8.0E-07	1.3E-04	7.3E-04	3.9E-01
¹³⁵ Cs	1.5E-08	7.2E-08	1.3E-05	1.3E-05	3.5E-03
¹³⁶ Cs	7.5E-04	1.3E-07	2.0E-05	7.7E-04	4.5E-01
¹³⁷ Cs+I (c)	2.0E-04	2.7E-07	4.7E-05	2.5E-04	1.3E-01
¹³⁸ Cs	8.1E-04	1.9E-09	3.8E-07	8.1E-04	4.9E-01
¹³⁹ Ba	1.3E-05	3.4E-09	8.2E-07	1.4E-05	8.1E-03
¹⁴⁰ Ba+D (b)	4.0E-04	6.4E-08	1.7E-05	4.2E-04	2.4E-01
¹⁴⁰ Ba	6.3E-05	5.8E-08	1.8E-05	8.2E-05	4.3E-02
¹⁴¹ Ba+D (b)	1.1E-04	6.0E-08	3.1E-06	1.2E-04	6.8E-02
¹⁴¹ Ba	3.0E-04	1.6E-09	4.2E-07	3.0E-04	1.8E-01
¹⁴² Ba+D (b)	5.7E-04	3.0E-09	8.1E-07	5.8E-04	3.4E-01
¹⁴² Ba	3.2E-04	7.8E-10	2.2E-07	3.2E-04	1.9E-01
¹⁴⁰ La	7.6E-04	6.8E-08	1.7E-05	7.7E-04	4.6E-01
¹⁴¹ La+D (b)	2.1E-05	9.0E-08	4.4E-06	2.5E-05	1.4E-02
¹⁴¹ La	1.9E-05	1.2E-08	3.0E-06	2.2E-05	1.2E-02
¹⁴² La	8.8E-04	5.2E-09	1.4E-06	8.8E-04	5.3E-01
¹⁴¹ Ce	2.5E-05	1.7E-07	5.8E-06	3.1E-05	1.6E-02
¹⁴³ Ce+D (b)	4.3E-05	1.1E-07	9.3E-06	5.3E-05	2.8E-02
¹⁴³ Ce	8.9E-05	6.8E-08	9.2E-06	9.9E-05	5.6E-02
¹⁴⁴ Ce+D (b)	1.1E-05	3.6E-06	2.1E-05	3.5E-05	1.3E-02
¹⁴⁴ Ce	6.7E-06	7.2E-06	4.2E-05	5.6E-05	1.7E-02
¹⁴³ Pr	4.3E-07	1.6E-07	9.4E-06	1.0E-05	2.8E-03
^{144m} Pr+D (b)	1.0E-05	6.2E-10	1.7E-07	1.0E-05	6.1E-03
^{144m} Pr	5.1E-06	3.6E-10	9.6E-08	5.2E-06	3.1E-03
¹⁴⁴ Pr	1.6E-05	8.6E-10	2.4E-07	1.6E-05	9.4E-03
¹⁴⁷ Nd+D (b)	2.2E-05	4.4E-07	5.2E-06	2.8E-05	1.5E-02
¹⁴⁷ Nd	4.6E-05	1.3E-07	8.4E-06	5.5E-05	3.0E-02
¹⁴⁷ Pm	2.1E-08	7.6E-07	2.0E-06	2.8E-06	7.6E-04
^{148m} Pm+D (b)	7.1E-04	4.2E-07	1.6E-05	7.3E-04	4.3E-01
^{148m} Pm	7.6E-04	4.4E-07	1.5E-05	7.7E-04	4.6E-01
¹⁴⁸ Pm	2.1E-04	2.2E-07	2.2E-05	2.3E-04	1.3E-01
¹⁴⁹ Pm	4.2E-06	5.8E-08	8.2E-06	1.2E-05	4.8E-03
¹⁵¹ Pm	1.2E-04	3.6E-08	6.0E-06	1.2E-04	7.3E-02

TABLE 3.2. Annual Total Effective Dose Equivalent Factors for the Building Occupancy (Surface Activity) Scenario(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
¹⁴⁷ Sm	0.0E+00	1.5E-03	3.8E-04	1.8E-03	5.0E-01
¹⁵¹ Sm	1.1E-08	5.8E-07	7.6E-07	1.4E-06	3.7E-04
¹⁵³ Sm	2.5E-05	3.8E-08	6.0E-06	3.1E-05	1.6E-02
¹⁵² Eu	4.1E-04	4.0E-06	1.3E-05	4.3E-04	2.5E-01
¹⁵⁴ Eu	4.3E-04	5.2E-06	1.8E-05	4.5E-04	2.6E-01
¹⁵⁵ Eu	2.1E-05	7.8E-07	3.0E-06	2.4E-05	1.3E-02
¹⁵⁶ Eu	4.6E-04	2.8E-07	1.8E-05	4.8E-04	2.8E-01
¹⁵³ Gd	3.9E-05	4.6E-07	2.4E-06	4.2E-05	2.4E-02
¹⁶⁰ Tb	3.7E-04	4.8E-07	1.3E-05	3.8E-04	2.3E-01
^{166m} Ho	5.5E-04	1.4E-05	1.5E-05	5.8E-04	3.4E-01
¹⁸¹ W	1.2E-05	3.0E-09	5.8E-07	1.3E-05	7.4E-03
¹⁸⁵ W	9.3E-08	1.5E-08	3.2E-06	3.3E-06	9.2E-04
¹⁸⁷ W	1.7E-04	1.3E-08	4.2E-06	1.7E-04	1.0E-01
¹⁸⁷ Re	0.0E+00	1.1E-09	2.8E-08	2.9E-08	7.9E-06
¹⁸⁵ Os	2.5E-04	1.8E-07	4.4E-06	2.5E-04	1.5E-01
¹⁹¹ Os	2.4E-05	4.4E-08	4.6E-06	2.8E-05	1.6E-02
¹⁹² Ir	3.0E-04	5.2E-07	1.1E-05	3.1E-04	1.8E-01
²⁰³ Hg	6.9E-05	1.4E-07	2.2E-05	9.1E-05	4.7E-02
²¹⁰ Pb+D (b)	8.1E-07	1.5E-04	4.9E-03	5.0E-03	1.4E+00
²¹⁰ Pb	1.9E-06	2.6E-04	1.1E-02	1.1E-02	3.0E+00
²¹² Pb+D (b)	1.7E-04	1.2E-06	3.3E-05	2.0E-04	1.1E-01
²¹² Pb	5.0E-05	3.2E-06	9.8E-05	1.5E-04	5.8E-02
²¹⁰ Bi+D (b)	3.1E-07	8.6E-05	1.9E-03	2.0E-03	5.4E-01
²¹⁰ Bi	6.4E-07	3.8E-06	1.3E-05	1.7E-05	4.8E-03
²¹² Bi+I (c)	4.7E-04	1.8E-07	1.1E-06	4.7E-04	2.8E-01
²¹⁰ Po	3.1E-09	1.7E-04	3.8E-03	4.0E-03	1.1E+00
²²³ Ra+I (c)	1.0E-04	2.5E-05	9.0E-05	2.2E-04	9.2E-02
²²⁴ Ra+D (b)	8.3E-05	9.7E-06	6.0E-05	1.5E-04	6.9E-02
²²⁴ Ra+I (c)	3.7E-06	5.4E-05	2.6E-04	3.2E-04	8.7E-02
²²⁵ Ra+D (b)	1.2E-05	4.3E-05	9.4E-05	1.5E-04	4.4E-02
²²⁵ Ra	5.6E-06	1.4E-04	4.4E-04	5.9E-04	1.6E-01
²²⁶ Ra+D (b)	6.6E-05	6.4E-05	1.8E-03	2.0E-03	5.5E-01

TABLE 3.2. Annual Total Effective Dose Equivalent Factors for the Building Occupancy (Surface Activity) Scenario(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
^{226}Ra	1.7E-06	1.6E-04	1.9E-03	2.1E-03	5.6E-01
$^{226}\text{Ra}+\text{D}$ (b)	9.2E-05	7.1E-04	3.1E-04	1.1E-03	3.3E-01
^{228}Ra	1.1E-10	7.4E-05	1.7E-03	1.8E-03	4.7E-01
$^{225}\text{Ac}+\text{I}$ (c)	8.5E-05	2.6E-05	3.7E-05	1.5E-04	6.8E-02
$^{227}\text{Ac}+\text{D}$ (b)	1.7E-05	3.2E-03	3.5E-03	6.8E-03	1.8E+00
^{227}Ac	1.1E-07	2.6E-02	2.8E-02	5.4E-02	1.5E+01
$^{228}\text{Ac}+\text{D}$ (b)	1.0E-04	8.0E-04	1.4E-04	1.0E-03	3.2E-01
^{228}Ac	3.4E-04	2.2E-06	4.2E-06	3.4E-04	2.0E-01
$^{227}\text{Th}+\text{D}$ (b)	1.9E-05	6.6E-05	8.9E-05	1.7E-04	5.3E-02
^{227}Th	3.8E-05	3.2E-04	7.6E-05	4.3E-04	1.3E-01
$^{228}\text{Th}+\text{D}$ (b)	7.1E-05	9.1E-04	1.6E-04	1.1E-03	3.3E-01
^{228}Th	1.1E-06	6.2E-03	8.0E-04	7.0E-03	1.9E+00
$^{229}\text{Th}+\text{D}$ (b)	1.5E-05	4.3E-03	9.5E-04	5.2E-03	1.4E+00
^{229}Th	3.0E-05	3.4E-02	7.0E-03	4.1E-02	1.1E+01
$^{230}\text{Th}+\text{D}$ (b)	5.9E-05	5.6E-04	1.8E-03	2.4E-03	6.6E-01
^{230}Th	5.4E-07	5.0E-03	1.1E-03	6.1E-03	1.6E+00
$^{231}\text{Th}+\text{D}$ (b)	8.2E-07	1.6E-09	2.6E-07	1.1E-06	5.7E-04
^{231}Th	8.6E-06	1.6E-08	2.6E-06	1.1E-05	5.9E-03
$^{232}\text{Th}+\text{D}$ (b)	8.2E-05	2.8E-03	8.4E-04	3.7E-03	1.0E+00
Th-Nat (d)	8.2E-05	2.8E-03	8.4E-04	3.7E-03	1.0E+00
^{232}Th	4.9E-07	2.2E-02	5.6E-03	2.8E-02	7.5E+00
$^{234}\text{Th}+\text{D}$ (b)	5.1E-06	3.4E-07	1.3E-05	1.8E-05	6.7E-03
$^{234}\text{Th}+\text{I}$ (c)	9.5E-06	6.8E-07	2.6E-05	3.6E-05	1.3E-02
$^{231}\text{Pa}+\text{D}$ (b)	1.7E-05	4.7E-03	5.6E-03	1.0E-02	2.8E+00
^{231}Pa	1.4E-05	1.7E-02	2.2E-02	3.9E-02	1.0E+01
^{233}Pa	8.1E-05	1.8E-07	7.2E-06	8.8E-05	5.1E-02
^{234}Pa	6.9E-04	1.6E-08	4.4E-06	7.0E-04	4.2E-01
$^{232}\text{U}+\text{D}$ (b)	9.7E-08	1.7E-03	1.9E-05	1.7E-03	4.7E-01
^{232}U	7.0E-07	1.2E-02	1.4E-04	1.2E-02	3.3E+00
$^{233}\text{U}+\text{D}$ (b)	1.3E-05	4.0E-03	8.7E-04	4.9E-03	1.3E+00
^{233}U	2.9E-07	2.6E-03	5.2E-05	2.7E-03	7.2E-01
^{234}U	5.9E-07	2.6E-03	5.2E-05	2.7E-03	7.2E-01
$^{235}\text{U}+\text{D}$ (b)	2.4E-05	1.2E-03	2.8E-05	1.3E-03	3.5E-01
^{235}U	4.2E-05	2.4E-03	5.2E-05	2.5E-03	6.9E-01
^{236}U	5.4E-07	2.4E-03	4.8E-05	2.4E-03	6.6E-01
^{237}U	5.3E-05	7.0E-08	6.4E-06	6.0E-05	3.4E-02
$^{238}\text{U}+\text{D}$ (b)	3.6E-06	7.3E-04	2.5E-05	7.6E-04	2.1E-01
^{238}U	1.5E-06	2.4E-03	5.0E-05	2.5E-03	6.6E-01
U-Nat (e)	2.0E-06	2.5E-03	5.1E-05	2.6E-03	6.9E-01
$^{240}\text{U}+\text{D}$ (b)	4.3E-05	1.5E-08	3.1E-06	4.6E-05	2.7E-02
$^{240}\text{U}+\text{I}$ (c)	1.3E-04	4.4E-08	9.4E-06	1.4E-04	8.3E-02

TABLE 3.2. Annual Total Effective Dose Equivalent Factors for the Building Occupancy (Surface Activity) Scenario(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
²³⁷ Np+D (b)	4.5E-05	6.1E-03	5.2E-03	1.1E-02	3.1E+00
²³⁷ Np	1.1E-05	1.2E-02	1.0E-02	2.3E-02	6.1E+00
²³⁸ Np+D (b)	9.5E-05	2.8E-03	3.4E-04	3.2E-03	9.0E-01
²³⁸ Np	1.9E-04	8.0E-07	8.0E-06	2.0E-04	1.2E-01
²³⁹ Np+D (b)	3.0E-05	2.4E-08	3.3E-06	3.4E-05	1.9E-02
²³⁹ Np	6.3E-05	4.8E-08	6.6E-06	6.9E-05	3.9E-02
²³⁸ Pu	7.0E-07	1.4E-03	1.3E-04	1.6E-03	4.2E-01
²³⁷ Pu	2.0E-05	3.6E-08	8.6E-07	2.1E-05	1.2E-02
²³⁸ Pu	6.1E-07	5.6E-03	6.8E-04	6.3E-03	1.7E+00
²³⁹ Pu	2.5E-07	5.8E-03	7.4E-04	6.5E-03	1.8E+00
²⁴⁰ Pu	5.9E-07	5.8E-03	7.4E-04	6.5E-03	1.8E+00
²⁴¹ Pu+D (b)	4.1E-06	4.3E-03	3.6E-03	7.9E-03	2.1E+00
²⁴¹ Pu	1.6E-12	9.4E-05	1.4E-05	1.1E-04	2.9E-02
²⁴² Pu	4.9E-07	5.4E-03	6.8E-04	6.1E-03	1.6E+00
²⁴³ Pu+D (b)	2.2E-05	1.4E-09	3.2E-07	2.3E-05	1.3E-02
²⁴³ Pu	7.1E-06	2.8E-09	6.4E-07	7.7E-06	4.4E-03
²⁴⁴ Pu+D (b)	3.2E-05	1.3E-03	1.8E-04	1.5E-03	4.2E-01
²⁴⁴ Pu	4.2E-07	5.2E-03	7.0E-04	5.9E-03	1.6E+00
²⁴¹ Am	8.5E-06	8.6E-03	7.2E-03	1.6E-02	4.3E+00
^{242m} Am+D (b)	2.4E-06	3.3E-03	2.0E-03	5.3E-03	1.4E+00
^{242m} Am	1.7E-06	7.8E-03	7.0E-03	1.5E-02	4.0E+00
²⁴² Am+D (b)	2.6E-06	1.7E-03	2.6E-04	2.0E-03	5.3E-01
²⁴² Am	6.7E-06	1.0E-06	2.8E-06	1.1E-05	5.1E-03
²⁴³ Am+D (b)	2.5E-05	2.7E-03	2.4E-03	5.2E-03	1.4E+00
²⁴³ Am	1.6E-05	8.2E-03	7.2E-03	1.5E-02	4.2E+00
²⁴² Cm+D (b)	6.5E-07	3.2E-03	4.9E-04	3.7E-03	9.9E-01
²⁴² Cm	6.1E-07	3.0E-04	2.2E-04	5.2E-04	1.4E-01
²⁴³ Cm	4.7E-05	1.2E-02	5.8E-03	1.7E-02	4.7E+00
²⁴⁴ Cm+D (b)	2.6E-07	2.3E-03	2.0E-03	4.3E-03	1.2E+00
²⁴⁴ Cm	5.5E-07	4.6E-03	4.0E-03	8.6E-03	2.3E+00
²⁴⁵ Cm+D (b)	1.1E-05	5.7E-03	4.9E-03	1.1E-02	2.9E+00
²⁴⁵ Cm	2.7E-05	8.4E-03	7.4E-03	1.6E-02	4.3E+00
²⁴⁶ Cm	4.9E-07	8.4E-03	7.4E-03	1.6E-02	4.3E+00
²⁴⁷ Cm+D (b)	8.8E-05	3.9E-03	3.4E-03	7.4E-03	2.0E+00
²⁴⁷ Cm	1.3E-04	7.8E-03	6.8E-03	1.5E-02	4.0E+00
²⁴⁸ Cm	3.9E-07	3.0E-02	2.6E-02	5.6E-02	1.5E+01
²⁵² Cf	3.9E-07	2.6E-03	2.2E-03	4.8E-03	1.3E+00

(a) Based on 2000 h of exposure to removable surface activity at an activity level of 1 dpm/100cm² (1 Bq/100cm²).

TABLE 3.2. Annual Total Effective Dose Equivalent Factors for the Building Occupancy (Surface Activity) Scenario(a) (contd)

- (b) Where +D means "plus daughters in equilibrium" referring to explicit daughters, or daughters with half-lives greater than 10 minutes. Separate values are also included for parents and daughters so that combined factors for non-equilibrium cases can be determined. Note: in some cases +D also includes implicit daughters (i.e, uranium and thorium decay chains).
- (c) Where +I means "plus implicit daughters in equilibrium" referring to daughters with half-lives less than 10 minutes. The decay energies associated with these daughters have been assigned to the parent, and the appropriate branching ratios (described in Appendix D) have been considered.
- (d) Where Th-Nat includes an equilibrium mixture of ^{232}Th plus 10 daughters in the decay chain, as discussed in Appendix D.
- (e) Where 1 Ci U-Nat equals 48.9% ^{238}U plus 48.9% ^{234}U plus 2.25% ^{235}U .

3.2 SCENARIO DESCRIPTIONS FOR THE RELEASE OF CONTAMINATED LAND

A wide variety of conditions may exist for contaminated land: e.g., contaminated soil may: 1) be in a thick or thin layer, 2) reside on the soil surface or be buried under clean soil, 3) cover a small or large area, or 4) consist of many different radionuclides or mixtures of radionuclides. Two generic scenarios are provided that will address contaminated land in a conservative manner and account for near-term residential (surface soil) and long-term (drinking-water) use. These two scenarios are considered to be mutually exclusive; that is, each is designed to model a specific situation independently. To avoid accounting for the residual activity twice, the inventory is considered to be either in the surface soils available for agricultural activities, or in deeper soils migrating to the ground water. To further avoid accounting for the inventory twice, irrigation of the site with contaminated ground water is not considered. The residential use scenario is designed to provide an estimate of the potential dose resulting from specific concentrations of radionuclides (pCi/g or Bq/g) in surface soils. The drinking water scenario is designed to provide an estimate of the potential dose from the entire inventory of radioactive materials (the total pCi or Bq) estimated to be on a site as soil contamination or as a residual inventory in building materials that could be left as buried rubble. The scenarios are used to derive annual TEDE factors, expressed in mrem per pCi/g (and μSv per Bq/g) of surface soil and in mrem per pCi (and μSv per Bq) in soil for drinking-water consumption. The following sections describe the generic scenarios used to develop the annual TEDE factors.

3.2.1 Residential Use (Surface Soil) Scenario

The generically derived unit concentration committed effective dose equivalent conversion factors for surface soil, in units of mrem per pCi/g (and μSv per Bq/g), are based on a scenario accounting for reasonable use of the land. Previous studies for low-level radioactive waste management and decommissioning have provided an evaluation of this type of scenario (Healy, Rodgers, and Wienke 1979; Witherspoon 1982; Oztunali, et. al. 1981). Perhaps the most detailed evaluation was conducted for the intruder-agriculture scenario described in the Draft Environmental Impact Statement on 10 CFR Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste" (NRC 1981) and a supplementary document entitled Update of Part 61 Impacts Analysis Methodology (Oztunali and Roles 1986). This scenario accounts for residential use of the land with backyard gardening activities. The three major radiation exposure pathways considered for this scenario include inhalation of air contaminated by the resuspended soil, ingestion of agricultural products grown in the contaminated soil, and direct exposure to penetrating gamma radiation. Rainsplash of contaminated soil onto plant surfaces and indoor radon from residual ^{226}Ra in soils are not considered. For this scenario, an accounting is made of the various activities of the individual, in h/yr. The individual is assumed to spend 4380 h/yr residing at home, indoors, 1700 h/yr outdoors, and 100 h/yr outdoors in gardening activities on the site. The individual is assumed to breath air with an indoor dust loading of $5 \times 10^{-5} \text{ g/m}^3$, and average outdoor dust loading of

1×10^{-4} g/m³ from dusty work conditions, and an airborne dust loading while gardening of 5×10^{-4} g/m³. The individual is assumed to ingest 25% of his total diet, as defined in Regulatory Guide 1.109 (NRC 1977), from food grown in the contaminated soil at the site. Soil-to-plant transfer factors and other data for this pathway are consistent with data found in Oztunali et al. (1981), as discussed in Appendix B. For external exposure, the shielding factor afforded by the house is dependent on the type of house construction and the nature of the contaminated soil (i.e., the source thickness and size). Previous studies have considered shielding factors associated with the atmospheric deposition of radioactive material from passing plumes (Aldrich et al. 1978; Kocher 1978; Jensen 1985). Estimated shielding factors from these studies range from about 0.02 to 0.6, with the majority of values reported from 0.04 to about 0.4 (Aldrich et al. 1978). For this study, a representative shielding factor within this range of 0.33 is assumed.

These parameters and their expected ranges are summarized in Section 3.3 and are more fully discussed in Appendix B. The limited diet is used, assuming that the site is of limited size and that only backyard gardening is attempted. Even if larger sites are encountered where more vigorous agricultural practices may be possible, large-area farming in the United States usually results in the production of a single crop, which is not anticipated to increase to total dietary consumption of radioactive materials by an average individual. The diet for this analysis consists of 47.5 kg/yr of vegetable produce, 27.5 L/yr of milk, 19.2 kg/yr of meats (beef, pork, and poultry), and 4.8 kg/yr of eggs. Again, indoor radon is not considered.

The annual TEDE factors for the residential use scenario are derived by assuming that the land is uniformly contaminated to a depth of 15 cm (the assumed plow layer) over a relatively large area (in excess of 0.15 ha). No further dilution by mixing with non-contaminated soils is assumed. Doses from external exposure are estimated using a cylinder source solution with a radius of 5 m and a thickness of 15 cm. For radionuclides that have significant inhalation dose conversion factors, or for those that are mobile in the food chain, the derived surface soil annual TEDE factors are more restrictive than factors derived solely on the external dose rate. The annual TEDE factors derived for this scenario are designed to provide an estimate of the potential dose resulting from specific surface soil concentrations of radionuclides (in pCi/g or Bq/g). These factors are necessarily conservative because it is impossible to accurately account for the potential end-use of a site without including detailed site-specific data. However, the parameters used in this scenario have been selected to predict the potential dose to an average (not maximum) individual, as discussed in Section 3.3. The resulting annual TEDE factors for the residential use scenario are shown in Table 3.3 in units of mrem per pCi/g (and μ Sv per Bq/g) in soil. Table 3.3 lists the contribution by exposure pathway for about 200 radionuclides including key parent-daughter relationships. Again, the +I (implicit daughter) and +D (explicit daughter) notation has been used to provide maximum flexibility for consideration of all parent-daughter and decay chain situations. Further description of the parent-daughter and chain decay relationships used in this study is provided in Appendix D. Hand calculations were performed for selected radionuclides to verify that the pathway calculations were performed correctly.

TABLE 3.3. Annual Total Effective Dose Equivalent Factors
for the Residential Use (Surface Soil) Scenario(a)

Radionuclide	External (mrem)	Inhalation (mrem)	Food Ingestion ^(b) (mrem)	TEDE (mrem)	TEDE (μ Sv)
³ H	3.4E-11	3.6E-08	2.9E-08	6.5E-08	1.7E-05
¹⁰ Be	4.3E-04	1.5E-04	9.3E-05	6.7E-04	1.8E-01
¹⁴ C	7.3E-06	8.3E-07	9.0E-06	1.7E-05	4.6E-03
¹⁸ F	3.3E+00	3.4E-08	2.2E-05	3.3E+00	8.9E+02
²² Na	6.9E+00	3.8E-06	1.4E-01	7.1E+00	1.9E+03
²⁴ Na	1.3E+01	4.8E-07	4.3E-03	1.3E+01	3.6E+03
³² P	9.5E-03	2.4E-06	1.1E+00	1.1E+00	2.9E+02
³³ P	3.3E-05	2.5E-07	1.2E-01	1.2E-01	3.1E+01
³⁵ S	8.8E-06	1.1E-06	2.5E-02	2.5E-02	6.8E+00
³⁶ Cl	8.5E-04	7.9E-07	2.8E+00	2.8E+00	7.4E+02
⁴⁰ K	5.0E-01	4.3E-06	8.0E-01	1.3E+00	3.5E+02
⁴¹ Ca	4.6E-05	5.3E-07	5.8E-03	5.8E-03	1.6E+00
⁴⁵ Ca	3.5E-05	2.8E-06	1.3E-02	1.3E-02	3.4E+00
⁴⁶ Sc	6.4E+00	1.2E-05	6.3E-04	6.4E+00	1.7E+03
⁵¹ Cr	1.1E-01	1.4E-07	1.9E-06	1.1E-01	3.1E+01
⁵⁴ Mn	2.6E+00	2.7E-06	4.0E-03	2.6E+00	7.0E+02
⁵⁶ Mn	5.6E+00	1.4E-07	1.4E-03	5.6E+00	1.5E+03
⁵⁵ Fe	1.1E-04	5.3E-07	3.5E-05	1.4E-04	3.8E-02
⁵⁹ Fe	3.6E+00	5.3E-06	2.4E-04	3.6E+00	9.6E+02
⁵⁷ Co	2.5E-01	3.6E-06	4.3E-04	2.5E-01	6.6E+01
⁵⁸ Co	3.1E+00	4.4E-06	1.5E-03	3.1E+00	8.4E+02
⁶⁰ Co	7.7E+00	8.3E-05	6.0E-03	7.7E+00	2.1E+03
⁵⁹ Ni	1.3E-04	3.5E-07	4.8E-04	6.0E-04	1.6E-01
⁶³ Ni	1.9E-07	8.3E-07	1.3E-03	1.3E-03	3.4E-01
⁶⁵ Ni	1.8E+00	1.0E-07	5.8E-04	1.8E+00	4.9E+02
⁶⁴ Cu	6.3E-01	8.3E-08	3.0E-03	6.3E-01	1.7E+02
⁶⁵ Zn	2.0E+00	7.5E-06	9.5E-01	3.0E+00	8.0E+02
^{69m} Zn+D ^(c)	7.8E-01	1.8E-07	1.6E-02	8.0E-01	2.2E+02

TABLE 3.3. Annual Total Effective Dose Equivalent Factors for the Residential Use (Surface Soil) Scenario^(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Food Ingestion ^(b) (mrem)	TEDE (mrem)	TEDE (μ Sv)
^{69m} Zn	1.6E+00	3.4E-07	3.0E-02	1.6E+00	4.4E+02
⁶⁹ Zn	1.6E-03	1.7E-08	1.6E-03	3.3E-03	8.9E-01
⁷⁶ As	1.6E+00	1.7E-06	5.3E-04	1.6E+00	4.3E+02
⁷⁵ Se	9.5E-01	3.3E-06	1.2E-01	1.1E+00	2.9E+02
⁷⁹ Se	5.2E-06	3.9E-06	1.4E-01	1.4E-01	3.8E+01
⁸² Br	8.8E+00	4.8E-07	1.5E-02	8.8E+00	2.4E+03
⁸³ Br+D ^(c)	1.3E-02	2.0E-08	3.5E-04	1.3E-02	3.5E+00
⁸³ Br	2.6E-02	3.9E-08	7.0E-04	2.6E-02	7.1E+00
⁸⁴ Br	5.6E+00	4.1E-08	1.3E-03	5.6E+00	1.5E+03
⁸⁶ Rb	3.0E-01	2.5E-06	1.6E-01	4.5E-01	1.2E+02
⁸⁸ Rb	2.3E+00	3.6E-08	1.1E-03	2.3E+00	6.1E+02
⁸⁹ Rb+D ^(c)	3.1E+00	1.2E-06	6.9E-02	3.2E+00	8.6E+02
⁸⁹ Rb	6.6E+00	1.8E-08	5.8E-04	6.6E+00	1.8E+03
⁸⁵ Sr	1.7E+00	6.1E-07	2.8E-02	1.7E+00	4.6E+02
⁸⁹ Sr	6.9E-03	2.3E-06	1.4E-01	1.4E-01	3.9E+01
⁹⁰ Sr+D ^(c)	9.6E-03	4.6E-05	9.6E-01	9.7E-01	2.6E+02
⁹⁰ Sr	3.5E-04	8.8E-05	1.9E+00	1.9E+00	5.2E+02
⁹¹ Sr+D ^(c)	1.3E+00	8.2E-06	1.4E-02	1.3E+00	3.6E+02
⁹¹ Sr	2.2E+00	3.8E-07	3.3E-02	2.2E+00	6.0E+02
⁹² Sr+D ^(c)	2.6E+00	3.1E-07	1.1E-02	2.6E+00	7.1E+02
⁹² Sr	4.5E+00	2.6E-07	2.2E-02	4.5E+00	1.2E+03
⁹⁰ Y	1.9E-02	3.7E-06	1.3E-03	2.1E-02	5.6E+00
^{91m} Y+D ^(c)	1.0E+00	1.0E-05	5.6E-04	1.0E+00	2.7E+02
^{91m} Y	2.1E+00	1.6E-08	4.8E-06	2.1E+00	5.6E+02
⁹¹ Y	1.9E-02	2.1E-05	1.1E-03	2.0E-02	5.3E+00
⁹² Y	9.3E-01	3.5E-07	2.3E-04	9.3E-01	2.5E+02
⁹³ Y	3.2E-01	9.7E-07	5.5E-04	3.2E-01	8.5E+01
⁹³ Zr+D ^(c)	2.5E-05	2.4E-05	8.9E-04	9.4E-04	2.5E-01
⁹³ Zr	1.3E-07	3.5E-05	2.4E-05	5.9E-05	1.6E-02
⁹⁵ Zr+D ^(c)	2.4E+00	4.4E-06	1.1E-03	2.4E+00	6.5E+02
⁹⁵ Zr	2.4E+00	6.6E-06	3.8E-05	2.4E+00	6.4E+02
⁹⁷ Zr+D ^(c)	1.6E+00	5.8E-07	5.9E-05	1.6E+00	4.3E+02
⁹⁷ Zr	6.0E-01	1.7E-06	6.5E-05	6.0E-01	1.6E+02
^{93m} Nb	5.1E-05	1.3E-05	1.8E-03	1.8E-03	4.9E-01
⁹⁴ Nb	4.8E+00	1.6E-04	2.5E-02	4.8E+00	1.3E+03
^{95m} Nb+D ^(c)	1.3E+00	1.7E-06	1.7E-03	1.3E+00	3.6E+02
^{95m} Nb	1.6E-01	1.1E-06	1.1E-03	1.6E-01	4.4E+01

TABLE 3.3. Annual Total Effective Dose Equivalent Factors for the Residential Use (Surface Soil) Scenario^(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Food Ingestion ^(b) (mrem)	TEDE (mrem)	TEDE (μ Sv)
⁹⁵ Nb	2.6E+00	2.4E-06	2.2E-03	2.6E+00	7.0E+02
^{97m} Nb+D ^(c)	2.1E+00	1.8E-08	5.4E-05	2.1E+00	5.7E+02
^{97m} Nb	2.1E+00	5.3E-10	1.7E-06	2.1E+00	5.7E+02
⁹⁷ Nb	2.2E+00	3.6E-08	1.1E-04	2.2E+00	5.9E+02
⁹³ Mo+D ^(c)	1.5E-04	6.6E-06	6.0E-03	6.2E-03	1.7E+00
⁹³ Mo	2.5E-04	4.2E-07	1.0E-02	1.0E-02	2.8E+00
⁹⁹ Mo+D ^(c)	3.3E-01	4.7E-07	1.2E-02	3.4E-01	9.3E+01
⁹⁹ Mo	4.5E-01	8.3E-07	1.9E-02	4.7E-01	1.3E+02
^{99m} Tc	2.2E-01	1.4E-08	4.3E-03	2.3E-01	6.2E+01
⁹⁹ Tc	4.9E-05	3.9E-06	3.0E-01	3.0E-01	8.1E+01
¹⁰¹ Tc	1.2E+00	6.6E-09	4.0E-03	1.2E+00	3.4E+02
¹⁰³ Ru+D ^(c)	8.1E-01	1.9E-06	8.8E-03	8.2E-01	2.2E+02
¹⁰³ Ru	1.7E+00	3.8E-06	1.7E-02	1.7E+00	4.5E+02
¹⁰⁵ Ru+D ^(c)	9.2E-01	2.2E-07	6.9E-03	9.3E-01	2.5E+02
¹⁰⁵ Ru+I ^(d)	2.5E+00	2.3E-07	3.0E-03	2.5E+00	6.9E+02
¹⁰⁶ Ru+I ^(d)	7.5E-01	9.9E-05	2.9E-01	1.0E+00	2.8E+02
^{103m} Rh	3.3E-04	2.1E-09	1.4E-04	4.7E-04	1.3E-01
¹⁰⁵ Rh	2.8E-01	4.2E-07	1.8E-02	3.0E-01	8.1E+01
¹⁰³ Pd+D ^(c)	1.7E-03	3.3E-07	1.2E-03	2.8E-03	7.6E-01
¹⁰³ Pd	3.1E-03	6.6E-07	2.2E-03	5.3E-03	1.4E+00
¹⁰⁷ Pd	4.1E-09	5.3E-06	4.3E-04	4.3E-04	1.2E-01
¹⁰⁹ Pd+I ^(d)	9.5E-03	2.9E-07	3.3E-03	1.3E-02	3.4E+00
^{110m} Ag+I ^(d)	9.0E+00	1.8E-05	5.3E-01	9.5E+00	2.6E+03
¹¹¹ Ag	8.9E-02	1.4E-06	1.3E-01	2.2E-01	5.9E+01
¹⁰⁹ Cd	2.6E-03	4.8E-05	2.2E-01	2.2E-01	5.9E+01
^{113m} Cd	4.2E-04	6.1E-04	2.8E+00	2.8E+00	7.4E+02
^{115m} Cd+D ^(c)	3.9E-02	1.5E-05	1.4E-01	1.8E-01	4.8E+01
^{115m} Cd	8.1E-02	3.0E-05	2.8E-01	3.6E-01	9.6E+01
¹¹⁵ Cd	6.6E-01	1.7E-06	9.5E-02	7.6E-01	2.0E+02
¹¹¹ In	8.3E-01	2.4E-07	1.0E-04	8.3E-01	2.3E+02
^{114m} In+I ^(d)	3.6E-01	9.9E-06	6.1E-04	3.6E-01	9.8E+01
^{115m} In	5.4E-01	5.3E-08	2.8E-05	5.4E-01	1.5E+02
^{117m} Sn	2.3E-01	1.8E-06	2.4E-03	2.3E-01	6.1E+01
^{119m} Sn	1.8E-03	2.5E-06	1.2E-03	2.9E-03	7.9E-01
^{121m} Sn+D ^(c)	0.0E+00	2.7E-06	1.0E-03	1.0E-03	2.7E-01
^{121m} Sn	0.0E+00	4.8E-06	1.2E-03	1.2E-03	3.3E-01

TABLE 3.3. Annual Total Effective Dose Equivalent Factors for the Residential Use (Surface Soil) Scenario(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Food Ingestion (b) (mrem)	TEDE (mrem)	TEDE (μ Sv)
¹²¹ Sn	0.0E+00	2.1E-07	7.3E-04	7.3E-04	2.0E-01
¹²³ Sn	2.6E-02	1.4E-05	7.0E-03	3.3E-02	9.0E+00
¹²⁵ Sn+D (c)	1.1E+00	5.7E-06	4.3E-02	1.1E+00	3.1E+02
¹²⁵ Sn	1.0E+00	6.6E-06	9.8E-03	1.0E+00	2.7E+02
¹²⁶ Sn+D (c)	3.2E+00	2.0E-05	7.8E-03	3.2E+00	8.6E+02
¹²⁶ Sn	5.1E-02	4.1E-05	1.6E-02	6.7E-02	1.8E+01
¹²⁴ Sb	6.3E+00	1.1E-05	5.0E-03	6.3E+00	1.7E+03
¹²⁵ Sb+D (c)	1.2E+00	4.6E-06	7.1E-02	1.3E+00	3.4E+02
¹²⁵ Sb	1.5E+00	5.3E-06	1.4E-03	1.5E+00	4.1E+02
^{126m} Sb+D (c)	5.5E+00	6.5E-07	6.8E-04	5.5E+00	1.5E+03
^{126m} Sb	5.4E+00	1.3E-08	4.5E-05	5.4E+00	1.4E+03
¹²⁶ Sb	9.0E+00	4.8E-06	5.0E-03	9.0E+00	2.4E+03
¹²⁷ Sb+D (c)	9.9E-01	1.9E-06	1.1E-01	1.1E+00	2.9E+02
¹²⁷ Sb	2.2E+00	2.5E-06	3.5E-03	2.2E+00	5.9E+02
^{123m} Te	2.1E-01	4.4E-06	7.3E-01	9.4E-01	2.5E+02
^{125m} Te	8.6E-03	3.1E-06	3.5E-01	3.6E-01	9.7E+01
^{127m} Te+D (c)	1.1E-02	4.7E-06	5.5E-01	5.7E-01	1.5E+02
^{127m} Te	2.8E-03	9.2E-06	1.0E+00	1.0E+00	2.7E+02
¹²⁷ Te	1.9E-02	1.4E-07	4.3E-02	6.2E-02	1.7E+01
^{129m} Te+D (c)	1.3E-01	1.3E-04	2.6E+01	2.6E+01	7.1E+03
^{129m} Te	1.0E-01	2.1E-04	4.3E+01	4.3E+01	1.2E+04
¹²⁹ Te	1.9E-01	6.6E-08	1.6E-02	2.1E-01	5.6E+01
^{131m} Te+D (c)	2.6E+00	8.3E-06	5.8E-01	3.2E+00	8.5E+02
^{131m} Te	4.6E+00	5.3E-06	1.1E+00	5.7E+00	1.5E+03
¹³¹ Te+D (c)	1.2E+00	6.5E-06	1.0E-01	1.3E+00	3.5E+02
¹³¹ Te	1.3E+00	5.3E-08	1.3E-02	1.3E+00	3.5E+02
¹³² Te+D (c)	3.9E+00	2.9E-06	4.8E-01	4.4E+00	1.2E+03
¹³² Te	5.8E-01	5.3E-06	9.5E-01	1.5E+00	4.1E+02
^{133m} Te+D (c)	3.1E+00	8.1E-07	2.5E-02	3.2E+00	8.5E+02
^{133m} Te	7.5E+00	1.9E-07	4.8E-02	7.5E+00	2.0E+03
¹³³ Te+D (c)	1.7E+00	7.8E-07	1.2E-02	1.7E+00	4.5E+02
¹³³ Te	3.2E+00	3.8E-08	1.0E-02	3.2E+00	8.7E+02
¹³⁴ Te+D (c)	5.5E+00	5.3E-08	6.0E-03	5.5E+00	1.5E+03
¹³⁴ Te	2.8E+00	4.4E-08	1.2E-02	2.8E+00	7.5E+02
¹²⁵ I	9.3E-03	9.7E-06	1.6E-01	1.6E-01	4.4E+01
¹²⁹ I	5.4E-03	6.6E-05	1.2E+00	1.2E+00	3.2E+02
¹³⁰ I	6.9E+00	1.1E-06	1.2E-02	6.9E+00	1.9E+03
¹³¹ I+D (c)	1.1E+00	1.3E-05	2.0E-01	1.3E+00	3.6E+02
¹³¹ I	1.2E+00	1.3E-05	2.0E-01	1.4E+00	3.8E+02
¹³² I	7.6E+00	1.7E-07	1.8E-03	7.6E+00	2.0E+03
¹³³ I+D (c)	9.5E-01	1.1E-06	1.4E-02	9.6E-01	2.6E+02
¹³³ I	1.9E+00	2.3E-06	2.8E-02	2.0E+00	5.3E+02

TABLE 3.3. Annual Total Effective Dose Equivalent Factors for the Residential Use (Surface Soil) Scenario(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Food Ingestion ^(b) (mrem)	TEDE (mrem)	TEDE (μ Sv)
¹³⁴ I	8.3E+00	6.1E-08	6.8E-04	8.3E+00	2.3E+03
¹³⁵ I+D (c)	2.6E+00	2.2E-07	2.5E-03	2.7E+00	7.2E+02
¹³⁵ I	5.1E+00	4.8E-07	5.5E-03	5.1E+00	1.4E+03
^{134m} Cs+D (c)	1.8E-02	7.9E-09	7.9E-06	1.8E-02	4.9E+00
^{134m} Cs	3.7E-02	1.6E-08	1.6E-05	3.7E-02	1.0E+01
¹³⁴ Cs	5.3E+00	1.8E-05	5.0E-02	5.4E+00	1.5E+03
¹³⁵ Cs	1.4E-05	1.6E-06	4.8E-03	4.8E-03	1.3E+00
¹³⁶ Cs	6.7E+00	2.8E-06	6.0E-03	6.7E+00	1.8E+03
¹³⁷ Cs+I (d)	1.9E+00	5.9E-06	3.1E-03	1.9E+00	5.0E+02
¹³⁸ Cs	7.8E+00	4.2E-08	8.0E-05	7.8E+00	2.1E+03
¹³⁹ Ba	7.9E-02	7.5E-08	9.8E-05	8.0E-02	2.1E+01
¹⁴⁰ Ba+D (c)	3.9E+00	1.4E-06	1.6E-03	3.9E+00	1.1E+03
¹⁴⁰ Ba	6.0E-01	1.3E-06	2.2E-03	6.0E-01	1.6E+02
¹⁴¹ Ba+D (c)	9.7E-01	1.3E-06	1.8E-04	9.7E-01	2.6E+02
¹⁴¹ Ba	2.7E+00	3.4E-08	5.0E-05	2.7E+00	7.3E+02
¹⁴² Ba+D (c)	5.7E+00	6.6E-08	5.4E-05	5.7E+00	1.5E+03
¹⁴² Ba	2.8E+00	1.7E-08	2.5E-05	2.8E+00	7.7E+02
¹⁴⁰ La	7.1E+00	1.5E-06	9.5E-04	7.1E+00	1.9E+03
¹⁴¹ La+D (c)	1.4E-01	2.0E-06	2.5E-04	1.4E-01	3.9E+01
¹⁴¹ La	1.7E-01	2.5E-07	1.7E-04	1.7E-01	4.5E+01
¹⁴² La	8.9E+00	1.1E-07	8.3E-05	8.9E+00	2.4E+03
¹⁴¹ Ce	1.2E-01	3.7E-06	3.5E-04	1.2E-01	3.4E+01
¹⁴³ Ce+D (c)	3.4E-01	2.4E-06	5.4E-04	3.4E-01	9.2E+01
¹⁴³ Ce	6.7E-01	1.5E-06	5.3E-04	6.7E-01	1.8E+02
¹⁴⁴ Ce+D (c)	8.0E-02	7.8E-05	1.2E-03	8.2E-02	2.2E+01
¹⁴⁴ Ce	3.0E-02	1.6E-04	2.5E-03	3.3E-02	8.9E+00
¹⁴³ Pr	1.6E-03	3.4E-06	5.5E-04	2.2E-03	5.9E-01
^{144m} Pr+D (c)	7.0E-02	1.4E-08	9.8E-06	7.0E-02	1.9E+01
^{144m} Pr	5.2E-03	7.9E-09	5.5E-06	5.2E-03	1.4E+00
¹⁴⁴ Pr	1.4E-01	1.9E-08	1.4E-05	1.4E-01	3.7E+01
¹⁴⁷ Nd+D (c)	1.7E-01	9.7E-06	2.8E-04	1.7E-01	4.7E+01
¹⁴⁷ Nd	3.6E-01	2.9E-06	4.8E-04	3.6E-01	9.6E+01
¹⁴⁷ Pm	2.7E-05	1.7E-05	8.3E-05	1.3E-04	3.4E-02
^{148m} Pm+D (c)	6.5E+00	9.3E-06	6.0E-04	6.5E+00	1.8E+03
^{148m} Pm	7.0E+00	9.7E-06	6.0E-04	7.0E+00	1.9E+03
¹⁴⁸ Pm	2.0E+00	4.8E-06	8.8E-04	2.0E+00	5.3E+02
¹⁴⁹ Pm	3.1E-02	1.3E-06	3.3E-04	3.2E-02	8.5E+00
¹⁵¹ Pm	1.0E+00	7.9E-07	2.4E-04	1.0E+00	2.7E+02

TABLE 3.3. Annual Total Effective Dose Equivalent Factors for the Residential Use (Surface Soil) Scenario(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Food Ingestion (b) (mrem)	TEDE (mrem)	TEDE (μ Sv)
¹⁴⁷ Sm	0.0E+00	3.2E-02	2.0E-02	5.2E-02	1.4E+01
¹⁵¹ Sm	1.9E-06	1.3E-05	4.0E-05	5.5E-05	1.5E-02
¹⁵³ Sm	9.4E-02	8.3E-07	3.0E-04	9.5E-02	2.6E+01
¹⁵² Eu	3.7E+00	8.8E-05	8.3E-04	3.7E+00	9.9E+02
¹⁵⁴ Eu	3.8E+00	1.1E-04	1.2E-03	3.8E+00	1.0E+03
¹⁵⁵ Eu	8.8E-02	1.7E-05	2.0E-04	8.8E-02	2.4E+01
¹⁵⁶ Eu	4.4E+00	6.1E-06	1.1E-03	4.4E+00	1.2E+03
¹⁵³ Gd	1.3E-01	1.0E-05	4.5E-04	1.3E-01	3.4E+01
¹⁶⁰ Tb	3.3E+00	1.1E-05	1.7E-04	3.3E+00	8.9E+02
^{168m} Ho	4.8E+00	3.2E-04	1.1E-03	4.8E+00	1.3E+03
¹⁸¹ W	2.7E-02	6.6E-08	2.5E-04	2.7E-02	7.4E+00
¹⁸⁵ W	2.1E-04	3.3E-07	1.4E-03	1.6E-03	4.3E-01
¹⁸⁷ W	1.5E+00	2.9E-07	1.8E-03	1.5E+00	4.1E+02
¹⁸⁷ Re	0.0E+00	2.5E-08	1.5E-07	1.7E-07	4.6E-05
¹⁸⁶ Os	2.2E+00	4.0E-06	0.0E+00	2.2E+00	5.9E+02
¹⁹¹ Os	9.7E-02	9.7E-07	0.0E+00	9.7E-02	2.6E+01
¹⁹² Ir	2.8E+00	1.1E-05	4.5E-03	2.8E+00	7.6E+02
²⁰³ Hg	5.1E-01	3.0E-06	9.5E-02	6.0E-01	1.6E+02
²¹⁰ Pb+D (c)	1.3E-03	3.2E-03	4.2E-01	4.2E-01	1.1E+02
²¹⁰ Pb	1.0E-03	5.7E-03	1.0E+00	1.0E+00	2.8E+02
²¹² Pb+D (c)	1.6E+00	2.6E-05	5.3E-03	1.6E+00	4.4E+02
²¹² Pb	3.6E-01	7.0E-05	9.0E-03	3.6E-01	9.8E+01
²¹⁰ Bi+D (c)	1.4E-03	1.9E-03	1.2E-01	1.2E-01	3.2E+01
²¹⁰ Bi	2.8E-03	8.3E-05	4.5E-02	4.8E-02	1.3E+01
²¹² Bi+I (d)	4.7E+00	4.0E-06	3.8E-03	4.7E+00	1.3E+03
²¹⁰ Po	2.7E-05	3.7E-03	1.5E-01	1.6E-01	4.2E+01
²²³ Ra+I (d)	8.2E-01	5.5E-04	3.0E-02	8.5E-01	2.3E+02
²²⁴ Ra+D (c)	8.3E-01	2.1E-04	1.8E-02	8.4E-01	2.3E+02
²²⁴ Ra+I (d)	2.8E-02	1.2E-03	9.0E-02	1.2E-01	3.2E+01
²²⁵ Ra+D (c)	1.1E-01	9.4E-04	2.3E-02	1.4E-01	3.7E+01
²²⁵ Ra	7.2E-03	3.1E-03	1.5E-01	1.6E-01	4.4E+01
²²⁶ Ra+D (c)	6.4E-01	1.4E-03	2.1E-01	8.5E-01	2.3E+02

TABLE 3.3. Annual Total Effective Dose Equivalent Factors for the Residential Use (Surface Soil) Scenario(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Food Ingestion ^(b) (mrem)	TEDE (mrem)	TEDE (μ Sv)
²²⁶ Ra	9.0E-03	3.5E-03	6.8E-01	6.9E-01	1.9E+02
²²⁶ Ra+D ^(c)	8.7E-01	1.6E-02	8.6E-02	9.7E-01	2.6E+02
²²⁸ Ra	1.1E-08	1.6E-03	5.8E-01	5.8E-01	1.6E+02
²²⁵ Ac+I ^(d)	7.7E-01	5.8E-04	1.2E-03	7.7E-01	2.1E+02
²²⁷ Ac+D ^(c)	1.3E-01	7.1E-02	1.3E-01	3.4E-01	9.1E+01
²²⁷ Ac	2.5E-04	5.7E-01	9.0E-01	1.5E+00	4.0E+02
²²⁸ Ac+D ^(c)	9.8E-01	1.8E-02	2.3E-02	1.0E+00	2.7E+02
²²⁸ Ac	3.1E+00	4.8E-05	1.4E-04	3.1E+00	8.4E+02
²²⁷ Th+D ^(c)	1.5E-01	1.4E-03	2.7E-02	1.8E-01	4.8E+01
²²⁷ Th	2.7E-01	7.0E-03	7.5E-03	2.8E-01	7.6E+01
²²⁸ Th+D ^(c)	7.1E-01	2.0E-02	2.6E-02	7.5E-01	2.0E+02
²²⁸ Th	3.3E-03	1.4E-01	7.8E-02	2.2E-01	5.9E+01
²²⁹ Th+D ^(c)	1.1E-01	9.3E-02	1.1E-01	3.1E-01	8.4E+01
²²⁹ Th	1.3E-01	7.5E-01	7.0E-01	1.6E+00	4.3E+02
²³⁰ Th+D ^(c)	5.7E-01	1.2E-02	2.0E-01	7.9E-01	2.1E+02
²³⁰ Th	4.0E-04	1.1E-01	1.1E-01	2.2E-01	5.8E+01
²³¹ Th+D ^(c)	1.4E-03	3.6E-08	2.5E-05	1.4E-03	3.9E-01
²³¹ Th	1.4E-02	3.6E-07	2.5E-04	1.5E-02	3.9E+00
²³² Th+D ^(c)	7.8E-01	6.1E-02	1.3E-01	9.7E-01	2.6E+02
²³² Th-Nat ^(e)	7.8E-01	6.1E-02	1.3E-01	9.7E-01	2.6E+02
²³² Th	2.1E-04	4.8E-01	5.5E-01	1.0E+00	2.8E+02
²³⁴ Th+D ^(c)	3.7E-02	7.5E-06	1.4E-03	3.8E-02	1.0E+01
²³⁴ Th+I ^(d)	6.4E-02	1.5E-05	2.8E-03	6.6E-02	1.8E+01
²³¹ Pa+D ^(c)	1.3E-01	1.0E-01	6.4E-01	8.7E-01	2.3E+02
²³¹ Pa	9.1E-02	3.7E-01	4.8E+00	5.2E+00	1.4E+03
²³³ Pa	6.9E-01	4.0E-06	1.5E-03	6.9E-01	1.9E+02
²³⁴ Pa	6.2E+00	3.6E-07	9.3E-04	6.2E+00	1.7E+03
²³² U+D ^(c)	4.2E-05	3.8E-02	1.2E-03	3.9E-02	1.0E+01
²³² U	3.0E-04	2.6E-01	8.3E-03	2.7E-01	7.3E+01
²³³ U+D ^(c)	9.9E-02	8.8E-02	9.5E-02	2.8E-01	7.6E+01
²³³ U	4.7E-04	5.7E-02	3.3E-03	6.1E-02	1.6E+01
²³⁴ U	1.8E-04	5.7E-02	3.3E-03	6.1E-02	1.6E+01
²³⁵ U+D ^(c)	1.2E-01	2.6E-02	1.8E-03	1.5E-01	4.1E+01
²³⁵ U	2.3E-01	5.3E-02	3.3E-03	2.9E-01	7.8E+01
²³⁶ U	9.6E-05	5.3E-02	3.0E-03	5.6E-02	1.5E+01
²³⁷ U	3.0E-01	1.5E-06	3.8E-04	3.0E-01	8.1E+01
²³⁸ U+D ^(c)	2.4E-02	1.6E-02	1.8E-03	4.2E-02	1.1E+01
²³⁸ U	5.4E-03	5.3E-02	3.0E-03	6.1E-02	1.6E+01
²³⁸ U-Nat ^(f)	8.0E-03	5.5E-02	3.1E-03	6.6E-02	1.8E+01
²⁴⁰ U+D ^(c)	3.8E-01	3.2E-07	1.8E-04	3.8E-01	1.0E+02
²⁴⁰ U+I ^(d)	1.2E+00	9.7E-07	5.5E-04	1.2E+00	3.2E+02

TABLE 3.3. Annual Total Effective Dose Equivalent Factors for the Residential Use (Surface Soil) Scenario(a) (contd)

Radionuclide	External (mrem)	Inhalation (mrem)	Food Ingestion ^(b) (mrem)	TEDE (mrem)	TEDE (μ Sv)
²³⁷ Np+D (c)	3.4E-01	1.3E-01	3.0E-01	7.7E-01	2.1E+02
²³⁷ Np	2.9E-02	2.7E-01	6.0E-01	9.0E-01	2.4E+02
²³⁸ Np+D (c)	8.9E-01	6.1E-02	4.7E-03	9.5E-01	2.6E+02
²³⁸ Np	1.8E+00	1.8E-05	4.8E-04	1.8E+00	4.9E+02
²³⁹ Np+D (c)	1.9E-01	5.3E-07	1.9E-04	1.9E-01	5.2E+01
²³⁹ Np	3.9E-01	1.1E-06	3.8E-04	3.9E-01	1.1E+02
²³⁸ Pu	9.2E-05	3.2E-02	1.7E-03	3.3E-02	9.0E+00
²³⁷ Pu	9.3E-02	7.9E-07	1.1E-05	9.3E-02	2.5E+01
²³⁸ Pu	6.1E-05	1.2E-01	8.8E-03	1.3E-01	3.6E+01
²³⁹ Pu	1.4E-04	1.3E-01	9.8E-03	1.4E-01	3.7E+01
²⁴⁰ Pu	6.1E-05	1.3E-01	9.6E-03	1.4E-01	3.7E+01
²⁴¹ Pu+D (c)	6.8E-03	9.4E-02	5.1E-01	6.1E-01	1.7E+02
²⁴¹ Pu	1.1E-10	2.1E-03	1.8E-04	2.2E-03	6.1E-01
²⁴² Pu	5.1E-05	1.2E-01	9.1E-03	1.3E-01	3.4E+01
²⁴³ Pu+D (c)	1.4E-01	3.1E-08	4.1E-06	1.4E-01	3.8E+01
²⁴³ Pu	3.2E-02	6.1E-08	8.3E-06	3.2E-02	8.7E+00
²⁴⁴ Pu+D (c)	2.9E-01	2.9E-02	2.5E-03	3.2E-01	8.6E+01
²⁴⁴ Pu	3.6E-05	1.1E-01	9.3E-03	1.2E-01	3.3E+01
²⁴¹ Am	1.4E-02	1.9E-01	1.0E+00	1.2E+00	3.3E+02
^{242m} Am+D (c)	7.1E-03	7.2E-02	2.6E-01	3.4E-01	9.2E+01
^{242m} Am	5.7E-04	1.7E-01	9.8E-01	1.1E+00	3.1E+02
²⁴² Am+D (c)	9.4E-03	3.7E-02	6.7E-03	5.3E-02	1.4E+01
²⁴² Am	2.7E-02	2.3E-05	3.5E-04	2.7E-02	7.4E+00
²⁴³ Am+D (c)	1.5E-01	6.0E-02	3.4E-01	5.5E-01	1.5E+02
²⁴³ Am	5.1E-02	1.8E-01	1.0E+00	1.3E+00	3.4E+02
²⁴² Cm+D (c)	6.3E-05	7.0E-02	1.2E-02	8.2E-02	2.2E+01
²⁴² Cm	5.8E-05	6.6E-03	1.3E-02	1.9E-02	5.2E+00
²⁴³ Cm	2.9E-01	2.5E-01	3.0E-01	8.4E-01	2.3E+02
²⁴⁴ Cm+D (c)	2.4E-05	5.0E-02	1.2E-01	1.7E-01	4.5E+01
²⁴⁴ Cm	4.9E-05	1.0E-01	2.3E-01	3.3E-01	9.0E+01
²⁴⁵ Cm+D (c)	4.7E-02	1.2E-01	4.8E-01	6.6E-01	1.8E+02
²⁴⁵ Cm	1.3E-01	1.8E-01	4.3E-01	7.4E-01	2.0E+02
²⁴⁶ Cm	4.1E-05	1.8E-01	4.3E-01	6.1E-01	1.6E+02
²⁴⁷ Cm+D (c)	7.8E-01	8.6E-02	2.0E-01	1.1E+00	2.9E+02
²⁴⁷ Cm	1.3E+00	1.7E-01	4.0E-01	1.9E+00	5.0E+02
²⁴⁸ Cm	3.7E-05	6.6E-01	1.6E+00	2.2E+00	6.0E+02
²⁵² Cf	4.1E-05	5.7E-02	2.8E-02	8.5E-02	2.3E+01

(a) Based on a surface soil activity level of 1 pCi/g (1 Bq/g).

TABLE 3.3. Annual Total Effective Dose Equivalent Factors
for the Residual Use (Surface Soil) Scenario(a) (contd)

- (b) Based on the total air deposition and root uptake contributions using an air concentration of 5×10^{-5} pCi/m³ and root uptake factors as described in Appendix B.
- (c) Where +D means "plus daughters in equilibrium" referring to explicit daughters, or daughters with half-lives greater than 10 minutes. Separate values are also included for parents and daughters so that combined factors for non-equilibrium cases can be determined. Note: in some cases +D also includes implicit daughters (i.e., uranium and thorium decay chains).
- (d) Where +I means "plus implicit daughters in equilibrium" referring to daughters with half-lives less than 10 minutes. The decay energies associated with these daughters have been assigned to the parent, and the appropriate branching ratios (described in Appendix D) have been considered.
- (e) Where Th-Nat includes an equilibrium mixture of ²³²Th plus 10 daughters in the decay chain, as discussed in Appendix D.
- (f) Where 1 Ci U-Nat equals 48.9% ²³⁸U plus 48.9% ²³⁴U plus 2.25% ²³⁵U.

3.2.2. Drinking Water Use Scenario

To account for potential contamination of ground water used as a drinking water source, a drinking water scenario is defined (see the discussion of the ground-water resource model in Appendix B). This scenario is intended to account for the potential impacts on drinking water sources of residual radioactivity in soil and in structures that may be demolished and left onsite as buried rubble. For this scenario, an individual is assumed to ingest 730 L/yr (2 L/d) of drinking water, obtained from an aquifer with a concentration calculated using the ground-water resource model discussed in Appendix B. The aquifer concentration is derived in a generic and somewhat conservative manner; thus, the magnitude of the annual TEDE factors for a given inventory may provide only an indication of when additional site specific data or modeling sophistication are warranted. For example, site specific considerations may include measured parameters such as leach rate and retention. The calculated annual TEDE factors for this scenario are shown in Table 3.4. The values shown are in units of mrem (and μSv) for a soil inventory of 1 pCi (1 Bq) for a listing of over 200 radionuclides. The +I (implicit daughter) and +D (explicit daughter) notation has been used to provide maximum flexibility for consideration of all parent-daughter and decay chain situations. Further description of the parent-daughter and chain decay relationships used in this study is provided in Appendix D. Also included in Table 3.4 are listings by radionuclide of the maximum organ dose in mrem/yr ($\mu\text{Sv/yr}$) and the organ of concern. Again, the maximum organ dose rates shown in Table 3.4 are based on the dosimetry models, metabolic data, and recommendations of the ICRP found in Publication 30 (1979-1988). Because of changes in the metabolic data and the modeling approach, the maximum organ dose listings based on ICRP 30 do not always agree with information from ICRP 2 (1959).

Hand calculations were performed to verify the computer calculations for selected radionuclides using the pathway factors from Section 2.0 and the drinking water scenario assumptions. The results of the calculations indicated that drinking water concentrations and the resulting annual TEDE values in Table 3.4 were calculated correctly. An additional evaluation of the determination of the maximum organ dose was conducted. This is not always an easy evaluation, given the complexity of the ICRP 30 dosimetry system. For example, at first glance it may seem that a soluble element like Cs should produce a rather uniform dose to internal organs. However, the non-weighted target organ dose shows a maximum for either the small intestine wall or the stomach wall, depending on the isotope considered. Although somewhat of a calculational artifact, this result was verified by comparison with the information in Federal Guidance Report No. 11 (Eckerman, Wolbarst, and Richardson 1988).

TABLE 3.4. Drinking Water Scenario Annual Committed Effective Dose Equivalent Factors for Exposure to Residual Radioactive Materials^(a)

Radionuclide	TEDE (mrem)	TEDE (μ Sv)	Maximum Organ Dose		
			(mrem)	(μ Sv)	Organ ^(b)
³ H	2.0E-12	5.5E-10	2.4E-12	6.5E-10	SI Wall
¹⁰ Be	1.5E-11	4.0E-09	1.6E-10	4.2E-08	LLI Wall
¹⁴ C	7.1E-12	1.9E-09	8.6E-12	2.3E-09	LLI Wall
¹⁸ F	7.4E-20	2.0E-17	7.4E-19	2.0E-16	Stomach Wall
²² Na	6.1E-14	1.7E-11	1.0E-13	2.7E-11	Bone Surface
²⁴ Na	8.9E-20	2.4E-17	2.8E-19	7.6E-17	Stomach Wall
³² P	2.2E-15	6.0E-13	8.1E-15	2.2E-12	Red Marrow
³³ P	7.2E-16	1.9E-13	3.9E-15	1.1E-12	Bone Surface
³⁵ S	2.9E-14	7.9E-12	1.5E-13	3.9E-11	LLI Wall
³⁸ Cl	1.0E-11	2.8E-09	1.2E-11	3.2E-09	SI Wall
⁴⁰ K	8.2E-14	2.2E-11	9.7E-14	2.6E-11	SI Wall
⁴¹ Ca	3.8E-13	1.0E-10	4.8E-12	1.3E-09	Bone Surface
⁴⁵ Ca	3.8E-13	1.0E-10	2.3E-12	6.3E-10	Bone Surface
⁴⁸ Sc	3.9E-15	1.1E-12	2.3E-14	6.3E-12	LLI Wall
⁵¹ Cr	1.4E-16	3.7E-14	9.0E-16	2.4E-13	LLI Wall
⁵⁴ Mn	6.8E-14	1.8E-11	2.1E-13	5.6E-11	LLI Wall
⁵⁶ Mn	1.5E-20	3.9E-18	7.6E-20	2.1E-17	ULI Wall
⁵⁵ Fe	2.3E-13	6.3E-11	8.5E-13	2.3E-10	Spleen
⁵⁹ Fe	1.9E-13	5.1E-11	9.0E-13	2.4E-10	LLI Wall
⁵⁷ Co	2.0E-13	5.3E-11	1.3E-12	3.4E-10	LLI Wall
⁵⁸ Co	1.9E-13	5.1E-11	9.2E-13	2.5E-10	LLI Wall
⁶⁰ Co	4.4E-12	1.2E-09	1.9E-11	5.1E-09	LLI Wall
⁵⁹ Ni	9.1E-14	2.5E-11	4.7E-13	1.3E-10	LLI Wall
⁶³ Ni	2.4E-13	6.6E-11	1.5E-12	4.1E-10	LLI Wall
⁶⁵ Ni	1.1E-19	2.9E-17	5.9E-19	1.6E-16	ULI Wall
⁶⁴ Cu	1.4E-17	3.7E-15	8.2E-17	2.2E-14	LLI Wall
⁶⁵ Zn	3.2E-12	8.7E-10	4.2E-12	1.1E-09	LLI Wall
^{69m} Zn+D ^(c)	3.4E-18	9.3E-16	2.2E-17	5.9E-15	LLI Wall

TABLE 3.4. Drinking Water Scenario Annual Committed Effective Dose Equivalent Factors for Exposure to Residual Radioactive Materials(a) (contd)

Radionuclide	TEDE (mrem)	TEDE (μ Sv)	Maximum Organ Dose		
			(mrem)	(μ Sv)	Organ(b)
^{69m} Zn	6.4E-18	1.7E-15	4.4E-17	1.2E-14	LLI Wall
⁶⁹ Zn	2.0E-21	5.4E-19	1.7E-20	4.7E-18	Stomach Wall
⁷⁶ As	6.5E-16	1.8E-13	5.4E-15	1.5E-12	LLI Wall
⁷⁵ Se	9.7E-13	2.6E-10	2.8E-12	7.6E-10	Kidneys
⁷⁹ Se	3.1E-12	8.4E-10	1.9E-11	5.0E-09	Kidneys
⁸² Br	4.0E-16	1.1E-13	7.5E-16	2.0E-13	Stomach Wall
⁸³ Br+D(c)	5.4E-20	1.5E-17	6.4E-19	1.7E-16	Stomach Wall
⁸³ Br	1.1E-19	2.9E-17	1.3E-18	3.4E-16	Stomach Wall
⁸⁴ Br	1.0E-20	2.8E-18	1.5E-19	4.0E-17	Stomach Wall
⁸⁶ Rb	5.2E-16	1.4E-13	1.5E-15	4.2E-13	Bone Surface
⁸⁸ Rb	4.5E-24	1.2E-21	7.1E-23	1.9E-20	Stomach Wall
⁸⁹ Rb+D(c)	8.3E-23	2.2E-20	7.3E-22	2.0E-19	LLI Wall
⁸⁹ Rb	1.8E-24	4.8E-22	2.6E-23	7.1E-21	Stomach Wall
⁸⁵ Sr	6.5E-14	1.7E-11	2.0E-13	5.3E-11	LLI Wall
⁸⁹ Sr	2.1E-13	5.8E-11	1.9E-12	5.2E-10	LLI Wall
⁹⁰ Sr+D(c)	2.0E-11	5.5E-09	2.2E-10	5.9E-08	Bone Surface
⁹⁰ Sr	3.8E-11	1.0E-08	4.4E-10	1.2E-07	Bone Surface
⁹¹ Sr+D(c)	7.3E-18	2.0E-15	7.9E-17	2.1E-14	LLI Wall
⁹¹ Sr	3.8E-18	1.0E-15	2.2E-17	5.9E-15	LLI Wall
⁹² Sr+D(c)	2.3E-19	6.2E-17	1.5E-18	4.1E-16	ULI Wall
⁹² Sr	2.0E-19	5.5E-17	1.4E-18	3.8E-16	ULI Wall
⁹⁰ Y	7.9E-15	2.1E-12	8.7E-14	2.3E-11	LLI Wall
^{91m} Y+D(c)	5.7E-19	1.5E-16	6.6E-18	1.8E-15	LLI Wall
^{91m} Y	4.9E-21	1.3E-18	2.3E-20	6.2E-18	Stomach Wall
⁹¹ Y	3.0E-12	8.2E-10	3.5E-11	9.6E-09	LLI Wall
⁹² Y	4.4E-18	1.2E-15	2.9E-17	7.8E-15	ULI Wall
⁹³ Y	8.6E-17	2.3E-14	6.3E-16	1.7E-13	LLI Wall
⁹³ Zr+D(c)	3.4E-13	9.1E-11	5.3E-12	1.4E-09	Bone Surface
⁹³ Zr	5.1E-13	1.4E-10	1.1E-11	2.8E-09	Bone Surface
⁹⁵ Zr+D(c)	1.2E-13	3.1E-11	8.1E-13	2.2E-10	LLI Wall
⁹⁵ Zr	1.4E-13	3.7E-11	1.1E-12	2.9E-10	LLI Wall
⁹⁷ Zr+D(c)	1.4E-17	3.9E-15	1.1E-16	3.0E-14	LLI Wall
⁹⁷ Zr	4.2E-17	1.1E-14	3.3E-16	9.0E-14	LLI Wall
^{93m} Nb	1.7E-13	4.7E-11	2.0E-12	5.3E-10	LLI Wall
⁹⁴ Nb	2.6E-12	7.0E-10	1.7E-11	4.7E-09	LLI Wall
^{95m} Nb+D(c)	3.5E-16	9.6E-14	2.9E-15	7.7E-13	LLI Wall
^{95m} Nb	3.4E-16	9.1E-14	3.5E-15	9.5E-13	LLI Wall

TABLE 3.4. Drinking Water Scenario Annual Committed Effective Dose Equivalent Factors for Exposure to Residual Radioactive Materials(a) (contd)

Radionuclide	TEDE (mrem)	TEDE (μ Sv)	Maximum Organ Dose		
			(mrem)	(μ Sv)	Organ(b)
^{95}Nb	3.4E-14	9.3E-12	2.1E-13	5.6E-11	LLI Wall
$^{97\text{m}}\text{Nb}+\text{D}$ (c)	6.5E-25	1.8E-22	3.8E-24	1.0E-21	Stomach Wall
$^{97\text{m}}\text{Nb}$	2.1E-26	5.7E-24	1.5E-25	3.9E-23	Stomach Wall
^{97}Nb	6.8E-21	1.8E-18	3.9E-20	1.1E-17	Stomach Wall
$^{93}\text{Mo}+\text{D}$ (c)	3.4E-12	9.1E-10	1.2E-11	3.4E-09	Liver
^{93}Mo	5.2E-12	1.4E-09	2.5E-11	6.7E-09	Liver
$^{99}\text{Mo}+\text{D}$ (c)	1.4E-15	3.9E-13	5.6E-15	1.5E-12	LLI Wall
^{99}Mo	2.7E-15	7.4E-13	9.7E-15	2.6E-12	LLI Wall
$^{99\text{m}}\text{Tc}$	6.1E-19	1.6E-16	3.0E-18	8.1E-16	ULI Wall
^{99}Tc	1.2E-11	3.1E-09	1.0E-10	2.7E-08	Thyroid
^{101}Tc	8.5E-22	2.3E-19	6.5E-21	1.7E-18	ULI Wall
$^{103}\text{Ru}+\text{D}$ (c)	2.7E-13	7.2E-11	2.1E-12	5.8E-10	LLI Wall
^{103}Ru	5.4E-13	1.4E-10	4.3E-12	1.2E-09	LLI Wall
$^{105}\text{Ru}+\text{D}$ (c)	3.6E-18	9.7E-16	2.7E-17	7.2E-15	LLI Wall
$^{105}\text{Ru}+\text{I}$ (d)	5.2E-18	1.4E-15	2.8E-17	7.5E-15	ULI Wall
$^{106}\text{Ru}+\text{I}$ (d)	3.1E-11	8.4E-09	3.1E-10	8.4E-08	LLI Wall
$^{103\text{m}}\text{Rh}$	1.8E-21	5.0E-19	1.5E-20	4.0E-18	Stomach Wall
^{105}Rh	3.3E-16	8.9E-14	3.1E-15	8.3E-13	LLI Wall
$^{103}\text{Pd}+\text{D}$ (c)	1.2E-14	3.1E-12	1.2E-13	3.4E-11	LLI Wall
^{103}Pd	2.3E-14	6.2E-12	2.5E-13	6.7E-11	LLI Wall
^{107}Pd	4.9E-13	1.3E-10	5.5E-12	1.5E-09	LLI Wall
$^{109}\text{Pd}+\text{I}$ (d)	4.1E-17	1.1E-14	3.3E-16	9.0E-14	LLI Wall
$^{110\text{m}}\text{Ag}+\text{I}$ (d)	4.6E-14	1.2E-11	3.5E-13	9.4E-11	LLI Wall
^{111}Ag	4.7E-17	1.3E-14	5.0E-16	1.4E-13	LLI Wall
^{109}Cd	4.4E-12	1.2E-09	5.0E-11	1.4E-08	Kidneys
$^{113\text{m}}\text{Cd}$	7.4E-11	2.0E-08	9.7E-10	2.6E-07	Kidneys
$^{115\text{m}}\text{Cd}+\text{D}$ (c)	2.3E-13	6.3E-11	1.5E-12	3.9E-10	LLI Wall
$^{115\text{m}}\text{Cd}$	4.7E-13	1.3E-10	2.9E-12	7.9E-10	LLI Wall
^{115}Cd	4.5E-16	1.2E-13	4.2E-15	1.1E-12	LLI Wall
^{111}In	1.0E-15	2.8E-13	5.9E-15	1.6E-12	LLI Wall
$^{114\text{m}}\text{In}+\text{I}$ (d)	1.9E-12	5.0E-10	2.0E-11	5.4E-09	LLI Wall
$^{115\text{m}}\text{In}$	1.2E-18	3.2E-16	7.0E-18	1.9E-15	ULI Wall
$^{117\text{m}}\text{Sn}$	9.3E-17	2.5E-14	9.6E-16	2.6E-13	LLI Wall
$^{119\text{m}}\text{Sn}$	4.2E-15	1.1E-12	4.5E-14	1.2E-11	LLI Wall
$^{121\text{m}}\text{Sn}+\text{D}$ (c)	6.4E-15	1.7E-12	6.7E-14	1.8E-11	LLI Wall
$^{121\text{m}}\text{Sn}$	7.8E-15	2.1E-12	8.3E-14	2.2E-11	LLI Wall

TABLE 3.4. Drinking Water Scenario Annual Committed Effective Dose Equivalent Factors for Exposure to Residual Radioactive Materials(a) (contd)

Radionuclide	TEDE (mrem)	TEDE (μ Sv)	Maximum Organ Dose		
			(mrem)	(μ Sv)	Organ(b)
^{121}Sn	1.9E-19	5.1E-17	1.9E-18	5.0E-16	LLI Wall
^{123}Sn	1.3E-14	3.6E-12	1.5E-13	4.1E-11	LLI Wall
$^{126}\text{Sn}+\text{D}(\text{c})$	1.1E-16	3.0E-14	1.1E-15	3.0E-13	LLI Wall
^{126}Sn	1.8E-16	4.9E-14	2.0E-15	5.4E-13	LLI Wall
$^{126}\text{Sn}+\text{D}(\text{c})$	5.2E-14	1.4E-11	4.2E-13	1.1E-10	LLI Wall
^{126}Sn	1.0E-13	2.7E-11	8.4E-13	2.3E-10	LLI Wall
^{124}Sb	5.4E-15	1.5E-12	4.7E-14	1.3E-11	LLI Wall
$^{126}\text{Sb}+\text{D}(\text{c})$	1.3E-14	3.5E-12	1.0E-13	2.7E-11	LLI Wall
^{126}Sb	1.2E-14	3.4E-12	1.1E-13	2.9E-11	LLI Wall
$^{126m}\text{Sb}+\text{D}(\text{c})$	3.8E-23	1.0E-20	2.5E-22	6.7E-20	LLI Wall
^{126m}Sb	2.6E-24	7.0E-22	2.7E-23	7.4E-21	Stomach Wall
^{126}Sb	2.5E-16	6.8E-14	1.8E-15	4.8E-13	LLI Wall
$^{127}\text{Sb}+\text{D}(\text{c})$	1.0E-17	2.8E-15	9.7E-17	2.6E-14	LLI Wall
^{127}Sb	1.8E-17	4.7E-15	1.8E-16	4.9E-14	LLI Wall
^{123m}Te	5.2E-12	1.4E-09	8.3E-11	2.3E-08	Bone Surface
^{125m}Te	1.2E-12	3.2E-10	1.6E-11	4.2E-09	Bone Surface
$^{127m}\text{Te}+\text{D}(\text{c})$	3.6E-12	9.8E-10	3.2E-11	8.6E-09	Bone Surface
^{127m}Te	6.6E-12	1.8E-09	6.3E-11	1.7E-08	Bone Surface
^{127}Te	1.1E-17	3.0E-15	7.4E-17	2.0E-14	LLI Wall
$^{129m}\text{Te}+\text{D}(\text{c})$	3.8E-11	1.0E-08	1.5E-10	4.0E-08	Testes
^{129m}Te	6.1E-11	1.7E-08	2.4E-10	6.5E-08	Testes
^{129}Te	6.1E-20	1.7E-17	3.5E-19	9.6E-17	Stomach Wall
$^{131m}\text{Te}+\text{D}(\text{c})$	4.7E-15	1.3E-12	1.3E-13	3.4E-11	Thyroid
^{131m}Te	2.7E-15	7.3E-13	2.2E-14	6.0E-12	Thyroid
$^{131}\text{Te}+\text{D}(\text{c})$	7.6E-19	2.1E-16	2.4E-17	6.6E-15	Thyroid
^{131}Te	6.4E-21	1.7E-18	1.0E-19	2.7E-17	Thyroid
$^{132}\text{Te}+\text{D}(\text{c})$	8.1E-15	2.2E-12	8.6E-14	2.3E-11	Thyroid
^{132}Te	1.6E-14	4.4E-12	1.6E-13	4.4E-11	Thyroid
$^{133m}\text{Te}+\text{D}(\text{c})$	5.2E-19	1.4E-16	1.5E-17	4.0E-15	Thyroid
^{133m}Te	1.2E-19	3.2E-17	2.0E-18	5.3E-16	Thyroid
$^{133}\text{Te}+\text{D}(\text{c})$	2.5E-20	6.7E-18	7.5E-19	2.0E-16	Thyroid
^{133}Te	1.2E-21	3.3E-19	2.3E-20	6.1E-18	Thyroid
$^{134}\text{Te}+\text{D}(\text{c})$	1.9E-20	5.2E-18	1.6E-19	4.4E-17	Thyroid
^{134}Te	1.6E-20	4.4E-18	1.8E-19	4.8E-17	Thyroid
^{125}I	1.4E-11	3.8E-09	4.7E-10	1.3E-07	Thyroid
^{129}I	9.3E-10	2.5E-07	3.1E-08	8.3E-06	Thyroid
^{130}I	1.4E-16	3.7E-14	3.7E-15	1.0E-12	Thyroid
$^{131}\text{I}+\text{D}(\text{c})$	3.7E-13	1.0E-10	1.2E-11	3.2E-09	Thyroid
^{131}I	3.8E-13	1.0E-10	1.2E-11	3.3E-09	Thyroid
^{132}I	7.4E-19	2.0E-16	1.1E-17	2.9E-15	Thyroid
$^{133}\text{I}+\text{D}(\text{c})$	4.2E-16	1.1E-13	1.3E-14	3.5E-12	Thyroid
^{133}I	8.5E-16	2.3E-13	2.6E-14	7.1E-12	Thyroid

TABLE 3.4. Drinking Water Scenario Annual Committed Effective Dose Equivalent Factors for Exposure to Residual Radioactive Materials^(a) (contd)

Radionuclide	TEDE (mrem)	TEDE (μ Sv)	Maximum Organ Dose		
			(mrem)	(μ Sv)	Organ ^(b)
¹³⁴ I	4.0E-20	1.1E-17	3.3E-19	8.8E-17	Stomach Wall
¹³⁵ I+D ^(c)	8.5E-18	2.3E-15	2.1E-16	5.7E-14	Thyroid
¹³⁵ I	1.8E-17	5.0E-15	4.6E-16	1.2E-13	Thyroid
^{134m} Cs+D ^(c)	4.3E-23	1.2E-20	4.9E-22	1.3E-19	Stomach Wall
^{134m} Cs	8.6E-23	2.3E-20	9.8E-22	2.7E-19	Stomach Wall
¹³⁴ Cs	2.8E-13	7.6E-11	3.7E-13	1.0E-10	SI Wall
¹³⁵ Cs	3.4E-14	9.1E-12	4.1E-14	1.1E-11	SI Wall
¹³⁶ Cs	2.9E-16	7.7E-14	4.0E-16	1.1E-13	SI Wall
¹³⁷ Cs+I ^(d)	1.2E-13	3.3E-11	1.5E-13	4.1E-11	SI Wall
¹³⁸ Cs	1.6E-23	4.2E-21	2.2E-22	6.0E-20	Stomach Wall
¹³⁹ Ba	1.5E-22	4.1E-20	9.7E-22	2.6E-19	Stomach Wall
¹⁴⁰ Ba+D ^(c)	1.6E-16	4.2E-14	1.5E-15	4.0E-13	LLI Wall
¹⁴⁰ Ba	1.7E-16	4.5E-14	1.8E-15	4.8E-13	LLI Wall
¹⁴¹ Ba+D ^(c)	2.8E-23	7.5E-21	2.4E-22	6.4E-20	LLI Wall
¹⁴¹ Ba	3.8E-24	1.0E-21	2.5E-23	6.9E-21	Stomach Wall
¹⁴² Ba+D ^(c)	2.5E-24	6.8E-22	1.2E-23	3.4E-21	Stomach Wall
¹⁴² Ba	6.8E-25	1.8E-22	4.6E-24	1.2E-21	Stomach Wall
¹⁴⁰ La	2.6E-18	7.1E-16	2.0E-17	5.4E-15	LLI Wall
¹⁴¹ La+D ^(c)	6.7E-21	1.8E-18	5.7E-20	1.6E-17	LLI Wall
¹⁴¹ La	4.5E-21	1.2E-18	2.9E-20	7.8E-18	ULI Wall
¹⁴² La	3.5E-22	9.3E-20	1.6E-21	4.4E-19	Stomach Wall
¹⁴¹ Ce	1.4E-15	3.9E-13	1.6E-14	4.3E-12	LLI Wall
¹⁴³ Ce+D ^(c)	4.2E-18	1.1E-15	4.5E-17	1.2E-14	LLI Wall
¹⁴³ Ce	4.1E-18	1.1E-15	4.0E-17	1.1E-14	LLI Wall
¹⁴⁴ Ce+D ^(c)	8.9E-14	2.4E-11	1.1E-12	2.9E-10	LLI Wall
¹⁴⁴ Ce	1.8E-13	4.8E-11	2.1E-12	5.8E-10	LLI Wall
¹⁴³ Pr	8.8E-14	2.4E-11	1.0E-12	2.8E-10	LLI Wall
^{144m} Pr+D ^(c)	2.2E-22	5.8E-20	2.7E-21	7.2E-19	Stomach Wall
^{144m} Pr	1.2E-22	3.3E-20	1.4E-21	3.8E-19	Stomach Wall
¹⁴⁴ Pr	1.7E-21	4.7E-19	2.3E-20	6.3E-18	Stomach Wall
¹⁴⁷ Nd+D ^(c)	3.2E-14	8.6E-12	3.4E-13	9.3E-11	LLI Wall
¹⁴⁷ Nd	5.1E-14	1.4E-11	5.4E-13	1.5E-10	LLI Wall
¹⁴⁷ Pm	2.7E-12	7.3E-10	3.3E-11	8.8E-09	LLI Wall
^{148m} Pm+D ^(c)	1.3E-12	3.6E-10	9.3E-12	2.5E-09	LLI Wall
^{148m} Pm	1.3E-12	3.5E-10	8.8E-12	2.4E-09	LLI Wall
¹⁴⁸ Pm	3.2E-14	8.7E-12	3.5E-13	9.5E-11	LLI Wall
¹⁴⁹ Pm	2.0E-15	5.5E-13	2.2E-14	5.9E-12	LLI Wall
¹⁵¹ Pm	4.2E-16	1.1E-13	3.8E-15	1.0E-12	LLI Wall

TABLE 3.4. Drinking Water Scenario Annual Committed Effective Dose Equivalent Factors for Exposure to Residual Radioactive Materials(a) (contd)

Radionuclide	TEDE (mrem)	TEDE (μ Sv)	Maximum Organ Dose		
			(mrem)	(μ Sv)	Organ(b)
¹⁴⁷ Sm	6.2E-10	1.7E-07	1.0E-08	2.8E-06	Bone Surface
¹⁵¹ Sm	1.2E-12	3.3E-10	1.2E-11	3.2E-09	LLI Wall
¹⁵³ Sm	1.2E-15	3.1E-13	1.2E-14	3.1E-12	LLI Wall
¹⁵² Eu	2.2E-14	5.9E-12	1.3E-13	3.5E-11	LLI Wall
¹⁵⁴ Eu	3.1E-14	8.5E-12	2.3E-13	6.2E-11	LLI Wall
¹⁵⁵ Eu	4.9E-15	1.3E-12	4.3E-14	1.2E-11	LLI Wall
¹⁵⁶ Eu	2.4E-16	6.4E-14	2.2E-15	6.0E-13	LLI Wall
¹⁵³ Gd	2.0E-12	5.4E-10	1.7E-11	4.5E-09	LLI Wall
¹⁶⁰ Tb	3.0E-12	8.1E-10	2.5E-11	6.8E-09	LLI Wall
^{166m} Ho	2.5E-11	6.7E-09	1.3E-10	3.6E-08	LLI Wall
¹⁸¹ W	2.7E-13	7.2E-11	1.7E-12	4.7E-10	LLI Wall
¹⁸⁵ W	7.8E-13	2.1E-10	8.2E-12	2.2E-09	LLI Wall
¹⁸⁷ W	2.1E-16	5.7E-14	1.7E-15	4.6E-13	LLI Wall
¹⁸⁷ Re	4.5E-14	1.2E-11	2.9E-13	7.9E-11	ULI Wall
¹⁸⁵ Os	1.5E-12	4.0E-10	6.7E-12	1.8E-09	LLI Wall
¹⁹¹ Os	5.2E-14	1.4E-11	5.5E-13	1.5E-10	LLI Wall
¹⁹² Ir	2.7E-12	7.3E-10	2.3E-11	6.1E-09	LLI Wall
²⁰³ Hg	2.4E-12	6.3E-10	1.5E-11	4.0E-09	Kidneys
²¹⁰ Pb+D(c)	3.2E-10	8.6E-08	3.5E-09	9.4E-07	Bone Surface
²¹⁰ Pb	7.0E-10	1.9E-07	1.0E-08	2.8E-06	Bone Surface
²¹² Pb+D(c)	1.4E-17	3.7E-15	1.8E-16	4.9E-14	Bone Surface
²¹² Pb	4.0E-17	1.1E-14	5.5E-16	1.5E-13	Bone Surface
²¹⁰ Bi+D(c)	2.4E-12	6.5E-10	2.0E-11	5.5E-09	Spleen
²¹⁰ Bi	1.6E-14	4.3E-12	1.4E-13	3.8E-11	LLI Wall
²¹² Bi+I(d)	9.8E-20	2.7E-17	5.3E-19	1.4E-16	Stomach Wall
²¹⁰ Po	8.2E-11	2.2E-08	6.9E-10	1.9E-07	Spleen
²²³ Ra+I(d)	2.4E-14	6.6E-12	3.7E-13	1.0E-10	Bone Surface
²²⁴ Ra+D(c)	1.6E-15	4.4E-13	1.7E-14	4.7E-12	Bone Surface
²²⁴ Ra+I(d)	7.1E-15	1.9E-12	6.5E-14	1.8E-11	Bone Surface
²²⁵ Ra+D(c)	4.3E-14	1.2E-11	7.7E-13	2.1E-10	Bone Surface
²²⁵ Ra	2.0E-13	5.4E-11	5.1E-12	1.4E-09	Bone Surface
²²⁶ Ra+D(c)	1.2E-10	3.3E-08	1.5E-09	4.0E-07	Bone Surface

TABLE 3.4. Drinking Water Scenario Annual Committed Effective Dose Equivalent Factors for Exposure to Residual Radioactive Materials^(a) (contd)

Radionuclide	TEDE (mrem)	TEDE (μ Sv)	Maximum Organ Dose		
			(mrem)	(μ Sv)	Organ ^(b)
²²⁶ Ra	1.3E-10	3.4E-08	3.1E-09	8.3E-07	Bone Surface
²²⁸ Ra+D ^(c)	1.9E-11	5.2E-09	4.1E-10	1.1E-07	Bone Surface
²²⁸ Ra	1.0E-10	2.8E-08	2.5E-09	6.6E-07	Bone Surface
²²⁶ Ac+I ^(d)	7.6E-15	2.1E-12	6.9E-14	1.9E-11	LLI Wall
²²⁷ Ac+D ^(c)	2.3E-10	6.2E-08	4.1E-09	1.1E-06	Bone Surface
²²⁷ Ac	1.8E-09	4.9E-07	3.3E-08	8.8E-06	Bone Surface
²²⁸ Ac+D ^(c)	2.0E-17	5.3E-15	3.7E-16	1.0E-13	Bone Surface
²²⁸ Ac	5.7E-19	1.5E-16	3.0E-18	8.0E-16	Bone Surface
²²⁷ Th+D ^(c)	6.4E-14	1.7E-11	8.9E-13	2.4E-10	Bone Surface
²²⁷ Th	5.5E-14	1.5E-11	4.9E-13	1.3E-10	LLI Wall
²²⁸ Th+D ^(c)	8.5E-12	2.3E-09	1.6E-10	4.5E-08	Bone Surface
²²⁸ Th	4.2E-11	1.1E-08	9.3E-10	2.5E-07	Bone Surface
²²⁹ Th+D ^(c)	6.3E-11	1.7E-08	1.6E-09	4.2E-07	Bone Surface
²²⁹ Th	4.7E-10	1.3E-07	1.2E-08	3.2E-06	Bone Surface
²³⁰ Th+D ^(c)	1.2E-10	3.2E-08	1.6E-09	4.3E-07	Bone Surface
²³⁰ Th	7.2E-11	1.9E-08	1.7E-09	4.7E-07	Bone Surface
²³¹ Th+D ^(c)	6.1E-19	1.6E-16	6.1E-18	1.6E-15	LLI Wall
²³¹ Th	6.1E-18	1.6E-15	6.1E-17	1.6E-14	LLI Wall
²³² Th+D ^(c)	5.4E-11	1.5E-08	1.3E-09	3.5E-07	Bone Surface
Th-Nat ^(e)	5.4E-11	1.5E-08	1.3E-09	3.5E-07	Bone Surface
²³² Th	3.6E-10	9.8E-08	8.9E-09	2.4E-06	Bone Surface
²³⁴ Th+D ^(c)	1.6E-14	4.2E-12	1.9E-13	5.2E-11	LLI Wall
²³⁴ Th+I ^(d)	3.1E-14	8.5E-12	3.9E-13	1.0E-10	LLI Wall
²³¹ Pa+D ^(c)	3.7E-10	1.0E-07	7.7E-09	2.1E-06	Bone Surface
²³¹ Pa	1.5E-09	4.0E-07	3.6E-08	9.7E-06	Bone Surface
²³³ Pa	1.1E-14	2.9E-12	1.1E-13	3.0E-11	LLI Wall
²³⁴ Pa	7.1E-19	1.9E-16	3.9E-18	1.0E-15	ULI Wall
²³² U+D ^(c)	3.9E-14	1.0E-11	5.5E-13	1.5E-10	Bone Surface
²³² U	2.7E-13	7.3E-11	3.9E-12	1.0E-09	Bone Surface
²³³ U+D ^(c)	1.7E-12	4.7E-10	4.2E-11	1.1E-08	Bone Surface
²³³ U	1.0E-13	2.8E-11	7.6E-13	2.1E-10	LLI Wall
²³⁴ U	1.0E-13	2.8E-11	7.6E-13	2.1E-10	LLI Wall
²³⁵ U+D ^(c)	5.9E-14	1.6E-11	4.4E-13	1.2E-10	LLI Wall
²³⁵ U	1.1E-13	3.0E-11	8.4E-13	2.3E-10	LLI Wall
²³⁶ U	9.6E-14	2.6E-11	6.8E-13	1.8E-10	LLI Wall
²³⁷ U	1.8E-17	4.9E-15	1.9E-16	5.1E-14	LLI Wall
²³⁸ U+D ^(c)	7.2E-14	2.0E-11	6.5E-13	1.7E-10	LLI Wall
²³⁸ U	1.5E-13	4.0E-11	1.1E-12	2.9E-10	LLI Wall
U-Nat ^(f)	1.3E-13	3.4E-11	9.1E-13	2.5E-10	LLI Wall
²⁴⁰ U+D ^(c)	6.8E-20	1.8E-17	5.4E-19	1.4E-16	LLI Wall
²⁴⁰ U+I ^(d)	2.0E-19	5.5E-17	1.6E-18	4.3E-16	LLI Wall

TABLE 3.4. Drinking Water Scenario Annual Committed Effective Dose Equivalent Factors for Exposure to Residual Radioactive Materials(a) (contd)

Radionuclide	TEDE (mrem)	TEDE (μ Sv)	Maximum Organ Dose		
			(mrem)	(μ Sv)	Organ(b)
²³⁷ Np+D (c)	3.9E-11	1.1E-08	9.1E-10	2.5E-07	Bone Surface
²³⁷ Np	7.9E-11	2.1E-08	1.8E-09	4.9E-07	Bone Surface
²³⁸ Np+D (c)	3.6E-16	9.8E-14	6.3E-15	1.7E-12	Bone Surface
²³⁸ Np	8.5E-18	2.3E-15	7.2E-17	2.0E-14	LLI Wall
²³⁹ Np+D (c)	4.3E-18	1.2E-15	4.3E-17	1.2E-14	LLI Wall
²³⁹ Np	8.7E-18	2.3E-15	8.7E-17	2.3E-14	LLI Wall
²³⁸ Pu	8.1E-13	2.2E-10	1.0E-11	2.7E-09	Bone Surface
²³⁷ Pu	4.1E-16	1.1E-13	3.5E-15	9.5E-13	LLI Wall
²³⁸ Pu	5.1E-12	1.4E-09	8.9E-11	2.4E-08	Bone Surface
²³⁹ Pu	5.6E-12	1.5E-09	1.0E-10	2.7E-08	Bone Surface
²⁴⁰ Pu	5.6E-12	1.5E-09	1.0E-10	2.7E-08	Bone Surface
²⁴¹ Pu+D (c)	2.6E-11	7.1E-09	5.0E-10	1.3E-07	Bone Surface
²⁴¹ Pu	1.0E-13	2.7E-11	1.9E-12	5.1E-10	Bone Surface
²⁴² Pu	5.1E-12	1.4E-09	9.2E-11	2.5E-08	Bone Surface
²⁴³ Pu+D (c)	2.8E-21	7.5E-19	1.8E-20	4.9E-18	ULI Wall
²⁴³ Pu	5.6E-21	1.5E-18	3.7E-20	9.9E-18	ULI Wall
²⁴⁴ Pu+D (c)	1.4E-12	3.7E-10	2.3E-11	6.2E-09	Bone Surface
²⁴⁴ Pu	5.3E-12	1.4E-09	9.3E-11	2.5E-08	Bone Surface
²⁴¹ Am	4.8E-10	1.3E-07	8.9E-09	2.4E-06	Bone Surface
^{242m} Am+D (c)	1.3E-10	3.6E-08	2.5E-09	6.7E-07	Bone Surface
^{242m} Am	4.6E-10	1.3E-07	8.5E-09	2.3E-06	Bone Surface
²⁴² Am+D (c)	2.4E-16	6.6E-14	4.1E-15	1.1E-12	Bone Surface
²⁴² Am	2.6E-18	7.0E-16	1.8E-17	4.8E-15	LLI Wall
²⁴³ Am+D (c)	1.6E-10	4.3E-08	3.0E-09	8.0E-07	Bone Surface
²⁴³ Am	4.8E-10	1.3E-07	8.9E-09	2.4E-06	Bone Surface
²⁴² Cm+D (c)	1.4E-12	3.8E-10	2.4E-11	6.4E-09	Bone Surface
²⁴² Cm	6.3E-13	1.7E-10	9.2E-12	2.5E-09	Bone Surface
²⁴³ Cm	4.3E-11	1.2E-08	7.7E-10	2.1E-07	Bone Surface
²⁴⁴ Cm+D (c)	1.5E-11	4.0E-09	2.7E-10	7.2E-08	Bone Surface
²⁴⁴ Cm	3.0E-11	8.0E-09	5.3E-10	1.4E-07	Bone Surface
²⁴⁵ Cm+D (c)	3.7E-11	9.9E-09	7.1E-10	1.9E-07	Bone Surface
²⁴⁵ Cm	5.6E-11	1.5E-08	1.0E-09	2.8E-07	Bone Surface
²⁴⁶ Cm	5.6E-11	1.5E-08	1.1E-09	2.9E-07	Bone Surface
²⁴⁷ Cm+D (c)	2.6E-11	6.9E-09	4.8E-10	1.3E-07	Bone Surface
²⁴⁷ Cm	5.1E-11	1.4E-08	9.7E-10	2.6E-07	Bone Surface
²⁴⁸ Cm	2.0E-10	5.3E-08	3.8E-09	1.0E-06	Bone Surface
²⁵² Cf	1.2E-10	3.3E-08	2.5E-09	6.7E-07	Bone Surface

(a) Based on ingestion of 730 L of drinking water from a ground-water source and an inventory of 1 pCi (1 Bq) of activity, per radionuclide in soil.

TABLE 3.4. Drinking Water Scenario Annual Committed Effective Dose
Equivalent Factors for Exposure to Residual Radioactive
Materials(a) (contd)

- (b) Where SI is Small Intestine, ULI is Upper Large Intestine, and LLI is Lower Large Intestine.
- (c) Where +D means "plus daughters in equilibrium" referring to explicit daughters, or daughters with half-lives greater than 10 minutes. Separate values are also included for parents and daughters so that combined factors for non-equilibrium cases can be determined. Note: in some cases +D also includes implicit daughters (i.e., uranium and thorium decay chains).
- (d) Where +I means "plus implicit daughters in equilibrium" referring to daughters with half-lives less than 10 minutes. The decay energies associated with these daughters have been assigned to the parent, and the appropriate branching ratios (described in Appendix D) have been considered.
- (e) Where Th-Nat includes an equilibrium mixture of ^{232}Th plus 10 daughters in the decay chain, as discussed in Appendix D.
- (f) Where 1 Ci U-Nat equals 48.9% ^{238}U plus 48.9% ^{234}U plus 2.25% ^{235}U .

3.3 SCENARIO PARAMETER SELECTIONS

The input parameters and assumptions for each exposure pathway and scenario are selected to provide a reasonable estimate of the likely radiation dose to an average individual in a population. The parameters and assumptions were not selected to be overly conservative; however, they still should overestimate the average potential radiation dose received. In general, default parameter values were selected to match literature values (such as those published by the ICRP), selected from values given in Regulatory Guide 1.109 (NRC 1977) or Oztunali et al. (1981), or are considered standard default values that are referenced by various national or international authorities. A specific listing of the major parameters or assumptions for the scenarios identified for unrestricted release of buildings and land, their expected ranges, and a listing of the values selected for this study is given in Table 3.5. A discussion of the additional parameters and assumptions used in the analysis, listed by exposure pathway, is included in Appendix B. In every case, an attempt has been made to select values within the expected range--not at the extremes of the expected range. For example, the dietary intake rate was assumed to be 25% of the total diet defined in Regulatory Guide 1.109 (NRC 1977). Of additional concern is the use of potential dilution factors that may reduce the concentrations of material considered for each pathway and scenario. However, for this analysis, no dilution was considered and an initial concentration of 1 pCi/g (1 Bq/g) or 1 dpm/100 cm² (1 Bq/100 cm²) was used.

Modified unit concentration TEDE factors can be obtained by multiplying the pathway dose conversion factors, discussed in Section 2.0, by appropriate modification factors, as described in Appendix B. In addition to dilution, the modification factors can account for changes in exposure duration, radionuclide concentrations in various media, and other pathway-specific parameters. For example, to change the exposure duration for the facility-inventory scenario for 2000 h/yr to 4000 h/yr the unit concentration TEDE factors for a given scenario are simply multiplied by 2. In general, a simple linear multiplication should be used because linear chain models have been used.

Table 3.5. Expected Ranges for Major Scenario or Pathway Parameters and the Selected Values Used in This Study

Scenario or Pathway Parameter	Expected Range	Selected Value	Comments
<u>Building Renovation or Occupancy</u>			
• Inhalation			
- Duration	0 to 8760 h	500 h or 2000 h	Renovation work; Normal work year (50 work-weeks)
- Breathing rate	125 to 333 cm ³ /sec	270 cm ³ /sec	ICRP recommendations for standard man (1975)
- Concentration	10 ⁻⁶ to 10 ⁻³ g/m ³	10 ⁻⁴ g/m ³	Dusty workplace (as discussed in Appendix B)
- Particle size	0.1 to 10 µm AMAD	1.0 µm AMAD(a)	ICRP generic value from ICRP 30 (1979- 1988)
• Secondary Ingestion			
- Ingestion rate	0 to 0.05 g/h	0.01 or 0.001 g/h	Literature value (as discussed in Appendix B)
- Duration	0 to 8760 h	500 h or 2000 h	Renovation work; Normal work year (50 work-weeks)
• External			
- Duration	0 to 8760 h	500 h or 2000 h	Renovation work; Normal work year
<u>Residential Use Surface Soil Scenario</u>			
• Inhalation			
- Duration	0 to 8760 h	100 h 1700 h 4380 h	Gardening; Outdoors; Indoors
- Breathing rate	125 to 333 cm ³ /sec	270 cm ³ /sec	ICRP recommendations for standard man (1975)

Table 3.5. Expected Ranges for Major Scenario or Pathway Parameters and the Selected Values Used in This Study (contd)

<u>Scenario or Pathway Parameter</u>	<u>Expected Range</u>	<u>Selected Value</u>	<u>Comments</u>
<u>Residential Use</u>			
<u>Surface Soil Scenario</u>			
<u>(contd)</u>			
- Concentration	10 ⁻⁶ to 10 ⁻³ g/m ³	5x10 ⁻⁴ g/m ³ 1x10 ⁻⁵ g/m ³ 5x10 ⁻⁵ g/m ³	Gardening dust; Yardwork dust; EPA standard (indoors)
- Particle size	0.1 to 10 μm AMAD	1.0 μm AMAD	ICRP generic value from ICRP 30 (1979-1988)
• External			
- Duration	0 to 8760 h	1800 h 4380 h	Outdoors; Indoors work-weeks)
- Shielding factor	0 to 1.0	0.33	House shielding factor
• Ingestion			
- Vegetables	0 to 190 kg/yr	47.5 kg/yr	25% of diet
- Milk	0 to 110 L/yr	27.5 L/yr	25% of diet
- Meat	0 to 76.5 kg/yr	19.2 kg/yr	25% of diet
- Eggs	0 to 19 kg/yr	4.8 kg/yr	25% of diet
• Air concentration for leaf deposition	10 ⁻⁶ to 10 ⁻³ g/m ³	5x10 ⁻⁵	EPA standard (annual average)
<u>Drinking Water Scenario</u>			
• Ingestion rate	0 to 4 L/d	2 L/d	NRC (1977)

(a) Where AMAD means the activity mean aerodynamic diameter of the airborne particulate material.

4.0 EXAMPLE DOSE CALCULATIONS FOR REFERENCE BUILDINGS AND LAND

This section describes example calculations performed to estimate the potential annual TEDE for a specified year of exposure after decommissioning, using the unit concentration TEDE factors discussed in Section 3.0. Example calculations are performed for illustration purposes only and are not intended to represent the exact mixtures or contamination levels found at any existing facility. The calculations in this section are performed using a radionuclide mixture for deposited surface contamination at a reference light-water power reactor, 30 years after shutdown. Additional example calculations for mixtures of radionuclides that potentially may be found at uranium facilities and radiopharmaceutical/industrial-source manufacturing plants are included in Appendix C. The calculated annual TEDEs are presented for each of the four major scenarios discussed in Section 3.0, and for exposure to residual radioactive materials during building renovation, normal building occupancy, residential use of surface soil, and drinking water from ground water sources.

4.1 REFERENCE RADIONUCLIDE MIXTURE

To illustrate the use of the unit concentration annual TEDE factors, a reference radionuclide mixture is defined for deposited surface contamination at light-water power reactor stations (Smith, Konzek, and Kennedy 1978; Oak et al. 1980). This mixture and the descriptions of the reference light-water reactor are discussed in detail in the referenced documents. The mixture of radionuclides for power reactors and the additional mixtures discussed in Appendix C are provided in terms of the relative activity (normalized to unity for the total mixture for each decay period), by radionuclide. No consideration is given to the total quantity present for the example calculations because actual contamination levels will vary depending on the success of decontamination procedures. For the example mixture calculations, concentrations of 100 pCi/g for volume sources (building material and soils) and 10,000 dpm/100 cm² for building surface source levels are assumed. It is doubtful that any real facility would actually have radionuclide mixtures consisting of the exact relative activities or assumed concentrations of the radionuclides shown in the reference lists; they are intended to serve only as a basis for the example calculations.

For the reference light-water reactor, information from both a pressurized-water reactor (Smith, Konzek, and Kennedy 1978) and a boiling-water reactor (Oak et al. 1980) was reviewed. The mixture of radionuclides is anticipated to vary as a function of the operating history of the reactor, the plant design, the location within the facility, and the success of decontamination operations. In addition, potentially there will be mixtures resulting from neutron activation and mixtures containing fission products from the fuel. Thus, it is difficult to develop generic radionuclide mixtures that are truly representative of overall plant conditions. For illustrative purposes, a mixture associated with general surface contamination is defined, as shown in Table 4.1. This mixture contains both key activation and fission products that may be present during plant

TABLE 4.1. Estimated Relative Activity of Radionuclides in Deposited Surface Contamination at the Reference Power Reactor(a)

Radio-nuclides	Half-Life (yr)	Relative Activity	
		10 Years After Shutdown	30 Years After Shutdown
⁵⁴ Mn	8.2E-01	8.5E-07	-(b)
⁵⁵ Fe	2.7E+00	9.2E-02	1.1E-03
⁶⁰ Co	5.3E+00	2.9E-01	5.1E-02
⁶³ Ni	1.0E+02	1.2E-02	2.5E-02
⁶⁵ Zn	6.7E-01	1.7E-06	-
⁹⁰ Sr+D(c)	2.8E+01	8.8E-02	1.3E-01
^{110m} Ag	6.8E-01	1.2E-09	-
¹³⁴ Cs	2.1E+00	1.1E-03	3.4E-06
¹³⁷ Cs+I(d)	3.0E+01	5.2E-01	8.2E-01
¹⁴⁴ Ce	7.8E-01	1.1E-07	-
Total		1.0	1.0

(a) Based on information in Smith, Konzek, and Kennedy (1978) and Oak et al. (1980).

(b) A dash indicates a value less than 10⁻⁸.

(c) Where +D means "plus explicit daughters in equilibrium" as discussed in Appendix D.

(d) Where +I means "plus implicit daughters in equilibrium" as discussed in Appendix D.

operations. Table 4.1 shows the variation in the relative activity of the mixture at 10 years and 30 years after plant shutdown; however, for purposes of the example calculations that follow, only the mixture after 30 years of radioactive decay is used. This decay period is chosen to be representative of decommissioning after a period of safe storage that allows for radioactive decay. After 30 years of decay, the level of ⁶⁰Co will have decayed to about 1% of its initial value, and about 82% of the activity for the mixture is ¹³⁷Cs+I. About 13% of the mixture is ⁹⁰Sr+D and about 5% is ⁶⁰Co. For reactors where fission product releases from the fuel are minimal, the radionuclide mixture would be dominated by activation products, most notably ⁶⁰Co. However, the mixture of activation and fission products shown in Table 4.1 is used in this analysis to demonstrate the pathway contribution and relative importance of radionuclides from both sources.

4.2 EXAMPLE DOSE CALCULATIONS FOR THE BUILDING RENOVATION SCENARIO

As a demonstration of the application of the unit concentration annual TEDE factors for the building renovation scenario (described in Section 3.1.1) example calculations are next performed. The results shown in

TABLE 4.2. Estimated Annual Total Effective Dose Equivalents for the Building Renovation (Volume Activity) Scenario Using the Light-Water Power Reactor Surface Contamination Inventory(a)

Radio-nuclide(b)	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
⁵⁵ Fe	1.8E-06	6.6E-09	3.2E-07	2.1E-06	2.1E-05
⁶⁰ Co	4.2E-01	4.8E-05	2.6E-04	4.2E-01	4.2E+00
⁶³ Ni	2.5E-08	2.4E-07	6.3E-06	6.8E-06	6.8E-05
⁹⁰ Sr+D(c)	1.4E-03	6.7E-05	4.2E-03	5.7E-03	5.7E-02
¹³⁴ Cs	1.9E-05	6.8E-10	1.1E-07	1.9E-05	1.9E-04
¹³⁷ Cs+I(d)	1.6E+00	5.5E-05	9.8E-03	1.6E+00	1.6E+01
Total	2.0E+00	1.7E-04	1.4E-02	2.0E+00	2.0E+01

- (a) Using the radionuclide mixture shown in Table 4.1 with 30 years of radioactive decay and the annual TEDE factors from Table 3.1.
- (b) With an assumed contamination level of 100 pCi/g (3.7 Bq/g) of the radionuclide mixture.
- (c) Where +D means "plus explicit daughters in equilibrium" as discussed in Appendix D.
- (d) Where +I means "plus implicit daughters in equilibrium" as discussed in Appendix D.

Table 4.2 are in terms of the dose by pathway and the annual TEDE from a year of exposure to an individual (mrem and μ Sv) for the light-water power reactor inventory decayed to 30 years after shutdown. The contamination level for volume sources in buildings was assumed to be 100 pCi/g (3.7 Bq/g). The results are the product of the annual TEDE factors in Table 3.1 (by radionuclide), the relative activity level for each radionuclide in the mixture, and the assumed contamination level for this example problem. The dominant radionuclide contributors to the dose in the mixture are ¹³⁷Cs+I, ⁶⁰Co, and ⁹⁰Sr+D. For this mixture and scenario, the most important exposure pathways are external exposure followed by secondary ingestion. The estimated annual TEDE resulting from a year of exposure to 100 pCi/g (3.7 Bq/g) concentration of the radionuclide mixture is 2.0 mrem (20 μ Sv).

4.3 EXAMPLE DOSE CALCULATIONS FOR THE BUILDING OCCUPANCY SCENARIO

Example calculations are next performed for the building occupancy scenario using the radionuclide mixture in Table 4.1, decayed to 30 years after shutdown. The assumed contamination level for the calculations is 10,000 dpm/100 cm² (167 Bq/100 cm²) of the mixture. The results for an assumed year of exposure are shown in Table 4.3 in terms of the dose by exposure pathway and the annual TEDE to an individual (mrem and μ Sv). These

TABLE 4.3. Estimated Annual Total Effective Dose Equivalents for the Building Occupancy (Surface Activity) Scenario Using the Light-Water Power Reactor Surface Contamination Inventory(a)

Radio-nuclide(b)	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
⁵⁵ Fe	1.6E-05	2.6E-07	1.3E-05	2.9E-05	2.9E-04
⁶⁰ Co	4.3E-01	1.9E-03	1.0E-02	4.4E-01	4.4E+00
⁶³ Ni	2.0E-07	9.5E-06	2.5E-04	2.5E-04	2.5E-03
⁹⁰ Sr+D(c)	2.1E-03	2.7E-03	1.7E-01	1.7E-01	1.7E+00
¹³⁴ Cs	2.0E-05	2.7E-08	4.4E-06	2.4E-05	2.4E-04
¹³⁷ Cs+I(d)	<u>1.6E+00</u>	<u>2.2E-03</u>	<u>3.8E-01</u>	<u>2.0E+00</u>	<u>2.0E+01</u>
Total	2.0E+00	6.8E-03	5.6E-01	2.6E+00	2.6E+01

- (a) Using the radionuclide mixture shown in Table 4.1 with 30 years of radioactive decay and the annual TEDE factors from Table 3.2.
 (b) With an assumed contamination level of 10,000 dpm/100 cm² (167 Bq/100 cm²) of the radionuclide mixture.
 (c) Where +D means "plus explicit daughters in equilibrium" as discussed in Appendix D.
 (d) Where +I means "plus implicit daughters in equilibrium" as discussed in Appendix D.

results are the product of the unit concentration annual TEDE factors for this scenario from Table 3.2 by radionuclide, the relative activity level for each radionuclide in the mixture, and the assumed contamination level. The dominant radionuclide contributors to dose for this scenario are ¹³⁷Cs+I and ⁶⁰Co, and the most important exposure pathway is external exposure. The estimated annual TEDE resulting from a 10000 dpm/100 cm² (167 Bq/100 cm²) contamination level is 2.6 mrem (26 μ Sv).

4.4 EXAMPLE DOSE CALCULATIONS FOR THE SURFACE SOIL ACTIVITY SCENARIO

Example calculations for the surface soil activity scenario are conducted using an initial soil concentration of 100 pCi/g (3.7 Bq/g) of soil using the inventory in Table 4.1, decayed to 30 years after plant shutdown. The results for one year of exposure are shown in Table 4.4 in terms of the dose by exposure pathway and the annual TEDE to an individual (mrem and μ Sv). The results are the product of the annual TEDE factors for this scenario by radionuclide from Table 3.3, the relative activity level for each radionuclide in the mixture, and the assumed contamination level.

The dominant radionuclide contributors to dose are ¹³⁷Cs+I, ⁶⁰Co, and ⁹⁰Sr+D and the dominant exposure pathways are food ingestion and external

TABLE 4.4. Estimated Annual Total Effective Dose Equivalents for the Residential Use (Surface Soil) Scenario Using the Light-Water Power Reactor Surface Contamination Inventory(a)

Radio-nuclide(b)	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
⁵⁵ Fe	1.2E-05	3.3E-08	3.8E-06	1.5E-05	1.5E-04
⁶⁰ Co	3.9E+01	4.2E-04	3.1E-02	3.9E+01	3.9E+02
⁶³ Ni	4.8E-07	2.1E-06	3.2E-03	3.2E-03	3.2E-02
⁹⁰ Sr+D(c)	1.2E-01	6.0E-04	1.2E+01	1.2E+01	1.2E+02
¹³⁴ Cs	1.8E-03	6.1E-09	1.7E-05	1.8E-03	1.8E-02
¹³⁷ Cs+I(d)	1.6E+02	4.8E-04	2.5E-01	1.6E+02	1.6E+03
Total	2.0E+02	1.5E-03	1.2E+01	2.1E+02	2.1E+03

- (a) Using the radionuclide mixture shown in Table 4.1 with 30 years of radioactive decay and the annual TEDE factors from Table 3.3.
(b) With an assumed contamination level of 100 pCi/g (3.7 Bq/g).
(c) Where +D means "plus explicit daughters in equilibrium" as discussed in Appendix D.
(d) Where +I means "plus implicit daughters in equilibrium" as discussed in Appendix D.

exposure. The estimated annual TEDE for the reference mixture with a concentration of 100 pCi/g (3.7 Bq/g) is 210 mrem, or 2100 μ Sv.

4.5 EXAMPLE DOSE CALCULATIONS FOR THE DRINKING WATER SCENARIO

Example calculations for the drinking water scenario are conducted using an assumed contaminated area of 1000 m², to a depth of 15 cm, at a level of 100 pCi/g (3.7 Bq/g). Assuming a soil density of 1.6 g/cm³, the total inventory is 24 mCi (890 MBq). For the mixture of radionuclides shown in Table 4.1, decayed to 30 years after plant shutdown, the results for drinking water for 1 year are shown in Table 4.5 in terms of the annual TEDE to an individual (mrem and μ Sv) and the maximum organ dose rate by radionuclide. The results are the product of the annual TEDE factors by radionuclide from Table 3.4, the relative activity level for each radionuclide in the mixture, and the assumed contamination level for this example. The dominant contributors to dose for the mixture are ¹³⁷Cs+I and ⁹⁰Sr+D. The estimated annual TEDE for the mixture of radionuclides at the light-water power reactor is 0.073 mrem (0.73 μ Sv) and the maximum organ dose for the mixture is 0.69 mrem (6.9 μ Sv) to bone surface. The dominant contributor to organ dose for this mixture is ⁹⁰Sr+D.

TABLE 4.5. Estimated Annual Total Effective Dose Equivalents for the Drinking Water Scenario Using the Light-Water Power Reactor Surface Contamination Inventory(a)

Radio-nuclide	TEDE (mrem)	TEDE (μ Sv)	Maximum Organ Dose		
			(mrem)	(μ Sv)	Organ(c)
⁵⁵ Fe	6.1E-06	6.1E-05	2.2E-05	2.2E-04	Spleen
⁶⁰ Co	5.4E-03	5.4E-02	2.3E-02	2.3E-01	LLI Wall
⁶³ Ni	1.4E-04	1.4E-03	9.0E-04	9.0E-03	LLI Wall
⁹⁰ Sr+D(d)	6.2E-02	6.1E-01	6.9E-01	6.9E+00	Bone Surface
¹³⁴ Cs	2.3E-08	2.3E-07	3.0E-08	3.0E-07	SI Wall
¹³⁷ Cs+I(e)	2.4E-03	2.4E-02	3.0E-03	3.0E-02	SI Wall
Total	7.3E-02	7.3E-01	6.9E-01	6.9E+00	Bone Surface

- (a) Using the mixture of radionuclides shown in Table 4.1 with 30 years of radioactive decay and the annual TEDE factors from Table 3.4.
- (b) Assuming a contaminated area of 1000 m², to a depth of 15 cm, at a level of 100 pCi/g. Assuming a soil density of 1.6 g/cm³, the total inventory is 24 mCi (890 MBq).
- (c) Where LLI is lower large intestine, and SI is small intestine.
- (d) Where +D means "plus explicit daughters in equilibrium" as discussed in Appendix D.
- (e) Where +I means "plus implicit daughters in equilibrium" as discussed in Appendix D.

5.0 DISCUSSION

In support of the NRC's development of expanded criteria governing residual radioactive contamination for unrestricted use, a modeling evaluation was performed producing annual TEDE factors for anticipated radiation exposure pathways and scenarios. This section discusses the generic modeling approach, the generic scenarios and their limitations, and the relationship with existing standards.

5.1 GENERIC MODELING APPROACH

The generic modeling evaluation relies on a radiation exposure scenario analysis, including the major exposure pathways of direct exposure to penetrating radiation, inhalation, and ingestion. The modeling analysis is used to derive the annual TEDE to an average individual in a population exposed to residual radioactive material after decommissioning. The input parameters for each exposure pathway and scenario are selected to provide a reasonable estimate of the annual radiation dose. The parameters do not represent average conditions for all individuals exposed and were not selected to perform a worst case (overly conservative) analysis of the potential radiation dose to a maximum individual. Rather, the parameters were chosen from documented sources and previous analyses on the basis of the professional judgment of the study contributors. Although the dose estimates produced may be overestimations, in some cases, they are considered to be generally realistic as opposed to large overestimations (bounding cases). It is possible that for a few situations the parameters chosen could lead to an underestimate of the annual TEDE; however, the potential for underestimation is judged to be small, and the amount of the underestimation is unlikely to be large enough (or occur often enough) to warrant a more conservative approach. A more detailed consideration of the nuances of generic modeling follows.

Generic modeling evaluations, similar to the one described in this document, have become a rather common approach to setting risk-based radiation protection standards. They are useful in evaluating a wide variety of conditions; however, they often have limitations that need to be recognized. Models are intended to be an approximation of reality. Because of data limitations or lack of knowledge, sometimes generic modeling provides an oversimplification of actual conditions and may not account for important physical or chemical processes. When this occurs, or when it is suspected, attempts are made to use conservative assumptions and parameter selections to ensure that potential adverse consequences are overestimated. That is, where detailed knowledge is unavailable, there is an intentional error to provide greater safety. The results obtained by overestimating the adverse consequences may not be very useful because they may lead to prohibitive expenses for clean-up to meet regulatory requirements. However, for simple cases where trivial contamination exists, compliance reached by generic modeling is beneficial because it eliminates unwarranted regulation and expense while not significantly affecting public health and safety.

For more complex situations, where a wide variation of contamination levels, mixtures, and physical/chemical properties exist, generic models and data sets may not produce a very convincing assurance of compliance. When complex conditions occur, there should be a reliance on site-specific data, if possible, and modifications to the generic approach should be made to account for the actual conditions. For example, direct measurements of radiation fields and their variation provide more meaningful information than generic attempts to model dose rates from contamination levels (i.e., actual measurements may obviate the need to model). A dilemma occurs when the costs of characterizing a site escalate beyond the basic demolition and waste disposal costs. The tendency in this situation may be to comply with a more restrictive generic limit than to attempt a full site characterization and compliance with a site-specific limit.

The pathway dose conversion factors and annual TEDE factors are presented for a listing of about 200 individual radionuclides. Key parent-daughter combinations and decay chains in equilibrium (i.e., for uranium and thorium) have been included. Daughters with half-lives less than 10 minutes are always assumed to be in equilibrium with their parent and are referred to as implicit daughters. Because the pathway-specific dose factors are based on unit activity, it is important to note that the unit activity includes contributions from both the parent and implicit daughters. To accomplish this, a +I notation for the radionuclides listings and an appropriate footnote are included with all dose factor or example problem result tables. Daughters with half-lives greater than 10 minutes that may not be in equilibrium with their parents are referred to as explicit daughters. These are shown in equilibrium conditions with the parent by a +D notation with an appropriate footnote. Separate values for the parents and daughters are also included so that values for non-equilibrium cases can be determined. For cases where there is a short-lived parent with a long-lived daughter, separate listings for the parent and daughter are provided with no +D listing. Finally, for decay chains, the listings include parents alone, parents with +D and +I notations (to include both implicit and explicit daughters) and daughters alone so that equilibrium and non-equilibrium cases can be considered. A further description of parent-daughter and decay chain situations is included in Appendix D.

5.2 GENERIC SCENARIOS

For residual contamination in buildings, this document provides derived annual TEDE factors that account for both potential building renovation (accounting for volume contamination sources) and routine building occupancy (accounting for surface contamination sources). These two scenarios were developed in an attempt to account for questions about the relative importance of volume versus surface activity and fixed versus removable contamination. For many alpha- and beta-emitting radionuclides, direct survey measurements may only account for surface activity because of self shielding. Surface measurement methods may not detect subsurface sources, and significant inventories of radioactive material may be missed. Surface contamination that is fixed (i.e., not easily removed by smearing) at the time of release may become removable with time. Loose surface contamination

may result in additional radiation exposure pathways and higher estimated radiation doses, as described by scenarios and parameter values defined in this document. Because unrestricted release is considered, it cannot be assumed that subsurface sources or fixed contamination will remain that way after license termination. The two scenarios identified for buildings attempt to account for this potential situation. Because of modeling complexity, no attempt was made to model indoor radon concentrations that may result from residual uranium mixtures in buildings.

Residual radioactive soil contamination may be in a thin or thick soil layer, reside on the surface or be stabilized under a clean soil layer, cover a large or small area, and consist of many different radionuclides or mixtures of radionuclides. The derived annual TEDE factors provided in this document, in units of mrem per pCi/g (μ Sv per Bq/g) of soil, relate to surface soils and are based on a scenario analysis that considers a combination of inhalation; external; contaminated drinking water ingestion; and agricultural food product ingestion exposure pathways. It is recognized that, for sites located in industrial locations, the potential for even light agricultural activities may be remote. Again, because of modeling complexity, no attempt was made to model indoor radon concentrations that could result from residual soil contamination.

Potential ingestion of contaminated drinking water required a simplified, yet conservative analysis. The model estimates the potential effect of the total radionuclide inventory on the ground-water resources. Perhaps this scenario and model are the most controversial aspects of the modeling analysis. The wide variability of physical and chemical conditions that potentially influence ground water, and the dependence on many parameters that may have a coupled dependency, make it difficult to model ground-water systems. In addition, a conceptual model of a ground-water system may not represent all the behavior of that system. Generic attempts at modeling ground-water systems generally encourage the use of overly conservative parameters, assumptions, and models. As a result, most generic modeling attempts have little meaning when compared with a real system. The existence of site-specific data may encourage a site-specific modeling effort, but such data are relatively costly to obtain, may be point values (both in time and location), and may not appropriately represent the actual system being modeled. The purpose of the generic modeling in this document was to derive an aquifer concentration from residual radioactive materials in soil (or in building materials that may ultimately be buried as rubble onsite) in a conservative manner that would indicate when additional site data or modeling sophistication are warranted. This approach is not intended for broader applications such as application to buried sources, disposed wastes, or sites with a history of spills contaminating soil deeper than 15 cm.

The modeling approach considers leaching using leach-rate factors from previous NRC waste management literature (Oztunali et al. 1981) and simple dilution in a constant volume of ground water. No ground-water transport modeling is attempted. This approach was adopted to obtain results that are useful given the stated purpose of this document, especially in the recognition of cases with trivial contamination from a ground-water

protection point of view. Because of the potential wide variation in parameter values, the selection of leach-rate factors associated with humid (high rainfall) sites from low-level radioactive waste literature is judged to be adequate for the generic analysis. In a similar manner, the infiltration rate and porosity values were chosen based on the high end of the range of infiltration rates and porosities determined for humid areas of the United States. The ground-water parameter values and concentration equations selected for this analysis are judged to provide a conservative analysis of potential ground-water concentrations.

As a demonstration of the application of the unit annual TEDE factors, example problems were developed. These example problems used mixtures of radionuclides that may be encountered for uranium facilities, light-water power reactors, and radiopharmaceutical/industrial source manufacturing facilities. For completeness, mixtures were defined for a uranium fuel fabrication facility and for depleted and enriched uranium materials. As shown in Appendix C, the results for all scenarios for the depleted and enriched uranium mixtures were within about 5%. This similarity occurred because of the dominance of the inhalation pathway and the similarity of the inhalation committed dose equivalent factors for the major isotopes of uranium. When the uranium chains are present in equilibrium, the daughter products provide additional contributions to the dose analysis, as shown by the results for the mixture defined for the uranium fuel fabrication facility.

To ensure that the modeling results were produced correctly, hand calculations were performed to test the results of the computer analysis. In addition, the GENII computer software package has been extensively tested and reviewed in an effort to minimize computational errors. Separate hand calculations were performed during the development of the GENII program, and the results are included with the software documentation (Napier et al. 1988). Additional informal tests and comparisons with other modeling studies were made to determine if the generic modeling analysis was reasonable. Although some initial comparisons were made with existing regulations, these comparisons are not very useful, as described in the following section.

5.3 RELATIONSHIP TO EXISTING STANDARDS

The scenario-specific annual TEDE factors contained in this document were derived independently of existing standards or criteria concerning residual radioactive materials in buildings or soils. They are intended to provide a consistent basis for consideration of more than 200 radionuclides that potentially may be of interest at licensed facilities. Therefore, they may not compare with existing standards or regulations for specific facilities or mixtures of radionuclides. For example, current EPA regulations for cleanup of land and buildings contaminated with residual radioactive materials from inactive uranium processing sites (40 CFR 192, Subpart B) limit radium ^{226}Ra concentrations in surface soils to 5 pCi/g. Using the annual TEDE factors for ^{226}Ra plus its daughters in equilibrium in surface soils (from Table 3.3) at a concentration of 5 pCi/g, the result is an annual TEDE of approximately 1.3 mrem (13 μSv). Although this comparison

may be interesting, it is not completely valid because the residential use (surface soil) scenario does not include an estimate of the indoor radon pathway, accounted for by the EPA standard. Similar difficulties (i.e., the use of different bases and assumptions) are encountered when attempting to compare the surface contamination limits with Regulatory Guide 1.86 or the soil limits with existing NRC guidance for uranium mill tailings. Thus, it is not practical to directly compare the values provided in this report with existing standards.

For the drinking water scenario, dose rate factors are included for determining the dose to the limiting organ. This was done to provide an approximate comparison with existing drinking water standards that limit the organ dose to 4 mrem/yr from concentrations of radionuclides in drinking water. The organ doses provided in this document were calculated using ICRP 30 methods, and the EPA regulations refer to ICRP 2 methods. The use of different dosimetry models and metabolic data means that the two values are not directly comparable for most radionuclides; however, they are useful in providing a rough estimate of the maximum organ dose. For most significant radionuclides, the ICRP 30 maximum organ dose rate times the weighting factor for the organ will not equal the annual TEDE because of the influence of the other organs in the analysis. An evaluation of the maximum organ dose determination was conducted as part of the review of the methods and results of this study. This was not an easy evaluation given the complexity of the ICRP 30 dosimetry system. For example, at first glance it may seem that a soluble element like cesium should produce a rather uniform dose to internal organs. However, the non-weighted target organ dose shows a maximum (by a few percent) for either the small intestine wall or the stomach wall, depending on the isotope considered. This occurs as somewhat of a calculational artifact (i.e., the computer program is able to recognize differences in the third significant figure and beyond to determine a maximum). Successful attempts were made to verify this result using information from the ICRP and other federal guidance.

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APPENDIX A

EXTERNAL EXPOSURE MODEL SENSITIVITY STUDIES

APPENDIX A

EXTERNAL EXPOSURE MODELING SENSITIVITY STUDIES

Several potentially important conditions exist that may affect the selection of modeling methods used in the external exposure pathway analysis. Significant conditions include: 1) the relationship between external dose rate and source area for various source energies; 2) the relationship between external dose rate and room volume (with various surface contamination conditions); 3) the external dose rate for both surface and volume sources, as a function of room size; and 4) the dose rate versus fractional hectare of contaminated soil source area for both shielded and non-shielded conditions.

To determine how to best model these situations for the purposes of this study, a series of sensitivity studies were conducted using a generic modeling approach. The results of these sensitivity studies should also serve as useful illustrations of the determination of the important conditions that may contribute external exposure. When conducting the dose calculations for determining the unit concentration dose conversion factors for the external exposure pathway, described in Section 2.2.1, dose factors generated by the GENII software package were used. These factors are in terms of the effective dose equivalent and account for the sum of weighted organ doses (Kocher 1981).

For each situation considered in the sensitivity studies, only the equivalent penetrating gamma component of the radiation was modeled. That is, for each situation the exposure in air (mR/h) was converted to approximate dose equivalent rate (mrem/h) by calculating the dose at the center of a sphere of tissue with a radius of 5 cm. The 5-cm tissue depth was used only in the sensitivity studies and not as the basis for the external exposure pathway dose rate conversion factors developed and described in Section 2.2.1. This procedure eliminated the surface effects from low energy photons, but enabled a determination of the appropriate modeling approach for external exposure in buildings and on land surfaces. The results of the sensitivity studies for each of the modeling considerations for the external exposure pathway are described in the following sections.

A.1 WHOLE BODY DOSE RATE VERSUS SOURCE AREA

As a first step in evaluating external whole body dose rate relationships, a series of calculations for specific gamma-emitters from Kennedy et al. (1987) was considered to determine the influence of source size on the approximate whole-body dose rate. The dose rates for the sensitivity study were estimated using a version of the ISOSHL computer program (Engel et al. 1966) that employed a single disk source geometry. The dose rates were calculated for selected radionuclides at a 5-cm tissue depth located 1 m in air above the source. The results of these calculations are shown in Figure A.1 (Kennedy et al. 1987) in units of mrem/h. Because the curves in Figure A.1 are parallel, the correction factor for a reduced source area is uniform over a large range of gamma energies. This result occurs

FIGURE A.1. Estimated Tissue Dose Rate Versus Source Area

because the penetrating gamma component (through 5 cm of body tissue) was calculated, eliminating the low-energy photon effects. This result indicates that there is a large, but uniform, variation of the predicted external dose rate versus source size.

A.2 EXTERNAL DOSE RATE VERSUS ROOM VOLUME

The ISOSHLD (Engel et al. 1966) computer program was next used to estimate the relationships between the external dose rate and the size of contaminated room, for both uniform and non-uniform contamination conditions.

It is important to determine this relationship so that an adequate modeling basis for a generic room can be established. The results of the calculations are shown in Figure A.2 for a range of room volumes, assuming a room height of 3 m, and for both uniform and non-uniform contamination conditions (Oak et al. 1980). The curves in Figure A.2 were calculated for the gamma energies of ^{60}Co ; however, this basic relationship is valid over a wide range of gamma energies, and parallel curves could be developed as discussed in Section A.1. As in the previous sensitivity study, the approximate dose rates (mrem/h) are estimated at a depth of 5 cm in tissue.

The dose rates were calculated for ^{60}Co alone, assuming a contamination level of 1 Ci/m^2 on the floor. Because there is a definite relationship between dose rate and source energy, the shape of the curves in Figure A.2 should be similar for the source energies considered in Figure A.1, even though the magnitude of the dose rate will vary. Figure A.2 graphically illustrates the difference between an evenly contaminated room and one whose walls and ceiling contain 50% and 10%, respectively, of the floor contamination level. For reference, the straight line represents the dose rate from an infinite flat-plane source of evenly distributed ^{60}Co contamination with a concentration of 1 Ci/m^2 . It can be seen that the dose rate for a large, non-uniformly contaminated room may slightly exceed that of a uniformly contaminated infinite plane because of contributions to the dose

FIGURE A.2. Estimated Tissue Dose Rate at 1 m Above a Floor Having 1 Ci/m^2 as a Function of Room Volume

rate from the ceiling and walls. However, for most structures where the contamination levels are predicted to be lower on the walls and ceiling, dose rates calculated for an infinite flat plane provide a close approximation to the more complicated model that accounts for contaminated walls and ceiling. For situations where there may be a significant contribution from walls or ceilings, a modified approach to estimating dose rates in rooms should be adopted.

A.3 EXTERNAL DOSE RATE VERSUS SOURCE CONFIGURATION

Residual contamination on various surfaces in contaminated rooms will vary between surface and volume contamination conditions, depending on the type of surface and the mixture of radionuclides encountered. The potential effect of such variations on the external whole body dose rate was investigated for the mixture of radionuclides found in 3% enriched (un-irradiated) uranium after 10 years of radioactive decay (Elder and Blahnik 1980). This mixture is shown in Table 4.1 in Section 4.1. For this mixture, the dose rate in (mrem/h) for selected source conditions as a function of room volume are shown in Figure A.3. All curves shown are based on the non-uniform distribution of contamination shown in Figure A.2 (i.e., the walls and ceiling have 50% and 10%, respectively, of the contamination level found on the floor).

As a reference, the external whole-body dose rate expected from ^{60}Co surface contamination (from Figure A.2) is also shown in Figure A.3. For this mixture of radionuclides, three source configurations on (or in) concrete are plotted: 1) surface contamination (representing non-porous surfaces); 2) a volume source consisting of 90% of the activity in the first centimeter, with the remaining 10% of the activity uniformly distributed to a depth of 6 cm; and 3) a volume source uniformly distributed to a depth of 6 cm. For all curves shown in Figure A.3, the units have been normalized to mrem/h per Ci/m²; that is, for the volume sources, 1 Ci of the mixture of radionuclides is assumed to be diluted in each volume source (up to a maximum depth of 6 cm) per square meter of area. For surface contamination, the concentration is 1 Ci/m². Thus, the distribution of radionuclides in the volume sources is different than for the surface source, but the total Ci/m² in both stays the same. As shown by the curves in Figure A.3, the external effective dose rate for the mixture of radionuclides in the 3% enriched uranium inventory is quite small compared with the estimated external effective dose rate for a pure ^{60}Co source, at the same contamination level. This result is consistent with a comparison of the total gamma energy for the uranium mixture and ^{60}Co .

A.4 EXTERNAL DOSE RATES FOR SOIL CONTAMINATION CONDITIONS

The levels and mixtures of residual radioactivity in soil can vary widely depending on the type of facility considered and its operating history. A series of calculations were next performed to determine the potential variation of external dose rate as a function of source area, source volume, and depth of cover material. The results of sequential

FIGURE A.3. Estimated Tissue Dose Rate for Selected Source Configurations Versus Room Volume for an Effective Contamination Level of 1 Ci/m²

calculations made for these different soil contamination conditions are shown as a family of curves in Figure A.4. The source areas were varied from about 1 m² to 1 ha (10,000 m²). Three source thicknesses of 1, 15, and 100 cm were considered. In addition, calculations were performed for two thicknesses of overburden (clean soil as a shield in the calculations), with layers of 0.15 and 0.5 m, to illustrate the effect of soil shielding on the estimated dose rate. As for the calculations made supporting Figure A.3, the units in Figure A.4 have been normalized to mrem/h per Ci/m²; that is, for the volume sources, 1 Ci of the mixture of radionuclides for the reference uranium fuel fabrication facility was assumed to be diluted in slabs of 1, 15, and 100 cm thickness for each square meter of surface area. As a result, the concentration in Ci/m³ of soil varies, but the total activity per unit area

remains constant. As a comparison, the results for a 1-m-thick slab of soil containing ^{60}Co are also shown in Figure A.4. These results show that the external whole body dose rate decreases with increasing overburden and

FIGURE A.4. Estimated Tissue Dose Rate for Selected Conditions Versus Area of Soil Contamination for an Effective Concentration of 1 Ci/m^2

decreases with increasing source thickness as the concentration decreases. The calculated results shown in Figure A.4 agree with what should be expected for these source/shield configurations.

A.5 EXTERNAL DOSE RATE MODELING APPROACH

The external exposure dose rate conversion factors for the study were generated using the GENII software package. As part of this package, the EXTDF module allows easy and uniform calculation of plane or slab sources of contamination. The EXTDF code is a modification and enhancement of the well-known shielding code ISOSHLTD (Engel, Greenberg, and Hendrickson 1966). The data libraries of radionuclide decay information and gamma and beta yields are based on the original DRALIST compilation of Kocher (1981b) as updated by Oak Ridge National Laboratory (ORNL 1981). External exposure rates for unit quantities of individual radionuclides are calculated considering contributions from electromagnetic radiation from gamma- and x-rays; bremsstrahlung from the slowing-down of beta particles, auger electrons, and conversion electrons; and annihilation radiation from positrons. Alpha particles are not calculated to contribute to the exposure rates. The source of the radionuclide data is the DRALIST file (Oak Ridge National Laboratory 1981), which was adapted for GENII by including implicit daughter energies with their parents. This is an extremely comprehensive list, containing most known radiations, including many with very low frequencies of occurrence (e.g., a 0.8 MeV gamma ray from Po-210 which only occurs once in every 10⁵ decays).

Some radionuclides are pure alpha emitters (e.g. Sm-147). These nuclides will have a calculated exposure rate of zero. Some radionuclides are considered to have "no" emissions, but in actuality have very infrequent or very low-energy radiations. Examples of these types are Fe-55 or Ni-59, which usually decay via internal conversion. Each of these two radionuclides actually has a number of low-energy auger or internal conversion electrons, which may lead to low-energy bremsstrahlung, and also have a few very-low-energy gamma or x-rays associated with their decays.

Bremsstrahlung is calculated as a function of the energy of the electron emitted, and the atomic number of the source matrix, using the procedure of the ISOSHLTD shielding code (Engel, Greenberg, and Hendrickson 1966). This technique assigns a number and energy of emitted photons as a function of the electron energy. Energies less than 5 keV do not result in emitted photons. An example radionuclide with a beta particle emitted 100% of the time, but at a very low energy, is Re-187. The maximum beta energy per decay of Re-187 is 0.0026 keV, and thus no contribution from bremsstrahlung is included. For radionuclides which emit positrons, the energy of the annihilation gamma is treated as if the gamma were from any other source.

The ISOSHLTD code uses a point kernel integration technique (i.e., the dose at the exposure point is the contribution from a large number of individual point sources). A numerical integration is carried out over the source volume to obtain the total dose. The geometries available in the EXTDF code are the standard 14 available in ISOSHLTD.

The ISOSHL model works on discrete energy groups, rather than individual energies. Twenty-five energy groups are included in the model. The lowest energy group is from 0.01 to 0.02 MeV (10 to 20 keV). Any photon radiations of energies lower than this value are lumped into the 0.01 to 0.02 MeV group. This tends to somewhat overestimate the resultant exposure rate, because the average energy of this group, 0.015 MeV, may over-represent the actual energy value for a given radionuclide. This is done to provide a conservative value of the dose response. However, for such radionuclides, even the overestimation is a very small number, relative to those radionuclides with significant energy photon emissions.

Conversion of the calculated exposure rates to effective dose equivalent rates is done via an energy-dependent external-exposure-to-effective-dose conversion factor. It includes attenuation in the body to the depth of each exposed organ. This factor is applied to each of the ISOSHL energy groups. As for the shielding calculation, doses for photons of energy less than 0.01 MeV are lumped into the 0.01 to 0.02 MeV group. This has the effect of somewhat overestimating doses from very-low-energy photons. However, for such radionuclides, even the overestimation will be a very small number, relative to those radionuclides with significant emissions.

A.6 SUMMARY

To best determine how to model a wide variety of external exposure conditions for buildings and soils for this study, a series of sensitivity studies were conducted. The results of these studies were used to determine the source geometry configurations described in Section 2.1.2. In summary:

- For buildings with non-homogeneous distributions of source materials (i.e., higher contamination concentrations on the floor than on the walls or ceiling), dose rate factors for an infinite flat plane provide an appropriate solution over a wide variation of room volumes (as shown in Figure A.2). For situations where the ceiling may be a significant source, the infinite flat plane conversion factors may be doubled to account for two-plane sources.
- For surface soils, the use of a large cylinder source solution, with an assumed radius of 5 m and a contamination depth of 15 cm (the assumed plow layer) will provide an adequate modeling basis for source areas greater than about 80 m² (as shown in Figure A.4). Although sub-surface sources may be important, for this study the external exposure pathway dose factors represent a surface soil, volume source.

APPENDIX B

PATHWAY ANALYSIS PARAMETERS, ASSUMPTIONS, AND MODIFICATIONS

APPENDIX B

PATHWAY ANALYSIS PARAMETERS, ASSUMPTIONS, AND MODIFICATIONS

This appendix contains supporting information to the radiation exposure pathway and scenario analysis conducted for residual radioactive materials in buildings and on land. The support information includes discussions of the derivation of the concentrations in specific media (air, food products, and ground water); describes the key model parameters and assumptions used in the analysis; and describes modifications that can be applied to create site-specific scenarios and annual TEDE factors.

B.1 EXTERNAL EXPOSURE

The equation used to model external exposure is shown in Equation 2.1 of Section 2.2.1 of this document. In this equation, the radiation dose equivalent from external sources is the product of the concentration of radionuclides (C_{ip}), the usage factor or exposure duration (U_p), and a dose rate equivalent factor (D_{ip}). Details concerning the sensitivity studies conducted to determine the best modeling approach for the external exposure dose equivalent factor (D_{ip}) for the scenarios considered in this study are described in Appendix A. The assumed concentration used in the scenario-specific annual TEDE factors shown in Section 3.0 were either 1 pCi/g (1 Bq/g) for volume sources, 1 dpm/100 cm² (1 Bp/100 cm²) for surface sources, or an inventory of 1 pCi (1 Bq) for estimating concentrations in ground water sources. The assumed exposure duration varied for each scenario, as described in Section 3.0.

Simple modifications can be made to the external exposure pathway and annual TEDE factors in this document by a ratio multiplication. To account for a different exposure duration, the external dose conversion factors must be multiplied by the desired exposure duration and divided by the assumed exposure duration. For example, if an external exposure duration of 4000 h/yr is desired for the building occupancy (surface activity) scenario instead of the assumed 2000 h/yr duration, the external exposure pathway factors in Table 3.2 must be modified by multiplying by 2 (i.e., 4000/2000). Then, the modified annual TEDE is obtained by adding the modified external exposure factors to the other pathway factors. If inhalation and secondary ingestion parameters are also modified, the respective dose rates should be multiplied by the ratio of the parameters. Then the modified pathway dose rates should be summed to get the modified annual TEDE factor.

For example, to account for a concentration (C_{ip}) different than the assumed unit levels, the unit concentration annual TEDE factors should be multiplied by the desired concentration. If the modified concentration of radionuclide i for the building renovation (volume activity) scenario is 5 pCi/g instead of 1 pCi/g, the individual pathway dose rates, and consequently the annual TEDE value shown in Table 3.1, should be multiplied by 5.

More significant changes to the basic dose equivalent factors, accounting for different geometry conditions (radionuclides in smaller source areas or mixed to different depths) or different types of materials (perhaps wood instead of concrete surfaces) require the generation of modified external exposure files using the GENII software package. Details on how to accomplish these changes are found in the documentation of the GENII software (Napier et al. 1988). Appendix D shows the input to the GENII code prepared for developing the external exposure factors used in this analysis and the report generators used to develop the tables of dose rate, committed effective dose rate and annual TEDE factor tables found in Sections 2.0 and 3.0.

B.2 INHALATION

For inhalation, the model used to describe inhalation exposures is shown in Equation 2.2 of Section 2.2.2. In this equation, the committed effective dose equivalent is found as the product of the ventilation (breathing) rate (V), the exposure duration (t), the concentration of respirable dust in the air (C_d), the concentration of radioactive material in the dust ($C_{w,i}$), and the inhalation dose conversion factor ($DF_{INH,i}$). As previously described for external exposure, simple modifications can be made to the inhalation pathway and annual TEDE factors accounting for a modified exposure duration or radionuclide concentration. In a similar way, the pathway factors can be modified accounting for a modified ventilation rate by multiplying by the desired value and dividing by the assumed value.

The concentration of respirable dust (C_d) in the air will vary depending upon a variety of factors, including the physical condition (such as the particle size) of the material being handled, the quantity of the material present, and the building ventilation or wind conditions. There are three generic modeling approaches for estimating the concentrations of respirable dust in the air: the use of resuspension factors, resuspension rates, and mass loading factors. A summary of reported resuspension information is shown in Table B.1.

For the resuspension factor method, the average airborne concentration is a function of a resuspension factor and the surface contamination level as shown in Equation B.1.

$$\chi = S_f S_A \quad (B.1)$$

where χ = average airborne concentration, pCi/m³ (Bq/m³)

S_f = resuspension factor, m⁻¹

S_A = surface radioactivity, pCi/m² (Bq/m²).

The typical ranges for reported resuspension factors from Table B.1 is from about 10⁻¹¹ to 10⁻⁵ m⁻¹. To apply a resuspension factor analysis, there

TABLE B.1. Reported Resuspension Information

<u>Condition, Author and Reference</u>	<u>Resuspended Contaminant and Form</u>	<u>Factor or Rate Range</u>
Wind Stress on:		
Bare Soil (Stewart 1964)	91Y aqueous chloride	2E-11 to 8E-9 m ⁻¹
(Stewart 1964)	210Po as oxide	9E-8 to 1E-7 m ⁻¹
(Stewart 1964)	U ₃ O ₈	9E-8 to 5E-7 m ⁻¹
(Mishima and Schwendiman 1972)	UO ₂ powder	1.2E-4 to 1.6E-4 h ⁻¹
Vegetation:		
(Healy and Fuquay 1959)	Flourescent powder	2.9E-8 to 6E-7 m ⁻¹
(Mishima and Schwendiman 1972)	UO ₂ powder	7E-7 to 5.9E-5 h ⁻¹
(Sehmel and Lloyd 1976)	Calcium molybdate	1E-10 to 1E-8 sec ⁻¹
(Stewart 1964)	U ₃ O ₈	3E-8 to 5E-5 m ⁻¹
(Sehmel 1974)	ZnS	3.4E-8 sec ⁻¹
(Anspaugh 1974)	Pu	2.7E-12 to 4.8E-10 sec ⁻¹
Mechanical Mixing:		
(Stewart 1964)	Pu	1.5E-6 to 3E-4 m ⁻¹
(Sehmel 1976)	ZnS	1E-5 to 2E-4 per pass
(Sehmel 1974)	ZnS	4.8E-5 to 1.1E-2 per pass
(Milham et al. 1975)	Environmental Pu	3E-9 to 1E-6 sec ⁻¹
(Healy 1971)	PuO ₂ on floors	1E-6 to 5E-3 h ⁻¹

must be a reasonably uniform level of removable surface contamination, as would be found for soil contamination conditions. Inside buildings after decontamination operations, it is unlikely that significant removable surface contamination would be present.

Alternatively, the resuspension rate method is often used to predict air concentrations within buildings. The average air concentration can be expressed as a function of the resuspension rate and the room ventilation rate by (Healy 1971):

$$\chi = \frac{fASA}{Vn} \quad (B.2)$$

where f = the resuspension rate, h^{-1}

A = the surface area from which resuspension occurs, m^2

V = the volume of air in the room, m^3

n = the rate of room air exchange, h^{-1}

and where χ and SA are as previously defined.

(NOTE: $\chi/SA = Sf$, the resuspension factor, m^{-1}).

The typical range of reported resuspension rates from Table B.1 is 10^{-6} to $10^{-3} h^{-1}$.

Perhaps the simplest method of estimating air concentrations is to use mass loading factors. For this method, the average air concentration is assumed in terms of g/m^3 of air. This concentration is converted to units of activity using the concentration of the source material. For this analysis, air concentrations have been assumed in the range of 10^{-5} to $10^{-3} g/m^3$. This range is roughly consistent with the reported resuspension factor and rate ranges, for selected conditions, and includes the EPA standard for long-term dust loading, namely $5 \times 10^{-5} g/m^3$. Local annual averaged dust loadings may be higher or lower than this reference value, depending on soil and wind conditions. Modifications to the assumed air concentrations for each scenario can be made by dividing the inhalation pathway factors by the assumed air concentration and multiplying by the modified concentration in a manner similar to the corrections that can be made for modified exposure durations or ventilation rates. Because of the linear form of Equation 2.2, doubling the air concentration will have the effect of doubling the committed effective dose equivalent from inhalation.

More significant changes to the basic dose equivalent factors, accounting for different solubility classes or particle sizes, require the generation of modified inhalation exposure pathway files using the GENII software package. Details on how to modify the inhalation pathway factors can be found in the recommendations of the ICRP in Publication 30 (1979-1988) and in the documentation of the GENII software (Napier et al. 1988). For

this analysis, the inhalation committed effective dose equivalent factors were calculated using an assumed particle size distribution of $1\text{ }\mu\text{m}$ AMAD. A listing of the assumed solubility classes, by element, used for this analysis is shown in Table B.2. These solubility classes were selected to maximize the potential inhalation dose as calculated using the ICRP lung model.

B.3 SECONDARY INGESTION

For secondary ingestion, the model used to describe the committed effective dose equivalent is shown in Equation 2.3 of Section 2.2.3. In this equation, the committed effective dose equivalent is found as the product of the intake rate (I), the exposure duration (t), the concentration in the removable surface contamination ($C_{\text{ING},i}$), and the ingestion dose conversion factor ($DF_{\text{ING},i}$). In general, the most soluble form of each element was assumed to maximize the calculated ingestion dose. As previously described for external exposure, simple modifications to the pathway dose conversion factors can be made for the exposure duration and concentration of removable surface contamination by multiplying by the desired parameter value and dividing by the assumed value.

To estimate the ingestion or intake rate, a literature survey was conducted. Previous dose evaluations of the ingestion of surface contamination have been directed toward chronic occupational exposure situations (Dunster 1962; Gibson and Wrixon 1979; Healy 1971; Kennedy et al. 1981). Additional studies have been conducted in estimating the quantities of lead contamination that could be ingested by different age groups (Sayre et al. 1974; Lepow et al. 1975; Walter, Yankel, and Von Lindern 1980; Gallacher et al. 1984; LaGoy 1987). A summary of the referenced surface contamination ingestion data is given in Table B.3. A review of previous work on secondary ingestion pathways indicates that no quantitative data for radioactive materials are available. Because of this lack of data, previous dose estimates for secondary ingestion have relied on assumed ingestion rates. Quantitative data for ingestion of lead by children indicate that they may ingest 11 to 50 mg of lead from hand surfaces with a frequency of up to 10 times per day (Sayre et al. 1974; Lepow et al. 1975; Walter, Yankel, and Von Lindern 1980; Gallacher et al. 1984; LaGoy 1987). The total quantity ingested per day by children may range upward from about 0.1 g.

For our analysis, adult workers are assumed to ingest less removable contamination than children, and renovation workers are assumed to ingest at a higher rate than workers who have routine occupancy. To estimate the potential radiation doses resulting from secondary ingestion, adult renovation workers are assumed to ingest 10 mg of contamination per hour of exposure. Workers during routine building occupancy are assumed to ingest surface contamination at a rate of 1 mg of contamination per hour of exposure.

Modifications to the pathway dose rate factors and annual TEDE factors to account for a modified secondary ingestion rate can be made by a simple ratio multiplication, as previously described. Again, because of the linear form of Equation 2.3, doubling the secondary ingestion rate will have the

TABLE B.2. Inhalation Solubility Class Information

<u>Element</u>	<u>Inhalation Solubility Class(a)</u>	<u>Element</u>	<u>Inhalation Solubility Class(a)</u>
H	D	Sb	W
Be	Y	Te	W
C	D	I	D
N	D	Cs	D
F	D	Ba	D
Na	D	La	D
P	D	Ce	Y
S	W	Pr	Y
Cl	D	Nd	Y
K	D	Pm	Y
Ca	W	Sm	W
Sc	Y	Eu	W
Cr	Y	Gd	D
Mn	W	Tb	W
Fe	W	Ho	W
Co	Y	W	D
Ni	W	Re	W
Cu	D	Os	D
Zn	Y	Ir	Y
As	W	Hg	D
Se	W	Pb	D
Br	D	Bi	W
Rb	D	Po	W
Sr	D	Fr	D
Y	Y	Ra	W
Zr	W	Ac	Y
Nb	Y	Th	Y
Mo	D	Pa	Y
Tc	W	U	Y
Ru	Y	Np	W
Rh	Y	Pu	Y
Pd	Y	Am	W
Ag	D	Cm	W
Cd	D	Cf	W
In	D		
Sn	W		

(a) Where D, W, and Y correspond to the ICRP definitions and roughly relate to lung clearance times of: D = days, W = weeks, and Y = years.

TABLE B.3. Referenced Surface-Contamination Ingestion Data

Author and Reference	Reported Ingestion Rate or Other Value	Comments
Dunster (1962)	10^{-3} m ² /day	Chronic ingestion of MPC _w values of ²²⁶ Ra, ⁹⁰ Sr, and ²¹⁰ Pb to derive permissible levels of skin contamination.
Gibson and Wrixon (1979)	10^{-3} m ² /day	Chronic ingestion. No data available to improve Dunster's model (MPC _w analysis)
Healy (1971)	10^{-4} m ² /h	Chronic ingestion during 8 h for workers, 24 h for members of the public. These are arbitrary assumptions in an effort to account for presumed higher intake by children-- 2.4×10^{-3} m ² /day.
Kennedy et al. (1981)	10^{-4} m ² /h	Chronic ingestion of removable surface contamination on transportation containers. Dose estimates for both workers and members of the public. (2000 h/yr exposure).
Sayre et al. (1974)	0.018 m ² of dust on hands (children)	Dirt-hand-mouth ingestion route by children for intake of lead dust. Measurement of the amount of lead dust on children's hands compared with the level present on surfaces in a house.
Lepow et al. (1975)	0.1 g/day (children)	"Hands-in-mouth" exposure route is the principal cause of excessive lead ingestion. Mean measured weight on children's hands was 11 mg. Assuming a mouthing frequency of 10 times/d for small children yields an estimate of 0.1 g of dirt ingested/d.
Water, Yankel, and Von Lindern (1980)	Age dependent	Secondary risk factors for lead ingestion were found to be age dependent. Household dustiness is a factor for ages 2 years and under; soil lead is a factor for ages 2 to 7 years.
Gallacher et al. (1984)	10^{-3} to 3×10^{-3} (children)	Data comparing environmental and hand contamination of lead on children's hands was equivalent to 20 to 50 mg. This level was estimated to equal about 1×10^{-3} to 3×10^{-3} m ² at the level present in outdoor areas.

effect of doubling the committed effective dose equivalent rate from secondary ingestion.

B.4 INGESTION OF AGRICULTURAL FOOD PRODUCTS

For ingestion of agricultural food products, the model used to describe the committed effective dose equivalent is shown in Equation 2.4 of Section 2.2.4. This equation contains many parameters describing the behavior of radionuclides in soil and in various food products. The first term in the brackets of Equation 2.4 relates to the concentration resulting from direct deposition of airborne and irrigation-borne material on foliage during the growing season. The airborne material considered is resuspended material from the soil in which the plants are growing. The second term relates to the plant uptake from the soil. The third and fourth terms account for uptake of radionuclides contained in the plow layer (0.15 m) and material below the plow layer (below a depth of 0.15 m).

Although the form of Equation 2.4 is complicated and contains many terms, simple modifications to selected parameters can be made using the ratio methods previously discussed. These modifications include changes to the soil concentration, total assumed diet, and air concentration from resuspension (for the air deposition values in Table 2.4). Again, the modification procedure is to multiply the annual TEDE shown in Table 3.3 by the desired parameter value and divide by the previously assumed value.

Additional details concerning the GENII input parameters and implicit assumptions are contained in Appendix D. A computer-readable listing of the food transfer coefficients, by element, is given in Appendix D. More detailed information concerning the default data for the agriculture food product ingestion pathway is provided in Section B.6.

B.5 DRINKING WATER INGESTION

Residual radioactive contamination in soil has the potential to contaminate ground water in either the saturated or unsaturated zones. The primary mechanisms controlling potential ground-water contamination include infiltration and leaching, transport through the unsaturated zone, and transport through the saturated zone. Many additional processes influence these mechanisms, including precipitation rates, land surface properties, soil properties, the chemical nature of the radioactive contamination, spatial distributions of the contamination, and advection/retardation in the aquifer. More complete discussions of ground water can be found in Freeze and Cherry (1979), Isherwood (1981), and Wilson and Miller (1979). Previous efforts by the NRC have established a family of models that have fairly broad application to matters related to waste management. These models include those in references by Goode et al. (1986); Konikow and Bredehoeft (1978); Tracy (1982); Codell, Key, and Whelan (1982); and Codell (1984).

The wide variability of physical and chemical conditions that potentially influence ground water, and the dependence on many parameters that may have a coupled dependency, makes it difficult to model ground-water systems. In addition, a conceptual model of a ground-water system is an

approximation of reality and may not represent all of the behavior of that system. The cost of site characterization, model selection, and model validation may be prohibitive if a trivial source of contamination exists. As a result of the potential system variability, modeling uncertainty, and data collection/modeling costs, generic modeling attempts generally encourage the use of worst-case (overly conservative) parameters, assumptions, and models to avoid under-prediction of a ground-water system response. The existence of site data may allow the use of more realistic and sophisticated models, but the data may be point values (in both location and time) and may still not appropriately represent the actual system being modeled.

A middle ground between costly site characterization and overly conservative generic modeling may be the use of simple generic models for estimating drinking water concentrations with the use of data and assumptions that should be readily available for any site. The purpose of generic modeling conducted for this document is to derive an aquifer concentration from residual radioactive materials in soil in a conservative manner that will indicate when additional site data or modeling sophistication are warranted. It is recognized that the results may be prohibitive for all but trivial cases. However, it is also recognized that the types of data and assumptions used in the generic approach should be easily obtained for any given site so that some site-specific modifications are possible.

The modeling approach developed for the onsite disposal of radioactive wastes (Goode et al. 1986) is potentially applicable to residual radioactive soil contamination. Goode et al. (1986) provide a discussion of a methodology for estimating the potential contamination of ground water by materials disposed in soils by licensees. Their methodology includes the formulation of a conceptual model, representation of the conceptual model mathematically, estimation of conservative parameters, and prediction of receptor concentrations. Conservative models, assumptions, and parameter selections (i.e., those that are likely to overestimate the receptor concentration) are used for their methodology because of the need to ensure that underestimates of the potential consequences do not occur. When valid site data exist, they recommend that more realistic parameters and models should be used to refine the predictions. In an appendix, Goode et al. (1986) provide an overview of the types of mathematical models that should be considered when developing a detailed evaluation of potential waste disposal impacts on ground-water resources.

Goode et al. (1986) provide a methodology for predicting the well concentrations for an individual who drinks water from an onsite well. The simple conceptual model considers immediate release of materials to the soil. The total radionuclide inventory is assumed to be dispersed in the annual flow rate in the aquifer, F , taken to be 91,250 L of ground water. This volume of water represents the annual volume of water from a domestic well, or 250 L/day (Miller 1980), used by one person for all purposes, of which 2 L/day are assumed to be consumed as drinking water. The concentration of each radionuclide in the water is simply the total inventory divided by 91,250, corrected for radioactive decay. This concentration is described mathematically, Equation B.3, (Goode et al. 1986) as:

$$C_a(t) = \frac{M_0}{(1 \text{ yr})(F)} \int_0^1 e^{(-\lambda_R t)} dt \quad (\text{B.3})$$

where C_a = the concentration of each radionuclide in the aquifer at time t , pCi/L (Bq/L)

M_0 = the total radioactivity at the time of site release, pCi (Bq)

λ_R = the radioactive decay constant for each radionuclide considered, yr⁻¹

F = the dilution flow, 91,250 L/yr for an individual

t = an averaging time of 1 year.

Equation B.3 does not account for the leach rate of the radionuclide inventory in soils. A conservative method of estimating the concentration of radionuclides in a ground-water aquifer is to use a simple leach-rate model. Leach rates are dependent on the chemical properties of the radionuclides and soil, and the rate of local water movement. For this model, it is assumed that radionuclides are transferred to the ground water because of contact with infiltrating water (i.e., as a function of the solubility of material in water with no retardation in soils). For most sites, saturation conditions occur only during part of the year; however for this analysis, continuous saturated conditions are assumed. This condition is unlikely for surface soils, as considered for the residential use scenario and should define a conservative case.

To account for leach rate conditions, Equation B.3 can be modified through the following procedure. Figure B.1 shows a representation of the movement of material from a simple two-box leach model. Box 1 in the figure represents the initial inventory, with removal of material by either radioactive decay or leaching into Box 2. The initial quantity of material in Box 1, $Q_1(0)$, equals M_0 . The initial quantity of material in Box 2, $Q_2(0)$, equals zero. The material in Box 2 serves as the material used to estimate the annual average concentration in the ground-water system.

FIGURE B.1. Two-Box Representation of a Simple Leach-Rate System

The rate of removal of material from Box 1 is described by:

$$\frac{dQ_1}{dt} = -(\lambda_R + \lambda_L) Q_1 \quad (B.4)$$

and the change of material from Box 2 is described by:

$$\frac{dQ_2}{dt} = \lambda_L Q_1 - \lambda_R Q_2 \quad (B.5)$$

where λ_L = the leach rate constant, yr^{-1}

Q_1 = the quantity of material in the initial inventory, pCi (Bq)

Q_2 = the quantity of material leached from the initial inventory, pCi (Bq)

λ_R = the radioactive decay constant for each radionuclide considered, yr^{-1} .

The quantity in Box 1 equals:

$$Q_1 = M_0 e^{-(\lambda_R + \lambda_L)t} \quad (B.6)$$

where the parameters are as previously defined.

Solving for the quantity in Box 2, results in:

$$Q_2 = M_0 e^{-\lambda_R t} (1 - e^{-(\lambda_L)t}) \quad (B.7)$$

where the parameters are as previously defined.

The average concentration in the aquifer is defined by:

$$\bar{W} = \frac{\int_0^t Q_2 dt}{\int_0^t F dt} \quad (B.8)$$

The average concentration in the aquifer, $\bar{W}$, is the ratio of integrals defined in Equation B.8. Solving these integrals, $\bar{W}$ equals:

$$\bar{W} = \frac{M_0}{Ft} \left[\frac{1 - e^{-\lambda_R t}}{\lambda_R} - \left(\frac{1 - e^{-(\lambda_R + \lambda_L)t}}{(\lambda_R + \lambda_L)} \right) \right] \quad (B.9)$$

The dilution flow in the aquifer is assumed to be 9.1×10^4 L/yr, or enough water to supply an average person. The leach rate, λ_L , is defined as follows:

$$\lambda_L = kI (Hn) \quad (B.10)$$

where k = the partition coefficient, listed by element in Table B.4, from Oztunali et al. (1981)

I = the infiltration rate, chosen to be 0.18 m/yr based on the high end of the range of infiltration rates determined for humid areas of the United States (Oztunali, et al. 1981)

H = the assumed thickness of the soil layer containing the residual radioactive material, chosen to be 15 cm (consistent with previous plow layer assumptions for the agricultural food pathway)

n = the porosity of the waste/soil mixture, chosen to be 0.3, associated with only partially compacted soils, as described in Oztunali et. al. (1981).

Again, the use of partition coefficients assumes movement with the saturated water and does not account for further retardation by the soils. The data from Oztunali et al. (1981) are representative of Maxey Flats and West Valley low-level waste disposal trenches. Because of the presence of organic chemicals and chelating agents at these sites, and because of the continuous full saturation conditions that exist there, these data represent extreme leachability conditions (Oztunali et al. 1981). No attempt was made to reduce the leach rate conditions to account for periods when full saturation does not occur. This approach is not consistent with previous assumptions for low-level waste disposal (Oztunali et al. 1981) where waste-soil leach rates were assumed to be a linear function of the degree of saturation. However, it is consistent with recent literature reports (Oblath 1989).

Selection of 0.18 m/yr as the infiltration rate determined for humid areas should provide a bounding assumption because many sites are located in areas of lower annual rainfall. Also, selection of 0.3 as the porosity of the soil was intended to provide a bounding analysis. However, these parameters should be readily available and site-specific modifications to this generic model should be possible.

TABLE B.4. Ground Water Partition Coefficient Information

<u>Element</u>	<u>Ground Water Partition Coefficient(a)</u>	<u>Element</u>	<u>Ground Water Partition Coefficient(a)</u>
H	1.15	Sb	1.62E-4
Be	0.1	Te	0.1
C	1.15E-1	I	1.15E-1
N	0.1	Cs	1.62E-4
F	1.15E-1	Ba	1.11E-4
Na	1.61E-4	La	1.11E-4
P	1.26E-3	Ce	4.67E-4
S	1.20E-2	Pr	0.1
Cl	1.15E-1	Nd	0.1
K	1.62E-4	Pm	0.1
Ca	9.86E-3	Sm	0.1
Sc	1.11E-4	Eu	1.11E-4
Cr	1.26E-3	Gd	0.1
Mn	1.26E-3	Tb	0.1
Fe	1.48E-2	Ho	0.1
Co	1.48E-2	W	0.1
Ni	1.48E-2	Re	0.1
Cu	0.1	Os	0.1
Zn	1.48E-2	Ir	0.1
As	0.1	Hg	0.1
Se	1.20E-2	Pb	4.11E-3
Br	1.15E-1	Bi	0.1
Rb	1.62E-4	Po	4.11E-3
Sr	9.86E-3	Fr	0.1
Y	0.1	Ra	4.11E-3
Zr	9.86E-3	Ac	4.11E-3
Nb	1.11E-2	Th	4.11E-3
Mo	1.15E-1	Pa	4.11E-3
Tc	1.15E-1	U	1.24E-4
Ru	1.15E-1	Np	4.67E-4
Rh	0.1	Pu	4.67E-4
Pd	0.1	Am	4.11E-3
Ag	1.62E-4	Cm	4.67E-4
Cd	1.48E-2	Cf	4.11E-3
In	0.1		
Sn	1.62E-4		

(a) Based on information in the data base supporting 10 CFR 61 (Oztunali et al. 1981).

As stated before, this method does not include any correction for retardation; that is, materials are assumed to move with water. For short-lived radionuclides, this method is conservative because retardation would provide a hold-up period of several years to several decades during ground-water transport. For longer lived radionuclides, this method may also be quite conservative because the expected ground-water plume for long-lived materials may be spread out over a long period of time, at a lower concentration. Alternative parameter values could be obtained for the partition coefficients based on alternative referenced data. Although the data selected for the partition coefficient are from a reference concerning low-level radioactive waste disposal, the values used in this study are felt to be generic, conservative, and adequate for the level of analysis considered in this document. As described in Section 3.0, these ground-water equations are used to estimate drinking water concentrations resulting from residual radioactive material inventories in surface soils. These drinking water concentrations allow for the calculation of annual TEDE factors through a drinking water scenario. Again, the results of the analysis are intended to provide an indication of when additional site data or modeling sophistication are warranted.

Modifications can be made to the derived annual TEDE factors to account for modified assumptions concerning the quantity of drinking water ingested and the concentrations of radionuclides in the water supply. To obtain modified annual TEDE factors, simply multiply the TEDE factor in Table 3.4 by the modified parameter value and divide by the previously assumed parameter value.

B.6 INTERNAL PATHWAY PARAMETERS USED IN THE GENII COMPUTER PROGRAM

Additional parameter values have been used in the calculation of pathway dose conversion factors using the GENII computer program. Listings of the major parameters, the values assumed, and notes concerning the reference used for the values are found in Table B.5. Table B.5 provides information for each of the major pathways of exposure and identifies the parameter name used by the GENII program. Additional details about the input for the GENII program, with computer-readable files for the generation of the pathway dose conversion factors and the annual TEDE factors, are found in Appendix D.

TABLE B.5. Parameter Values Used by the GENII Computer Program for Calculation of Internal Dose Conversion Factors

Pathway/ GENII Parameter Name	Value	Definition/Notes
<u>Inhalation Pathway</u>		
INHCON	1 pCi/m ³	Air concentration for inhalation.
RINH	270 cm ³ /sec	Inhalation rate (ICRP 1975; Napier et al. 1988).
HRINH	1 hr/yr	Inhalation exposure duration.
<u>Secondary Ingestion Pathway</u>		
DWCON	1 pCi/L	Unit concentration as a basis.
DWUSAG	1 L/yr	Unit consumption rate as a basis.
<u>Ingestion Pathway - Air Contribution</u>		
ARFCON	1 pCi/m ³	Air concentration for plant uptake.
DPVL	8.0E-4 m/sec(a)	Deposition velocity from Oztunali et al. (1981).(a)
DEPFR1		Air interception fraction based on standing biomass and dry/wet weight of food type as discussed in Section 4.7.4, Vol. 1 of Napier et al. (1988). Values used for standing biomass and dry-to-wet ratios were taken from Table 4.25, Vol. 1 of Napier et al. (1988).
WTIM	14 d	Weathering half-time (Oztunali et al. 1981, Napier et al. 1988).

(a) Exceptions: For iodine a value of 1.0E-2 m/sec and for noble gases a value of 0.0 m/sec were used.

TABLE B.5. Parameter Values Used by the GENII Computer Program for Calculation of Internal Dose Conversion Factors (contd)

Pathway/ GENII Parameter Name	Value	Definition/Notes
<u>Ingestion Pathway - Soil Contribution</u>		
SOLCON	1 pCi/g	Soil concentration for plant uptake.
BVI	(a)	Soil-to-plant transfer factor by radionuclide and plant type. Values from Oztunali et al. (1981) were used when available. Additional values from NRC (1977) and Napier et al. (1988) were used, when necessary.
<u>Ingestion Pathway - Both Air and Soil</u>		
GRWP	60 d(b)	Growing period for plants (NRC 1977).
YELD	2 kg/m ² (c)	Average crop yield (NRC 1977).
CONSUM	50 kg/d	Animal consumption rate of feed and forage (Oztunali et al. 1981; NRC 1977).
FMI	(d)	Transfer coefficient that relates daily intake rate by an animal to the concentration in an edible animal product. Values from Oztunali et al. (1981) were used when available. Additional values from NRC (1977) and Napier et al. (1988) were used, when necessary.

- (a) Dry plant/dry soil. Values in NRC (1977) and Oztunali et al. (1981) converted to dry plant weight using dry-to-wet ratios from Table 4.25, Vol. 1 of Napier et al. (1988), by radionuclide. See Table D.5 in Appendix D.
- (b) With the exception of 30 d for fresh forage eaten by milk cow.
- (c) With exception of fresh forage where a value of 0.7 kg/m² was indicated.
- (d) Concentrations in pCi/kg in meat or milk per pCi/d ingested by animal. Radionuclide-specific. See columns 6 (beef) and 8 (milk cow) of Table D.5 in Appendix D.

TABLE B.5. Parameter Values Used by the GENII Computer Program for Calculation of Internal Dose Conversion Factors (contd)

Pathway/ GENII Parameter Name	Value	Definition/Notes
DIETFR	100% stored (beef) 100 % fresh (cows)	Animal diet fraction for feed and fresh forage. Beef cattle are assumed to eat stored feed exclusively and milk cows are assumed to eat fresh forage exclusively based on an implicit assumption in NRC (1977)
STORTM		Storage time between harvest of animal feed and animal consumption (NRC 1977):
	90 d	Beef
	0 d	Milk
HOLDUP		Holdup time between harvest or slaughter and human consumption of food (NRC 1977):
	1 d	Leafy vegetables
	14 d	Other vegetables, fruit, grain
	20 d	Beef
	2 d	Milk
CONS		Human consumption rate of food (NRC 1977, Oztunali et al. 1981):
	9.8 kg/yr	Leafy vegetables
	91 kg/yr	Other vegetables
	42 kg/yr	Fruit
	47 kg/yr	Grains and cereal
		Values based on a total of 190 kg/yr in NRC (1977) and Oztunali et al. (1981), pro-rated by food type based of food type distribution for the average individual in Napier et al. (1988).
CONSA		Human consumption of animal products (NRC 1977; Oztunali et al. 1981):
	95 kg/yr	Beef
	110 L/yr	Milk

APPENDIX C

EXAMPLE DOSE CALCULATIONS FOR REFERENCE BUILDINGS AND LAND

APPENDIX C

EXAMPLE DOSE CALCULATIONS FOR REFERENCE BUILDINGS AND LAND

This appendix contains additional example calculations performed to estimate the potential annual TEDE from mixtures of radionuclides associated with reference facilities after decommissioning. This appendix is an extension to the discussion on example calculations presented in Section 4.0. The calculations are performed for illustrative purposes using the unit concentration annual TEDE factors from Section 3.0 of this report and reference radionuclide mixtures for example facilities obtained from literature sources. The reference mixtures represent the types of radionuclides and relative activity levels that potentially may be found at uranium facilities, light-water power reactors, and radiopharmaceutical/industrial-source manufacturing plants. The mixtures and assumed levels are not intended to represent the exact mixtures or levels found at any existing facility. The example calculations consider both residual radioactive contamination in buildings and on land. The results are presented in terms of the calculated annual TEDE for exposure during building renovation and routine occupancy, and during residential use of surface soil and drinking water from ground-water sources.

C.1 REFERENCE RADIONUCLIDE MIXTURES

As an illustration of the use of the unit concentration annual TEDE factors, reference radionuclide mixtures are defined that are representative of those expected to be found at a uranium facilities (Elder and Blahník 1980; 10 CFR 20, App. B), light-water power reactor stations (Smith, Konzek, and Kennedy 1978; Oak et al. 1980), and a plant that manufactures a variety of radiopharmaceutical/industrial sources (Kennedy et al. 1981). These mixtures and the descriptions of the reference facilities are discussed in detail in the referenced documents. Each of the mixtures is provided in terms of the relative activity (normalized to unity for the total mixture), by radionuclide, in the mixture without consideration of the total quantity present. For the example mixture calculations, assumed concentrations of 100 pCi/g for volume sources (building material and soils) and 10,000 dpm/100 cm² for surface source levels are assumed. It is doubtful that any real facility would actually have radionuclide mixtures consisting of the exact relative activities or assumed concentrations of the radionuclides shown in the reference mixtures. They are intended to serve only as a generic basis for the example calculations.

The mixture of radionuclides found 10 years after plant shutdown at a reference uranium fuel fabrication facility are listed in Table C.1 (Elder and Blahník 1980). The facility was assumed to operate for a plant life of 40 years allowing the buildup of a residual inventory of material within the facility and on the surrounding land. Because of the long half-lives of the uranium isotopes, and because the uranium has been chemically separated from its full decay chain, only the primary decay products through thorium have been included. Because of the long half-lives of most of the radionuclides shown, the relative activity of the radionuclides is fairly constant over time. Thus, the relative activity is shown only for a decay period of 10

years after plant shutdown. For this mixture, approximately 51% of the activity is from ^{234}U , 16% from each of ^{234}Th and ^{234}Pa , and 12% from ^{238}U .

Other types of uranium facilities may handle either depleted or enriched mixtures of uranium isotopes. Estimates of the activity by major radionuclide are obtained from the footnotes to 10 CFR 20, Appendix B. For depleted uranium, the total specific activity is defined as 3.6×10^{-7} Ci/g consisting of equal parts of ^{238}U and ^{234}U . For enriched uranium, the footnotes to Appendix B of 10 CFR 20 provide a formula for estimating specific activity:

$$\text{SA} = (0.4 + 0.38E + 0.0034E^2) \times 10^{-6}, \quad E \geq 0.72 \quad (\text{C.1})$$

where SA = the specific activity of the uranium mixture (Ci/g of uranium activity per gram of uranium, and

E = the percentage, by weight, of ^{235}U .

Mixtures of radionuclides for depleted and enriched uranium that may be encountered at various facilities are shown in Table C.2.

For the reference light-water reactor, information from both a pressurized-water reactor (Smith, Konzek, and Kennedy 1978) and a boiling-water reactor (Oak et al. 1980) was reviewed. The mixture of radionuclides is anticipated to vary as a function of the operating history of the reactor, the plant design, the location within the facility, and the success of decontamination operations. In addition to the surface contamination mixture discussed in Section 4.1, a mixture representing neutron-activated concrete is shown in Table C.3. The mixture of radionuclides for activated concrete will vary depending on the nature of the concrete and its neutron-activation history; the mixture shown is felt to be an adequate basis for the example dose calculations that follow. Table C.3 shows the variation in the relative activity of the mixture at 10 years and 30 years after plant shutdown; however, for purposes of the example calculations that follow, only the mixture after 30 years of decay is used. For this mixture, about 89% of the relative activity is from ^{63}Ni , and about 8.5% is from ^{60}Co . For periods of less decay (i.e., closer to plant shutdown), the mixture is dominated by ^{60}Co instead of the longer lived ^{63}Ni , and the activity level is much greater. For purposes of this example, only the mixture after 30 years of decay is used because it is representative of the potential safe storage period before dismantlement occurs. The 30-year decay period is intended to allow overall dose rates and inventories of short-lived activation products to decay so that occupational doses during dismantlement will be optimized.

There are a large number of radionuclides that are used to make radiopharmaceuticals or as industrial sources. For this study, we have assumed that the representative mixture shown in Table C.4 is handled at a facility that supplies both radiopharmaceuticals and industrial sources. The relative contamination level of each radionuclide in the mixture is assumed at plant shutdown with a fractional activity of either 0.1 or 0.05. The effect of radioactive decay on this mixture is shown for a 5-year decay

TABLE C.1. Estimated Relative Activity of Radionuclides
at a Reference Uranium Fuel Fabrication
Facility 10 Years After Shutdown(a)

<u>Radionuclide</u>	<u>Half-Life (yr)</u>	<u>Relative Activity</u>
²³⁰ Th	7.7E+04	1.6E-04
²³⁴ U	2.4E+05	5.1E-01
²³⁵ U	7.0E+08	2.3E-02
²³¹ Th	2.9E-03	2.3E-02
²³¹ Pa	3.3E+04	1.5E-05
²³⁸ U	4.5E+09	1.2E-01
²³⁴ Th+I	6.6E-02	2.3E-01
²³⁴ Pa	7.6E-04	1.2E-04
Total		<u>1.0</u>

(a) Based on information in Table 7.1-1 of Elder and Blahnik (1980) and Table 4.1 of Witherspoon (1982).

TABLE C.2. Estimated Relative Activity of Radionuclides
in Depleted and Enriched Uranium Mixtures(a)

<u>Radionuclide</u>	<u>Half-Life (yr)</u>	<u>Relative Activity</u>
<u>Depleted</u>		
²³⁴ U	2.4E+05	8.4E-02
²³⁵ U	7.0E+08	1.5E-02
²³⁸ U	4.5E+09	9.0E-01
Total		<u>1.0</u>
<u>Enriched (4%)</u>		
²³⁴ U	6.6E-02	7.7E-01
²³⁵ U	7.0E+08	2.8E-02
²³⁸ U	4.5E+09	2.0E-01
Total		<u>1.0</u>

(a) Based on information in the footnotes to Appendix B of 10 CFR 20 using the activities of the uranium isotopes only.

TABLE C.3. Estimated Relative Activity of Radionuclides in Neutron-Activated Concrete at the Reference Power Reactor(a)

Radionuclide	Half-Life (yr)	Relative Activity	
		10 Years After Shutdown	30 Years After Shutdown
³ H	1.2E+01	4.6E-06	4.4E-06
¹⁴ C	5.7E+03	4.3E-04	1.3E-03
³⁶ Cl	3.1E+05	3.9E-06	1.2E-05
⁴⁰ K	1.3E+09	1.2E-04	3.6E-04
⁴¹ Ca	8.0E+04	2.6E-03	7.8E-03
⁵⁵ Fe	2.7E+00	2.7E-01	4.1E-03
⁶⁰ Co	5.3E+00	3.8E-01	8.5E-02
⁵⁹ Ni	8.0E+04	2.7E-03	8.1E-03
⁶³ Ni	1.0E+02	3.4E-01	8.9E-01
^{93m} Nb	1.4E+01	6.5E-06	2.0E-05
⁹³ Mo	3.5E+03	1.3E-06	4.1E-06
⁹⁹ Tc	2.1E+05	1.5E-07	4.4E-07
¹⁵¹ Sm	9.0E+01	8.4E-08	2.2E-07
¹⁵² Eu	1.4E+01	1.5E-03	5.5E-04
¹⁵⁴ Eu	8.8E+00	1.4E-04	1.1E-05
^{166m} Ho	1.2E+03	3.3E-06	1.0E-04
Total		1.0	1.0

(a) Based on information in Smith, Konzek, and Kennedy (1978) and Oak et al. (1980).

TABLE C.4. Estimated Relative Activity of Radionuclides at the Reference Radiopharmaceutical/Industrial-Source Facility^(a)

Radionuclide	Half-Life (yr)	Relative Activity	
		At Shutdown	5 Years After Shutdown
³ H	1.2E+01	1.0E-01	1.4E-01
¹⁴ C	5.7E+03	5.0E-02	9.6E-02
²² Na	2.6E+00	1.0E-01	5.2E-02
⁵⁹ Fe	1.2E-01	5.0E-02	-(b)
⁵⁷ Co	7.4E-01	5.0E-02	9.2E-04
⁶⁰ Co	5.3E+00	1.0E-01	1.0E-01
^{99m} Tc	6.9E-04	5.0E-02	-
¹²⁵ I	1.6E-01	5.0E-02	-
¹³¹ I	2.2E-02	5.0E-02	-
¹³⁴ Cs	2.1E+02	5.0E-02	1.8E-02
¹³⁷ Cs+I (c)	3.0E+01	1.0E-01	1.7E-01
¹⁹² Ir	2.0E-01	5.0E-02	-
²¹⁰ Pb	2.2E+01	5.0E-02	1.9E-01
²¹⁰ Po	3.8E-01	5.0E-02	1.1E-01
²²⁶ Ra	1.6E+03	1.0E-01	1.1E-01
Total		1.0	1.0

(a) Based on information in Kennedy et al. (1981).

(b) A dash indicates a value less than 10⁻⁸.

(c) Where +I means "plus implicit daughters in equilibrium" as discussed in Appendix D

period after shutdown. Because many of the radionuclides commonly used as radiopharmaceuticals or as industrial sources have short half-lives, five of the radionuclides included at plant shutdown have decayed to trivial levels. Only, ^3H , ^{60}Co , ^{210}Pb , ^{210}Po , and ^{226}Ra have activity levels greater or equal to 10% of the total for the mixture. For the example problems that follow, only the mixture after 5 years of decay is considered.

C.2 EXAMPLE DOSE CALCULATIONS FOR THE BUILDING RENOVATION SCENARIO

Example calculations are next performed for the reference mixtures and assumed levels of radionuclides discussed in the previous section for the building renovation (volume activity) scenario. The results are presented in Tables C.5 through C.8 as the estimated rate by exposure pathway and the annual TEDE to an individual (in mrem and μSv of exposure). The initial contamination level was assumed to be 100 pCi/g for each mixture. As shown in these tables, the estimated dose varies depending on the mixture.

Because of the long half-lives of the uranium decay chain, the example calculations for the uranium fuel fabrication facility are performed for only one decay period--10 years after plant shutdown. The reference mixture of radionuclides is shown in Table C.1. The resulting estimated annual TEDE for the building renovation scenario for the uranium fuel fabrication facility are shown in Table C.5. The annual TEDE is 0.46 mrem ($4.6 \mu\text{Sv}$). The dominant contributor to the dose is ^{234}U through the inhalation pathway.

For the depleted and enriched uranium mixtures shown in Table C.2, the resulting estimated annual TEDEs for the building renovation scenario are shown in Table C.6. The annual TEDE from depleted uranium is 0.62 mrem ($6.2 \mu\text{Sv}$). The dominant exposure pathway for depleted uranium is inhalation and the dominant radionuclide is ^{238}U . The annual TEDE from enriched uranium is 0.66 mrem ($6.6 \mu\text{Sv}$). The dominant exposure pathway is inhalation and the dominant radionuclide in the mixture is ^{234}U .

For the neutron-activated concrete mixture at the light-water power reactor, the calculations were performed for the mixture decayed to 30 years after plant shutdown. The reference mixture of radionuclides is shown in Table C.3 and the resulting annual TEDEs are shown in Table C.7. The estimated annual TEDE for this mixture is 0.71 mrem ($7.1 \mu\text{Sv}$), dominated by ^{60}Co and the external exposure pathway.

Example annual TEDEs for the radiopharmaceutical/industrial source mixture with 5 years of radioactive decay, shown in Table C.4, for the building renovation scenario are shown in Table C.8. The estimated annual TEDE for this mixture and exposure scenario is 2.3 mrem ($23 \mu\text{Sv}$). The dominant radionuclide contributors to the dose in the mixture are ^{60}Co , ^{137}Cs , and ^{22}Na . The dominant exposure pathway is external exposure.

C.3 EXAMPLE DOSE CALCULATIONS FOR THE BUILDING OCCUPANCY SCENARIO

Example calculations are next performed that consider the reference mixtures and assumed levels of radionuclides discussed in the previous section for the building occupancy (surface activity) scenario. The results

are presented in Tables C.9 through C.12 in terms of the estimated dose by exposure pathway and the annual TEDE to an individual (in mrem and μSv). The initial contamination level for this scenario was assumed to be 10000 dpm/100 cm^2 (167 Bq/100 cm^2) for each mixture. As shown in these tables, the estimated dose varies depending on the mixture and exposure pathway.

The example calculations for the uranium fuel fabrication facility were performed for the mixture shown in Table C.1 with 10 years of decay after plant shutdown. The resulting estimated annual TEDE for the building occupancy scenario for the uranium fuel fabrication facility are shown in Table C.9. The annual TEDE from surface sources is 34 mrem (340 μSv). The dominant contributor to the dose is ^{234}U through the inhalation pathway.

For the depleted and enriched uranium mixtures shown in Table C.2, the resulting estimated annual TEDEs for the building occupancy scenario are shown in Table C.10. The annual TEDE from depleted uranium is 25 mrem (250 μSv). Inhalation is the dominant pathway and ^{238}U is the dominant radionuclide contributor to dose. For enriched uranium, the annual TEDE is 27 mrem (270 μSv). The dominant contributor to dose is ^{234}U through the inhalation pathway.

For the neutron-activated concrete mixture at the light-water power reactor, the calculations were performed for the mixture decayed to 30 years after plant shutdown. The results are shown in Table C.11. The estimated annual TEDE for this mixture and scenario is 0.74 mrem (7.4 μSv), dominated by ^{60}Co and the external exposure pathway.

Example annual TEDEs for the radiopharmaceutical/industrial-source mixture with 5 years of radioactive decay for the building surface activity scenario are shown in Table C.12. The estimated annual TEDE for this mixture and exposure scenario is 29 mrem/yr (290 $\mu\text{Sv/yr}$). The dominant radionuclide contributors to the dose in the mixture are ^{210}Pb , ^{210}Po , and ^{226}Ra . The dominant exposure pathway is secondary ingestion.

TABLE C.5. Estimated Annual Total Effective Dose Equivalents for the Building Renovation (Volume Activity) Scenario Using the Uranium Fuel Fabrication Facility Inventory 10 Years After Shutdown(a)

Radio-nuclide(b)	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
^{238}Th	1.8E-07	2.2E-04	7.0E-04	9.3E-04	9.3E-03
^{231}Th	6.2E-04	9.4E-08	1.5E-05	6.4E-04	6.4E-03
$^{234}\text{Th}+\text{I}(\text{c})$	1.7E-02	3.9E-05	1.5E-03	1.9E-03	1.9E-01
^{234}Pa	7.9E-04	4.9E-10	1.3E-07	7.9E-04	7.9E-03
^{234}U	4.2E-04	3.3E-01	6.6E-03	3.4E-01	3.4E+00
^{235}U	7.4E-03	1.4E-02	3.0E-04	2.1E-02	2.1E-01
^{238}U	9.4E-04	7.2E-02	1.6E-03	7.4E-02	7.4E-01
Total	<u>2.7E-02</u>	<u>4.2E-01</u>	<u>1.1E-02</u>	<u>4.6E-01</u>	<u>4.6E+00</u>

- (a) Using the radionuclide mixture shown in Table C.1 with 10 years of radioactive decay and the annual TEDE factors from Table 3.1.
(b) With an assumed contamination level of 100 pCi/g (3.7 Bq/g) of the radionuclide mixture.
(c) Where +I means "plus implicit daughters in equilibrium" as discussed in Appendix D.

TABLE C.6. Estimated Annual Total Effective Dose Equivalents for the Building Renovation (Volume Activity) Scenario Using the Depleted and Enriched Uranium Mixture(a)

Radio-nuclide(b)	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
<u>Depleted</u>					
^{234}U	6.9E-05	5.5E-02	1.1E-03	5.5E-02	5.5E-01
^{235}U	4.8E-03	9.0E-03	2.0E-04	1.4E-02	1.4E-01
^{238}U	7.2E-03	5.4E-01	1.2E-02	5.6E-01	5.6E+00
Total	<u>1.2E-02</u>	<u>6.0E-01</u>	<u>1.3E-02</u>	<u>6.2E-01</u>	<u>6.2E+00</u>
<u>Enriched (4%)</u>					
^{234}U	6.6E-04	5.0E-01	1.0E-02	5.1E-01	5.1E+00
^{235}U	9.0E-03	1.7E-02	3.6E-04	2.6E-02	2.6E-01
^{238}U	4.1E-05	1.2E-01	2.6E-03	1.2E-01	1.2E+00
Total	<u>9.7E-03</u>	<u>6.4E-01</u>	<u>1.3E-02</u>	<u>6.6E-01</u>	<u>6.6E+00</u>

- (a) Using the uranium isotope mixture shown in Table C.2 and the annual TEDE factors from Table 3.1.
(b) With an assumed contamination level of 100 pCi/g (3.7 Bq/g) of the radionuclide mixture.

TABLE C.7. Estimated Annual Total Effective Dose Equivalents for the Building Renovation (Volume Activity) Scenario Using the Neutron-Activated Power Reactor Concrete Inventory 30 Years After Shutdown(a)

Radio-nuclide(b)	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
^3H	2.2E-15	1.8E-12	1.2E-10	1.3E-10	1.3E-09
^{14}C	2.7E-08	1.2E-08	1.2E-06	1.3E-06	1.3E-06
^{36}Cl	1.6E-08	1.1E-10	1.7E-08	3.2E-08	3.2E-07
^{40}K	1.9E-04	1.8E-08	3.1E-06	2.0E-04	2.0E-03
^{41}Ca	5.4E-06	4.7E-08	4.7E-06	1.0E-05	1.0E-04
^{55}Fe	6.6E-06	2.5E-08	1.2E-06	7.8E-06	7.8E-05
^{60}Co	7.1E-01	8.1E-05	4.2E-04	7.1E-01	7.1E+00
^{59}Ni	1.5E-05	3.2E-08	7.7E-07	1.6E-05	1.6E-04
^{63}Ni	8.8E-07	8.5E-06	2.2E-04	2.4E-04	2.4E-03
$^{93\text{m}}\text{Nb}$	1.5E-08	3.0E-09	5.0E-09	2.4E-08	2.4E-07
^{93}Mo	1.5E-08	1.9E-11	2.9E-09	1.8E-08	1.8E-07
^{99}Tc	4.8E-11	1.9E-11	6.6E-10	7.5E-10	7.5E-09
^{151}Sm	2.6E-12	3.3E-11	4.2E-11	7.7E-11	7.7E-10
^{152}Eu	2.2E-03	5.5E-07	1.7E-06	2.2E-03	2.2E-02
^{154}Eu	4.5E-05	1.4E-08	5.1E-08	4.5E-05	4.5E-04
$^{166\text{m}}\text{Ho}$	5.1E-04	3.6E-07	3.8E-07	5.1E-04	5.1E-03
Total	7.1E-01	9.1E-05	6.5E-04	7.1E-01	7.1E+00

- (a) Using the radionuclide mixture shown in Table C.3 with 30 years of radioactive decay and the annual TEDE factors from Table 3.1.
(b) With an assumed contamination level of 100 pCi/g (3.7 Bq/g) of the radionuclide mixture.

TABLE C.8. Estimated Annual Total Effective Dose Equivalents for the Building Renovation (Volume Activity) Scenario Using the Reference Radiopharmaceutical/Industrial-Source Inventory 5 Years After Shutdown(a)

Radio-nuclide(b)	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
³ H	7.1E-11	5.7E-08	3.9E-06	4.0E-06	4.0E-05
¹⁴ C	2.0E-06	9.1E-07	9.1E-05	9.4E-05	9.4E-04
²² Na	3.6E-01	2.2E-06	3.6E-04	3.4E-01	3.4E+00
⁵⁷ Co	3.1E-04	3.8E-08	3.5E-07	3.1E-04	3.1E-03
⁶⁰ Co	8.3E-01	9.5E-05	5.0E-04	8.3E-01	8.3E+00
¹³⁴ Cs	1.0E-01	3.6E-06	5.9E-04	1.0E-01	1.0E+00
¹³⁷ Cs+I(c)	3.2E-01	1.1E-05	2.0E-03	3.2E-01	3.2E+00
²¹⁰ Pb	6.8E-04	1.2E-02	5.1E-01	5.3E-01	5.3E+00
²¹⁰ Po	3.3E-06	4.6E-03	1.0E-01	1.1E-01	1.1E+00
²²⁶ Ra	1.3E-03	4.4E-03	5.2E-02	5.8E-02	5.8E-01
Total	1.6E+00	2.1E-02	6.6E-01	2.3E+00	2.3E+01

- (a) Using the radionuclide mixture shown in Table C.4 with 5 years of radioactive decay and the annual TEDE factors from Table 3.1.
- (b) With an assumed contamination level of 100 pCi/g (3.7 Bq/g) of the radionuclide mixture.
- (c) Where +I means "plus implicit daughters in equilibrium" as discussed in Appendix D.

TABLE C.9. Estimated Annual Total Effective Dose Equivalents for the Building Occupancy (Surface Activity) Scenario Using the Uranium Fuel Fabrication Facility Inventory 10 Years After Shutdown^(a)

Radio-nuclide ^(b)	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
²³⁰ Th	8.6E-07	9.0E-03	2.9E-02	3.7E-02	3.7E-01
²³¹ Th	2.0E-03	3.7E-06	6.0E-04	2.5E-03	2.5E-02
²³⁴ Th+I ^(c)	2.2E-02	1.6E-03	6.0E-02	8.3E-02	8.3E-01
²³⁴ Pa	8.3E-04	1.9E-08	5.3E-06	8.4E-04	8.4E-03
²³⁴ U	6.5E-03	2.9E+01	5.7E-01	3.0E+01	3.0E+02
²³⁵ U	9.7E-03	5.5E-01	1.2E-02	5.8E-01	5.8E+00
²³⁸ U	1.8E-03	2.9E+00	6.0E-02	3.0E+00	3.0E+01
Total	<u>4.3E-02</u>	<u>3.2E+01</u>	<u>7.3E-01</u>	<u>3.4E+01</u>	<u>3.4E+02</u>

(a) Using the radionuclide mixture shown in Table C.1 with 10 years of radioactive decay and the annual TEDE factors from Table 3.2.

(b) With an assumed contamination level of 10,000 dpm/cm² (167 Bq/100 cm²) of the radionuclide mixture.

(c) Where +I means "plus implicit daughters in equilibrium" as discussed in Appendix D.

TABLE C.10. Estimated Annual Total Effective Dose Equivalents for the Building Occupancy (Surface Activity) Scenario Using the Depleted and Enriched Uranium Mixture^(a)

Radio-nuclide ^(b)	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
<u>Depleted</u>					
²³⁴ U	5.0E-04	2.2E+00	4.4E-02	2.3E+00	2.2E+01
²³⁵ U	6.3E-03	3.6E-01	7.8E-03	3.8E-01	3.8E+00
²³⁸ U	1.4E-02	2.2E+01	4.5E-01	2.2E+01	2.2E+02
Total	<u>1.8E-02</u>	<u>2.5E+01</u>	<u>5.0E-01</u>	<u>2.5E+01</u>	<u>2.5E+02</u>
<u>Enriched (4%)</u>					
²³⁴ U	4.5E-03	2.0E+01	4.0E-01	2.1E+01	2.1E+02
²³⁵ U	1.2E-02	6.7E-01	1.5E-02	7.0E-01	7.0E+00
²³⁸ U	3.0E-03	4.8E+00	1.0E-01	5.0E+00	5.0E+01
Total	<u>2.0E-03</u>	<u>2.6E+01</u>	<u>5.2E-01</u>	<u>2.7E+01</u>	<u>2.7E+02</u>

(a) Using the uranium isotope mixture shown in Table C.2 and the annual TEDE factors from Table 3.2.

(b) With an assumed contamination level of 10,000 dpm/cm² (167 Bq/100 cm²) of the radionuclide mixture.

TABLE C.11. Estimated Annual Total Effective Dose Equivalents for the Building Occupancy (Surface Activity) Scenario Using the Neutron-Activated Power Reactor Concrete Inventory 30 Years After Shutdown(a)

Radio-nuclide(b)	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
³ H	2.1E-14	7.0E-11	4.8E-09	4.8E-09	4.8E-08
¹⁴ C	1.3E-07	4.9E-07	4.9E-05	4.9E-05	4.9E-04
³⁸ Cl	3.1E-08	4.3E-09	6.7E-07	7.1E-07	7.1E-06
⁴⁰ K	1.9E-04	7.2E-07	1.2E-04	3.2E-04	3.2E-03
⁴¹ Ca	5.1E-06	1.9E-06	1.9E-04	4.2E-04	4.2E-03
⁵⁵ Fe	6.2E-05	9.8E-07	4.9E-05	1.1E-04	1.1E-03
⁶⁰ Co	7.1E-01	3.2E-03	1.7E-02	7.3E-01	7.3E+00
⁵⁹ Ni	1.5E-04	1.3E-06	3.1E-05	1.8E-04	1.8E-03
⁶³ Ni	7.2E-06	3.4E-04	8.9E-03	9.8E-03	9.8E-02
^{93m} Nb	1.4E-07	1.2E-07	2.0E-07	4.6E-07	4.6E-06
⁹³ Mo	1.4E-07	7.8E-10	1.2E-07	2.6E-07	2.6E-06
⁹⁹ Tc	1.7E-10	7.9E-10	2.7E-08	2.8E-08	2.8E-07
¹⁵¹ Sm	2.4E-11	1.3E-09	1.7E-09	3.1E-09	3.1E-08
¹⁵² Eu	2.3E-03	2.2E-05	7.2E-05	2.4E-03	2.4E-02
¹⁵⁴ Eu	4.7E-05	5.7E-07	2.0E-06	4.9E-05	4.9E-04
^{166m} Ho	5.5E-04	1.4E-05	1.5E-05	5.8E-04	5.8E-03
Total	7.1E-01	3.6E-03	2.6E-02	7.4E-01	7.4E+00

- (a) Using the radionuclide mixture shown in Table C.3 with 30 years of radioactive decay and the annual TEDE factors from Table 3.2.
(b) With an assumed contamination level of 10,000 dpm/100 cm² (167 Bq/100 cm²) of the radionuclide mixture.

TABLE C.12 Estimated Annual Total Effective Dose Equivalents for the Building Occupancy (Surface Activity) Scenario Using the Reference Radiopharmaceutical/Industrial Source Inventory 5 Years After Shutdown(a)

Radio-nuclide(b)	External (mrem)	Inhalation (mrem)	Secondary Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
³ H	6.7E-10	2.2E-06	1.5E-04	1.5E-04	1.5E-03
¹⁴ C	9.6E-06	3.6E-05	3.6E-03	3.6E-03	3.6E-02
²² Na	3.7E-01	8.8E-05	1.5E-02	3.9E-01	3.9E+00
⁵⁷ Co	4.3E-04	1.6E-06	1.4E-05	4.5E-04	4.5E-03
⁶⁰ Co	8.4E-01	3.8E-03	2.0E-02	8.6E-01	8.6E+00
¹³⁴ Cs	1.1E-01	1.4E-04	2.3E-02	1.3E-01	1.3E+00
¹³⁷ Cs+I(c)	3.4E-01	4.6E-04	8.0E-02	4.2E-01	4.2E+00
²¹⁰ Pb	3.6E-03	4.9E-01	2.1E+01	2.1E+01	2.1E+02
²¹⁰ Po	3.4E-06	1.9E-01	4.2E+00	4.4E+00	4.4E+01
²²⁶ Ra	1.9E-03	1.8E-01	2.1E+00	2.3E+00	2.3E+01
Total	<u>1.7E+00</u>	<u>8.6E-01</u>	<u>2.7E+01</u>	<u>2.9E+01</u>	<u>2.9E+02</u>

- (a) Using the radionuclide mixture shown in Table C.4 with 5 years of radioactive decay and the annual TEDE factors from Table 3.2.
- (b) With an assumed contamination level of 10,000 dpm/100 cm² (167 Bq/100 cm²) of the radionuclide mixture.
- (c) Where +I means "plus implicit daughters in equilibrium" as discussed in Appendix D.

C.4 EXAMPLE DOSE CALCULATIONS FOR THE RESIDENTIAL USE (SURFACE SOIL) SCENARIO

Example calculations that consider the reference mixtures and assumed levels of radionuclides discussed in Section C.1 for the residential use (surface soil) activity scenario follow. The results are presented in Tables C.13 through C.16 in terms of the estimated dose by exposure pathway and the annual TEDE to an individual (in mrem and μSv). The initial contamination level for this scenario was assumed to be 100 pCi/g in soil for each mixture.

The example calculations for the uranium fuel fabrication facility are performed for the inventory shown in Table C.1 for 10 years after plant shutdown. The resulting estimated annual TEDEs for the surface soil activity scenario for the uranium fuel fabrication facility are shown in Table C.13. The annual TEDE from 1 year of residential use of surface soil is 6.1 mrem (61 μSv). The dominant contributor to the dose is ^{234}U through the inhalation pathway.

For the depleted and enriched uranium mixtures shown in Table C.2, the resulting estimated annual TEDEs for the residential use scenario are shown in Table C.14. The annual TEDE from depleted uranium is 6.4 mrem (64 μSv). The dominant exposure pathway for depleted uranium is inhalation and the dominant contributor to dose is ^{238}U . For enriched uranium, the annual TEDE is 6.7 mrem (67 μSv), dominated by inhalation of ^{234}U .

For the neutron-activated concrete mixture at the light-water power reactor, the calculations were performed for the mixture shown in Table C.2 decayed to 30 years after plant shutdown. The results are shown in Table C.15. The estimated annual TEDE for this mixture is 66 mrem (660 μSv), dominated by ^{60}Co and the external exposure pathway.

Example annual TEDEs for the radiopharmaceutical/industrial source mixture shown in Table C.3 with 5 years of radioactive decay for the surface soil activity scenario are shown in Table C.16. The estimated annual TEDE for this mixture and exposure scenario is 180 mrem (1800 μSv). The dominant radionuclide contributors to the dose in the mixture are ^{60}Co , $^{137}\text{Cs}+\text{I}$, and ^{22}Na . The dominant exposure pathway is external exposure.

TABLE C.13. Estimated Annual Total Effective Dose Equivalents for the Residential Use (Surface Soil) Scenario Using the Uranium Fuel Fabrication Facility Inventory 10 Years After Shutdown(a)

Radio-nuclide(b)	External (mrem)	Inhalation (mrem)	Food Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
²³⁰ Th	6.4E-06	1.9E-03	3.2E-02	3.4E-02	3.4E-01
²³¹ Th	3.2E-02	8.3E-07	5.8E-04	3.4E-02	3.4E-01
²³⁴ Th+I(c)	1.5E+00	3.4E-04	6.4E-02	1.5E+00	1.5E+01
²³⁴ Pa	7.4E-02	4.3E-09	1.1E-05	7.4E-02	7.4E-01
²³⁴ U	9.1E-03	2.9E+00	1.7E-01	3.1E+00	3.1E+01
²³⁵ U	5.3E-01	1.2E-01	7.6E-03	6.6E-01	6.6E+00
²³⁸ U	6.5E-02	6.4E-01	3.6E-02	7.3E-01	7.3E+00
Total	2.2E+00	3.7E+00	3.0E-01	6.1E+00	6.1E+01

- (a) Using the radionuclide mixture shown in Table C.1 with 10 years of radioactive decay and the annual TEDE factors from Table 3.3.
- (b) With an assumed contamination level of 100 pCi/g (3.7 Bq/g) of the radionuclide mixture.
- (c) Where +I means "plus implicit daughters in equilibrium" as discussed in Appendix D.

TABLE C.14. Estimated Annual Total Effective Dose Equivalents for Residential Use (Surface Soil) Scenario Using the Depleted and Enriched Uranium Mixture(a)

Radio-nuclide(b)	External (mrem)	Inhalation (mrem)	Food Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
<u>Depleted</u>					
²³⁴ U	1.5E-03	4.8E-01	2.8E-02	5.1E-01	5.1E+00
²³⁵ U	3.4E-01	8.0E-02	5.0E-03	4.4E-01	4.4E+00
²³⁸ U	4.9E-01	4.8E+00	2.7E-01	5.5E+00	5.5E+01
Total	8.3E-01	5.4E+00	3.0E-01	6.4E+00	6.4E+01
<u>Enriched (4%)</u>					
²³⁴ U	1.4E-02	4.4E+00	2.5E-01	4.7E+00	4.7E+01
²³⁵ U	6.4E-01	1.5E-01	9.2E-03	8.1E-01	8.1E+00
²³⁸ U	1.1E-01	1.1E+00	6.0E-02	1.2E+00	1.2E+01
Total	7.6E-01	5.6E+00	3.2E-01	6.7E+00	6.7E+01

- (a) Using the uranium isotope mixture shown in Table C.2 with 10 years of radioactive decay and the annual TEDE factors from Table 3.3.
- (b) With an assumed contamination level of 100 pCi/g (3.7 Bq/g) of the radionuclide mixture.

TABLE C.15. Estimated Annual Total Effective Dose Equivalents for the Residential Use (Surface Soil) Scenario Using the Neutron-Activated Power Reactor Concrete Inventory 30 Years After Shutdown(a)

Radio-nuclide(b)	External (mrem)	Inhalation (mrem)	Food Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
³ H	1.5E-14	1.5E-11	1.3E-11	2.9E-11	2.9E-10
¹⁴ C	9.5E-07	1.1E-07	1.2E-06	2.2E-06	2.2E-05
³⁶ Cl	1.0E-06	9.5E-10	3.4E-03	3.4E-03	3.4E-02
⁴⁰ K	1.8E-02	1.6E-07	2.9E-02	4.7E-02	4.7E-01
⁴¹ Ca	3.6E-05	4.1E-07	4.5E-03	4.5E-03	4.5E-02
⁵⁵ Fe	4.5E-05	2.2E-07	1.4E-05	5.7E-05	5.7E-04
⁶⁰ Co	6.6E+01	7.1E-04	5.1E-02	6.6E+01	6.6E+02
⁵⁹ Ni	1.0E-04	2.8E-07	3.9E-04	4.9E-04	4.9E-03
⁶³ Ni	1.7E-05	7.4E-05	1.2E-01	1.2E-01	1.2E+00
^{93m} Nb	1.0E-07	2.6E-08	3.6E-06	3.6E-06	3.6E-05
⁹³ Mo	1.0E-07	1.7E-10	4.1E-06	4.2E-06	4.2E-05
⁹⁹ Tc	2.2E-09	1.7E-10	1.3E-05	1.3E-05	1.3E-04
¹⁵¹ Sm	4.2E-11	2.9E-10	8.8E-10	1.2E-09	1.2E-08
¹⁵² Eu	2.0E-01	4.8E-06	4.6E-05	2.0E-01	2.0E+00
¹⁵⁴ Eu	4.2E-03	1.2E-07	1.3E-06	4.2E-03	4.2E-02
^{166m} Ho	4.8E-02	3.4E-06	1.1E-05	4.8E-02	4.8E-01
Total	6.6E+01	7.8E-04	2.1E-01	6.6E+01	6.6E+02

- (a) Using the radionuclide mixture shown in Table C.3 with 30 years of radioactive decay and the annual TEDE factors from Table 3.3.
(b) With an assumed contamination level of 100 pCi/g (3.7 Bq/g) of the radionuclide mixture.

TABLE C.16. Estimated Annual Total Effective Dose Equivalents for the Residential Use (Surface Soil) Scenario Using the Reference Radiopharmaceutical/Industrial-Source Inventory 5 Years After Shutdown(a)

Radio-nuclide(b)	External (mrem)	Inhalation (mrem)	Food Ingestion (mrem)	TEDE (mrem)	TEDE (μ Sv)
³ H	4.8E-10	5.0E-07	4.1E-07	9.1E-07	9.1E-06
¹⁴ C	7.0E-05	7.9E-06	8.6E-05	1.6E-04	1.6E-03
²² Na	3.6E+01	2.0E-05	7.3E-01	3.7E+01	3.7E+02
⁵⁷ Co	2.3E-02	3.3E-07	4.0E-05	2.3E-02	2.3E-01
⁶⁰ Co	7.7E+01	8.3E-04	6.0E-02	7.7E+01	7.7E+02
¹³⁴ Cs	9.5E+00	3.2E-05	9.0E-02	9.7E+00	9.7E+01
¹³⁷ Cs+I(c)	3.2E+01	1.0E-04	5.3E-02	3.2E+01	3.2E+02
²¹⁰ Pb	1.9E-02	1.1E-01	1.9E+01	1.9E+01	1.9E+02
²¹⁰ Po	2.9E-04	4.1E-02	1.6E+00	1.6E+00	1.6E+01
²²⁶ Ra	9.9E-02	3.9E-02	7.5E+00	7.6E+00	7.6E+01
Total	1.6E+02	1.9E-01	2.9E+01	1.8E+02	1.8E+03

- (a) Using the radionuclide mixture shown in Table C.4 with 5 years of radioactive decay and the annual TEDE factors from Table 3.3.
- (b) With an assumed contamination level of 100 pCi/g (3.7 Bq/g) of the radionuclide mixture.
- (c) Where +I means "plus implicit daughters in equilibrium" as discussed in Appendix D.

C.5 EXAMPLE DOSE CALCULATIONS FOR THE DRINKING WATER SCENARIO

Example calculations that consider the reference mixtures and assumed levels of radionuclides discussed in Section C.1 for the drinking water scenario follow. The results are presented in Tables C.17 through C.20 in terms of the estimated annual TEDE to an individual (in mrem and μSv) and the maximum organ dose. The initial contamination level for this scenario was assumed to be 100 pCi/g over a contaminated area of 1000 m² to a depth of 0.15 m (the plow layer used for the surface soil scenario). Assuming a soil density of 1.6 g/cm³, the total inventory for this example is 24 mCi (890 MBq). As shown in these tables, the estimated dose varies depending on the mixture.

The example calculations for the uranium fuel fabrication facility were performed for the radionuclide mixture shown in Table C.1 for 10 years of decay after plant shutdown. The resulting estimated annual TEDE for the drinking water scenario are shown in Table C.17. The annual TEDE from drinking water is 0.0064 mrem (0.064 μSv). The estimated maximum organ dose for this mixture is 0.061 mrem (0.61 μSv), and the critical organ is bone surface. The dominant radionuclide for the organ dose is ²³⁰Th.

For the depleted and enriched uranium mixtures shown in Table C.2, the estimated TEDEs are shown for the drinking water scenario in Table C.18. The estimated annual TEDE for depleted uranium is 0.0035 mrem (0.035 μSv). The critical organ dose is 0.026 mrem (0.26 μSv) and the critical organ is lower large intestine wall. The dominant contributor to dose is ²³⁸U. The estimated annual TEDE for enriched uranium is 0.0026 mrem (0.026 μSv). The critical organ dose is 0.02 mrem (0.2 μSv), and the critical organ is lower large intestine. The dominant radionuclide contributor to organ dose is ²³⁴U.

For the neutron-activated concrete mixture at the light-water power reactor, the calculations were performed for the mixture decayed to 30 years after plant shutdown. The results for the drinking water scenario are shown in Table C.19. The estimated annual TEDE for this mixture is 0.014 mrem (0.14 μSv), dominated by ⁶⁰Co and ⁶³Ni. The estimated maximum organ dose is 0.072 mrem (0.72 μSv), and the critical organ is lower large intestine wall. The dominant radionuclide contributor to organ dose is ⁶⁰Co.

Example annual TEDEs for the radiopharmaceutical/industrial-source mixture with 5 years of radioactive decay for the drinking water scenario are shown in Table C.20. The estimated annual TEDE for this mixture and exposure scenario is 3.8 mrem (38 μSv). The dominant radionuclide contributors to the dose in the mixture are ²¹⁰Pb and ²²⁶Ra. The estimated maximum organ dose is 54 mrem (540 μSv), and the critical organ is bone surface. The dominant contributor to organ dose is ²¹⁰Pb.

TABLE C.17. Estimated Annual Total Effective Dose Equivalents for the Drinking Water Scenario Using the Uranium Fuel Fabrication Facility Inventory 10 Years After Shutdown(a)

Radio-nuclide(b)	TEDE (mrem)	TEDE (μ Sv)	Maximum Organ Dose		
			(mrem)	(μ Sv)	Organ(c)
^{230}Th	4.6E-03	4.6E-02	6.1E-02	6.1E-01	Bone Surface
^{231}Th	3.4E-09	3.4E-08	3.4E-08	3.4E-07	LLI Wall
$^{234}\text{Th}+\text{I}(\text{d})$	1.7E-04	1.7E-03	2.2E-03	2.2E-02	LLI Wall
^{234}Pa	2.0E-12	2.0E-11	1.1E-11	1.1E-10	ULI Wall
^{234}U	1.2E-03	1.2E-02	9.3E-03	9.3E-02	LLI Wall
^{235}U	6.1E-05	6.1E-04	4.6E-04	4.6E-03	LLI Wall
^{238}U	4.3E-04	4.3E-03	3.2E-03	3.2E-02	LLI Wall
Total	<u>6.4E-03</u>	<u>6.4E-02</u>	<u>6.1E-02</u>	<u>6.1E-01</u>	<u>Bone Surface</u>

(a) Using the radionuclide mixture shown in Table C.1 with 10 years of radioactive decay and the annual TEDE factors from Table 3.4.

(b) Assuming a contaminated area of 1,000 m², to a depth of 15 cm, at a level of 100 pCi/g. Assuming a soil density of 1.6 g/cm³, the total inventory is 24 mCi (890 MBq).

(c) Where LLI is lower large intestine and ULI is upper large intestine.

(d) Where +I means "plus implicit daughters in equilibrium" as discussed in Appendix D.

TABLE C.18. Estimated Annual Total Effective Dose Equivalents for the Drinking Water Scenario Using the Depleted and Enriched Uranium Mixtures(a)

Radio-nuclide(b)	TEDE (mrem)	TEDE (μSv)	Maximum Organ Dose		
			(mrem)	(μSv)	Organ(c)
<u>Depleted</u>					
²³⁴ U	2.2E-04	2.2E-03	1.5E-03	1.5E-02	LLI Wall
²³⁵ U	4.0E-05	4.0E-04	3.0E-04	3.0E-03	LLI Wall
²³⁸ U	3.2E-03	3.2E-02	2.4E-02	2.4E-01	LLI Wall
Total	<u>3.5E-03</u>	<u>3.5E-02</u>	<u>2.6E-02</u>	<u>2.6E-01</u>	<u>LLI Wall</u>
<u>Enriched</u>					
²³⁴ U	1.8E-03	1.8E-02	1.4E-02	1.4E-01	LLI Wall
²³⁵ U	7.4E-05	7.4E-04	5.6E-04	5.6E-03	LLI Wall
²³⁸ U	7.2E-04	7.2E-03	5.3E-03	5.3E-02	LLI Wall
Total	<u>2.6E-03</u>	<u>2.6E-02</u>	<u>2.0E-02</u>	<u>2.0E-01</u>	<u>LLI Wall</u>

- (a) Using the uranium isotope mixture shown in Table C.2 and the annual TEDE factors from Table 3.4.
- (b) Assuming a contaminated area of 1,000 m², to a depth of 15 cm, at a level of 100 pCi/g. Assuming a soil density of 1.6 g/cm³, the total inventory is 24 mCi (890 MBq).
- (c) Where LLI is lower large intestine.

TABLE C.19. Estimated Annual Total Effective Dose Equivalents for the Drinking Water Scenario Using the Neutron-Activated Power Reactor Concrete Inventory 30 Years After Shutdown(a)

Radio-nuclide(b)	TEDE (mrem)	TEDE (μ Sv)	Maximum Organ Dose		
			(mrem)	(μ Sv)	Organ(c)
³ H	2.1E-07	2.1E-06	2.5E-07	2.5E-06	SI Wall
¹⁴ C	2.2E-04	2.2E-03	2.7E-04	2.7E-03	LLI Wall
³⁶ Cl	2.9E-06	2.9E-05	3.5E-06	3.5E-05	SI Wall
⁴⁰ K	7.1E-07	7.1E-06	8.4E-07	8.4E-06	SI Wall
⁴¹ Ca	7.1E-05	7.1E-04	9.0E-04	9.0E-03	Bone Surface
⁵⁵ Fe	2.3E-05	2.3E-04	8.4E-05	8.4E-04	Spleen
⁶⁰ Co	9.0E-03	9.0E-02	3.9E-02	3.9E-01	LLI Wall
⁵⁹ Ni	1.8E-05	1.8E-04	9.1E-05	9.1E-04	LLI Wall
⁶³ Ni	5.1E-03	5.1E-02	3.2E-02	3.2E-01	LLI Wall
^{93m} Nb	8.2E-08	8.2E-07	9.6E-07	9.6E-06	LLI Wall
⁹³ Mo	5.1E-07	5.1E-06	2.5E-06	2.5E-05	Liver
⁹⁹ Tc	1.3E-07	1.3E-06	1.1E-06	1.1E-05	Thyroid
¹⁵¹ Sm	6.3E-09	6.3E-08	6.3E-08	6.3E-07	LLI Wall
¹⁵² Eu	2.9E-07	2.9E-06	1.7E-06	1.7E-05	LLI Wall
¹⁵⁴ Eu	8.2E-09	8.2E-08	6.1E-08	6.1E-07	LLI Wall
^{166m} Ho	6.0E-05	6.0E-04	3.1E-04	3.1E-03	LLI Wall
Total	1.4E-02	1.4E-01	7.2E-02	7.2E-01	LLI Wall

- (a) Using the radionuclide mixture shown in Table C.3 with 30 years of radioactive decay and the annual TEDE factors from Table 3.4.
- (b) Assuming a contaminated area of 1000 m² to a depth of 1.5 cm, at a level of 100 pCi/g. Assuming a soil density of 1.6 g/cm³, the total inventory is 24 mCi (890 MBq).
- (c) Where SI is small intestine and LLI is lower large intestine.

TABLE C.20. Estimated Annual Total Effective Dose Equivalents for the Drinking Water Scenario Using the Reference Radiopharmaceutical/Industrial-Source Inventory 5 Years After Shutdown(a)

Radio-nuclide(b)	TEDE (mrem)	TEDE (μ Sv)	Maximum Organ Dose		
			(mrem)	(μ Sv)	Organ(c)
^3H	6.7E-03	6.7E-02	8.1E-03	8.1E-02	SI Wall
^{14}C	1.6E-02	1.6E-01	2.0E-02	2.0E-01	LLI Wall
^{22}Na	7.6E-05	7.6E-04	1.2E-04	1.2E-03	Bone Surface
^{57}Co	4.4E-06	4.4E-05	2.9E-05	2.9E-04	LLI Wall
^{60}Co	1.1E-02	1.1E-01	4.6E-02	4.6E-01	LLI Wall
^{134}Cs	1.2E-04	1.2E-03	1.6E-04	1.6E-03	SI Wall
$^{137}\text{Cs}+\text{I}(\text{d})$	4.9E-04	4.9E-03	6.1E-04	6.1E-03	SI Wall
^{210}Pb	3.2E+00	3.2E+01	4.6E+01	4.6E+02	Bone Surface
^{210}Po	2.0E-01	2.0E+00	1.7E+00	1.7E+01	Spleen
^{226}Ra	3.4E-01	3.4E+00	8.2E+00	8.2E+01	Bone Surface
Total	3.8E+00	3.8E+01	5.4E+01	5.4E+02	Bone Surface

- (a) Using the radionuclide mixture shown in Table C.4 with 5 years of radioactive decay and the annual TEDE factors from Table 3.4.
- (b) Assuming a contaminated area of 1000 m² to a depth of 15 cm, at a level of 100 pCi/g. Assuming a soil density of 1.6 g/cm³, the total inventory is 24 mCi (890 MBq).
- (c) Where SI is small intestine and LLI is lower large intestine.
- (d) Where +I means "plus implicit daughters in equilibrium" as discussed in Appendix D.

APPENDIX D

COMPUTERIZED MODEL INPUT/OUTPUT

APPENDIX D

COMPUTERIZED MODEL INPUT/OUTPUT

This appendix discusses radionuclide chain decay as applied in the generation of the dose rate or committed effective dose rate conversion factors (Tables 2.1 through 2.5) and the TEDE rate factors (Tables 3.1 through 3.4) and a description of the computerized approach used in the preparation of those tables. In addition, listings are included of the computer programs, data libraries, and associated data files used in the generation of the dose rate, committed effective dose rate conversion factors, and TEDE rate factors.

D.1 Radioactive Chain Decay

Radioactive nuclei sometimes decay through a number of unstable daughters before reaching a stable (or very-long-lived) end state. These decay chains are important in that the decay energies of the daughter products contribute to the total dose received from intake of the parent. Tables 2.1 through 2.5 and Tables 3.1 through 3.4 contain listings for both: 1) radionuclides with daughters in equilibrium with their parents and 2) as individual radionuclides without any daughter contributions. The dose rate factors for radionuclides with daughters in equilibrium are useful for cases where the equilibrium conditions are not known. The individual radionuclide entries allow the user to calculate dose rate factors for mixtures where radionuclide daughters may not be in equilibrium with their parents.

The data on radionuclide half-lives, decay chains, and various fractional branching ratios within chains used in GENII are largely taken from the DRALIST data of Kocher (1981b) for consistency with gamma energy data used elsewhere in the GENII code package. Radionuclides of half-life less than 10 minutes are of little importance in environmental calculations and in terms of internal dose, except where they are members of longer decay chains. Daughters of half-life less than 10 minutes are always assumed to be in equilibrium with their parent and are referred to here as implicit daughters. These daughters are given a +I notation in the dose factor tables with a footnote explaining the meaning. An example of a radionuclide with the +I notation is $^{137}\text{Cs}+I$. In GENII, the decay energies associated with these short-lived daughters have been assigned to the parent. This assignment includes correction of the SEE factors in the dose calculations. The appropriate branching ratios have been considered.

Daughters with half-lives greater than 10 minutes that may not be in equilibrium with their parents are referred to here as explicit daughters. These daughters are given a +D notation in the dose factor tables with a footnote explaining the meaning. An example of a radionuclide with the +D notation is $^{90}\text{Sr}+D$. The GENII software tracks explicit daughters independently throughout all calculations. Radionuclide decay and daughter ingrowth chain organization, branching ratios, and explicit/implicit daughter

classification used for the generation of Tables 2.1 through 2.5 and Tables 3.1 through 3.4 are presented in Table D.1.

For cases where there is a short-lived parent with a long-lived daughter, no attempt is made to combine the parent and daughter. Instead, listings for both parent and daughter are included separately so that the user may define the equilibrium condition. Finally, for decay chains, the listings include parents with +D to include explicit daughters, as determined by the decay chain data. For example, $^{224}\text{Ra}+D$ is listed to include the implicit daughters ^{220}Ra and ^{216}Po , plus the explicit daughters ^{212}Pb and ^{212}Bi with its implicit daughters ^{212}Po and ^{208}Tl , and ^{224}Ra is listed separately to permit separate equilibrium calculations. Table D.1 contains listings of the data concerning the decay schemes, branching ratios, and explicit/implicit daughter classifications used in the decay chain calculations.

The computer programs within the GENII package include a generalized chain decay processor. This processor can give the activity of any member of a decay chain as a function of time from any initializing condition. The chain processor operates on a recursive application of the Bateman equations (Bateman 1910). The Bateman equations provide a simple means of solving the differential equations describing chain decay. The basic form of the equation is

$$A_n = N_{10} [C_1 e^{-\lambda_1 t} + C_2 e^{-\lambda_2 t} + \dots + C_n e^{-\lambda_n t}] \quad (\text{D.1})$$

$$C_i = \frac{\lambda_1 \lambda_2 \dots \lambda_{i-1}}{(\lambda_j - \lambda_i)} \quad (\text{D.2})$$

$\begin{matrix} j=1 \\ j \neq i \end{matrix}$

where A_n = the activity of the nth daughter
 N_{10} = the initial activity of the parent at time $t=0$
 λ_i = the decay constant for nuclide i of the chain.

A variant in general decay schemes is branching decay. For this case the Bateman solution is applied in GENII by using partial decay constants (that is, the decay constant times the branching fraction) in the numerator of the constants C_j . If the decay chain branches and subsequently the two branches are rejoined (as in the natural radioactive series), the two branches are treated by this method as separate chains. The production of a common member beyond the branch point is the sum of the two paths.

An option can be activated in GENII where initial concentrations of daughters are brought to equilibrium with the parent identified on input. This feature was used to calculate dose rate factors (Tables 2.1 through 2.5) for radionuclides where daughters were assumed to be in equilibrium with their parents (+D designation in the tables). To calculate dose rate factors in GENII without contribution from explicit daughters, a special version of

the radionuclide decay library was prepared where radionuclides were treated without progeny.

D.2 Computerized Model Input/Output

This section contains listings of the computer programs and data files used to produce the dose rate or committed effective dose rate conversion factors (Tables 2.1 through 2.5) and the TEDE rate factors (Tables 3.1 through 3.4). These computer programs are essentially report generators operating on the output from the GENII computer program to produce the tables in a usable form. The tables in Section 2.0 contain dose rate or committed effective dose rate conversion factors, by exposure pathway, for exposure to residual radioactive contamination. The tables in Section 3.0 contain TEDE rate factors for unit concentrations of radionuclides in building volume and surface materials, and in soil for the four identified radiation exposure scenarios.

The FORTRAN-language computer program PHASE8, listed in Table D.2 was developed and used to generate the basic values shown in tables in Sections 2 and 3, complete with word processing commands. PHASE8 processed five input files: RMDLIBDA.SHT, EXTERNAL.DF, EXTDAU.DF, INTERNAL.DF, and INTNODAU.DF. The latter four files were created by programs in the GENII Software System (Versions 1.425, 1.429, and 1.430).

The file RMDLIBDA.SHT, shown as Table D.3, contains the control list of radionuclides to be included in the tables. This file is shown in its computer-readable format and also contains the radionuclide half-life in days, the radionuclide decay chain equilibrium multiplier, the default solubility classification for inhalation, and the partitioning coefficient for the leach-rate calculations included for the drinking water scenario.

The file EXTERNAL.DF, shown as Table D.4, contains external dose factors for radionuclides considered individually. EXTERNAL.DF was created from output files of the program EXTDF of the GENII software system. This file is shown in computer-readable format. It contains dose factors for three configurations: 1) an infinite disk surface source of concrete; 2) a 1-cm-thick, 5-m-diameter cylinder source of concrete; and 3) a 15-cm-thick infinite slab source of soil. Units are rem/h per Ci/cm² or cm³, depending on whether a surface or volume source is considered. The file EXTDAU.DF shown as Table D.5 contains external dose factors where daughters are in equilibrium with their parents (used for radionuclides with the +D designation in Tables 2.1-2.5 and 3.1-3.4). This file is shown in computer-readable format. It contains dose factors for the three configurations considered in file EXTERNAL.DF as discussed above. For the surface source configuration, units are rem/h per pCi-m/effective m². For the volume and soil sources, units are rem/h per pCi/effective g.

The files INTERNAL.DF, shown as Table D.6, and INTNODAU.DF, shown as Table D.7, consist of inhalation committed effective dose rate equivalents, secondary ingestion committed effective dose rate equivalents, ingestion committed effective dose rate equivalents (air contribution and soil

contribution from ingestion of food products), and drinking water maximum organ dose rate factors that were created from GENII DOSEQA.OUT files. The organ receiving the highest dose from the drinking water pathway is also identified. Tables D.6 and D.7 are shown in computer-readable format. The units considered are as follows: for inhalation, rem/h per pCi/m³; for secondary ingestion, rem per pCi ingested; for the air contribution to the ingestion pathway, rem per pCi/m³ of air; for the soil contribution to the ingestion pathway, rem per pCi/g of soil; and for drinking water ingestion, rem per pCi. INTERNAL.DF (Table D.6) contains dose factors where daughters are in equilibrium with their parents (used for radionuclides with the +D designation in Tables 2.1-2.5 and 3.1-3.4). INTNODAU.DF (Table D.7) contains dose factors for radionuclides considered individually.

The EXTDF output files used to generate EXTERNAL.DF for the three configurations are shown as Tables D.8-D.10. Table D.8 shows the results for an infinite disk surface source of concrete. Table D.9 shows the results for a 1-cm-thick, 5-m-diameter cylinder source of concrete. Table D.10 shows the results for a 15-cm-thick infinite slab source of soil. The files are shown in computer-generated format. The file EXTERNAL.DF (Table D.4) was generated from the output files shown in Tables D.8 through D.10.

The file EXTDAU.DF (Table D.5) was constructed by extracting appropriate columns from three DOSEQA.OUT files generated from multiple runs of the GENII software. The GENII DOSEQA.OUT files allow tabulation and quality-control checking of multiple GENII runs. The organization of the DOSEQA.OUT file is described in Section 2.2.17, Volume 2 of the GENII documentation. Three BASIC-language programs were written to control GENII execution, each producing a separate DOSEQA.OUT file. EXTDAU.DF was then constructed manually from the DOSEQA.OUT files. Table D.11 lists the BASIC-language GENII-control program GENEXT1.BAS used to generate dose factors for an infinite disk source of concrete (first column of file EXTDAU.DF). The GENII-control program used to generate dose factors for the remaining two configurations are not shown because of their similarity to GENEXT1.BAS; only filenames differ. The GENII input file templates, EXTOPT.TPL and EXTPAR.TPL are shown in computer-readable format in Tables D.12 and D.13, respectively. Unique versions of the GENII external dose factor file (GRDF.DAT) were used for each of the three configurations. These files were created by running EXTDF with the EXTDF input files shown in Tables D.8-D.10, modified so that the output is in GENII-compatible units. The output from EXTDF was substituted for the surface soil exposure dose rate factor column in three versions of the GRDF.DAT file used in the three GENII runs used to generate EXTDAU.DF.

The files INTERNAL.DF (Table D.6) and INTNODAU.DF were constructed by extracting appropriate columns from eight DOSEQA.OUT files generated from multiple runs of the GENII software. The GENII DOSEQA.OUT files allow tabulation and quality-control checking of multiple GENII runs. The organization of the DOSEQA.OUT is described in Section 2.2.17, Volume 2 of the GENII documentation. Eight BASIC-language control programs were written to control GENII executions, each producing a separate DOSEQA.OUT file. INTERNAL.DF (Table D.6) and INTNODAU.DF (Table D.7) were then constructed manually from the DOSEQA.OUT files. Four control programs were used to

control pathway calculations factors for each of the internal dose factor files. Table D.14 summarizes program and file usage for generation of INTERNAL.DF (Table D.6) and INTNODAU.DF (Table D.7). Tables D.15 through D.18 list the BASIC-language GENII-control programs GENALL.BAS, GENALL2.BAS, GENALL3.BAS, and GENALL4.BAS, respectively. The programs GENALLN.BAS, GENALL2N.BAS, GENALL3N.BAS, and GENALL4N.BAS are not shown because of their similarity to the files shown in Table D.15 through D.18; only filenames differ. The GENII input file templates SOILOPT.TPL, SOILPAR.TPL, DRINKOPT.TPL, and DRINKPAR.TPL are shown in computer-readable format as Tables D.19 through D.22, respectively.

To create EXTDAU.DF (Table D.5) and INTERNAL.DF (Table D.6), the GENII radionuclide master library (RMDLIB.DAT), shown as Table D.23 in computer-readable format, was used to control radionuclide chain decay. To generate INTNODAU.DF (Table D.7), a special version of the radionuclide master library where all radionuclides are processed without daughters, shown as Table D.24, was used. The GENII executions used a modified version of the food transfer coefficient library to track the data base for 10 CFR 61 and Regulatory Guide 1.109 (NRC 1977) values. Table D.25 contains the version of FTRANS.DAT (food transfer coefficient data), in computer-readable format, used by GENII to generate the food product ingestion TEDE factors from the soil contribution to ingestion. For the air contribution to ingestion, calculations were made using a version of this file with the soil-to-plant uptake factors set to 0.0. Values used from this file are identified in Table B.4 of Appendix B.

TABLE D.1. Radionuclide Decay and Daughter Ingrowth Chain
Organization in the Radionuclide Master Library (a)

Chain Position Index(c)	Radio- nuclide(d)	<u>Explicit Daughters(b)</u>		<u>Implicit Daughters(g)</u>
		<u>Primary Precursor/ Branching Ratio(e)</u>	<u>Alternate Precursor/ Branching Ratio(f)</u>	
1	ZN69M			
2	ZN69	1 1.0		
1	RB89			
2	SR89	1 1.0		
1	SR90			
2	Y 90	1 1.0		
1	SR91			
2	Y 91M	1 0.5740		
3	Y 91	2 1.0	1 0.4260	
1	SR92			
2	Y 92	1 1.0		
1	MO93			
2	ZR93			
3	NB93M	1 1.0	2 1.0	
1	ZR95			
2	NB95M	1 0.0080		
3	NB95	2 0.9450	1 0.9922	
1	ZR97			
2	NB97M	1 0.9470		
3	NB97	2 1.0	1 0.0530	
1	MO99			
2	TC99M	1 0.8860		
1	RU103			
2	PD103			
3	RH103M	1 0.9974	2 0.9997	
1	RU105			RH105M 1.000
2	RH105	1 1.0		
1	RU106			RH106 1.000
1	PD109			AG109M 1.000
1	AG110M			AG110 0.985

TABLE D.1. Radionuclide Decay and Daughter Ingrowth Chain Organization in the Radionuclide Master Library^(a) (contd)

Chain Position Index(c)	Radio- nuclide(d)	Explicit Daughters(b)		Implicit Daughters(g)
		Primary Precursor/ Branching Ratio(e)	Alternate Precursor/ Branching Ratio(f)	
1	CD115M			
2	CD115			
3	IN115M	2 1.0		
1	IN114M			IN114 0.957
1	SN113			
2	IN113M	1 1.0		
1	SN125			
2	SB125	1 1.0		
3	TE125M	2 0.2310		
1	SN126			
2	SB126M	1 1.0		
3	SB126	2 0.1400		
1	SB127			
2	TE127M	1 0.1690		
3	TE127	2 0.9820	1 0.8310	
1	TE129M			
2	TE129	1 0.6290		
1	TE131M			
2	TE131	1 0.2220		
3	I 131	2 1.0	1 0.7780	
1	TE132			
2	I 132	1 1.0		
1	TE133M			
2	TE133	1 0.1300		
3	I 133	2 1.0	1 0.8700	
1	TE134			
2	I 134	1 1.0		

TABLE D.1. Radionuclide Decay and Daughter Ingrowth Chain Organization in the Radionuclide Master Library^(a) (contd)

Chain Position Index(c)	Radio- nuclide(d)	Explicit Daughters(b)		Implicit Daughters(g)
		Primary Precursor/ Branching Ratio(e)	Alternate Precursor/ Branching Ratio(f)	
1	I 135			
2	XE135M	1 0.1650		
3	XE135	2 1.0	1 0.8350	
1	CS137			BA137M 0.946
1	CS139			
2	BA139	1 1.0		
1	BA140			
2	LA140	1 1.0		
1	BA141			
2	LA141	1 1.0		
3	CE141	2 1.0		
1	BA142			
2	LA142	1 1.0		
1	CE143			
2	PR143	1 1.0		
1	CE144			
2	PR144M	1 0.0143		
3	PR144	2 1.0	1 0.9857	
1	ND147			
2	PM147	1 1.0		
1	PM148M			
2	PM148	1 0.0420		
1	TH230			
2	RA226	1 1.0		
3	RN222	2 1.0		P0218 1.0 PB214 1.0 BI214 1.0 P0214 1.0
4	PB210	3 1.0		
5	BI210	4 1.0		
6	P0210	5 1.0		

TABLE D.1. Radionuclide Decay and Daughter Ingrowth Chain Organization in the Radionuclide Master Library^(a) (contd)

Chain Position Index(c)	Radio- nuclide(d)	Explicit Daughters(b)		Implicit Daughters(g)	
		Primary Precursor/ Branching Ratio(e)	Alternate Precursor/ Branching Ratio(f)		
1	TH232				
2	RA228	1 1.0			
3	AC228	2 1.0			
4	TH228	3 1.0			
5	RA224	4 1.0		RN220 1.0 P0216 1.0	
6	PB212	5 1.0			
7	BI212	6 1.0		P0212 0.6407 TL208 0.3593	
1	U 235				
2	TH231	1 1.0			
1	PA231				
2	AC227	1 1.0			
3	TH227	2 0.9862			
4	FR223	2 0.0138			
5	RA223	3 1.0	4 1.0	RN219 1.0 P0215 1.0 PB211 1.0 BI211 1.0 TL207 1.0	
1	NP237				
2	PA233	1 1.0			
1	U 233				
2	TH229	1 1.0			
3	RA225	2 1.0			
4	AC225	3 1.0		FR221 1.0 AT217 1.0 BI213 1.0 P0213 0.9784 TL209 0.0216 PB209 1.0	
1	U 238				
2	TH234	1 1.0		PA234M 0.998	
3	PA234	2 0.0016			

TABLE D.1. Radionuclide Decay and Daughter Ingrowth Chain Organization in the Radionuclide Master Library^(a) (contd)

Chain Position Index(c)	Radio- nuclide(d)	Explicit Daughters(b)		Implicit Daughters(g)
		Primary Precursor/ Branching Ratio(e)	Alternate Precursor/ Branching Ratio(f)	
1	AM242M			
2	AM242	1 1.0		
3	CM242	2 0.8270		
4	PU238	3 1.0		
1	NP238			
2	PU238	1 1.0		
1	PU244			
2	U 240	1 0.9988		NP240M 1.0
1	CM245			
2	PU241	1 1.0		
3	AM241	2 1.0		
1	CM247			
2	PU243	1 1.0		
1	CM243			
2	AM243	1 0.0024		
3	NP239	2 1.0		
4	PU239	2 0.9976		

-
- (a) The radionuclide master library (RMDLIB.DAT) contains all radiological decay and daughter ingrowth data used by the GENII Software System to calculate internal and external dose factors included in this document. In RMDLIB.DAT radionuclides are organized into chains controlled by integer indices.
- (b) Daughters of half-life greater than 10 minutes that may not be in equilibrium with its parent. Explicit daughters are tracked independently throughout the system.
- (c) Indicator of relative position in the decay chain (where 1 is highest position).
- (d) Radionuclide name as specified in RMDLIB.DAT.
- (e) Chain position index of primary precursor in decay chain (as defined in the first column of this table) followed by the branching ratio.
- (f) Chain position index of alternate precursor in decay chain (as defined in the first column of this table) followed by the branching ratio.

TABLE D.1. Radionuclide Decay and Daughter Ingrowth Chain Organization in the Radionuclide Master Library^(a) (contd)

- (g) Daughters of half-life less than 10 minutes that are always assumed to be in equilibrium with their parent. The decay energies associated with these short-lived daughters has been assigned to the parent. This assignment includes correction of radioactive decay energies for both internal and external dose calculations. Listed in the table are the implicit daughters and their branching ratios included for the parent listed in the second column of the table.

TABLE D.2. PHASE8 Computer Program Listing

```

C-----
C
C   PROGRAM PHASE8
C
C   NRC Residual Radioactivity
C   Last modification: 28-Jan-90 RAP
C-----
C
C   File usage:
C
C   -Lun-  --Filename--  -----Description-----
C
C       1    RMDLIBDA.SHT  Master list of radionuclides for table genera-
C                        tion, sorted by element then isotope, no noble
C                        gases. File includes equilibrium multiplier.
C                        (Input)
C
C       2    INTERNAL.DF   Inhalation, secondary ingestion, ingestion
C                        (air contribution and soil contribution), dose
C                        factors for radionuclide chains. Created from
C                        GENII DOSEQA.OUT files generated by programs:
C                        1) GENALL.BAS (ingestion - soil)
C                        2) GENALL3.BAS (ingestion - air)
C                        3) GENALL2.BAS (inhalation and secondary
C                        ingestion)
C                        4) GENALL4.BAS (secondary ingestion [drinking
C                        water] critical organ).
C                        GENALL and GENALL3 use template files SOILOPT.TPL
C                        and SOILPAR.TPL. GENALL2 and GENALL4 use template
C                        files DRINKOPT.TPL and DRINKPAR.TPL. Units are
C                        rem/h per pCi/g soil or water, rem/h per pCi/m3
C                        air. (Input)
C
C       13   INTNODAU.DF   Inhalation, secondary ingestion, ingestion
C                        (air contribution and soil contribution), dose
C                        factors for radionuclides without daughter con-
C                        tributions. Created from GENII DOSEQA.OUT files
C                        generated by programs:
C                        1) GENALLN.BAS (ingestion - soil)
C                        2) GENALL3N.BAS (ingestion - air)
C                        3) GENALL2N.BAS (inhalation and secondary
C                        ingestion)
C                        4) GENALL4N.BAS (secondary ingestion [drinking
C                        water] critical organ).
C                        GENALLN and GENALL3N use template files
C                        SOILOPT.TPL and SOILPAR.TPL. GENALL2N and
C                        GENALL4N use template files DRINKOPT.TPL and
C                        DRINKPAR.TPL. Units are rem/h per pCi/g soil
C                        or water, rem/h per pCi/m3 air. (Input)

```

TABLE D.2. PHASE8 Computer Program Listing (contd)

3	EXTERNAL.DF	External dose factors for radionuclides without daughters: 1) Infinite disk surface source, concrete 1) 1 cm thick disk source, 5m source, concrete 3) 15 cm thick infinite slab source, soil. Created from EXTDF runs SURC, VOLC1, and VOLSOL15. Units are rem/h per Ci/cm2 or cm3. (Input)
4	TABLE2.1	External dose conversion factors for exposure to residual radioactive materials. (Output)
5	TABLE2.2	Inhalation committed effective dose conversion factors for exposure to residual radioactive materials. (Output)
6	TABLE2.3	Secondary ingestion committed effective dose conversion factors for exposure to residual radioactive materials. (Output)
7	TABLE2.5	Agricultural food product ingestion committed effective dose conversion factors for exposure to residual radioactive materials. (Output)
12	TABLE2.4	Maximum organ dose conversion factors for ingestion of drinking water. (Output)
7	TABLE2.5	Agricultural food product ingestion committed effective dose conversion factors for exposure to residual radioactive materials. (Output)
8	TABLE3.1	Total effective dose equivalents for the building volume activity scenario. (Output)
9	TABLE3.2	Total effective dose equivalents for the building surface activity scenario. (Output)
10	TABLE3.3	Total effective dose equivalent for the surface soil scenario. (Output)
11	TABLE3.4	Drinking water committed effective dose equivalents for exposure to residual radioactive materials. (Output)
14	TABLE.1	Allowable levels of contamination following decommissioning of nuclear facilities-- building volume and surface sources. (Output)
15	TABLE.2	Allowable levels of contamination following

TABLE D.2. PHASE8 Computer Program Listing (contd)

```

C      decommissioning of nuclear facilities--
C      surface soil total inventory sources. (Output)
C
C      16      EXTDAU.DF      External dose factors for radionuclides with
C                          daughters:
C                          1) Infinite disk surface source, concrete
C                          1) 1 cm thick disk source, 5m source, concrete
C                          3) 15 cm thick infinite slab source, soil.
C                          GRDF1.DAT, GRDF2.DAT, and GRDF3.DAT created from
C                          EXTDF runs EXT1, EXT2, and EXT3. BASIC programs
C                          GENEXT1, GENEXT2, and GENEXT3 were then run and
C                          this file was then created from the DOSEQA.OUT
C                          files. Units are rem/h per pCi/m2. (Input)
C
C      17      CONTROL.1      TABLE 3.1 Internal controlling dose list
C      18      CONTROL.2      TABLE 3.2 Internal controlling dose list
C      19      CONTROL.3      TABLE 3.3 Internal controlling dose list
C
C      20      PHASE8.QA      External dose factor QA file for verification
C
C-----
C
REAL REXT(3,300), REXTD(3,300),
.   RINH(300), RING(2,300), RSING(300), DWORG(300),
.   RINH(300), RINGN(2,300), RSINGN(300),
.   DWORGN(300)

REAL*8 RLAM, RLAML, REXP, REXP2, CONV1, CONV2

CHARACTER ELTM*2, ELT*2, AWM*6, AW*6,
.   ORGAN*21(300), ORGNO*21(300),
.   ORG*21, ORG4A*21, ORG5A*21, ORG8A*21,
.   ORG4B*21, ORG5B*21, ORG8B*21,
.   ELT1*2(300), AW1*6(300), DUM*5, ELT2*2(300), AW2*6(300),
.   ADVUP*1, ADVDOWN*1, NEXTAB*1,
.   LITFNT*6, BIGFNT*6,
.   RITNAM*29(3), UNAT*29(3), THNAT*29(3),
.   ELTOLD*2, TMPNAM*29, FOOT*3(6), DESIG*2(2), CNTRL*10(2)

INTEGER IBETA, IMPDAU
LOGICAL U234, U235, U238, TH232

DATA ELTOLD /' ' /
DATA FOOT /'(a)','(b)','(c)','(d)','(e)','(f)'/
DATA DESIG /'+D','+I'/
DATA CNTRL /'Inhalation','Ingestion '/

ALOG = 0.6931

```

TABLE D.2. PHASEB Computer Program Listing (contd)

```
ADVUP = CHAR (190)
ADVDWN = CHAR (191)
NEXTAB = CHAR (9)
```

```
LITFNT (1:) = CHAR (203)
LITFNT (2:) = CHAR (12)
LITFNT (3:) = CHAR (1)
LITFNT (4:) = CHAR (18)
LITFNT (5:) = CHAR (3)
LITFNT (6:) = CHAR (203)
```

```
BIGFNT (1:) = CHAR (203)
BIGFNT (2:) = CHAR (18)
BIGFNT (3:) = CHAR (3)
BIGFNT (4:) = CHAR (12)
BIGFNT (5:) = CHAR (1)
BIGFNT (6:) = CHAR (203)
```

```
ITHEND = 29
DO 500 I = 1, 3
  TMPNAM = ' '
  TMPNAM (1:) = LITFNT
  TMPNAM (7:) = ADVUP
  TMPNAM (12:) = ADVDWN
  TMPNAM (13:) = BIGFNT
  TMPNAM (19:) = 'Th-Nat'
  TMPNAM (25:) = ADVUP
  TMPNAM (26:) = FOOT(2+I)
  TMPNAM (29:) = ADVDWN
  THNAT(i) = TMPNAM
```

500 CONTINUE

```
IUEND = 28
DO 501 I = 1, 3
  TMPNAM = ' '
  TMPNAM (1:) = LITFNT
  TMPNAM (7:) = ADVUP
  TMPNAM (12:) = ADVDWN
  TMPNAM (13:) = BIGFNT
  TMPNAM (19:) = 'U-Nat'
  TMPNAM (24:) = ADVUP
  TMPNAM (25:) = FOOT(3+I)
  TMPNAM (28:) = ADVDWN
  UNAT(I) = TMPNAM
```

501 CONTINUE

C---- Open and read input files -----

```
OPEN (1, FILE='rmdlibda.sht', STATUS='OLD')
READ (1, ' (A)') DUM
```

TABLE D.2. PHASE8 Computer Program Listing (contd)

```
OPEN (2, FILE='internal.df', STATUS='OLD')
READ (2, ' (A)') DUM
READ (2, ' (A)') DUM
I = 1
101 CONTINUE
    READ (2, 1, END=102) ELT1(I), AW1(I), RINH(I), RSING(I),
        RING(1,I), RING(2,I), DWORG(I), ORGAN(I)
    I = I + 1
    GOTO 101
102 CONTINUE
    N2 = I
    CLOSE (2)

OPEN (13, FILE='intnodau.df', STATUS='OLD')
READ (13, ' (A)') DUM
READ (13, ' (A)') DUM
I = 1
103 CONTINUE
    READ (13, 1, END=104) ELT, AW, RINH(I), RSING(I),
        RINGN(1,I), RINGN(2,I), DWORGN(I), ORGNO(I)
    IF (ELT .NE. ELT1(I) .AND. AW .NE. AW1(I)) THEN
        WRITE (*,*) ' Error with INTNODAU.DF order',
            ELT, ELT1(I), AW, AW1(I)
    ENDIF
    I = I + 1
    GOTO 103
104 CONTINUE
    CLOSE (13)

OPEN (3, FILE='external.df', STATUS='OLD')
READ (3, ' (A)') DUM
READ (3, ' (A)') DUM
READ (3, ' (A)') DUM
READ (3, ' (A)') DUM
I = 1
111 CONTINUE
    READ (3, 2, END=112) ELT2(I), AW2(I), (REXT(J,I), J=1,3)
    I = I + 1
    GOTO 111
112 CONTINUE
    N3 = I
    CLOSE (3)

OPEN (16, FILE='extdau.df', STATUS='OLD')
READ (16, ' (A)') DUM
READ (16, ' (A)') DUM
```

TABLE D.2. PHASE8 Computer Program Listing (contd)

```

READ (16, ' (A)') DUM
READ (16, ' (A)') DUM
I = 1
120 CONTINUE
    READ (16, 1, END=121) ELT, AW,
        REXTD(1,I), REXTD(2,I), REXTD(3,I)
    .
C    WRITE (*,*) ' ',ELT, AW, REXTD(1,I), REXTD(2,I), REXTD(3,I)
    IF (ELT .NE. ELT1(I) .AND. AW .NE. AW1(I)) THEN
        WRITE (*,*) ' Error with EXTDAU.DF order',
            .
            ELT, ELT1(I), AW, AW1(I), '#'
    .
    ENDIF
    I = I + 1
    GOTO 120
121 CONTINUE
    CLOSE (16)

C---- Open output files and print headings -----

    OPEN (4, FILE='table2.1', STATUS='OLD', ACCESS='APPEND')
    WRITE (4,'(6A)')
    .
C    CHAR(199), CHAR(0), CHAR(1), CHAR(0), CHAR(6), CHAR(199)
C    . 'TABLE2.1 External dose conversion factors for exposure',
C    . '
        to residual radioactive materials'

    OPEN (5, FILE='table2.2', STATUS='OLD', ACCESS='APPEND')
    WRITE (5,'(6A)')
    .
C    CHAR(199), CHAR(0), CHAR(1), CHAR(0), CHAR(16), CHAR(199)
C    . 'TABLE2.2 Inhalation committed effective dose conversion fac-',
C    . '
        tors for exposure to residual radioactive materials'

    OPEN (6, FILE='table2.3', STATUS='OLD', ACCESS='APPEND')
    WRITE (6,'(6A)')
    .
C    CHAR(199), CHAR(0), CHAR(1), CHAR(0), CHAR(25), CHAR(199)
C    . 'TABLE2.3 Secondary ingestion committed effective dose conver-',
C    . '
        sion factors for exposure to residual radioactive',
C    . '
        materials.'

    OPEN (7, FILE='table2.4', STATUS='OLD', ACCESS='APPEND')
    WRITE (7,'(6A)')
    .
C    CHAR(199), CHAR(0), CHAR(1), CHAR(0), CHAR(35), CHAR(199)
C    . 'TABLE2.4 Maximum organ dose conversion factors for',
C    . '
        ingestion of drinking water'

    OPEN (12, FILE='table2.5', STATUS='OLD', ACCESS='APPEND')
    WRITE (12,'(6A)')
    .
C    CHAR(199), CHAR(0), CHAR(1), CHAR(0), CHAR(47), CHAR(199)
C    . 'TABLE2.5 Agricultural food product ingestion committed',
C    . '
        effective dose conversion factors for exposure',
C    . '
        to residual radioactive materials ',

```

TABLE D.2. PHASE8 Computer Program Listing (contd)

```

C      . '          (air and soil contributions)'

      OPEN (8, FILE='table3.1', STATUS='OLD', ACCESS='APPEND')
      WRITE (8, '(6A)')
      . CHAR(199), CHAR(0), CHAR(1), CHAR(0), CHAR(4), CHAR(199)
C      . 'TABLE3.1 Total effective dose equivalents for the',
C      . '          building volume activity scenario'

      OPEN (9, FILE='table3.2', STATUS='OLD', ACCESS='APPEND')
      WRITE (9, '(6A)')
      . CHAR(199), CHAR(0), CHAR(1), CHAR(0), CHAR(14), CHAR(199)
C      . 'TABLE3.2 Total effective dose equivalents for the',
C      . '          building surface activity scenario'

      OPEN (10, FILE='table3.3', STATUS='OLD', ACCESS='APPEND')
      WRITE (10, '(6A)')
      . CHAR(199), CHAR(0), CHAR(1), CHAR(0), CHAR(25), CHAR(199)
C      . 'TABLE3.3 Total effective dose equivalent for the surface',
C      . '          soil scenario'

      OPEN (11, FILE='table3.4', STATUS='OLD', ACCESS='APPEND')
      WRITE (11, '(6A)')
      . CHAR(199), CHAR(0), CHAR(1), CHAR(0), CHAR(35), CHAR(199)
C      . 'TABLE3.4 Drinking water committed effective dose equivalents',
C      . '          for exposure to residual radioactive materials'

      OPEN (14, FILE='table.1', STATUS='OLD', ACCESS='APPEND')
      WRITE (14, '(6A)')
      . CHAR(199), CHAR(0), CHAR(1), CHAR(0), CHAR(4), CHAR(199)

      OPEN (15, FILE='table.2', STATUS='OLD', ACCESS='APPEND')
      WRITE (15, '(6A)')
      . CHAR(199), CHAR(0), CHAR(1), CHAR(0), CHAR(14), CHAR(199)

      OPEN (17, FILE='control.1', STATUS='unknown')
      OPEN (18, FILE='control.2', STATUS='unknown')
      OPEN (19, FILE='control.3', STATUS='unknown')

C      OPEN (20, FILE='phase8.qa', STATUS='unknown')

C---- Process master list -----
7 CONTINUE

      U234 = .FALSE.
      U235 = .FALSE.
      U238 = .FALSE.
      TH232 = .FALSE.

      READ (1, 14, END=9)  ELTM, AWM, HL, CHADJ, PC, IBETA, IMPDAU,

```

TABLE D.2. PHASE8 Computer Program Listing (contd)

CHADJI

```

DO 201 IINT = 1, N2
  IF (ELT1(IINT) .EQ. ELTM .AND. AW1(IINT) .EQ. AWM) GOTO 202
201 CONTINUE
202 CONTINUE

DO 203 IEXT = 1, N3
  IF (ELT2(IEXT) .EQ. ELTM .AND. AW2(IEXT) .EQ. AWM) GOTO 204
203 CONTINUE
204 CONTINUE

TEMP = CHADJ - CHADJI
IF (TEMP .NE. 1.0) THEN
C   Explicit daughter--
    NT = 2
    IFOOT = 1
    IDESIG = 1
ELSEIF (IMPDAU .GT. 0.0) THEN
C   Implicit daughter--
    NT = 1
    IFOOT = 2
    IDESIG = 2
ELSE
    NT = 1
    IFOOT = 0
    IDESIG = 0
ENDIF

IF (ELTM .EQ. 'U ') THEN
  IF (AWM .EQ. '234 ') U234 = .TRUE.
  IF (AWM .EQ. '235 ') U235 = .TRUE.
  IF (AWM .EQ. '238 ') U238 = .TRUE.
ELSEIF (ELTM .EQ. 'TH' .AND. AWM .EQ. '232 ') THEN
  TH232 = .TRUE.
ENDIF

DO 400 IT = 1, NT

C----- Construct name for printing -----

  IF (IT .EQ. 2 .AND. IMPDAU .GT. 0) THEN
    IDESIG = 2
    IFOOT = 2
  ENDIF

  DO 401 K = 1, 3
    TMPNAM = '
    TMPNAM (1:) = LITFNT
    TMPNAM (7:) = ADVUP

```

TABLE D.2. PHASE8 Computer Program Listing (contd)

```

DO 8 I = 1, 4
  IF (AWM(I:I) .NE. ' ') IPOS = I
8  CONTINUE
  TMPNAM(12-IPOS:) = AWM
  IPOS = IPOS + 1

C  Change M to m--
  IF (TMPNAM(11:11) .EQ. 'M') TMPNAM(11:11) = 'm'
  TMPNAM(12:) = ADVDOWN
  TMPNAM(13:) = BIGFNT
  TMPNAM(19:) = ELTM(1:1)

  IF (ELTM(2:2) .EQ. ' ') THEN
    ISTART = 20
  ELSE
    IASC = ICHAR(ELTM(2:2))
    IASC = IASC + 32
    TMPNAM(20:20) = CHAR(IASC)
    ISTART = 21
  ENDIF

  IEND = ISTART
  IF ((IT .EQ. 1 .AND. IDESIG .GT. 0) .OR.
      (IT .EQ. 2 .AND. IMPDAU .GT. 0)) THEN
    TMPNAM(ISTART:) = DESIG(IDESIG)
    TMPNAM(ISTART+2:) = ADVUP
    TMPNAM(ISTART+3:) = FOOT(IFOOT+K-1)
    TMPNAM(ISTART+6:) = ADVDOWN
    IEND = ISTART + 6
  ENDIF

  RITNAM(K) = TMPNAM

401 CONTINUE

  IF (ELTM .NE. ELTOLD .AND. IT .EQ. 1) THEN
    DO 301 K = 4, 12
      WRITE(K,*) ' '
301  CONTINUE
      WRITE(14,*) ' '
      WRITE(15,*) ' '
    ENDIF

```

```

C----- Table 2.1 - External -----
C
C  No daughters:
C  -----
C
C  Surface:

```

TABLE D.2. PHASE8 Computer Program Listing (contd)

```

C      rem cm2 1000 mrem      Ci      dps      1
C      --- --- -----
C      h Ci      rem      3.7E10 dps 60 dpm 100      = 4.50E-12 mrem/h per
                                                    dpm/100 cm2

```

C Volume and soil:

```

C      rem cm3 1000 mrem      Ci      2.4 g
C      --- --- -----
C      h Ci      rem      1E12 pCi cm3      = 2.4E-9 mrem/h per pCi/g

```

C With daughters:

C -----

C Surface - EXTDF conversion to GENII surface units:

```

C      rem cm2      Sv      8766 h      Ci      m2
C      --- --- -----
C      h Ci 100 rem      yr      3.7E10 Bq 1.E4 cm2      = 2.37E-13 Sv/h per
                                                    Bq/m2

```

C Surface - in GENII:

```

C      Sv m2 0.037 Bq      yr      100 rem      "m2"
C      -- -- -----
C      yr Bq      pCi      8766 h      Sv      0.15 m3      = 2.8E-3 rem/h per
                                                    pCi-m /"m2"

```

C Surface:

```

C      rem "m2"      pCi      0.15 m3 dps      1.0E4 cm2      1      1000 mrem
C      --- --- -----
C      h pCi m 0.037 dps      "m2"      60 dpm      m2      100      rem
C
C      = 6.76 mrem/h per dpm/100 cm2

```

C Volume and soil - EXTDF conversion to GENII surface units:

```

C      rem cm3      Sv      8766 h      Ci      m3
C      --- --- -----
C      h Ci 100 rem      yr      3.7E10 Bq 1.E6 cm3      = 2.37E-15 Sv/h per
                                                    Bq/m3

```

C Note: EXTDF was run with IEXTU=6 instead of IEXTU=3 for these
C runs (GENII soil default), consequently a unit conversion of
C 2.37E-13 was used instead of 2.37-15 (# cm2 vs. cm3). A
C correction of 100.0 is applied in the final step.

TABLE D.2. PHASE8 Computer Program Listing (contd)

```

C      Volume and soil - in GENII:
C
C      Sv m3 0.037 Bq   yr   100 rem "m2"   2.24E5 "g"
C      --- --
C      yr Bq   pCi     8766 h   Sv    0.15 m3   "m2"   = 630 rem/h per
C                                     pCi/"g"

C      Volume and soil:
C
C      rem "g"  1  1000 mrem   "m2"   0.15 m3  1.0E6 cm3  2.4 g
C      --- --
C      h  pCi 100    rem    2.24E5 "g"   "m2"       m3      cm3

C      = 16.07 mrem/h per pCi/g

C      Si unit conversions:
C      -----
C
C      mrem      dpm      dps      Bq      10 uSv
C      --- --
C      h      100 cm2   60 dpm   dps      mrem
C
C      = 1.67E-1 uSv/h per Bq/100 cm2

C
C      mrem g  10 uSv  27 pCi
C      --- --
C      h  pCi mrem      Bq
C
C      = 270 uSv per Bq/g

IF (IT .EQ. 1 .AND. NT .GT. 1) THEN

    REXT1 = REXTD(1,IINT) * 6.76E3 / CHADJ
    REXT2 = REXTD(2,IINT) * 16.07 / CHADJ
    REXT3 = REXTD(3,IINT) * 16.07 / CHADJ

    RTEST1 = REXT1
    RTEST2 = REXT(1,IEXT) * 4.50E-12
    IF (RTEST2 .GT. 0) THEN
        RTEST5 = RTEST1/RTEST2
    ELSE
        RTEST5 = 0.0
    ENDIF

    RTEST1 = REXT2
    RTEST2 = REXT(2,IEXT) * 2.4E-9
    IF (RTEST2 .GT. 0) THEN
        RTEST4 = RTEST1/RTEST2
    ELSE
        RTEST4 = 0.0
    ENDIF

```

TABLE D.2. PHASE8 Computer Program Listing (contd)

```

RTEST1 = REXT3
RTEST2 = REXT(3,IEXT) * 2.4E-9
IF (RTEST2 .GT. 0) THEN
  RTEST3 = RTEST1/RTEST2
ELSE
  RTEST3 = 0.0
ENDIF

WRITE (*,89) ELTM, AWM, CHADJ, RTEST5, RTEST4, RTEST3
WRITE (20,89) ELTM, AWM, CHADJ, RTEST5, RTEST4, RTEST3
FORMAT (' ',A2, A4, 1P, 4G10.2)

```

ELSE

```

REXT1 = REXT(1,IEXT) * 4.50E-12
REXT2 = REXT(2,IEXT) * 2.4E-9
REXT3 = REXT(3,IEXT) * 2.4E-9

```

ENDIF

```

WRITE (4,12) NEXTAB, RITNAM(1) (1:IEND), NEXTAB,
.      REXT1, NEXTAB, REXT1 * 1.67E-1, NEXTAB,
.      REXT2, NEXTAB, REXT2 * 270.0, NEXTAB,
.      REXT3, NEXTAB, REXT3 * 270.0

```

U-nat, Th-nat handling--

IF (U234 .AND. IT .EQ. 1) THEN

```

REXT14 = 0.489 * REXT1
REXT24 = 0.489 * REXT2
REXT34 = 0.489 * REXT3

```

ELSEIF (U235 .AND. IT .EQ. 2) THEN

```

REXT15 = 0.0225 * REXT1
REXT25 = 0.0225 * REXT2
REXT35 = 0.0225 * REXT3

```

ELSEIF (U238 .AND. IT .EQ. 2) THEN

```

REXT18 = 0.489 * REXT1
REXT28 = 0.489 * REXT2
REXT38 = 0.489 * REXT3

```

```

REXT1 = REXT14 + REXT15 + REXT18
REXT2 = REXT24 + REXT25 + REXT28
REXT3 = REXT34 + REXT35 + REXT38

```

TABLE D.2. PHASE8 Computer Program Listing (contd)

```

WRITE (4,12) NEXTAB, UNAT(1) (1:IUEND), NEXTAB,
.      REXT1, NEXTAB, REXT1 * 1.67E-1, NEXTAB,
.      REXT2, NEXTAB, REXT2 * 270.0, NEXTAB,
.      REXT3, NEXTAB, REXT3 * 270.0

ELSEIF (TH232 .AND. IT .EQ. 1) THEN

WRITE (4,12) NEXTAB, THNAT(1) (1:ITHEND), NEXTAB,
.      REXT1, NEXTAB, REXT1 * 1.67E-1, NEXTAB,
.      REXT2, NEXTAB, REXT2 * 270.0, NEXTAB,
.      REXT3, NEXTAB, REXT3 * 270.0

ENDIF

C----- Table 2.2-2.5 - Ingestions -----
C      rem m3 1000 mrem
C      --- --- ----- = 1000 mrem/h per pCi/m3      (air)
C      h pCi      rem

C      rem g 1000 mrem
C      --- --- ----- = 1000 mrem/h per pCi/g      (soil)
C      h pCi      rem

C      rem L 1000 mrem
C      --- --- ----- = 1000 mrem/h per pCi/L      (drinking water)
C      h pCi      rem

IF (IT .EQ. 1) THEN
  RINH1 = RINH(IINT) * 1000.0 / CHADJ
  RSING1 = RSING(IINT) * 1000.0 / CHADJ
  RING1 = RING(1,IINT) * 1000.0 / CHADJ
  RING2 = RING(2,IINT) * 1000.0 / CHADJ
  DW = DWORG(IINT) * 1000.0 / CHADJ
  ORG = ORGAN(IINT)
ELSE
  RINH1 = RINH(IINT) * 1000.0
  RSING1 = RSING(IINT) * 1000.0
  RING1 = RING(1,IINT) * 1000.0
  RING2 = RING(2,IINT) * 1000.0
  DW = DWORG(IINT) * 1000.0
  ORG = ORG(IINT)
ENDIF

C      WRITE (*,89) IT, ELTM, AWM, IINT, RINH1,
C      .      RINH(IINT), RINH(IINT), CHADJ

WRITE (5,12) NEXTAB, RITNAM(2) (1:IEND), NEXTAB,
.      RINH1, NEXTAB, RINH1 * 270.0

```

TABLE D.2. PHASE8 Computer Program Listing (contd)

```

.      WRITE (6,12) NEXTAB, RITNAM(1) (1:IEND), NEXTAB,
.          RSING1, NEXTAB, RSING1 * 270.0
.
.      WRITE (7,13) NEXTAB, RITNAM(2) (1:IEND), NEXTAB,
.          DW, NEXTAB, DW * 270.0, NEXTAB,
.          ORG
.
.      WRITE (12,12) NEXTAB, RITNAM(1) (1:IEND), NEXTAB,
.          RING1, NEXTAB, RING1 * 270.0, NEXTAB,
.          RING2, NEXTAB, RING2 * 270.0

```

C   U-nat, Th-nat handling--

```

IF (U234 .AND. IT .EQ. 1) THEN

```

```

    AINH14 = 0.489 * RINH1
    ASING14 = 0.489 * RSING1
    AING14 = 0.489 * RING1
    AING24 = 0.489 * RING2
    AW4 = 0.489 * DW
    ORG4A = ORG

```

C   WRITE (*,*) 'U-234 set'

```

ELSEIF (U235 .AND. IT .EQ. 2) THEN

```

```

    AINH15 = 0.0225 * RINH1
    ASING15 = 0.0225 * RSING1
    AING15 = 0.0225 * RING1
    AING25 = 0.0225 * RING2
    AW5 = 0.0225 * DW
    ORG5A = ORG

```

C   WRITE (*,*) 'U-235 set - 2', ORG5A

```

ELSEIF (U238 .AND. IT .EQ. 2) THEN

```

```

    AINH18 = 0.489 * RINH1
    ASING18 = 0.489 * RSING1
    AING18 = 0.489 * RING1
    AING28 = 0.489 * RING2
    AW8 = 0.489 * DW
    ORG8A = ORG

```

C   WRITE (*,*) 'U-238 set - 2', ORG8A, IT

```

    RINH1 = AINH14 + AINH15 + AINH18
    RSING1 = ASING14 + ASING15 + ASING18

```

TABLE D.2. PHASE8 Computer Program Listing (contd)

```
RING1 = AING14 + AING15 + AING18
RING2 = AING24 + AING25 + AING28
DW = AW4 + AW5 + AW8
```

```
IF (ORG4A .NE. ORG5A .OR. ORG4A .NE. ORG8A) THEN
  WRITE (*,*) 'Maximum Organ Mismatch'
  WRITE (*,*) ORG4A
  WRITE (*,*) ORG5A
  WRITE (*,*) ORG8A
  ORG = ORG4A
ELSE
  ORG = ORG4A
ENDIF
```

```
.      WRITE (5,12) NEXTAB, UNAT(2) (1:IUEND), NEXTAB,
.      RINH1, NEXTAB, RINH1 * 270.0
```

```
.      WRITE (6,12) NEXTAB, UNAT(1) (1:IUEND), NEXTAB,
.      RSING1, NEXTAB, RSING1 * 270.0
```

```
.      WRITE (7,13) NEXTAB, UNAT(2) (1:IUEND), NEXTAB,
.      DW, NEXTAB, DW * 270.0, NEXTAB,
.      ORG
```

```
.      WRITE (12,12) NEXTAB, UNAT(1) (1:IUEND), NEXTAB,
.      RING1, NEXTAB, RING1 * 270.0, NEXTAB,
.      RING2, NEXTAB, RING2 * 270.0
```

```
ELSEIF (TH232 .AND. IT .EQ. 1) THEN
```

```
.      WRITE (5,12) NEXTAB, THNAT(2) (1:ITHEND), NEXTAB,
.      RINH1, NEXTAB, RINH1 * 270.0
```

```
.      WRITE (6,12) NEXTAB, THNAT(1) (1:ITHEND), NEXTAB,
.      RSING1, NEXTAB, RSING1 * 270.0
```

```
.      WRITE (7,13) NEXTAB, THNAT(2) (1:ITHEND), NEXTAB,
.      DW, NEXTAB, DW * 270.0, NEXTAB,
.      ORG
```

```
.      WRITE (12,12) NEXTAB, THNAT(1) (1:ITHEND), NEXTAB,
.      RING1, NEXTAB, RING1 * 270.0, NEXTAB,
.      RING2, NEXTAB, RING2 * 270.0
```

```
ENDIF
```

C----- Tabl scenario -----

C 500 hours exposure

TABLE D.2. PHASE8 Computer Program Listing (contd)

```

C      1.0E-4 pCi/m3 air concentration
C      0.01 pCi/h diet

      SEXT = REXT2 * 500.0
      SINH = RINH1 * 500.0 * 1.0E-4
      SSING = RSING1 * 500.0 * 0.01

      STOT = SEXT + SINH + SSING
      BVTOT = STOT

      INHFLG = 0
      INGFLG = 0

      QE = SEXT * 0.1
      IF (SINH .GT. QE) INHFLG = 1
      IF (SSING .GT. QE) INGFLG = 1

      IF (INHFLG .EQ. 1 .OR. INGFLG .EQ. 1) THEN

          ICNTRL = 1
          CNTDOS = SINH
          IF (SSING .GT. SINH) THEN
              ICNTRL = 2
              CNTDOS = SSING
          ENDIF

          WRITE (17,16) NEXTAB, RITNAM(2) (1:IEND), NEXTAB,
.              CNTRL(ICNTRL), NEXTAB, CNTDOS
      ENDIF

      WRITE (8,12) NEXTAB, RITNAM(2) (1:IEND), NEXTAB,
.          SEXT, NEXTAB, SINH, NEXTAB, SSING, NEXTAB,
.          STOT, NEXTAB, STOT * 270.0

C      U-nat, Th-nat handling--

      IF (U234 .AND. IT .EQ. 1) THEN

          SEXT4 = 0.489 * SEXT
          SINH4 = 0.489 * SINH
          SSING4 = 0.489 * SSING
          STOT4 = 0.489 * STOT

      ELSEIF (U235 .AND. IT .EQ. 2) THEN

          SEXT5 = 0.0225 * SEXT
          SINH5 = 0.0225 * SINH
          SSING5 = 0.0225 * SSING
          STOT5 = 0.0225 * STOT

```

TABLE D.2. PHASE8 Computer Program Listing (contd)

```

ELSEIF (U238 .AND. IT .EQ. 2) THEN

    SEXT8 = 0.489 * SEXT
    SINH8 = 0.489 * SINH
    SSING8 = 0.489 * SSING
    STOT8 = 0.489 * STOT

    SEXT = SEXT4 + SEXT5 + SEXT8
    SINH = SINH4 + SINH5 + SINH8
    SSING = SSING4 + SSING5 + SSING8
    STOT = STOT4 + STOT5 + STOT8

    INHFLG = 0
    INGFLG = 0

    QE = SEXT * 0.1
    IF (SINH .GT. QE) INHFLG = 1
    IF (SSING .GT. QE) INGFLG = 1

    IF (INHFLG .EQ. 1 .OR. INGFLG .EQ. 1) THEN

        ICNTRL = 1
        CNTDOS = SINH
        IF (SSING .GT. SINH) THEN
            ICNTRL = 2
            CNTDOS = SSING
        ENDIF

        WRITE (17,16) NEXTAB, UNAT(2) (1:IUEND), NEXTAB,
        .           CNTRL(ICNTRL), NEXTAB, CNTDOS
    ENDIF

    WRITE (8,12) NEXTAB, UNAT(2) (1:IUEND), NEXTAB,
    .           SEXT, NEXTAB, SINH, NEXTAB, SSING, NEXTAB,
    .           STOT, NEXTAB, STOT * 270.0

ELSEIF (TH232 .AND. IT .EQ. 1) THEN

    IF (INHFLG .EQ. 1 .OR. INGFLG .EQ. 1) THEN
        WRITE (17,16) NEXTAB, THNAT(2) (1:ITHEND), NEXTAB,
        .           CNTRL(ICNTRL), NEXTAB, CNTDOS
    ENDIF

    WRITE (8,12) NEXTAB, THNAT(2) (1:ITHEND), NEXTAB,
    .           SEXT, NEXTAB, SINH, NEXTAB, SSING, NEXTAB,
    .           STOT, NEXTAB, STOT * 270.0

ENDIF

```

TABLE D.2. PHASE8 Computer Program Listing (contd)

C----- Table 3.2 - Building surface activity scenario -----

```

C      2000 hours exposure
C      1.0E-5 pCi/m3 air concentration
C      0.001 pCi/h diet

      SEXT = REXT1 * 2000.0
      SINH = RINH1 * 2000.0 * 1.0E-5
      SSING = RSING1 * 2000.0 * 0.001

      STOT = SEXT + SINH + SSING
      STOT2 = SEXT * 600.0 + (SINH + SSING) * 270.0
      BSTOT = STOT
      BSTOT2 = STOT

      INHFLG = 0
      INGFLG = 0

      QE = SEXT * 0.1
      IF (SINH .GT. QE) INHFLG = 1
      IF (SSING .GT. QE) INGFLG = 1

      IF (INHFLG .EQ. 1 .OR. INGFLG .EQ. 1) THEN

          ICNTRL = 1
          CNTDOS = SINH
          IF (SSING .GT. SINH) THEN
              ICNTRL = 2
              CNTDOS = SSING
          ENDIF

          WRITE (18,16) NEXTAB, RITNAM(2) (1:IEND), NEXTAB,
.              CNTRL(ICNTRL), NEXTAB, CNTDOS
      ENDIF

      WRITE (9,12) NEXTAB, RITNAM(2) (1:IEND), NEXTAB,
.      SEXT, NEXTAB, SINH, NEXTAB, SSING, NEXTAB,
.      STOT, NEXTAB, STOT2

C      U-nat, Th-nat handling--

      IF (U234 .AND. IT .EQ. 1) THEN

          BEXT4 = 0.489 * SEXT
          BINH4 = 0.489 * SINH
          BSING4 = 0.489 * SSING
          BTOT4 = 0.489 * STOT
          BTOT24 = 0.489 * STOT2
    
```


TABLE D.2. PHASE8 Computer Program Listing (contd)

```
ELSEIF (U235 .AND. IT .EQ. 2) THEN
```

```
  BEXT5 = 0.0225 * SEXT
  BINH5 = 0.0225 * SINH
  BSING5 = 0.0225 * SSING
  BTOT5 = 0.0225 * STOT
  BTOT25 = 0.0225 * STOT2
```

```
ELSEIF (U238 .AND. IT .EQ. 2) THEN
```

```
  BEXT8 = 0.489 * SEXT
  BINH8 = 0.489 * SINH
  BSING8 = 0.489 * SSING
  BTOT8 = 0.489 * STOT
  BTOT28 = 0.489 * STOT2
```

```
  SEXT = BEXT4 + BEXT5 + BEXT8
  SINH = BINH4 + BINH5 + BINH8
  SSING = BSING4 + BSING5 + BSING8
  STOT = BTOT4 + BTOT5 + BTOT8
  STOT2 = BTOT24 + BTOT25 + BTOT28
```

```
  INHFLG = 0
  INGFLG = 0
```

```
  QE = SEXT * 0.1
  IF (SINH .GT. QE) INHFLG = 1
  IF (SSING .GT. QE) INGFLG = 1
```

```
  IF (INHFLG .EQ. 1 .OR. INGFLG .EQ. 1) THEN
```

```
    ICNTRL = 1
    CNTDOS = SINH
    IF (SSING .GT. SINH) THEN
      ICNTRL = 2
      CNTDOS = SSING
    ENDIF
```

```
    WRITE (18,16) NEXTAB, UNAT(2) (1:IUEND), NEXTAB,
      CNTL(ICNTRL), NEXTAB, CNTDOS
  ENDIF
```

```
  WRITE (9,12) NEXTAB, UNAT(2) (1:IUEND), NEXTAB,
    SEXT, NEXTAB, SINH, NEXTAB, SSING, NEXTAB,
    STOT, NEXTAB, STOT2
```

```
ELSEIF (TH232 .AND. IT .EQ. 1) THEN
```

```
  IF (INHFLG .EQ. 1 .OR. INGFLG .EQ. 1) THEN
    WRITE (18,16) NEXTAB, THNAT(2) (1:ITHEND), NEXTAB,
```

TABLE D.2. PHASE8 Computer Program Listing (contd)

```

      CNTRL(ICNTRL), NEXTAB, CNTDOS
    .
    ENDIF

    WRITE (9,12) NEXTAB, THNAT(2) (1:ITHEND), NEXTAB,
    .      SEXT, NEXTAB, SINH, NEXTAB, SSING, NEXTAB,
    .      STOT, NEXTAB, STOT2

    ENDIF

C----- Table 3.3 - Surface soil scenario -----
C
C      2000 hours exposure
C      5.0E-5 pCi/m3 mass loading
C      0.25 diet

    SEXT = (REXT3 * 1800.0) + (4380.0 * 0.33 * REXT3)
    SINH = (RINH1 * 100.0 * 5.0E-4) + (RINH1 * 1700.0 * 1.0E-4) +
    .      (RINH1 * 4380.0 * 5.0E-5)
    .

    SSING = (RING1*5.0E-5 + RING2) * 0.25

    STOT = SEXT + SINH + SSING
    SSTOT = STOT

    INHFLG = 0
    INGFLG = 0

    QE = SEXT * 0.1
    IF (SINH .GT. QE) INHFLG = 1
    IF (SSING .GT. QE) INGFLG = 1

    IF (INHFLG .EQ. 1 .OR. INGFLG .EQ. 1) THEN

        ICNTRL = 1
        CNTDOS = SINH
        IF (SSING .GT. SINH) THEN
            ICNTRL = 2
            CNTDOS = SSING
        ENDIF

        WRITE (19,16) NEXTAB, RITNAM(2) (1:IEND), NEXTAB,
    .      CNTRL(ICNTRL), NEXTAB, CNTDOS
    .
    ENDIF

    WRITE (10,12) NEXTAB, RITNAM(3) (1:IEND), NEXTAB,
    .      SEXT, NEXTAB, SINH, NEXTAB, SSING, NEXTAB,
    .      STOT, NEXTAB, STOT * 270.0

C      U-nat, Th-nat handling--

```

TABLE D.2. PHASE8 Computer Program Listing (contd)

IF (U234 .AND. IT .EQ. 1) THEN

CEXT4 = 0.489 * SEXT
CINH4 = 0.489 * SINH
CSING4 = 0.489 * SSING
CTOT4 = 0.489 * STOT

ELSEIF (U235 .AND. IT .EQ. 2) THEN

CEXT5 = 0.0225 * SEXT
CINH5 = 0.0225 * SINH
CSING5 = 0.0225 * SSING
CTOT5 = 0.0225 * STOT

ELSEIF (U238 .AND. IT .EQ. 2) THEN

CEXT8 = 0.489 * SEXT
CINH8 = 0.489 * SINH
CSING8 = 0.489 * SSING
CTOT8 = 0.489 * STOT

SEXT = CEXT4 + CEXT5 + CEXT8
SINH = CINH4 + CINH5 + CINH8
SSING = CSING4 + CSING5 + CSING8
STOT = CTOT4 + CTOT5 + CTOT8

INHFLG = 0
INGFLG = 0

QE = SEXT * 0.1
IF (SINH .GT. QE) INHFLG = 1
IF (SSING .GT. QE) INGFLG = 1

IF (INHFLG .EQ. 1 .OR. INGFLG .EQ. 1) THEN

ICNTRL = 1
CNTDOS = SINH
IF (SSING .GT. SINH) THEN
ICNTRL = 2
CNTDOS = SSING
ENDIF

WRITE (19,16) NEXTAB, UNAT(2) (1:IUEND), NEXTAB,
CNTRL(ICNTRL), NEXTAB, CNTDOS

ENDIF

WRITE (10,12) NEXTAB, UNAT(3) (1:IUEND), NEXTAB,
SEXT, NEXTAB, SINH, NEXTAB, SSING, NEXTAB,
STOT, NEXTAB, STOT * 270.0

TABLE D.2. PHASE8 Computer Program Listing (contd)

```

ELSEIF (TH232 .AND. IT .EQ. 1) THEN
    IF (INHFLG .EQ. 1 .OR. INGFLG .EQ. 1) THEN
        WRITE (19,16) NEXTAB, THNAT(2) (1:ITHEND), NEXTAB,
        CNTRL(ICNTRL), NEXTAB, CNTDOS
    ENDIF

    WRITE (10,12) NEXTAB, THNAT(3) (1:ITHEND), NEXTAB,
    SEXT, NEXTAB, SINH, NEXTAB, SSING, NEXTAB,
    STOT, NEXTAB, STOT * 270.0

ENDIF

```

C----- Table 3.4 - Drinking water scenario -----

```

RLAML = PC * 8.1E-3
RLAM = ALOG / (HL / 365.0)

IF (RLAM .GT. 50.0) THEN
    REXP = 0.0
ELSE
    REXP = DEXP (-RLAM)
ENDIF

IF (RLAM+RLAML .GT. 50.0) THEN
    REXP2 = 0.0
ELSE
    REXP2 = DEXP (-RLAM -RLAML)
ENDIF

CONV1 = (1.0 - REXP) / RLAM
CONV2 = (1.0 - REXP2) / (RLAM + RLAML)

WBAR = 1.0 / 91250.0 * (CONV1 - CONV2)
DWING = RSING1 * 730.0 * WBAR
DWO = DW * 730.0 * WBAR
TITOT = DWO

IF (IT .EQ. 1) THEN
    ORG = ORGAN(IINT)
ELSE
    ORG = ORGNO(IINT)
ENDIF

WRITE (11,15) NEXTAB, RITNAM(3) (1:IEND), NEXTAB,
DWING, NEXTAB, DWING * 270.0, NEXTAB,
DWO, NEXTAB, DWO * 270.0, NEXTAB, ORG

```

C U-nat, Th-nat handling--

TABLE D.2. PHASE8 Computer Program Listing (contd)

```

IF (U234 .AND. IT .EQ. 1) THEN

    DWING4 = 0.489 * DWING
    DWO4 = 0.489 * DWO
    ORG4B = ORG

ELSEIF (U235 .AND. IT .EQ. 2) THEN

    DWING5 = 0.0225 * DWING
    DWO5 = 0.0225 * DWO
    ORG5B = ORG
    WRITE (*,*) 'U-235 set - 3',ORG5B, IT

ELSEIF (U238 .AND. IT .EQ. 2) THEN

    DWING8 = 0.489 * DWING
    DWO8 = 0.489 * DWO
    ORG8B = ORG

    DWING = DWING4 + DWING5 + DWING8
    DWO = DWO4 + DWO5 + DWO8

    IF (ORG4B .NE. ORG5B .OR. ORG4B .NE. ORG8B) THEN
        WRITE (*,*) 'Maximum Organ Mismatch - 3',
            ORG4B, ORG5B, ORG8B
        ORG = ' '
    ELSE
        ORG = ORG4B
    ENDIF

    WRITE (11,15) NEXTAB, UNAT(3) (1:IUEND), NEXTAB,
        DWING, NEXTAB, DWING * 270.0, NEXTAB,
        DWO, NEXTAB, DWO * 270.0, NEXTAB, ORG

ELSEIF (TH232 .AND. IT .EQ. 1) THEN

    WRITE (11,15) NEXTAB, THNAT(3) (1:ITHEND), NEXTAB,
        DWING, NEXTAB, DWING * 270.0, NEXTAB,
        DWO, NEXTAB, DWO * 270.0, NEXTAB, ORG

ENDIF

```

C----- Table 1 - Allowable limits for buildings -----

RLIMRM = 10.0
RLIMSV = 100.0

C Building volume--

TABLE D.2. PHASE8 Computer Program Listing (contd)

```
BVLIMR = RLIMRM / BVTOT
BVLIMS = RLIMSV / (BVTOT * 270.0)
```

```
C      Building surface--
      BSLIMR = RLIMRM / BSTOT
      BSLIMS = RLIMSV / BSTOT2

      WRITE (14,12) NEXTAB, RITNAM(2) (1:IEND), NEXTAB,
      .           BVLIMR, NEXTAB, BVLIMS, NEXTAB,
      .           BSLIMR, NEXTAB, BSLIMS
```

```
C      U-nat, Th-nat handling--

      IF (U234 .AND. IT .EQ. 1) THEN
        BVTOT4 = 0.489 * BVTOT
        BSTOT4 = 0.489 * BSTOT
        BST42 = 0.489 * BSTOT2

      ELSEIF (U235 .AND. IT .EQ. 2) THEN
        BVTOT5 = 0.0225 * BVTOT
        BSTOT5 = 0.0225 * BSTOT
        BST52 = 0.0225 * BSTOT2

      ELSEIF (U238 .AND. IT .EQ. 2) THEN
        BVTOT8 = 0.489 * BVTOT
        BSTOT8 = 0.489 * BSTOT
        BST82 = 0.489 * BSTOT2

        BVTOT = BVTOT4 + BVTOT5 + BVTOT8
        BSTOT = BSTOT4 + BSTOT5 + BSTOT8
        BSTOT2 = BST42 + BST52 + BST82
```

```
C      Building volume--
      BVLIMR = RLIMRM / BVTOT
      BVLIMS = RLIMSV / (BVTOT * 270.0)
```

```
C      Building surface--
      BSLIMR = RLIMRM / BSTOT
      BSLIMS = RLIMSV / BSTOT2

      WRITE (14,12) NEXTAB, UNAT(2) (1:IUEND), NEXTAB,
      .           BVLIMR, NEXTAB, BVLIMS, NEXTAB,
      .           BSLIMR, NEXTAB, BSLIMS

      ELSEIF (TH232 .AND. IT .EQ. 1) THEN
        WRITE (14,12) NEXTAB, THNAT(2) (1:ITHEND), NEXTAB,
        .           BVLIMR, NEXTAB, BVLIMS, NEXTAB,
        .           BSLIMR, NEXTAB, BSLIMS
```

TABLE D.2. PHASE8 Computer Program Listing (contd)

```

ENDIF

C----- Table 2 - Allowable limits for soils -----

RLIMRM = 10.0
RLIMSV = 100.0

C      Surface soil--
      SSLIMR = RLIMRM / SSTOT
      SSLIMS = RLIMSV / (SSTOT * 270.0)

C      Total inventory--
      TILIMR = RLIMRM / TITOT
      TILIMS = RLIMSV / (TITOT * 270.0)

      WRITE (15,12) NEXTAB, RITNAM(2) (1:IEND), NEXTAB,
.              SSLIMR, NEXTAB, SSLIMS, NEXTAB,
.              TILIMS, NEXTAB, TILIMS

C      U-nat, Th-nat handling--

      IF (U234 .AND. IT .EQ. 1) THEN
        SSTOT4 = 0.489 * SSTOT
        TITOT4 = 0.489 * TITOT

      ELSEIF (U235 .AND. IT .EQ. 2) THEN
        SSTOT5 = 0.0225 * SSTOT
        TITOT5 = 0.0225 * TITOT

      ELSEIF (U238 .AND. IT .EQ. 2) THEN
        SSTOT8 = 0.489 * SSTOT
        TITOT8 = 0.489 * TITOT

      SSTOT = SSTOT4 + SSTOT5 + SSTOT8
      TITOT = TITOT4 + TITOT5 + TITOT8

C      Surface soil--
      SSLIMR = RLIMRM / SSTOT
      SSLIMS = RLIMSV / (SSTOT * 270.0)

C      Total inventory--
      TILIMR = RLIMRM / TITOT
      TILIMS = RLIMSV / (TITOT * 270.0)

      WRITE (15,12) NEXTAB, UNAT(2) (1:IUEND), NEXTAB,
.              SSLIMR, NEXTAB, SSLIMS, NEXTAB,
.              TILIMR, NEXTAB, TILIMS

      ELSEIF (TH232 .AND. IT .EQ. 1) THEN

```

TABLE D.2. PHASE8 Computer Program Listing (contd)

```

        WRITE (15,12) NEXTAB, THNAT(2) (1:ITHEND), NEXTAB,
.          SSLIMR, NEXTAB, SSLIMS, NEXTAB,
.          TILIMR, NEXTAB, TILIMS

        ENDIF

400    CONTINUE

        ELTOLD = ELTM
        GOTO 7
C----- End of loop -----

        9 CONTINUE

        DO 502 K = 4, 12
            CLOSE (K)
502    CONTINUE

        CALL EXIT (1)

C---- Format Statements -----

        1 FORMAT (A2, A5, 5E8.0, A21)
        2 FORMAT (A2, A6, 3(E8.0, 2X))
        3 FORMAT (' ', A)
        12 FORMAT (A1, A, A1, 1P, 6(E7.1, A1))
        13 FORMAT (A1, A, A1, 1P, 2(E7.1, A1), A21, A1)
        14 FORMAT (A2, A6, 3X, E8.0, E9.0, 11X, E7.0, 1X, 2I2, E7.0)
        15 FORMAT (A1, A, A1, 1P, 4(E7.1, A1), A21, A1)
        16 FORMAT (A1, A, A1, A, A1, 1PE7.1, A1)

C-----
        END

```


TABLE D.3. Radionuclide Control List (RMDLIBDA.SHT)

NRC: no noble gas, equil mult, leaching, beta, imp dau/chadji (10-Jan-90 RAP)						
H 3	4.49E+3	1.0	1	ND	1.15	1
BE10	5.84E+8	1.0	4	VY	0.1	1
C 14	2.09E+6	1.0	6	ND	1.15E-1	1
F 18	7.62E-2	1.0	9	SD	1.15E-1	0
NA22	9.50E+2	1.0	11	VD	1.61E-4	0
NA24	6.25E-1	1.0	11	VD	1.61E-4	0
P 32	1.43E+1	1.0	15	SD	1.26E-3	1
P 33	2.54E+1	1.0	15	VD	1.26E-3	1
S 35	8.74E+1	1.0	16	NW	1.20E-2	1
CL36	1.1E+8	1.0	17	ND	1.15E-1	0
K 40	4.67E11	1.0	19	ND	1.62E-4	0
CA41	3.67E+7	1.0	20	1 VW	9.86E-3	0
CA45	1.63E+2	1.0	20	1 VW	9.86E-3	0
SC46	8.38E+1	1.0	21	VY	1.11E-4	0
CR51	2.77E+1	1.0	24	VY	1.26E-3	0
MN54	3.13E+2	1.0	25	SW	1.26E-3	0
MN56	1.07E-1	1.0	25	SW	1.26E-3	0
FE55	9.86E+2	1.0	26	NW	1.48E-2	0
FE59	4.46E+1	1.0	26	NW	1.48E-2	0
CO57	2.71E+2	1.0	27	NY	1.48E-2	0
CO58	7.08E+1	1.0	27	NY	1.48E-2	0
CO60	1.92E+3	1.0	27 T	NY	1.48E-2	0
NI59	2.74E+7	1.0	28	NW	1.48E-2	0
NI63	3.65E+4	1.0	28	NW	1.48E-2	1
NI65	1.05E-1	1.0	28	NW	1.48E-2	0
CU64	5.29E-1	1.0	29	ND	0.1	0
ZN65	2.44E+2	1.0	30 T	VY	1.48E-2	0
ZN69M	5.73E-1	2.0	30	SY	1.48E-2	0
ZN69	3.86E-2	1.0	30	SY	1.48E-2	0
AS76	1.10E+0	1.0	33	NW	0.1	0
SE75	1.2E+2	1.0	34	NW	1.20E-2	0
SE79	2.37E+7	1.0	34	NW	1.20E-2	1
BR82	1.47E+0	1.0	35	ND	1.15E-1	0
BR83	9.96E-2	2.0	35	ND	1.15E-1	0
BR84	2.21E-2	1.0	35	ND	1.15E-1	0
RB86	1.87E+1	1.0	37	VD	1.62E-4	0
RB88	1.24E-2	1.0	37	VD	1.62E-4	0
RB89	1.07E-2	2.0	37	VD	1.62E-4	0
SR85	6.5E+1	1.0	38	1 VD	9.86E-3	0
SR89	5.06E+1	1.0	38	1 VD	9.86E-3	0
SR90	1.04E+4	2.0	38 T	1 VD	9.86E-3	0
SR91	3.96E-1	2.574	38	1 SD	9.86E-3	0
SR92	1.13E-1	2.0	38	1 SD	9.86E-3	0
Y 90	2.67E+0	1.0	39 T	SY	0.1	0
Y 91M	3.45E-2	2.0	39	SY	0.1	0
Y 91	5.85E+1	1.0	39	SY	0.1	0
Y 92	1.48E-1	1.0	39	SY	0.1	0
Y 93	4.21E-1	1.0	39	SY	0.1	0
ZR93	5.58E+8	2.0	40	SW	9.86E-3	1

TABLE D.3. Radionuclide Control List (RMDLIBDA.SHT) (contd)

ZR95	6.40E+1	2.007	40	SW	9.86E-3	0		
ZR97	7.04E-1	2.947	40	SW	9.86E-3	0		
NB93M	5.33E+3	1.0	41	VY	1.11E-2	0		
NB94	7.41E+6	1.0	41	VY	1.11E-2	0		
NB95M	3.61E+0	1.945	41	SY	1.11E-2	0		
NB95	3.51E+1	1.0	41	SY	1.11E-2	0		
NB97M	6.94E-4	2.0	41	SY	1.11E-2	0		
NB97	5.01E-2	1.0	41	SY	1.11E-2	0		
MO93	1.28E+6	2.0	42	SD	1.15E-1	0		
MO99	2.75E+0	1.886	42	SD	1.15E-1	0		
TC99M	2.51E-1	1.0	43	NW	1.15E-1	0		
TC99	7.77E+7	1.0	43 T	NW	1.15E-1	0		
TC101	9.86E-3	1.0	43	NW	1.15E-1	0		
RU103	3.94E+1	1.9974	44	NY	1.15E-1	0		
RU105	1.85E-1	3.0	44	NY	1.15E-1	0	1	1.0
RU106	3.68E+2	2.0	44 T	NY	1.15E-1	1	1	1.0
RH103M	3.90E-2	1.0	45	NY	0.1	0		
RH105	1.47E+0	1.0	45	NY	0.1	0		
PD103	1.70E+1	1.9997	46	VY	0.1	0		
PD107	2.37E+9	1.0	46	VY	0.1	1		
PD109	5.61E-1	2.0	46	VY	0.1	0	1	1.0
AG110M	2.50E+2	1.985	47	ND	1.62E-4	0	1	0.985
AG111	7.46E+0	1.0	47	ND	1.62E-4	0		
CD109	4.64E+2	1.0	48	ND	1.48E-2	0		
CD113M	5.00E+3	1.0	48	ND	1.48E-2	1		
CD115M	4.46E+1	2.0	48	ND	1.48E-2	0		
CD115	2.23E+0	1.0	48	ND	1.48E-2	0		
IN111	2.8E+0	1.0	49	VD	0.1	0		
IN114M	5.00E+1	1.957	49	VD	0.1	0	1	0.957
IN115M	1.82E-1	1.0	49	VD	0.1	0		
SN117M	1.40E+1	1.0	50	SW	1.62E-4	0		
SN119M	2.93E+2	1.0	50	VW	1.62E-4	0		
SN121M	2.01E+4	1.776	50	VW	1.62E-4	2		
SN121	1.13E+0	1.0	50	VW	1.62E-4	1		
SN123	1.29E+2	1.0	50	VW	1.62E-4	0		
SN125	9.64E+0	2.23	50	SW	1.62E-4	0		
SN126	3.65E+7	2.14	50	VW	1.62E-4	0		
SB124	6.02E+1	1.0	51	SW	1.62E-4	0		
SB125	1.01E+3	1.231	51	SW	1.62E-4	0		
SB126M	1.32E-2	1.14	51	SW	1.62E-4	0		
SB126	1.24E+1	1.0	51	SW	1.62E-4	0		
SB127	3.85E+0	2.166	51	SW	1.62E-4	0		
TE123M	1.20E+2	1.0	52	SW	0.1	0		
TE125M	5.80E+1	1.0	52	SW	0.1	0		
TE127M	1.09E+2	1.982	52	SW	0.1	0		
TE127	3.90E-1	1.0	52	SW	0.1	0		
TE129M	3.36E+1	1.629	52	SW	0.1	0		
TE129	4.83E-2	1.0	52	SW	0.1	0		
TE131M	1.25E+0	2.233	52	SW	0.1	0		
TE131	1.74E-2	2.0109	52 T	SW	0.1	0		

TABLE D.3. Radionuclide Control List (RMDLIBDA.SHT) (contd)

TE132	3.26E+0	2.0	52	SW	0.1	0
TE133M	3.85E-2	3.1588	52	SW	0.1	0
TE133	8.65E-3	3.0288	52	SW	0.1	0
TE134	2.90E-2	2.0	52	SW	0.1	0
I 125	6.01E+1	1.0	53	2 ND	1.15E-1	0
I 129	5.73E+9	1.0	53 T 2	ND	1.15E-1	0
I 130	5.15E-1	1.0	53	2 ND	1.15E-1	0
I 131	8.04E+0	1.0109	53 T 2	ND	1.15E-1	0
I 132	9.58E-2	1.0	53	2 ND	1.15E-1	0
I 133	8.67E-1	2.0288	53	2 ND	1.15E-1	0
I 134	3.65E-2	1.0	53	2 ND	1.15E-1	0
I 135	2.75E-1	2.165	53	2 ND	1.15E-1	0
CS134M	1.21E-1	2.0	55	ND	1.62E-4	0
CS134	7.53E+2	1.0	55	ND	1.62E-4	0
CS135	8.40E+8	1.0	55	ND	1.62E-4	1
CS136	1.32E+1	1.0	55	ND	1.62E-4	0
CS137	1.10E+4	1.946	55 T	ND	1.62E-4	1 1 0.946
CS138	2.24E-2	1.0	55	ND	1.62E-4	0
BA139	5.77E-2	1.0	56	1 SD	1.11E-4	0
BA140	1.28E+1	2.0	56 T 1	SD	1.11E-4	0
BA141	1.27E-2	3.0	56	1 SD	1.11E-4	0
BA142	7.43E-3	2.0	56	1 SD	1.11E-4	0
LA140	1.68E+0	1.0	57 T	SD	1.11E-4	0
LA141	1.64E-1	2.0	57	SD	1.11E-4	0
LA142	6.63E-2	1.0	57	SD	1.11E-4	0
CE141	3.25E+1	1.0	58	SY	4.67E-4	0
CE143	1.38E+0	2.0	58	SY	4.67E-4	0
CE144	2.84E+2	2.0143	58 T	SY	4.67E-4	0
PR143	1.36E+1	1.0	59	SY	0.1	0
PR144M	5.00E-3	2.0	59	SY	0.1	0
PR144	1.20E-2	1.0	59 T	SY	0.1	0
ND147	1.10E+1	2.0	60	SY	0.1	0
PM147	9.58E+2	1.0	61	SY	0.1	0
PM148M	4.13E+1	1.0420	61	SY	0.1	0
PM148	5.37E+0	1.0	61	SY	0.1	0
PM149	2.21E+0	1.0	61	SY	0.1	0
PM151	1.18E+0	1.0	61	SY	0.1	0
SM147	3.87E13	1.0	62	SW	0.1	1
SM151	3.29E+4	1.0	62	SW	0.1	0
SM153	1.95E+0	1.0	62	SW	0.1	0
EU152	4.96E+3	1.0	63	SW	1.11E-4	0
EU154	3.21E+3	1.0	63	SW	1.11E-4	0
EU155	1.81E+3	1.0	63	SW	1.11E-4	0
EU156	1.52E+1	1.0	63	SW	1.11E-4	0
GD153	2.42E+2	1.0	64	SD	0.1	0
TB160	7.23E+1	1.0	65	SW	0.1	0
HO166M	4.38E+5	1.0	67	SW	0.1	0
W 181	1.21E+2	1.0	74	VD	0.1	0
W 185	7.51E+1	1.0	74	VD	0.1	0
W 187	9.93E-1	1.0	74	SD	0.1	0

TABLE D.3. Radionuclide Control List (RMDLIBDA.SHT) (contd)

RE187	1.72E13	1.0	75	NW	0.1	1	
OS185	9.36E+1	1.0	76	ND	0.1	0	
OS191	1.5E+1	1.0	76	ND	0.1	0	
IR192	7.40E+1	1.0	77	NY	0.1	0	
HG203	4.66E+1	1.0	80	ND	0.1	0	
PB210	8.12E+3	3.0	82 T	VD	4.11E-3	0	
PB212	4.43E-1	3.0	82	SD	4.11E-3	0	
BI210	5.01E+0	2.0	83 T	NW	0.1	1	
BI212	4.20E-2	2.0	83	NW	0.1	0	2 1.0
PO210	1.38E+2	1.0	84 T	NW	4.11E-3	0	
RA223	1.14E+1	6.0	88 1	SW	4.11E-3	0	5 5.0
RA224	3.62E+0	6.0	88 1	SW	4.11E-3	0	2 2.0
RA225	1.48E+1	7.0	88 1	SW	4.11E-3	0	
RA226	5.84E+5	9.0	88 T 1	VW	4.11E-3	0	
RA228	2.10E+3	9.0	88 1	VW	4.11E-3	0	
AC225	1.00E+1	6.0	89	SY	4.11E-3	0	6 5.0
AC227	7.95E+3	8.0	89	SY	4.11E-3	0	
AC228	2.55E-1	8.0	89	SY	4.11E-3	0	
TH227	1.87E+1	7.0	90	SY	4.11E-3	0	
TH228	6.98E+2	7.0	90	SY	4.11E-3	0	
TH229	2.68E+6	8.0	90	SY	4.11E-3	0	
TH230	2.81E+7	1.0	90	SY	4.11E-3	0	
TH231	1.06E+0	10.0	90	SY	4.11E-3	0	
TH232	5.13E12	10.0	90	SY	4.11E-3	0	
TH234	2.41E+1	1.9996	90	SY	4.11E-3	0	1 0.998
PA231	1.36E+7	9.0	91	SY	4.11E-3	0	
PA233	2.70E+1	1.0	91	SY	4.11E-3	0	
PA234	2.79E-1	1.0	91	SY	4.11E-3	0	
U 232	2.36E+4	7.0	92	VY	1.24E-4	0	
U 233	5.58E+7	9.0	92	VY	1.24E-4	0	
U 234	8.29E+7	1.0	92	VY	1.24E-4	0	
U 235	2.57E11	2.0	92	VY	1.24E-4	0	
U 236	8.55E+9	1.0	92	VY	1.24E-4	0	
U 237	6.75E+0	1.0	92	SY	1.24E-4	0	
U 238	1.63E12	2.9996	92	VY	1.24E-4	0	
U 240	5.88E-1	3.0	92	SY	1.24E-4	0	1 1.0
NP237	7.81E+8	2.0	93	SW	4.67E-4	0	
NP238	2.12E+0	2.0	93	SW	4.67E-4	0	
NP239	2.36E+0	2.0	93	SW	4.67E-4	0	
PU236	1.04E+3	1.0	94	SY	4.67E-4	0	
PU237	4.53E+1	1.0	94	SY	4.67E-4	0	
PU238	3.20E+4	1.0	94	SY	4.67E-4	0	
PU239	8.81E+6	1.0	94 T	SY	4.67E-4	0	
PU240	2.40E+6	1.0	94	SY	4.67E-4	0	
PU241	5.26E+3	2.0	94	SY	4.67E-4	0	
PU242	1.37E+8	1.0	94	SY	4.67E-4	0	
PU243	1.92E-1	2.0	94	SY	4.67E-4	0	
PU244	3.01E10	3.9976	94	SY	4.67E-4	0	
AM241	1.58E+5	1.0	95 T	SW	4.11E-3	0	
AM242M	5.55E+4	3.827	95	SW	4.11E-3	0	

TABLE D.3. Radionuclide Control List (RMDLIBDA.SHT) (contd)

AM242	6.68E-1	2.827	95	SW	4.11E-3	0
AM243	2.69E+6	3.0	95	SW	4.11E-3	0
CM242	1.63E+2	1.8270	96	SW	4.67E-4	0
CM243	1.04E+4	1.0	96	SW	4.67E-4	0
CM244	6.61E+3	2.0	96	SW	4.67E-4	0
CM245	3.10E+6	3.0	96	SW	4.67E-4	0
CM246	1.73E+6	1.0	96	SW	4.67E-4	0
CM247	5.69E+9	2.0	96	SW	4.67E-4	0
CM248	1.24E+8	1.0	96	SW	4.67E-4	0
CF252	9.63E+2	1.0	98	SW	4.11E-3	0

TABLE D.4. External Dose Rate Factors for Individual Radionuclides (EXTERNAL.DF)

NRC Residual Radiation External DFs (rem/h per Ci/cm² or cm³) 21-Dec-89 RAP

Col 1: Infinite disk source, concrete

Col 2: 1 cm thick, 5m disk source, concrete

Col 3: 15 cm thick infinite slab source, soil

H 3	5.29E-05	4.23E-06	4.38E-06
BE10	1.89E+01	5.87E+00	5.48E+01
C 14	1.12E+00	1.71E-01	9.39E-01
N 13	3.68E+04	2.57E+04	4.36E+05
F 18	3.56E+04	2.49E+04	4.22E+05
NA22	7.98E+04	5.78E+04	8.89E+05
NA24	1.48E+05	1.14E+05	1.72E+06
SI31	1.63E+02	9.38E+01	1.22E+03
P 32	1.70E+02	9.46E+01	1.22E+03
P 33	3.33E+00	6.39E-01	4.25E+00
S 35	1.26E+00	1.99E-01	1.13E+00
CL36	2.91E+01	1.06E+01	1.09E+02
K 40	6.01E+03	4.50E+03	6.46E+04
AR39	1.88E+01	5.89E+00	5.52E+01
AR41	4.64E+04	3.45E+04	4.93E+05
CA41	7.19E+01	5.75E+00	5.95E+00
CA45	3.45E+00	6.71E-01	4.51E+00
SC46	7.92E+04	5.82E+04	8.28E+05
CR51	1.48E+03	9.28E+02	1.46E+04
MN54	3.27E+04	2.35E+04	3.31E+05
MN56	6.49E+04	4.84E+04	7.14E+05
FE55	1.64E+02	1.31E+01	1.36E+01
FE59	4.23E+04	3.14E+04	4.57E+05
CO57	5.25E+03	2.85E+03	3.15E+04
CO58	3.86E+04	2.76E+04	4.01E+05
CO60	9.34E+04	6.95E+04	9.93E+05
NI59	2.00E+02	1.60E+01	1.65E+01
NI63	8.94E-02	8.23E-03	2.39E-02
NI65	2.15E+04	1.60E+04	2.31E+05
CU64	6.92E+03	4.78E+03	8.05E+04
ZN65	2.44E+04	1.80E+04	2.58E+05
ZN69M	1.75E+04	1.22E+04	2.07E+05
ZN69	4.82E+01	1.93E+01	2.10E+02
GA72	1.02E+05	7.61E+04	1.13E+06
AS76	1.91E+04	1.36E+04	2.04E+05
SE75	1.46E+04	9.06E+03	1.22E+05
SE79	8.66E-01	1.26E-01	6.70E-01
BR82	1.07E+05	7.71E+04	1.13E+06
BR83	3.07E+02	2.00E+02	3.28E+03
KR83M	1.36E+02	1.10E+01	1.22E+01
BR84	6.23E+04	4.73E+04	7.21E+05
KR85M	5.77E+03	3.52E+03	4.54E+04
KR85	1.06E+02	6.50E+01	1.04E+03
KR87	3.10E+04	2.30E+04	3.60E+05
RB87	3.64E+00	7.30E-01	5.03E+00

TABLE D.4. External Dose Rate Factors for Individual Radionuclides (EXTERNAL.DF) (contd)

KR88	6.90E+04	5.25E+04	7.85E+05
RB88	2.55E+04	1.92E+04	2.90E+05
KR89	6.77E+04	5.06E+04	7.66E+05
RB89	7.62E+04	5.72E+04	8.52E+05
SR89	1.43E+02	7.09E+01	8.83E+02
SR87M	1.13E+04	7.69E+03	1.22E+05
RB86	3.58E+03	2.61E+03	3.85E+04
SR85	1.86E+04	1.28E+04	2.17E+05
SR90	1.61E+01	4.87E+00	4.47E+01
Y 90	3.47E+02	1.90E+02	2.50E+03
SR91	2.61E+04	1.89E+04	2.81E+05
Y 91M	2.49E+04	1.75E+04	2.65E+05
Y 91	2.87E+02	1.76E+02	2.38E+03
SR92	5.37E+04	4.04E+04	5.81E+05
Y 92	1.11E+04	8.11E+03	1.20E+05
Y 93	3.90E+03	2.77E+03	4.05E+04
MO93	3.84E+02	3.07E+01	3.18E+01
ZR93	7.09E-02	6.31E-03	1.68E-02
NB93M	7.97E+01	6.37E+00	6.60E+00
ZR95	2.95E+04	2.10E+04	3.05E+05
NB95M	2.62E+03	1.54E+03	2.07E+04
NB95	3.25E+04	2.34E+04	3.31E+05
ZR97	7.17E+03	5.19E+03	7.75E+04
NB97M	2.56E+04	1.80E+04	2.73E+05
NB97	2.65E+04	1.86E+04	2.82E+05
NB94	5.87E+04	4.19E+04	6.10E+05
MO99	5.72E+03	3.94E+03	5.74E+04
TC99M	4.52E+03	2.59E+03	2.88E+04
TC99	4.19E+00	8.86E-01	6.33E+00
TC101	1.47E+04	1.00E+04	1.59E+05
RU103	1.82E+04	1.27E+04	2.13E+05
PD103	1.04E+03	8.89E+01	3.95E+02
RH103M	1.36E+02	1.14E+01	4.18E+01
RU105	3.13E+04	2.14E+04	3.27E+05
RH105	3.37E+03	2.29E+03	3.64E+04
RU106	8.72E+03	6.08E+03	9.57E+04
PD107	5.45E-03	4.37E-04	5.21E-04
PD109	7.09E+02	1.35E+02	1.22E+03
AG110M	1.08E+05	7.83E+04	1.15E+06
AG111	1.11E+03	7.34E+02	1.14E+04
CD109	9.81E+02	8.16E+01	3.30E+02
CD113M	1.81E+01	5.73E+00	5.41E+01
CD115M	1.02E+03	7.17E+02	1.04E+04
CD115	7.33E+03	5.05E+03	8.49E+04
IN115M	6.90E+03	4.41E+03	6.97E+04
IN111	1.46E+04	8.38E+03	1.07E+05
IN114M	5.30E+03	3.23E+03	4.63E+04
SN113	1.28E+03	2.08E+02	1.96E+03
IN113M	9.23E+03	6.09E+03	9.66E+04

TABLE D.4. External Dose Rate Factors for Individual Radionuclides (EXTERNAL.DF) (contd)

SN117M	5.44E+03	2.65E+03	2.89E+04
SN119M	7.05E+02	5.86E+01	2.26E+02
SN121M	0.00E+00	0.00E+00	0.00E+00
SN121	0.00E+00	0.00E+00	0.00E+00
SN123	3.62E+02	2.37E+02	3.37E+03
I 125	2.25E+03	2.47E+02	1.20E+03
SN125	1.18E+04	8.68E+03	1.29E+05
SB125	1.83E+04	1.23E+04	1.94E+05
TE125M	1.90E+03	2.17E+02	1.10E+03
SN126	1.92E+03	7.21E+02	6.54E+03
SB126M	6.28E+04	4.41E+04	6.88E+05
SB126	1.07E+05	7.57E+04	1.16E+06
SB122	2.04E+04	1.43E+04	2.16E+05
SB124	7.40E+04	5.44E+04	8.10E+05
SB127	2.60E+04	1.82E+04	2.79E+05
TE127M	6.16E+02	6.92E+01	3.57E+02
TE127	2.33E+02	1.52E+02	2.49E+03
TE123M	5.00E+03	2.52E+03	2.75E+04
TE129M	1.67E+03	8.98E+02	1.31E+04
TE129	2.47E+03	1.54E+03	2.46E+04
I 129	1.22E+03	1.40E+02	6.98E+02
TE131M	5.74E+04	4.13E+04	5.93E+05
TE131	1.64E+04	1.11E+04	1.63E+05
I 131	1.44E+04	9.80E+03	1.54E+05
XE131M	9.57E+02	1.48E+02	1.06E+03
TE132	9.68E+03	5.58E+03	7.43E+04
I 132	9.14E+04	6.57E+04	9.72E+05
TE133M	8.91E+04	6.48E+04	9.58E+05
TE133	3.75E+04	2.69E+04	4.11E+05
I 133	2.16E+04	1.52E+04	2.48E+05
XE133M	1.85E+03	7.14E+02	8.89E+03
XE133	1.73E+03	6.32E+02	5.52E+03
TE134	3.52E+04	2.41E+04	3.57E+05
I 134	1.01E+05	7.33E+04	1.07E+06
CS134M	1.26E+03	4.85E+02	4.79E+03
CS134	6.56E+04	4.68E+04	6.85E+05
I 130	7.98E+04	5.62E+04	8.80E+05
I 135	6.01E+04	4.48E+04	6.53E+05
XE135M	1.51E+04	1.04E+04	1.77E+05
XE135	9.50E+03	6.10E+03	8.39E+04
CS135	1.67E+00	2.95E-01	1.82E+00
XE137	8.63E+03	6.02E+03	9.68E+04
CS137	2.24E+04	1.57E+04	2.38E+05
XE138	4.27E+04	3.17E+04	4.79E+05
CS138	9.00E+04	6.75E+04	1.00E+06
CS139	1.22E+04	9.05E+03	1.33E+05
BA139	1.46E+03	8.47E+02	1.02E+04
BA140	7.03E+03	4.65E+03	7.67E+04
LA140	8.39E+04	6.22E+04	9.14E+05

TABLE D.4. External Dose Rate Factors for Individual Radionuclides (EXTERNAL.DF) (contd)

CS136	8.28E+04	5.96E+04	8.64E+05
BA141	3.37E+04	2.36E+04	3.49E+05
LA141	2.10E+03	1.51E+03	2.15E+04
CE141	2.74E+03	1.47E+03	1.60E+04
BA142	3.50E+04	2.52E+04	3.65E+05
LA142	9.75E+04	7.42E+04	1.14E+06
CE143	9.94E+03	6.10E+03	8.60E+04
PR143	4.80E+01	1.93E+01	2.11E+02
CE144	7.49E+02	3.69E+02	3.90E+03
PR144M	5.71E+02	1.14E+02	6.70E+02
PR144	1.73E+03	1.20E+03	1.75E+04
PR142	2.33E+03	1.70E+03	2.42E+04
ND147	5.11E+03	3.04E+03	4.58E+04
PM147	2.38E+00	4.83E-01	3.44E+00
SM147	0.00E+00	0.00E+00	0.00E+00
PM148M	8.39E+04	5.93E+04	9.02E+05
PM148	2.36E+04	1.74E+04	2.54E+05
PM149	4.69E+02	2.93E+02	4.02E+03
PM151	1.32E+04	8.65E+03	1.29E+05
SM151	1.19E+00	9.88E-02	2.44E-01
SM153	2.73E+03	1.21E+03	1.21E+04
EU152M	1.26E+04	8.88E+03	1.27E+05
EU152	4.57E+04	3.27E+04	4.72E+05
EU154	4.73E+04	3.41E+04	4.91E+05
EU155	2.28E+03	1.12E+03	1.13E+04
EU156	5.09E+04	3.79E+04	5.60E+05
GD153	4.35E+03	1.75E+03	1.61E+04
GD159	1.57E+03	9.38E+02	1.40E+04
TB160	4.12E+04	2.97E+04	4.25E+05
TB161	9.49E+02	2.55E+02	1.87E+03
DY165	1.05E+03	6.22E+02	8.67E+03
HO166M	6.07E+04	4.22E+04	6.10E+05
HO166	1.29E+03	7.81E+02	1.03E+04
ER169	6.69E+00	1.44E+00	1.07E+01
ER171	1.51E+04	9.73E+03	1.43E+05
TA182	5.07E+04	3.67E+04	5.18E+05
W 181	1.34E+03	4.75E+02	3.47E+03
W 185	1.03E+01	3.01E+00	2.69E+01
W 187	1.86E+04	1.28E+04	1.95E+05
RE187	0.00E+00	0.00E+00	0.00E+00
OS185	2.78E+04	1.91E+04	2.82E+05
OS191	2.65E+03	1.26E+03	1.24E+04
IR192	3.34E+04	2.29E+04	3.63E+05
HG203	7.67E+03	4.84E+03	6.50E+04
TH230	5.98E+01	9.06E+00	5.15E+01
RA226	1.86E+02	1.04E+02	1.15E+03
RN222	6.85E+04	5.00E+04	7.38E+05
PB210	2.11E+02	2.99E+01	1.31E+02
BI210	7.08E+01	3.09E+01	3.58E+02

TABLE D.4. External Dose Rate Factors for Individual Radionuclides (EXTERNAL.DF) (contd)

PO210	3.45E-01	2.49E-01	3.51E+00
U 232	7.73E+01	9.06E+00	3.91E+01
TH232	5.44E+01	6.40E+00	2.68E+01
RA228	1.19E-02	9.54E-04	1.36E-03
AC228	3.74E+04	2.71E+04	4.01E+05
TH228	1.20E+02	4.13E+01	4.27E+02
RA224	4.06E+02	2.59E+02	3.55E+03
PB212	5.61E+03	3.44E+03	4.56E+04
BI212	5.18E+04	3.91E+04	5.99E+05
U 234	6.53E+01	6.85E+00	2.37E+01
U 236	6.03E+01	5.58E+00	1.23E+01
U 235	4.68E+03	2.64E+03	3.00E+04
TH231	9.54E+02	2.25E+02	1.84E+03
PA231	1.56E+03	8.08E+02	1.17E+04
AC227	1.19E+01	3.40E+00	3.23E+01
TH227	4.20E+03	2.52E+03	3.45E+04
FR223	2.09E+03	1.03E+03	1.23E+04
RA223	1.12E+04	7.20E+03	1.05E+05
U 237	5.93E+03	3.21E+03	3.83E+04
NP237	1.19E+03	3.94E+02	3.69E+03
PA233	9.01E+03	5.82E+03	8.84E+04
U 233	3.20E+01	7.10E+00	6.06E+01
TH229	3.35E+03	1.63E+03	1.73E+04
RA225	6.25E+02	1.51E+02	9.29E+02
AC225	9.39E+03	6.34E+03	9.89E+04
U 238	5.33E+01	4.93E+00	1.08E+01
TH234	1.05E+03	6.22E+02	8.18E+03
PA234	7.70E+04	5.48E+04	7.95E+05
PU236	7.76E+01	6.77E+00	1.18E+01
PU237	2.25E+03	1.12E+03	1.20E+04
AM242M	1.88E+02	1.98E+01	7.36E+01
AM242	7.44E+02	3.29E+02	3.45E+03
CM242	6.80E+01	5.64E+00	7.44E+00
PU238	6.83E+01	5.71E+00	7.88E+00
PU242	5.40E+01	4.55E+00	6.56E+00
NP238	2.15E+04	1.57E+04	2.33E+05
PU238	6.83E+01	5.71E+00	7.88E+00
CM244	6.06E+01	4.99E+00	6.35E+00
PU244	4.67E+01	3.83E+00	4.66E+00
U 240	1.49E+04	1.03E+04	1.53E+05
PU240	6.51E+01	5.48E+00	7.86E+00
CM245	3.01E+03	1.54E+03	1.67E+04
PU241	1.76E-04	1.41E-05	1.46E-05
AM241	9.39E+02	2.65E+02	1.79E+03
CM246	5.40E+01	4.40E+00	5.25E+00
CM247	1.43E+04	9.88E+03	1.66E+05
PU243	7.88E+02	3.92E+02	4.15E+03
CM243	5.18E+03	2.98E+03	3.69E+04
AM243	1.80E+03	7.62E+02	6.58E+03

TABLE D.4. External Dose Rate Factors for Individual Radionuclides (EXTERNAL.DF) (contd)

NP239	6.96E+03	4.05E+03	5.06E+04
PU239	2.81E+01	3.44E+00	1.75E+01
CM248	4.28E+01	3.56E+00	4.78E+00
CF252	4.29E+01	3.62E+00	5.32E+00

TABLE D.5. External Dose Rate Factors for Radionuclide Chains in Equilibrium (EXTDAU.DF)

NRC Resid. Rad. External DFs w/daughters (rem/h per pCi/m² or g) 27-Jan-90 RAP

Col 1: Infinite disk source, concrete

Col 2: 1 cm thick, 5m disk source, concrete

Col 3: 15 cm thick infinite slab source, soil

H 3	3.4E-20	6.2E-16	6.4E-16
BE10	1.2E-14	8.6E-10	8.0E-09
C 14	7.2E-16	2.5E-11	1.4E-10
F 18	2.3E-11	3.6E-06	6.2E-05
NA22	5.1E-11	8.4E-06	1.3E-04
NA24	9.5E-11	1.7E-05	2.5E-04
P 32	1.1E-13	1.4E-08	1.8E-07
P 33	2.1E-15	9.3E-11	6.2E-10
S 35	8.1E-16	2.9E-11	1.6E-10
CL36	1.9E-14	1.6E-09	1.6E-08
K 40	3.9E-12	6.6E-07	9.4E-06
CA41	4.6E-14	8.4E-10	8.7E-10
CA45	2.2E-15	9.8E-11	6.6E-10
SC46	5.1E-11	8.5E-06	1.2E-04
CR51	9.5E-13	1.4E-07	2.1E-06
MN54	2.1E-11	3.4E-06	4.8E-05
MN56	4.2E-11	7.1E-06	1.0E-04
FE55	1.1E-13	1.9E-09	2.0E-09
FE59	2.7E-11	4.6E-06	6.7E-05
CO57	3.4E-12	4.2E-07	4.6E-06
CO58	2.5E-11	4.0E-06	5.9E-05
CO60	6.0E-11	1.0E-05	1.4E-04
NI59	1.3E-13	2.3E-09	2.4E-09
NI63	5.8E-17	1.2E-12	3.5E-12
NI65	1.4E-11	2.3E-06	3.4E-05
CU64	4.4E-12	7.0E-07	1.2E-05
ZN65	1.6E-11	2.6E-06	3.8E-05
ZN69M	1.1E-11	1.8E-06	3.0E-05
ZN69	3.1E-14	2.8E-09	3.1E-08
AS76	1.2E-11	2.0E-06	3.0E-05
SE75	9.4E-12	1.3E-06	1.8E-05
SE79	5.6E-16	1.8E-11	9.8E-11
BR82	6.9E-11	1.1E-05	1.6E-04
BR83	2.9E-13	3.1E-08	4.8E-07
BR84	4.0E-11	6.9E-06	1.1E-04
RB86	2.3E-12	3.8E-07	5.6E-06
RB88	1.6E-11	2.8E-06	4.2E-05
RB89	4.9E-11	8.4E-06	1.2E-04
SR85	1.2E-11	1.9E-06	3.2E-05
SR89	9.2E-14	1.0E-08	1.3E-07
SR90	2.3E-13	2.8E-08	3.7E-07
SR91	2.6E-11	4.3E-06	6.5E-05
SR92	4.2E-11	7.1E-06	1.0E-04
Y 90	2.2E-13	2.8E-08	3.7E-07
Y 91M	1.6E-11	2.6E-06	3.9E-05

TABLE D.5. External Dose Rate Factors for Radionuclide Chains in Equilibrium (EXTDAU.DF) (contd)

Y 91	1.8E-13	2.6E-08	3.5E-07
Y 92	7.2E-12	1.2E-06	1.7E-05
Y 93	2.5E-12	4.0E-07	5.9E-06
ZR93	5.1E-14	9.3E-10	9.6E-10
ZR95	4.0E-11	6.5E-06	9.3E-05
ZR97	3.8E-11	6.0E-06	9.1E-05
NB93M	5.1E-14	9.3E-10	9.6E-10
NB94	3.8E-11	6.1E-06	8.9E-05
NB95M	2.3E-11	3.5E-06	4.9E-05
NB95	2.1E-11	3.4E-06	4.8E-05
NB97M	3.4E-11	5.4E-06	8.1E-05
NB97	1.7E-11	2.7E-06	4.1E-05
MO93	3.0E-13	5.4E-09	5.6E-09
MO99	6.3E-12	9.2E-07	1.2E-05
TC99M	2.9E-12	3.8E-07	4.2E-06
TC99	2.7E-15	1.3E-10	9.3E-10
TC101	9.5E-12	1.5E-06	2.3E-05
RU103	1.2E-11	1.9E-06	3.1E-05
RU105	2.2E-11	3.5E-06	5.3E-05
RU106	5.6E-12	8.9E-07	1.4E-05
RH103M	8.8E-14	1.7E-09	6.1E-09
RH105	2.2E-12	3.3E-07	5.3E-06
PD103	7.6E-13	1.5E-08	6.4E-08
PD107	3.5E-18	6.4E-14	7.6E-14
PD109	4.6E-13	2.0E-08	1.8E-07
AG110M	7.0E-11	1.1E-05	1.7E-04
AG111	7.1E-13	1.1E-07	1.7E-06
CD109	6.3E-13	1.2E-08	4.8E-08
CD113M	1.2E-14	8.4E-10	7.9E-09
CD115M	6.6E-13	1.0E-07	1.5E-06
CD115	9.2E-12	1.4E-06	2.3E-05
IN115M	4.4E-12	6.5E-07	1.0E-05
IN111	9.4E-12	1.2E-06	1.6E-05
IN114M	3.4E-12	4.7E-07	6.8E-06
SN117M	3.5E-12	3.9E-07	4.2E-06
SN119M	4.5E-13	8.6E-09	3.3E-08
SN121M	0.0E+00	0.0E+00	0.0E+00
SN121	0.0E+00	0.0E+00	0.0E+00
SN123	2.3E-13	3.5E-08	4.9E-07
SN125	2.0E-11	3.1E-06	4.7E-05
SN126	5.2E-11	8.1E-06	1.3E-04
SB124	4.7E-11	8.0E-06	1.2E-04
SB125	1.2E-11	1.8E-06	2.8E-05
SB126M	5.0E-11	8.0E-06	1.2E-04
SB126	6.9E-11	1.1E-05	1.7E-04
SB127	1.7E-11	2.7E-06	4.1E-05
TE123M	3.2E-12	3.7E-07	4.0E-06
TE125M	1.2E-12	3.2E-08	1.6E-07
TE127M	5.5E-13	3.2E-08	4.2E-07

TABLE D.5. External Dose Rate Factors for Radionuclide Chains in Equilibrium (EXTDAU.DF) (contd)

TE127	1.5E-13	2.2E-08	3.6E-07
TE129M	2.1E-12	2.8E-07	4.2E-06
TE129	1.6E-12	2.2E-07	3.6E-06
TE131M	4.9E-11	7.8E-06	1.1E-04
TE131	2.0E-11	3.1E-06	4.6E-05
TE132	6.5E-11	1.0E-05	1.5E-04
TE133M	7.6E-11	1.2E-05	1.9E-04
TE133	3.9E-11	6.2E-06	9.7E-05
TE134	8.8E-11	1.4E-05	2.1E-04
I 125	1.4E-12	3.6E-08	1.8E-07
I 129	7.8E-13	2.1E-08	1.0E-07
I 130	5.1E-11	8.2E-06	1.3E-04
I 131	9.3E-12	1.4E-06	2.2E-05
I 132	5.9E-11	9.6E-06	1.4E-04
I 133	1.5E-11	2.3E-06	3.7E-05
I 134	6.5E-11	1.1E-05	1.6E-04
I 135	4.6E-11	7.7E-06	1.1E-04
CS134M	8.1E-13	7.1E-08	7.0E-07
CS134	4.2E-11	6.8E-06	1.0E-04
CS135	1.1E-15	4.3E-11	2.7E-10
CS136	5.3E-11	8.7E-06	1.3E-04
CS137	1.4E-11	2.3E-06	3.5E-05
CS138	5.8E-11	9.9E-06	1.5E-04
CS139	8.8E-12	1.4E-06	2.1E-05
BA139	9.4E-13	1.2E-07	1.5E-06
BA140	5.9E-11	9.7E-06	1.5E-04
BA141	2.5E-11	3.9E-06	5.6E-05
BA142	8.5E-11	1.5E-05	2.2E-04
LA140	5.4E-11	9.1E-06	1.3E-04
LA141	3.1E-12	4.4E-07	5.5E-06
LA142	6.3E-11	1.1E-05	1.7E-04
CE141	1.8E-12	2.1E-07	2.3E-06
CE143	6.4E-12	9.0E-07	1.3E-05
CE144	1.6E-12	2.3E-07	3.1E-06
PR143	3.1E-14	2.8E-09	3.1E-08
PR144M	1.5E-12	1.9E-07	2.7E-06
PR144	1.1E-12	1.7E-07	2.6E-06
ND147	3.3E-12	4.4E-07	6.7E-06
PM147	1.5E-15	7.0E-11	5.0E-10
PM148M	5.5E-11	8.8E-06	1.3E-04
PM148	1.5E-11	2.5E-06	3.7E-05
PM149	3.0E-13	4.3E-08	5.9E-07
PM151	8.5E-12	1.3E-06	1.9E-05
SM147	0.0E+00	0.0E+00	0.0E+00
SM151	7.6E-16	1.4E-11	3.6E-11
SM153	1.8E-12	1.8E-07	1.8E-06
EU152	2.9E-11	4.8E-06	6.9E-05
EU154	3.0E-11	5.0E-06	7.2E-05
EU155	1.5E-12	1.6E-07	1.7E-06

TABLE D.5. External Dose Rate Factors for Radionuclide Chains in Equilibrium (EXTDAU.DF) (contd)

EU156	3.3E-11	5.5E-06	8.2E-05
GD153	2.8E-12	2.6E-07	2.4E-06
TB160	2.6E-11	4.3E-06	6.2E-05
HO166M	3.9E-11	6.2E-06	8.9E-05
W 181	8.6E-13	6.9E-08	5.1E-07
W 185	6.6E-15	4.4E-10	3.9E-09
W 187	1.2E-11	1.9E-06	2.8E-05
RE187	0.0E+00	0.0E+00	0.0E+00
OS185	1.8E-11	2.8E-06	4.1E-05
OS191	1.7E-12	1.8E-07	1.8E-06
IR192	2.1E-11	3.3E-06	5.3E-05
HG203	4.9E-12	7.1E-07	9.5E-06
PB210	1.8E-13	8.9E-09	7.2E-08
PB212	3.7E-11	6.2E-06	9.4E-05
BI210	4.6E-14	4.6E-09	5.3E-08
BI212	3.3E-11	5.7E-06	8.8E-05
PO210	2.2E-16	3.6E-11	5.1E-10
RA223	7.2E-12	1.1E-06	1.5E-05
RA224	3.7E-11	6.3E-06	9.5E-05
RA225	6.4E-12	9.5E-07	1.5E-05
RA226	4.4E-11	7.4E-06	1.1E-04
RA228	6.1E-11	1.0E-05	1.5E-04
AC225	6.0E-12	9.2E-07	1.4E-05
AC227	9.9E-12	1.4E-06	2.0E-05
AC228	6.1E-11	1.0E-05	1.5E-04
TH227	9.9E-12	1.4E-06	2.0E-05
TH228	3.7E-11	6.3E-06	9.5E-05
TH229	8.6E-12	1.2E-06	1.7E-05
TH230	4.4E-11	7.4E-06	1.1E-04
TH231	6.1E-13	3.3E-08	2.7E-07
TH232	6.1E-11	1.0E-05	1.5E-04
TH234	7.6E-13	1.0E-07	1.4E-06
PA231	1.1E-11	1.5E-06	2.2E-05
PA233	5.8E-12	8.5E-07	1.3E-05
PA234	5.0E-11	8.0E-06	1.2E-04
U 232	5.0E-14	1.3E-09	5.7E-09
U 233	8.6E-12	1.2E-06	1.7E-05
U 234	4.2E-14	1.0E-09	3.5E-09
U 235	3.6E-12	4.2E-07	4.7E-06
U 236	3.9E-14	8.1E-10	1.8E-09
U 237	3.8E-12	4.7E-07	5.6E-06
U 238	7.9E-13	1.0E-07	1.4E-06
U 240	9.6E-12	1.5E-06	2.2E-05
NP237	6.6E-12	9.1E-07	1.3E-05
NP238	1.4E-11	2.3E-06	3.4E-05
NP239	4.5E-12	5.9E-07	7.4E-06
PU236	5.0E-14	9.9E-10	1.7E-09
PU237	1.4E-12	1.6E-07	1.8E-06
PU238	4.4E-14	8.3E-10	1.2E-09

TABLE D.5. External Dose Rate Factors for Radionuclide
Chains in Equilibrium (EXTDAU.DF) (contd)

PU239	1.8E-14	5.0E-10	2.6E-09
PU240	4.2E-14	8.0E-10	1.1E-09
PU241	6.1E-13	3.9E-08	2.6E-07
PU242	3.5E-14	6.7E-10	9.6E-10
PU243	3.3E-12	4.3E-07	5.4E-06
PU244	9.6E-12	1.5E-06	2.2E-05
AM241	6.1E-13	3.9E-08	2.6E-07
AM242M	6.7E-13	5.2E-08	5.2E-07
AM242	5.5E-13	4.9E-08	5.1E-07
AM243	5.6E-12	7.0E-07	8.4E-06
CM242	8.8E-14	1.7E-09	2.2E-09
CM243	5.4E-13	6.0E-08	6.3E-07
CM244	3.9E-14	7.3E-10	9.3E-10
CM245	2.5E-12	2.6E-07	2.7E-06
CM246	3.5E-14	6.4E-10	7.6E-10
CM247	1.3E-11	1.9E-06	3.0E-05
CM248	2.7E-14	5.2E-10	7.0E-10
CF252	2.8E-14	5.3E-10	7.8E-10

TABLE D.6. Internal Dose Rate Factors for Radionuclide Chains in Equilibrium (INTERNAL.DF)

Internal DF's for NRC Residual Radioactivity (10-Jan-90 RAP)							
	Inh	2nd Ing	Air Ing	Soi Ing	Drink Water	Maximum	Organ Dose
H 3	8.2E-11	5.7E-11	2.3E-06	0.0E+00	6.7E-11	SI Wall	
BE10	3.4E-07	4.6E-09	5.7E-05	3.7E-07	4.8E-08	LLI Wall	
C 14	1.9E-09	1.9E-09	7.2E-04	0.0E+00	2.3E-09	LLI Wall	
F 18	7.7E-11	1.1E-10	7.8E-09	8.9E-08	1.1E-09	Stomach Wall	
NA22	8.6E-09	1.4E-08	1.7E-03	5.7E-04	2.3E-08	Bone Surface	
NA24	1.1E-09	1.4E-09	1.6E-06	1.7E-05	4.4E-09	Stomach Wall	
P 32	5.5E-09	8.5E-09	3.5E-04	4.3E-03	3.1E-08	Red Marrow	
P 33	5.6E-10	8.7E-10	4.6E-05	4.6E-04	4.8E-09	Bone Surface	
S 35	2.4E-09	4.0E-10	2.6E-05	1.0E-04	2.0E-09	LLI Wall	
CL36	1.8E-09	2.8E-09	2.1E-04	1.1E-02	3.2E-09	SI Wall	
K 40	9.9E-09	1.7E-08	5.9E-04	3.2E-03	2.0E-08	SI Wall	
CA41	1.2E-09	1.2E-09	6.1E-05	2.3E-05	1.5E-08	Bone Surface	
CA45	6.4E-09	3.1E-09	1.4E-04	5.0E-05	1.9E-08	Bone Surface	
SC46	2.8E-08	6.2E-09	6.9E-05	2.5E-06	3.7E-08	LLI Wall	
CR51	3.1E-10	1.4E-10	1.8E-06	7.6E-09	9.2E-10	LLI Wall	
MN54	6.1E-09	2.8E-09	3.5E-05	1.6E-05	8.5E-09	LLI Wall	
MN56	3.3E-10	1.0E-09	9.7E-08	5.5E-06	5.2E-09	ULI Wall	
FE55	1.2E-09	5.8E-10	1.3E-05	1.4E-07	2.1E-09	Spleen	
FE59	1.2E-08	6.5E-09	7.3E-05	9.5E-07	3.1E-08	LLI Wall	
C057	8.3E-09	7.5E-10	1.2E-05	1.7E-06	4.8E-09	LLI Wall	
C058	1.0E-08	2.9E-09	3.9E-05	5.9E-06	1.4E-08	LLI Wall	
C060	1.9E-07	1.0E-08	1.8E-04	2.4E-05	4.3E-08	LLI Wall	
NI59	7.9E-10	1.9E-10	8.1E-06	1.9E-06	9.7E-10	LLI Wall	
NI63	1.9E-09	5.1E-10	2.2E-05	5.1E-06	3.2E-09	LLI Wall	
NI65	2.3E-10	6.5E-10	6.2E-08	2.3E-06	3.6E-09	ULI Wall	
CU64	1.9E-10	4.8E-10	2.8E-07	1.2E-05	2.9E-09	LLI Wall	
ZN65	1.7E-08	1.3E-08	1.4E-03	3.8E-03	1.7E-08	LLI Wall	
ZN69M	8.2E-10	1.4E-09	1.3E-06	1.3E-04	8.9E-09	LLI Wall	
ZN69	3.8E-11	8.9E-11	3.2E-09	6.6E-06	7.8E-10	Stomach Wall	
AS76	3.8E-09	5.3E-09	5.0E-06	2.1E-06	4.4E-08	LLI Wall	
SE75	7.6E-09	8.9E-09	1.7E-03	4.6E-04	2.6E-08	Kidneys	
SE79	8.8E-09	8.0E-09	2.7E-03	5.7E-04	4.8E-08	Kidneys	
BR82	1.1E-09	1.6E-09	5.9E-06	6.0E-05	3.0E-09	Stomach Wall	
BR83	8.9E-11	9.4E-11	8.5E-09	2.8E-06	1.1E-09	Stomach Wall	
BR84	9.4E-11	1.8E-10	3.6E-09	5.2E-06	2.6E-09	Stomach Wall	
RB86	5.8E-09	9.1E-09	5.0E-04	6.2E-04	2.7E-08	Bone Surface	
RB88	8.3E-11	1.8E-10	2.0E-09	4.3E-06	2.8E-09	Stomach Wall	
RB89	5.3E-09	8.8E-09	1.3E-04	5.5E-04	7.8E-08	LLI Wall	
SR85	1.4E-09	1.7E-09	2.7E-05	1.1E-04	5.2E-09	LLI Wall	
SR89	5.3E-09	8.7E-09	1.3E-04	5.5E-04	7.8E-08	LLI Wall	
SR90	2.1E-07	1.3E-07	2.4E-03	7.7E-03	1.4E-06	Bone Surface	
SR91	4.8E-08	1.2E-08	9.9E-05	1.4E-04	1.3E-07	LLI Wall	
SR92	1.4E-09	3.6E-09	6.3E-07	8.9E-05	2.4E-08	ULI Wall	
Y 90	8.5E-09	1.1E-08	2.2E-05	5.0E-06	1.2E-07	LLI Wall	
Y 91M	4.7E-08	9.5E-09	9.8E-05	4.5E-06	1.1E-07	LLI Wall	
Y 91	4.7E-08	9.4E-09	9.8E-05	4.5E-06	1.1E-07	LLI Wall	
Y 92	8.0E-10	2.0E-09	2.6E-07	9.2E-07	1.3E-08	ULI Wall	

TABLE D.6. Internal Dose Rate Factors for Radionuclide Chains in Equilibrium (INTERNAL.DF) (contd)

Y 93	2.2E-09	4.8E-09	1.8E-06	2.2E-06	3.5E-08	LLI Wall
ZR93	1.1E-07	2.1E-09	8.1E-05	7.1E-06	3.3E-08	Bone Surface
ZR95	2.0E-08	6.3E-09	1.6E-04	9.1E-06	4.4E-08	LLI Wall
ZR97	3.9E-09	8.6E-09	5.2E-06	6.9E-07	6.7E-08	LLI Wall
NB93M	2.9E-08	5.0E-10	4.6E-05	7.0E-06	5.6E-09	LLI Wall
NB94	3.7E-07	7.2E-09	6.8E-04	1.0E-04	4.8E-08	LLI Wall
NB95M	7.6E-09	4.7E-09	6.1E-05	1.3E-05	3.8E-08	LLI Wall
NB95	5.5E-09	2.5E-09	5.1E-05	8.7E-06	1.5E-08	LLI Wall
NB97M	8.4E-11	2.4E-10	1.1E-08	4.3E-07	1.4E-09	Stomach Wall
NB97	8.3E-11	2.4E-10	1.1E-08	4.2E-07	1.4E-09	Stomach Wall
M093	3.0E-08	1.8E-09	7.0E-05	4.8E-05	6.7E-09	Liver
M099	2.0E-09	3.1E-09	8.0E-06	8.8E-05	1.2E-08	LLI Wall
TC99M	3.1E-11	8.3E-11	1.9E-08	1.7E-05	4.1E-10	ULI Wall
TC99	8.9E-09	3.1E-09	1.2E-04	1.2E-03	2.7E-08	Thyroid
TC101	1.5E-11	7.5E-11	6.8E-10	1.6E-05	5.7E-10	ULI Wall
RU103	8.7E-09	3.0E-09	6.3E-05	7.0E-05	2.4E-08	LLI Wall
RU105	1.5E-09	2.7E-09	2.5E-06	8.3E-05	2.0E-08	LLI Wall
RU106	4.5E-07	2.6E-08	2.6E-03	2.3E-03	2.6E-07	LLI Wall
RH103M	4.8E-12	1.2E-11	4.3E-10	5.6E-07	9.6E-11	Stomach Wall
RH105	9.6E-10	1.5E-09	2.1E-06	7.2E-05	1.4E-08	LLI Wall
PD103	1.5E-09	7.9E-10	1.1E-05	9.3E-06	8.5E-09	LLI Wall
PD107	1.2E-08	1.5E-10	3.8E-06	1.7E-06	1.7E-09	LLI Wall
PD109	1.3E-09	2.6E-09	1.4E-06	2.6E-05	2.1E-08	LLI Wall
AG110M	8.1E-08	3.3E-08	4.5E-03	4.2E-03	2.5E-07	LLI Wall
AG111	3.3E-09	5.1E-09	2.6E-04	5.2E-04	5.5E-08	LLI Wall
CD109	1.1E-07	1.3E-08	1.6E-04	8.7E-04	1.5E-07	Kidneys
CD113M	1.4E-06	1.6E-07	2.0E-03	1.1E-02	2.1E-06	Kidneys
CD115M	6.9E-08	1.6E-08	1.6E-04	1.1E-03	1.0E-07	LLI Wall
CD115	3.9E-09	6.1E-09	1.1E-05	3.8E-04	5.7E-08	LLI Wall
IN115M	1.2E-10	3.5E-10	5.7E-08	1.1E-07	2.1E-09	ULI Wall
IN111	5.4E-10	1.3E-09	2.9E-06	4.1E-07	7.4E-09	LLI Wall
IN114M	4.4E-08	1.5E-08	1.6E-04	4.8E-06	1.6E-07	LLI Wall
SN117M	4.2E-09	2.9E-09	2.3E-05	9.5E-06	3.0E-08	LLI Wall
SN119M	5.8E-09	1.4E-09	2.2E-05	4.6E-06	1.5E-08	LLI Wall
SN121M	1.1E-08	2.2E-09	3.8E-05	7.2E-06	2.3E-08	LLI Wall
SN121	4.8E-10	9.1E-10	9.3E-07	2.9E-06	8.9E-09	LLI Wall
SN123	3.1E-08	8.4E-09	1.2E-04	2.8E-05	9.6E-08	LLI Wall
SN125	2.9E-08	1.6E-08	1.4E-04	3.8E-04	1.6E-07	LLI Wall
SN126	9.6E-08	2.1E-08	3.6E-04	6.7E-05	1.7E-07	LLI Wall
SB124	2.5E-08	9.9E-09	1.2E-04	2.0E-05	8.5E-08	LLI Wall
SB125	1.3E-08	3.6E-09	6.5E-05	3.5E-04	2.8E-08	LLI Wall
SB126M	1.7E-09	1.5E-09	1.0E-05	3.1E-06	9.9E-09	LLI Wall
SB126	1.1E-08	1.0E-08	7.2E-05	2.0E-05	7.0E-08	LLI Wall
SB127	9.6E-09	9.3E-09	5.9E-05	9.1E-04	8.6E-08	LLI Wall
TE123M	1.0E-08	5.7E-09	1.3E-04	2.9E-03	9.2E-08	Bone Surface
TE125M	7.0E-09	3.7E-09	6.3E-05	1.4E-03	4.9E-08	Bone Surface
TE127M	2.1E-08	8.9E-09	2.0E-04	4.4E-03	7.8E-08	Bone Surface
TE127	3.2E-10	7.1E-10	2.4E-07	1.7E-04	4.8E-09	LLI Wall
TE129M	4.8E-07	5.4E-07	6.7E-03	1.7E-01	2.1E-06	Testes

TABLE D.6. Internal Dose Rate Factors for Radionuclide Chains in Equilibrium (INTERNAL.DF) (contd)

TE129	1.5E-10	2.6E-10	1.1E-08	6.3E-05	1.5E-09	Stomach Wall
TE131M	4.2E-08	6.7E-08	9.0E-03	5.2E-03	1.8E-06	Thyroid
TE131	3.0E-08	5.0E-08	8.9E-03	8.4E-04	1.6E-06	Thyroid
TE132	1.3E-08	1.5E-08	4.4E-05	3.8E-03	1.6E-07	Thyroid
TE133M	5.8E-09	1.1E-08	1.4E-04	3.1E-04	3.1E-07	Thyroid
TE133	5.4E-09	9.9E-09	1.4E-04	1.5E-04	3.0E-07	Thyroid
TE134	2.4E-10	4.5E-10	1.2E-07	4.8E-05	3.8E-09	Thyroid
I 125	2.2E-08	3.6E-08	1.4E-02	6.2E-04	1.2E-06	Thyroid
I 129	1.5E-07	2.5E-07	1.2E-01	4.7E-03	8.3E-06	Thyroid
I 130	2.4E-09	4.4E-09	2.9E-05	4.8E-05	1.2E-07	Thyroid
I 131	3.0E-08	5.0E-08	8.9E-03	7.9E-04	1.6E-06	Thyroid
I 132	3.8E-10	6.9E-10	7.5E-07	7.1E-06	1.0E-08	Thyroid
I 133	5.3E-09	9.7E-09	1.4E-04	1.1E-04	3.0E-07	Thyroid
I 134	1.4E-10	2.6E-10	1.1E-07	2.7E-06	2.1E-09	Stomach Wall
I 135	1.1E-09	2.1E-09	6.6E-06	2.2E-05	5.2E-08	Thyroid
CS134M	3.6E-11	3.6E-11	4.0E-09	6.3E-08	4.1E-10	Stomach Wall
CS134	4.0E-08	6.7E-08	2.0E-03	2.0E-04	8.8E-08	SI Wall
CS135	3.6E-09	6.4E-09	1.9E-04	1.9E-05	7.8E-09	SI Wall
CS136	6.4E-09	1.0E-08	1.4E-04	2.4E-05	1.4E-08	SI Wall
CS137	2.6E-08	4.6E-08	1.4E-03	2.4E-05	5.7E-08	SI Wall
CS138	9.6E-11	1.9E-10	3.8E-09	3.2E-07	2.7E-09	Stomach Wall
CS139	1.7E-10	4.1E-10	2.4E-08	3.9E-07	2.6E-09	Stomach Wall
BA139	1.7E-10	4.1E-10	2.1E-08	3.9E-07	2.6E-09	Stomach Wall
BA140	6.4E-09	1.7E-08	1.2E-04	1.3E-05	1.6E-07	LLI Wall
BA141	9.0E-09	4.6E-09	2.7E-05	2.2E-06	3.9E-08	LLI Wall
BA142	3.0E-10	8.1E-10	4.8E-08	4.3E-07	4.0E-09	Stomach Wall
LA140	3.4E-09	8.3E-09	1.1E-05	3.8E-06	6.3E-08	LLI Wall
LA141	9.0E-09	4.4E-09	2.7E-05	2.0E-06	3.8E-08	LLI Wall
LA142	2.6E-10	7.0E-10	4.2E-08	3.3E-07	3.3E-09	Stomach Wall
CE141	8.4E-09	2.9E-09	2.6E-05	1.4E-06	3.2E-08	LLI Wall
CE143	1.1E-08	9.3E-09	3.8E-05	4.3E-06	1.0E-07	LLI Wall
CE144	3.6E-07	2.1E-08	2.5E-04	1.0E-05	2.5E-07	LLI Wall
PR143	7.8E-09	4.7E-09	3.0E-05	2.2E-06	5.5E-08	LLI Wall
PR144M	6.2E-11	1.7E-10	2.1E-09	7.8E-08	2.1E-09	Stomach Wall
PR144	4.3E-11	1.2E-10	1.3E-09	5.6E-08	1.6E-09	Stomach Wall
ND147	4.4E-08	5.2E-09	3.7E-05	2.2E-06	5.6E-08	LLI Wall
PM147	3.8E-08	1.0E-09	1.4E-05	3.3E-07	1.2E-08	LLI Wall
PM148M	2.2E-08	8.1E-09	7.7E-05	2.5E-06	5.7E-08	LLI Wall
PM148	1.1E-08	1.1E-08	3.9E-05	3.5E-06	1.2E-07	LLI Wall
PM149	2.9E-09	4.1E-09	7.2E-06	1.3E-06	4.4E-08	LLI Wall
PM151	1.8E-09	3.0E-09	3.0E-06	9.5E-07	2.7E-08	LLI Wall
SM147	7.3E-05	1.9E-07	2.5E-03	8.0E-05	3.2E-06	Bone Surface
SM151	2.9E-08	3.8E-10	5.1E-06	1.6E-07	3.7E-09	LLI Wall
SM153	1.9E-09	3.0E-09	4.7E-06	1.2E-06	3.0E-08	LLI Wall
EU152	2.0E-07	6.3E-09	8.4E-05	3.3E-06	3.7E-08	LLI Wall
EU154	2.6E-07	9.2E-09	1.2E-04	4.8E-06	6.7E-08	LLI Wall
EU155	3.9E-08	1.5E-09	2.0E-05	7.8E-07	1.3E-08	LLI Wall
EU156	1.4E-08	9.1E-09	6.1E-05	4.2E-06	8.5E-08	LLI Wall
GD153	2.3E-08	1.2E-09	1.4E-05	1.8E-06	1.0E-08	LLI Wall

TABLE D.6. Internal Dose Rate Factors for Radionuclide Chains in Equilibrium (INTERNAL.DF) (contd)

TB160	2.4E-08	6.6E-09	7.1E-05	6.9E-07	5.5E-08	LLI Wall
HO166M	7.2E-07	7.7E-09	1.0E-04	4.4E-06	4.1E-08	LLI Wall
W 181	1.5E-10	2.9E-10	3.6E-06	1.0E-06	1.9E-09	LLI Wall
W 185	7.5E-10	1.6E-09	1.9E-05	5.6E-06	1.7E-08	LLI Wall
W 187	6.5E-10	2.1E-09	1.8E-06	7.2E-06	1.7E-08	LLI Wall
RE187	5.6E-11	1.4E-11	2.1E-07	5.8E-10	9.0E-11	ULI Wall
OS185	9.2E-09	2.2E-09	0.0E+00	0.0E+00	1.0E-08	LLI Wall
OS191	2.2E-09	2.3E-09	0.0E+00	0.0E+00	2.4E-08	LLI Wall
IR192	2.6E-08	5.7E-09	6.1E-05	1.8E-05	4.8E-08	LLI Wall
HG203	6.8E-09	1.1E-08	1.7E-04	3.8E-04	7.0E-08	Kidneys
PB210	2.2E-05	7.3E-06	9.3E-02	5.0E-03	8.0E-05	Bone Surface
PB212	1.8E-07	5.0E-08	1.9E-05	6.3E-05	6.7E-07	Bone Surface
BI210	8.6E-06	1.9E-06	2.4E-02	9.2E-04	1.6E-05	Spleen
BI212	1.8E-08	1.1E-09	4.2E-08	3.0E-05	5.9E-09	Stomach Wall
PO210	8.4E-06	1.9E-06	2.3E-02	6.1E-04	1.6E-05	Spleen
RA223	7.5E-06	2.7E-07	1.7E-03	7.3E-04	4.1E-06	Bone Surface
RA224	2.9E-06	1.8E-07	5.3E-04	4.2E-04	1.9E-06	Bone Surface
RA225	1.5E-05	3.3E-07	2.7E-03	6.4E-04	5.9E-06	Bone Surface
RA226	2.9E-05	8.2E-06	1.1E-01	7.7E-03	1.0E-04	Bone Surface
RA228	3.2E-04	1.4E-06	1.9E-02	3.1E-03	3.0E-05	Bone Surface
AC225	7.9E-06	1.1E-07	6.1E-04	2.8E-05	1.0E-06	LLI Wall
AC227	1.3E-03	1.4E-05	1.7E-01	4.3E-03	2.5E-04	Bone Surface
AC228	3.2E-04	5.8E-07	7.1E-03	7.3E-04	1.1E-05	Bone Surface
TH227	2.3E-05	3.1E-07	3.2E-03	7.6E-04	4.3E-06	Bone Surface
TH228	3.2E-04	5.7E-07	7.1E-03	7.3E-04	1.1E-05	Bone Surface
TH229	1.7E-03	3.8E-06	4.7E-02	3.4E-03	9.4E-05	Bone Surface
TH230	2.8E-04	8.8E-06	1.1E-01	8.1E-03	1.2E-04	Bone Surface
TH231	8.1E-10	1.3E-09	1.2E-06	1.0E-06	1.3E-08	LLI Wall
TH232	1.4E-03	4.2E-06	5.2E-02	5.2E-03	9.9E-05	Bone Surface
TH234	3.4E-08	1.3E-08	1.1E-04	1.1E-05	1.6E-07	LLI Wall
PA231	2.1E-03	2.5E-05	3.2E-01	2.3E-02	5.2E-04	Bone Surface
PA233	9.2E-09	3.6E-09	3.0E-05	6.0E-06	3.7E-08	LLI Wall
PA234	8.2E-10	2.2E-09	5.5E-07	3.7E-06	1.2E-08	ULI Wall
U 232	6.0E-04	6.8E-08	9.3E-04	3.3E-05	9.7E-07	Bone Surface
U 233	1.8E-03	3.9E-06	4.7E-02	3.4E-03	9.4E-05	Bone Surface
U 234	1.3E-04	2.6E-08	3.5E-04	1.3E-05	1.9E-07	LLI Wall
U 235	1.2E-04	2.8E-08	3.8E-04	1.4E-05	2.1E-07	LLI Wall
U 236	1.2E-04	2.4E-08	3.3E-04	1.2E-05	1.7E-07	LLI Wall
U 237	3.5E-09	3.2E-09	1.5E-05	1.5E-06	3.3E-08	LLI Wall
U 238	1.1E-04	3.7E-08	4.9E-04	2.2E-05	3.3E-07	LLI Wall
U 240	2.2E-09	4.7E-09	2.4E-06	2.2E-06	3.7E-08	LLI Wall
NP237	6.1E-04	5.2E-06	6.4E-02	2.4E-03	1.2E-04	Bone Surface
NP238	2.8E-04	3.4E-07	4.1E-03	3.7E-05	5.9E-06	Bone Surface
NP239	2.4E-09	3.3E-09	6.1E-06	1.5E-06	3.3E-08	LLI Wall
PU236	7.2E-05	6.3E-08	7.6E-04	6.6E-06	7.8E-07	Bone Surface
PU237	1.8E-09	4.3E-10	4.1E-06	4.4E-08	3.7E-09	LLI Wall
PU238	2.8E-04	3.4E-07	4.1E-03	3.5E-05	5.9E-06	Bone Surface
PU239	2.9E-04	3.7E-07	4.5E-03	3.9E-05	6.7E-06	Bone Surface
PU240	2.9E-04	3.7E-07	4.5E-03	3.8E-05	6.7E-06	Bone Surface

TABLE D.6. Internal Dose Rate Factors for Radionuclide Chains in Equilibrium (INTERNAL.DF) (contd)

PU241	4.3E-04	3.6E-06	4.7E-02	4.1E-03	6.8E-05	Bone Surface
PU242	2.7E-04	3.4E-07	4.2E-03	3.6E-05	6.1E-06	Bone Surface
PU243	1.4E-10	3.2E-10	5.6E-08	3.3E-08	2.1E-09	ULI Wall
PU244	2.6E-04	3.6E-07	4.4E-03	3.9E-05	6.1E-06	Bone Surface
AM241	4.3E-04	3.6E-06	4.7E-02	4.1E-03	6.7E-05	Bone Surface
AM242M	6.3E-04	3.8E-06	5.0E-02	4.0E-03	7.1E-05	Bone Surface
AM242	2.4E-04	3.7E-07	4.5E-03	7.6E-05	6.3E-06	Bone Surface
AM243	4.1E-04	3.6E-06	4.7E-02	4.1E-03	6.7E-05	Bone Surface
CM242	2.9E-04	4.5E-07	5.4E-03	8.6E-05	7.5E-06	Bone Surface
CM243	5.8E-04	2.9E-06	3.5E-02	1.2E-03	5.2E-05	Bone Surface
CM244	2.3E-04	2.0E-06	2.4E-02	9.3E-04	3.6E-05	Bone Surface
CM245	8.5E-04	7.3E-06	9.2E-02	5.8E-03	1.4E-04	Bone Surface
CM246	4.2E-04	3.7E-06	4.5E-02	1.7E-03	7.0E-05	Bone Surface
CM247	3.9E-04	3.4E-06	4.2E-02	1.6E-03	6.4E-05	Bone Surface
CM248	1.5E-03	1.3E-05	1.6E-01	6.2E-03	2.5E-04	Bone Surface
CF252	1.3E-04	1.1E-06	1.4E-02	1.1E-04	2.2E-05	Bone Surface

TABLE D.7. Internal Dose Rate Factors for Individual Radionuclides (INTNODAU.DF)

Internal DF's for NRC Residual Radioactivity - No Daughters (10-Jan-90 RAP)

	Inh	2nd Ing	Air Ing	Soi Ing	Drink	Water	Maximum	Organ	Dose
H 3	8.2E-11	5.7E-11	2.3E-06	0.0E+00	6.7E-11	SI Wall			
BE10	3.4E-07	4.6E-09	5.7E-05	3.7E-07	4.8E-08	LLI Wall			
C 14	1.9E-09	1.9E-09	7.2E-04	0.0E+00	2.3E-09	LLI Wall			
F 18	7.7E-11	1.1E-10	7.8E-09	8.9E-08	1.1E-09	Stomach Wall			
NA22	8.6E-09	1.4E-08	1.7E-03	5.7E-04	2.3E-08	Bone Surface			
NA24	1.1E-09	1.4E-09	1.6E-06	1.7E-05	4.4E-09	Stomach Wall			
P 32	5.5E-09	8.5E-09	3.5E-04	4.3E-03	3.1E-08	Red Marrow			
P 33	5.6E-10	8.7E-10	4.6E-05	4.6E-04	4.8E-09	Bone Surface			
S 35	2.4E-09	4.0E-10	2.6E-05	1.0E-04	2.0E-09	LLI Wall			
CL36	1.8E-09	2.8E-09	2.1E-04	1.1E-02	3.2E-09	SI Wall			
K 40	9.9E-09	1.7E-08	5.9E-04	3.2E-03	2.0E-08	SI Wall			
CA41	1.2E-09	1.2E-09	6.1E-05	2.3E-05	1.5E-08	Bone Surface			
CA45	6.4E-09	3.1E-09	1.4E-04	5.0E-05	1.9E-08	Bone Surface			
SC46	2.8E-08	6.2E-09	6.9E-05	2.5E-06	3.7E-08	LLI Wall			
CR51	3.1E-10	1.4E-10	1.8E-06	7.6E-09	9.2E-10	LLI Wall			
MN54	6.1E-09	2.8E-09	3.5E-05	1.6E-05	8.5E-09	LLI Wall			
MN56	3.3E-10	1.0E-09	9.7E-08	5.5E-06	5.2E-09	ULI Wall			
FE55	1.2E-09	5.8E-10	1.3E-05	1.4E-07	2.1E-09	Spleen			
FE59	1.2E-08	6.5E-09	7.3E-05	9.5E-07	3.1E-08	LLI Wall			
CO57	8.3E-09	7.5E-10	1.2E-05	1.7E-06	4.8E-09	LLI Wall			
CO58	1.0E-08	2.9E-09	3.9E-05	5.9E-06	1.4E-08	LLI Wall			
CO60	1.9E-07	1.0E-08	1.8E-04	2.4E-05	4.3E-08	LLI Wall			
NI59	7.9E-10	1.9E-10	8.1E-06	1.9E-06	9.7E-10	LLI Wall			
NI63	1.9E-09	5.1E-10	2.2E-05	5.1E-06	3.2E-09	LLI Wall			
NI65	2.3E-10	6.5E-10	6.2E-08	2.3E-06	3.6E-09	ULI Wall			
CU64	1.9E-10	4.8E-10	2.8E-07	1.2E-05	2.9E-09	LLI Wall			
ZN65	1.7E-08	1.3E-08	1.4E-03	3.8E-03	1.7E-08	LLI Wall			
ZN69M	7.8E-10	1.3E-09	1.2E-06	1.2E-04	8.9E-09	LLI Wall			
ZN69	3.8E-11	8.9E-11	3.2E-09	6.6E-06	7.8E-10	Stomach Wall			
AS76	3.8E-09	5.3E-09	5.0E-06	2.1E-06	4.4E-08	LLI Wall			
SE75	7.6E-09	8.9E-09	1.7E-03	4.6E-04	2.6E-08	Kidneys			
SE79	8.8E-09	8.0E-09	2.7E-03	5.7E-04	4.8E-08	Kidneys			
BR82	1.1E-09	1.6E-09	5.9E-06	6.0E-05	3.0E-09	Stomach Wall			
BR83	8.9E-11	9.4E-11	8.5E-09	2.8E-06	1.1E-09	Stomach Wall			
BR84	9.4E-11	1.8E-10	3.6E-09	5.2E-06	2.6E-09	Stomach Wall			
RB86	5.8E-09	9.1E-09	5.0E-04	6.2E-04	2.7E-08	Bone Surface			
RB88	8.3E-11	1.8E-10	2.0E-09	4.3E-06	2.8E-09	Stomach Wall			
RB89	4.2E-11	9.5E-11	9.3E-10	2.3E-06	1.4E-09	Stomach Wall			
SR85	1.4E-09	1.7E-09	2.7E-05	1.1E-04	5.2E-09	LLI Wall			
SR89	5.3E-09	8.7E-09	1.3E-04	5.5E-04	7.8E-08	LLI Wall			
SR90	2.0E-07	1.2E-07	2.2E-03	7.7E-03	1.4E-06	Bone Surface			
SR91	8.6E-10	2.4E-09	8.9E-07	1.3E-04	1.4E-08	LLI Wall			
SR92	5.9E-10	1.6E-09	1.6E-07	8.8E-05	1.1E-08	ULI Wall			
Y 90	8.5E-09	1.1E-08	2.2E-05	5.0E-06	1.2E-07	LLI Wall			
Y 91M	3.6E-11	4.1E-11	1.3E-09	1.9E-08	1.9E-10	Stomach Wall			
Y 91	4.7E-08	9.4E-09	9.8E-05	4.5E-06	1.1E-07	LLI Wall			
Y 92	8.0E-10	2.0E-09	2.6E-07	9.2E-07	1.3E-08	ULI Wall			

TABLE D.7. Internal Dose Rate Factors for Individual Radionuclides (INTNODAU.DF) (contd)

Y 93	2.2E-09	4.8E-09	1.8E-06	2.2E-06	3.5E-08	LLI Wall
ZR93	7.9E-08	1.6E-09	3.5E-05	9.5E-08	3.3E-08	Bone Surface
ZR95	1.5E-08	3.7E-09	4.6E-05	1.5E-07	2.9E-08	LLI Wall
ZR97	3.8E-09	8.4E-09	5.0E-06	2.6E-07	6.7E-08	LLI Wall
NB93M	2.9E-08	5.0E-10	4.6E-05	7.0E-06	5.6E-09	LLI Wall
NB94	3.7E-07	7.2E-09	6.8E-04	1.0E-04	4.8E-08	LLI Wall
NB95M	2.4E-09	2.3E-09	8.7E-06	4.5E-06	2.4E-08	LLI Wall
NB95	5.5E-09	2.5E-09	5.1E-05	8.7E-06	1.5E-08	LLI Wall
NB97M	1.2E-12	3.9E-12	2.5E-12	6.9E-09	2.7E-11	Stomach Wall
NB97	8.3E-11	2.4E-10	1.1E-08	4.2E-07	1.4E-09	Stomach Wall
MO93	9.5E-10	1.4E-09	2.4E-05	4.0E-05	6.7E-09	Liver
MO99	1.9E-09	3.1E-09	7.8E-06	7.4E-05	1.1E-08	LLI Wall
TC99M	3.1E-11	8.3E-11	1.9E-08	1.7E-05	4.1E-10	ULI Wall
TC99	8.9E-09	3.1E-09	1.2E-04	1.2E-03	2.7E-08	Thyroid
TC101	1.5E-11	7.5E-11	6.8E-10	1.6E-05	5.7E-10	ULI Wall
RU103	8.7E-09	3.0E-09	6.3E-05	6.9E-05	2.4E-08	LLI Wall
RU105	5.2E-10	1.3E-09	2.1E-07	1.2E-05	7.0E-09	ULI Wall
RU106	4.5E-07	2.6E-08	2.6E-03	2.3E-03	2.6E-07	LLI Wall
RH103M	4.8E-12	1.2E-11	4.3E-10	5.6E-07	9.6E-11	Stomach Wall
RH105	9.6E-10	1.5E-09	2.1E-06	7.2E-05	1.4E-08	LLI Wall
PD103	1.5E-09	7.8E-10	1.1E-05	8.8E-06	8.5E-09	LLI Wall
PD107	1.2E-08	1.5E-10	3.8E-06	1.7E-06	1.7E-09	LLI Wall
PD109	1.3E-09	2.6E-09	1.4E-06	2.6E-05	2.1E-08	LLI Wall
AG110M	8.1E-08	3.3E-08	4.5E-03	4.2E-03	2.5E-07	LLI Wall
AG111	3.3E-09	5.1E-09	2.6E-04	5.2E-04	5.5E-08	LLI Wall
CD109	1.1E-07	1.3E-08	1.6E-04	8.7E-04	1.5E-07	Kidneys
CD113M	1.4E-06	1.6E-07	2.0E-03	1.1E-02	2.1E-06	Kidneys
CD115M	6.9E-08	1.6E-08	1.6E-04	1.1E-03	1.0E-07	LLI Wall
CD115	3.8E-09	5.7E-09	1.0E-05	3.8E-04	5.5E-08	LLI Wall
IN115M	1.2E-10	3.5E-10	5.7E-08	1.1E-07	2.1E-09	ULI Wall
IN111	5.4E-10	1.3E-09	2.9E-06	4.1E-07	7.4E-09	LLI Wall
IN114M	4.4E-08	1.5E-08	1.6E-04	4.8E-06	1.6E-07	LLI Wall
SN117M	4.2E-09	2.9E-09	2.3E-05	9.5E-06	3.0E-08	LLI Wall
SN119M	5.8E-09	1.4E-09	2.2E-05	4.6E-06	1.5E-08	LLI Wall
SN121M	1.1E-08	1.5E-09	2.5E-05	4.9E-06	1.6E-08	LLI Wall
SN121	4.8E-10	9.1E-10	9.3E-07	2.9E-06	8.9E-09	LLI Wall
SN123	3.1E-08	8.4E-09	1.2E-04	2.8E-05	9.6E-08	LLI Wall
SN125	1.5E-08	1.2E-08	7.6E-05	3.9E-05	1.3E-07	LLI Wall
SN126	9.4E-08	1.9E-08	3.3E-04	6.4E-05	1.6E-07	LLI Wall
SB124	2.5E-08	9.9E-09	1.2E-04	2.0E-05	8.5E-08	LLI Wall
SB125	1.2E-08	2.8E-09	3.9E-05	5.6E-06	2.4E-08	LLI Wall
SB126M	2.9E-11	9.1E-11	1.1E-09	1.8E-07	9.6E-10	Stomach Wall
SB126	1.1E-08	1.0E-08	7.2E-05	2.0E-05	7.0E-08	LLI Wall
SB127	5.8E-09	7.2E-09	2.2E-05	1.4E-05	7.4E-08	LLI Wall
TE123M	1.0E-08	5.7E-09	1.3E-04	2.9E-03	9.2E-08	Bone Surface
TE125M	7.0E-09	3.7E-09	6.3E-05	1.4E-03	4.9E-08	Bone Surface
TE127M	2.1E-08	8.2E-09	1.9E-04	4.0E-03	7.8E-08	Bone Surface
TE127	3.2E-10	7.1E-10	2.4E-07	1.7E-04	4.8E-09	LLI Wall
TE129M	4.8E-07	5.4E-07	6.7E-03	1.7E-01	2.1E-06	Testes

TABLE D.7. Internal Dose Rate Factors for Individual Radionuclides (INTNODAU.DF) (contd)

TE129	1.5E-10	2.6E-10	1.1E-08	6.3E-05	1.5E-09	Stomach Wall
TE131M	1.2E-08	1.7E-08	2.0E-05	4.3E-03	1.4E-07	Thyroid
TE131	1.2E-10	2.1E-10	3.4E-09	5.3E-05	3.3E-09	Thyroid
TE132	1.2E-08	1.5E-08	4.2E-05	3.8E-03	1.5E-07	Thyroid
TE133M	4.3E-10	7.8E-10	2.8E-08	1.9E-04	1.3E-08	Thyroid
TE133	8.7E-11	1.6E-10	1.3E-09	4.0E-05	3.0E-09	Thyroid
TE134	1.0E-10	1.9E-10	4.9E-09	4.6E-05	2.1E-09	Thyroid
I 125	2.2E-08	3.6E-08	1.4E-02	6.2E-04	1.2E-06	Thyroid
I 129	1.5E-07	2.5E-07	1.2E-01	4.7E-03	8.3E-06	Thyroid
I 130	2.4E-09	4.4E-09	2.9E-05	4.8E-05	1.2E-07	Thyroid
I 131	3.0E-08	5.0E-08	8.9E-03	7.9E-04	1.6E-06	Thyroid
I 132	3.8E-10	6.9E-10	7.5E-07	7.1E-06	1.0E-08	Thyroid
I 133	5.3E-09	9.7E-09	1.4E-04	1.1E-04	3.0E-07	Thyroid
I 134	1.4E-10	2.6E-10	1.1E-07	2.7E-06	2.1E-09	Stomach Wall
I 135	1.1E-09	2.1E-09	6.6E-06	2.2E-05	5.2E-08	Thyroid
CS134M	3.6E-11	3.6E-11	4.0E-09	6.3E-08	4.1E-10	Stomach Wall
CS134	4.0E-08	6.7E-08	2.0E-03	2.0E-04	8.8E-08	SI Wall
CS135	3.6E-09	6.4E-09	1.9E-04	1.9E-05	7.8E-09	SI Wall
CS136	6.4E-09	1.0E-08	1.4E-04	2.4E-05	1.4E-08	SI Wall
CS137	2.6E-08	4.6E-08	1.4E-03	1.4E-04	5.7E-08	SI Wall
CS138	9.6E-11	1.9E-10	3.8E-09	3.2E-07	2.7E-09	Stomach Wall
CS139	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
BA139	1.7E-10	4.1E-10	2.1E-08	3.9E-07	2.6E-09	Stomach Wall
BA140	2.9E-09	9.1E-09	5.9E-05	8.7E-06	9.6E-08	LLI Wall
BA141	7.8E-11	2.1E-10	2.4E-09	2.0E-07	1.4E-09	Stomach Wall
BA142	3.9E-11	1.1E-10	7.4E-10	1.0E-07	7.4E-10	Stomach Wall
LA140	3.4E-09	8.3E-09	1.1E-05	3.8E-06	6.3E-08	LLI Wall
LA141	5.8E-10	1.5E-09	2.2E-07	6.8E-07	9.6E-09	ULI Wall
LA142	2.6E-10	7.0E-10	4.2E-08	3.3E-07	3.3E-09	Stomach Wall
CE141	8.4E-09	2.9E-09	2.6E-05	1.4E-06	3.2E-08	LLI Wall
CE143	3.4E-09	4.6E-09	5.3E-06	2.1E-06	4.4E-08	LLI Wall
CE144	3.6E-07	2.1E-08	2.5E-04	1.0E-05	2.5E-07	LLI Wall
PR143	7.8E-09	4.7E-09	3.0E-05	2.2E-06	5.5E-08	LLI Wall
PR144M	1.8E-11	4.8E-11	2.2E-10	2.2E-08	5.5E-10	Stomach Wall
PR144	4.3E-11	1.2E-10	1.3E-09	5.6E-08	1.6E-09	Stomach Wall
ND147	6.5E-09	4.2E-09	2.3E-05	1.9E-06	4.4E-08	LLI Wall
PM147	3.8E-08	1.0E-09	1.4E-05	3.3E-07	1.2E-08	LLI Wall
PM148M	2.2E-08	7.6E-09	7.2E-05	2.4E-06	5.2E-08	LLI Wall
PM148	1.1E-08	1.1E-08	3.9E-05	3.5E-06	1.2E-07	LLI Wall
PM149	2.9E-09	4.1E-09	7.2E-06	1.3E-06	4.4E-08	LLI Wall
PM151	1.8E-09	3.0E-09	3.0E-06	9.5E-07	2.7E-08	LLI Wall
SM147	7.3E-05	1.9E-07	2.5E-03	8.0E-05	3.2E-06	Bone Surface
SM151	2.9E-08	3.8E-10	5.1E-06	1.6E-07	3.7E-09	LLI Wall
SM153	1.9E-09	3.0E-09	4.7E-06	1.2E-06	3.0E-08	LLI Wall
EU152	2.0E-07	6.3E-09	8.4E-05	3.3E-06	3.7E-08	LLI Wall
EU154	2.6E-07	9.2E-09	1.2E-04	4.8E-06	6.7E-08	LLI Wall
EU155	3.9E-08	1.5E-09	2.0E-05	7.8E-07	1.3E-08	LLI Wall
EU156	1.4E-08	9.1E-09	6.1E-05	4.2E-06	8.5E-08	LLI Wall
GD153	2.3E-08	1.2E-09	1.4E-05	1.8E-06	1.0E-08	LLI Wall

TABLE D.7. Internal Dose Rate Factors for Individual Radionuclides (INTNODAU.DF) (contd)

TB160	2.4E-08	6.6E-09	7.1E-05	6.9E-07	5.5E-08	LLI Wall
HO166M	7.2E-07	7.7E-09	1.0E-04	4.4E-06	4.1E-08	LLI Wall
W 181	1.5E-10	2.9E-10	3.6E-06	1.0E-06	1.9E-09	LLI Wall
W 185	7.5E-10	1.6E-09	1.9E-05	5.6E-06	1.7E-08	LLI Wall
W 187	6.5E-10	2.1E-09	1.8E-06	7.2E-06	1.7E-08	LLI Wall
RE187	5.6E-11	1.4E-11	2.1E-07	5.8E-10	9.0E-11	ULI Wall
OS185	9.2E-09	2.2E-09	0.0E+00	0.0E+00	1.0E-08	LLI Wall
OS191	2.2E-09	2.3E-09	0.0E+00	0.0E+00	2.4E-08	LLI Wall
IR192	2.6E-08	5.7E-09	6.1E-05	1.8E-05	4.8E-08	LLI Wall
HG203	6.8E-09	1.1E-08	1.7E-04	3.8E-04	7.0E-08	Kidneys
PB210	1.3E-05	5.4E-06	6.7E-02	4.1E-03	8.0E-05	Bone Surface
PB212	1.6E-07	4.9E-08	1.9E-05	3.6E-05	6.7E-07	Bone Surface
BI210	1.9E-07	6.3E-09	2.3E-05	1.8E-04	5.5E-08	LLI Wall
BI212	1.8E-08	1.1E-09	4.2E-08	3.0E-05	5.9E-09	Stomach Wall
PO210	8.4E-06	1.9E-06	2.3E-02	6.1E-04	1.6E-05	Spleen
RA223	7.5E-06	2.7E-07	1.7E-03	7.3E-04	4.1E-06	Bone Surface
RA224	2.7E-06	1.3E-07	3.8E-04	3.6E-04	1.2E-06	Bone Surface
RA225	7.1E-06	2.2E-07	1.6E-03	6.1E-04	5.6E-06	Bone Surface
RA226	7.9E-06	9.5E-07	1.3E-02	2.7E-03	2.3E-05	Bone Surface
RA228	3.7E-06	8.4E-07	1.1E-02	2.3E-03	2.0E-05	Bone Surface
AC225	7.9E-06	1.1E-07	6.1E-04	2.8E-05	1.0E-06	LLI Wall
AC227	1.3E-03	1.4E-05	1.7E-01	3.6E-03	2.5E-04	Bone Surface
AC228	1.1E-07	2.1E-09	4.9E-07	5.4E-07	1.1E-08	Bone Surface
TH227	1.6E-05	3.8E-08	2.8E-04	3.0E-05	3.4E-07	LLI Wall
TH228	3.1E-04	4.0E-07	4.8E-03	3.1E-04	8.9E-06	Bone Surface
TH229	1.7E-03	3.5E-06	4.3E-02	2.8E-03	8.8E-05	Bone Surface
TH230	2.5E-04	5.4E-07	6.5E-03	4.2E-04	1.3E-05	Bone Surface
TH231	8.1E-10	1.3E-09	1.2E-06	1.0E-06	1.3E-08	LLI Wall
TH232	1.1E-03	2.8E-06	3.3E-02	2.2E-03	6.9E-05	Bone Surface
TH234	3.4E-08	1.3E-08	1.1E-04	1.1E-05	1.6E-07	LLI Wall
PA231	8.4E-04	1.1E-05	1.4E-01	1.9E-02	2.7E-04	Bone Surface
PA233	9.2E-09	3.6E-09	3.0E-05	6.0E-06	3.7E-08	LLI Wall
PA234	8.2E-10	2.2E-09	5.5E-07	3.7E-06	1.2E-08	ULI Wall
U 232	6.0E-04	6.8E-08	9.3E-04	3.3E-05	9.7E-07	Bone Surface
U 233	1.3E-04	2.6E-08	3.6E-04	1.3E-05	1.9E-07	LLI Wall
U 234	1.3E-04	2.6E-08	3.5E-04	1.3E-05	1.9E-07	LLI Wall
U 235	1.2E-04	2.6E-08	3.6E-04	1.3E-05	2.0E-07	LLI Wall
U 236	1.2E-04	2.4E-08	3.3E-04	1.2E-05	1.7E-07	LLI Wall
U 237	3.5E-09	3.2E-09	1.5E-05	1.5E-06	3.3E-08	LLI Wall
U 238	1.1E-04	2.4E-08	3.2E-04	1.1E-05	1.7E-07	LLI Wall
U 240	2.2E-09	4.7E-09	2.4E-06	2.2E-06	3.7E-08	LLI Wall
NP237	6.1E-04	5.2E-06	6.4E-02	2.4E-03	1.2E-04	Bone Surface
NP238	4.0E-08	4.0E-09	6.8E-06	1.9E-06	3.4E-08	LLI Wall
NP239	2.4E-09	3.3E-09	6.1E-06	1.5E-06	3.3E-08	LLI Wall
PU236	7.2E-05	6.3E-08	7.6E-04	6.6E-06	7.8E-07	Bone Surface
PU237	1.8E-09	4.3E-10	4.1E-06	4.4E-08	3.7E-09	LLI Wall
PU238	2.8E-04	3.4E-07	4.1E-03	3.5E-05	5.9E-06	Bone Surface
PU239	2.9E-04	3.7E-07	4.5E-03	3.9E-05	6.7E-06	Bone Surface
PU240	2.9E-04	3.7E-07	4.5E-03	3.8E-05	6.7E-06	Bone Surface

TABLE D.7. Internal Dose Rate Factors for Individual Radionuclides (INTNODAU.DF) (contd)

PU241	4.7E-06	6.8E-09	8.3E-05	7.1E-07	1.3E-07	Bone Surface
PU242	2.7E-04	3.4E-07	4.2E-03	3.6E-05	6.1E-06	Bone Surface
PU243	1.4E-10	3.2E-10	5.6E-08	3.3E-08	2.1E-09	ULI Wall
PU244	2.6E-04	3.5E-07	4.3E-03	3.7E-05	6.1E-06	Bone Surface
AM241	4.3E-04	3.6E-06	4.7E-02	4.1E-03	6.7E-05	Bone Surface
AM242M	3.9E-04	3.5E-06	4.5E-02	3.9E-03	6.4E-05	Bone Surface
AM242	5.2E-08	1.4E-09	8.2E-07	1.4E-06	9.6E-09	LLI Wall
AM243	4.1E-04	3.6E-06	4.7E-02	4.1E-03	6.7E-05	Bone Surface
CM242	1.5E-05	1.1E-07	1.3E-03	5.1E-05	1.6E-06	Bone Surface
CM243	2.9E-04	2.5E-06	3.0E-02	1.2E-03	4.5E-05	Bone Surface
CM244	2.3E-04	2.0E-06	2.4E-02	9.3E-04	3.6E-05	Bone Surface
CM245	4.2E-04	3.7E-06	4.5E-02	1.7E-03	6.8E-05	Bone Surface
CM246	4.2E-04	3.7E-06	4.5E-02	1.7E-03	7.0E-05	Bone Surface
CM247	3.9E-04	3.4E-06	4.2E-02	1.6E-03	6.4E-05	Bone Surface
CM248	1.5E-03	1.3E-05	1.6E-01	6.2E-03	2.5E-04	Bone Surface
CF252	1.3E-04	1.1E-06	1.4E-02	1.1E-04	2.2E-05	Bone Surface

TABLE D.8. EXTDF Output for Surface Source Configuration

EXTDF Dose Calculation Program
(Version 1.429 19-Dec-89)

Case title: 5m Surface - Residual Radioactivity

Executed on: 12/21/89 at 08:26:09

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Shield composition (gm/cc):

	1	2	3	4	5
AIR	1.3E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00

Shield thickness (cm):
0.0E+00

Geometry index: 6

DISC source

SLAB shield

Distance to detector: 1.00E+02 cm

Disc radius: 5.00E+02 cm

Taylor buildup data for shield: 1

with effective atomic number: 7.0

Units are rem/hr per Ci/cm2 or cm3

H 3	5.29E-05
BE10	1.89E+01
C 14	1.12E+00
N 13	3.68E+04
F 18	3.56E+04
NA22	7.98E+04
NA24	1.48E+05
SI31	1.63E+02
P 32	1.70E+02
P 33	3.33E+00
S 35	1.26E+00
CL36	2.91E+01
K 40	6.01E+03
AR39	1.88E+01
AR41	4.64E+04
CA41	7.19E+01
CA45	3.45E+00
SC46	7.92E+04
CR51	1.48E+03
MN54	3.27E+04
MN56	6.49E+04
FE55	1.64E+02
FE59	4.23E+04
C057	5.25E+03
C058	3.86E+04

TABLE D.8. EXTDF Output for Surface Source Configuration (contd)

CO60	9.34E+04
NI59	2.00E+02
NI63	8.94E-02
NI65	2.15E+04
CU64	6.92E+03
ZN65	2.44E+04
ZN69M	1.75E+04
ZN69	4.82E+01
GA72	1.02E+05
AS76	1.91E+04
SE75	1.46E+04
SE79	8.66E-01
BR82	1.07E+05
BR83	3.07E+02
KR83M	1.36E+02
BR84	6.23E+04
KR85M	5.77E+03
KR85	1.06E+02
KR87	3.10E+04
RB87	3.64E+00
KR88	6.90E+04
RB88	2.55E+04
KR89	6.77E+04
RB89	7.62E+04
SR89	1.43E+02
SR87M	1.13E+04
RB86	3.58E+03
SR85	1.86E+04
SR90	1.61E+01
Y 90	3.47E+02
SR91	2.61E+04
Y 91M	2.49E+04
Y 91	2.87E+02
SR92	5.37E+04
Y 92	1.11E+04
Y 93	3.90E+03
MO93	3.84E+02
ZR93	7.09E-02
NB93M	7.97E+01
ZR95	2.95E+04
NB95M	2.62E+03
NB95	3.25E+04
ZR97	7.17E+03
NB97M	2.56E+04
NB97	2.65E+04
NB94	5.87E+04
MO99	5.72E+03
TC99M	4.52E+03
TC99	4.19E+00
TC101	1.47E+04

TABLE D.8. EXTDF Output for Surface Source Configuration (contd)

RU103	1.82E+04
PD103	1.04E+03
RH103M	1.36E+02
RU105	3.13E+04
RH105	3.37E+03
RU106	8.72E+03
PD107	5.45E-03
PD109	7.09E+02
AG110M	1.08E+05
AG111	1.11E+03
CD109	9.81E+02
CD113M	1.81E+01
CD115M	1.02E+03
CD115	7.33E+03
IN115M	6.90E+03
IN111	1.46E+04
IN114M	5.30E+03
SN113	1.28E+03
IN113M	9.23E+03
SN117M	5.44E+03
SN119M	7.05E+02
SN121M	0.00E+00
SN121	0.00E+00
SN123	3.62E+02
I 125	2.25E+03
SN125	1.18E+04
SB125	1.83E+04
TE125M	1.90E+03
SN126	1.92E+03
SB126M	6.28E+04
SB126	1.07E+05
SB122	2.04E+04
SB124	7.40E+04
SB127	2.60E+04
TE127M	6.16E+02
TE127	2.33E+02
TE123M	5.00E+03
TE129M	1.67E+03
TE129	2.47E+03
I 129	1.22E+03
TE131M	5.74E+04
TE131	1.64E+04
I 131	1.44E+04
XE131M	9.57E+02
TE132	9.68E+03
I 132	9.14E+04
TE133M	8.91E+04
TE133	3.75E+04
I 133	2.16E+04
XE133M	1.85E+03

TABLE D.8. EXTDF Output for Surface Source Configuration (contd)

XE133	1.73E+03
TE134	3.52E+04
I 134	1.01E+05
CS134M	1.26E+03
CS134	6.56E+04
I 130	7.98E+04
I 135	6.01E+04
XE135M	1.51E+04
XE135	9.50E+03
CS135	1.67E+00
XE137	8.63E+03
CS137	2.24E+04
XE138	4.27E+04
CS138	9.00E+04
CS139	1.22E+04
BA139	1.46E+03
BA140	7.03E+03
LA140	8.39E+04
CS136	8.28E+04
BA141	3.37E+04
LA141	2.10E+03
CE141	2.74E+03
BA142	3.50E+04
LA142	9.75E+04
CE143	9.94E+03
PR143	4.80E+01
CE144	7.49E+02
PR144M	5.71E+02
PR144	1.73E+03
PR142	2.33E+03
ND147	5.11E+03
PM147	2.38E+00
SM147	0.00E+00
PM148M	8.39E+04
PM148	2.36E+04
PM149	4.69E+02
PM151	1.32E+04
SM151	1.19E+00
SM153	2.73E+03
EU152M	1.26E+04
EU152	4.57E+04
EU154	4.73E+04
EU155	2.28E+03
EU156	5.09E+04
GD153	4.35E+03
GD159	1.57E+03
TB160	4.12E+04
TB161	9.49E+02
DY165	1.05E+03
H0166M	6.07E+04

TABLE D.8. EXTDF Output for Surface Source Configuration (contd)

H0166	1.29E+03
ER169	6.69E+00
ER171	1.51E+04
TA182	5.07E+04
W 181	1.34E+03
W 185	1.03E+01
W 187	1.86E+04
RE187	0.00E+00
OS185	2.78E+04
OS191	2.65E+03
IR192	3.34E+04
HG203	7.67E+03
TH230	5.98E+01
RA226	1.86E+02
RN222	6.85E+04
PB210	2.11E+02
BI210	7.08E+01
P0210	3.45E-01
U 232	7.73E+01
TH232	5.44E+01
RA228	1.19E-02
AC228	3.74E+04
TH228	1.20E+02
RA224	4.06E+02
PB212	5.61E+03
BI212	5.18E+04
U 234	6.53E+01
U 236	6.03E+01
U 235	4.68E+03
TH231	9.54E+02
PA231	1.56E+03
AC227	1.19E+01
TH227	4.20E+03
FR223	2.09E+03
RA223	1.12E+04
U 237	5.93E+03
NP237	1.19E+03
PA233	9.01E+03
U 233	3.20E+01
TH229	3.35E+03
RA225	6.25E+02
AC225	9.39E+03
U 238	5.33E+01
TH234	1.05E+03
PA234	7.70E+04
PU236	7.76E+01
PU237	2.25E+03
AM242M	1.88E+02
AM242	7.44E+02
CM242	6.80E+01

TABLE D.8. EXTDF Output for Surface Source Configuration (contd)

PU238	6.83E+01
PU242	5.40E+01
NP238	2.15E+04
PU238	6.83E+01
CM244	6.06E+01
PU244	4.67E+01
U 240	1.49E+04
PU240	6.51E+01
CM245	3.01E+03
PU241	1.76E-04
AM241	9.39E+02
CM246	5.40E+01
CM247	1.43E+04
PU243	7.88E+02
CM243	5.18E+03
AM243	1.80E+03
NP239	6.96E+03
PU239	2.81E+01
CM248	4.28E+01
CF252	4.29E+01

TABLE D.9. EXTDF Output for Volume Source Configuration

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                        EXTDF Dose Calculation Program
                        (Version 1.429 19-Dec-89)

Case title:   5m Volume, 1cm thick - Residual Radioactivity
Executed on: 12/21/89 at 08:28:32
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Shield composition (gm/cc):

	1	2	3	4	5
ORDCONC	2.4E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
AIR	0.0E+00	1.3E-03	0.0E+00	0.0E+00	0.0E+00

Shield thickness (cm):

	1.0E+00	0.0E+00

Geometry index:

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END OF CYLINDER source

SLAB shields

Distance to detector:

1.010E+02 cm.

Source length:

1.000E+00 cm.

Source radius:

5.000E+02 cm.

End of source to detector:

1.000E+02 cm.

Source volume:

7.854E+05 cc.

Integration specs:

NTHETA:

11

NPSI:

1

DELR:

5.000E+00

NTHETA x NPSI x T(1) / DELR:

2.200E+00

Taylor buildup data for shield:

1

with effective atomic number:

10.0

Units are rem/hr per Ci/cm2 or cm3

H 3	4.23E-06
BE10	5.87E+00
C 14	1.71E-01
N 13	2.57E+04
F 18	2.49E+04
NA22	5.78E+04
NA24	1.14E+05
SI31	9.38E+01
P 32	9.46E+01
P 33	6.39E-01
S 35	1.99E-01
CL36	1.06E+01
K 40	4.50E+03
AR39	5.89E+00
AR41	3.45E+04
CA41	5.75E+00

TABLE D.9. EXTDF Output for Volume Source Configuration (contd)

CA45	6.71E-01
SC46	5.82E+04
CR51	9.28E+02
MN54	2.35E+04
MN56	4.84E+04
FE55	1.31E+01
FE59	3.14E+04
CO57	2.85E+03
CO58	2.76E+04
CO60	6.95E+04
NI59	1.60E+01
NI63	8.23E-03
NI65	1.60E+04
CU64	4.78E+03
ZN65	1.80E+04
ZN69M	1.22E+04
ZN69	1.93E+01
GA72	7.61E+04
AS76	1.36E+04
SE75	9.06E+03
SE79	1.26E-01
BR82	7.71E+04
BR83	2.00E+02
KR83M	1.10E+01
BR84	4.73E+04
KR85M	3.52E+03
KR85	6.50E+01
KR87	2.30E+04
RB87	7.30E-01
KR88	5.25E+04
RB88	1.92E+04
KR89	5.06E+04
RB89	5.72E+04
SR89	7.09E+01
SR87M	7.69E+03
RB86	2.61E+03
SR85	1.28E+04
SR90	4.87E+00
Y 90	1.90E+02
SR91	1.89E+04
Y 91M	1.75E+04
Y 91	1.76E+02
SR92	4.04E+04
Y 92	8.11E+03
Y 93	2.77E+03
MO93	3.07E+01
ZR93	6.31E-03
NB93M	6.37E+00
ZR95	2.10E+04
NB95M	1.54E+03

TABLE D.9. EXTDF Output for Volume Source Configuration (contd)

NB95	2.34E+04
ZR97	5.19E+03
NB97M	1.80E+04
NB97	1.86E+04
NB94	4.19E+04
MO99	3.94E+03
TC99M	2.59E+03
TC99	8.86E-01
TC101	1.00E+04
RU103	1.27E+04
PD103	8.89E+01
RH103M	1.14E+01
RU105	2.14E+04
RH105	2.29E+03
RU106	6.08E+03
PD107	4.37E-04
PD109	1.35E+02
AG110M	7.83E+04
AG111	7.34E+02
CD109	8.16E+01
CD113M	5.73E+00
CD115M	7.17E+02
CD115	5.05E+03
IN115M	4.41E+03
IN111	8.38E+03
IN114M	3.23E+03
SN113	2.08E+02
IN113M	6.09E+03
SN117M	2.65E+03
SN119M	5.86E+01
SN121M	0.00E+00
SN121	0.00E+00
SN123	2.37E+02
I 125	2.47E+02
SN125	8.68E+03
SB125	1.23E+04
TE125M	2.17E+02
SN126	7.21E+02
SB126M	4.41E+04
SB126	7.57E+04
SB122	1.43E+04
SB124	5.44E+04
SB127	1.82E+04
TE127M	6.92E+01
TE127	1.52E+02
TE123M	2.52E+03
TE129M	8.98E+02
TE129	1.54E+03
I 129	1.40E+02
TE131M	4.13E+04

TABLE D.9. EXTDF Output for Volume Source Configuration (contd)

TE131	1.11E+04
I 131	9.80E+03
XE131M	1.48E+02
TE132	5.58E+03
I 132	6.57E+04
TE133M	6.48E+04
TE133	2.69E+04
I 133	1.52E+04
XE133M	7.14E+02
XE133	6.32E+02
TE134	2.41E+04
I 134	7.33E+04
CS134M	4.85E+02
CS134	4.68E+04
I 130	5.62E+04
I 135	4.48E+04
XE135M	1.04E+04
XE135	6.10E+03
CS135	2.95E-01
XE137	6.02E+03
CS137	1.57E+04
XE138	3.17E+04
CS138	6.75E+04
CS139	9.05E+03
BA139	8.47E+02
BA140	4.65E+03
LA140	6.22E+04
CS136	5.96E+04
BA141	2.36E+04
LA141	1.51E+03
CE141	1.47E+03
BA142	2.52E+04
LA142	7.42E+04
CE143	6.10E+03
PR143	1.93E+01
CE144	3.69E+02
PR144M	1.14E+02
PR144	1.20E+03
PR142	1.70E+03
ND147	3.04E+03
PM147	4.83E-01
SM147	0.00E+00
PM148M	5.93E+04
PM148	1.74E+04
PM149	2.93E+02
PM151	8.65E+03
SM151	9.88E-02
SM153	1.21E+03
EU152M	8.88E+03
EU152	3.27E+04

TABLE D.9. EXTDF Output for Volume Source Configuration (contd)

EU154	3.41E+04
EU155	1.12E+03
EU156	3.79E+04
GD153	1.75E+03
GD159	9.38E+02
TB160	2.97E+04
TB161	2.55E+02
DY165	6.22E+02
H0166M	4.22E+04
H0166	7.81E+02
ER169	1.44E+00
ER171	9.73E+03
TA182	3.67E+04
W 181	4.75E+02
W 185	3.01E+00
W 187	1.28E+04
RE187	0.00E+00
OS185	1.91E+04
OS191	1.26E+03
IR192	2.29E+04
HG203	4.84E+03
TH230	9.06E+00
RA226	1.04E+02
RN222	5.00E+04
PB210	2.99E+01
BI210	3.09E+01
PO210	2.49E-01
U 232	9.06E+00
TH232	6.40E+00
RA228	9.54E-04
AC228	2.71E+04
TH228	4.13E+01
RA224	2.59E+02
PB212	3.44E+03
BI212	3.91E+04
U 234	6.85E+00
U 236	5.58E+00
U 235	2.64E+03
TH231	2.25E+02
PA231	8.08E+02
AC227	3.40E+00
TH227	2.52E+03
FR223	1.03E+03
RA223	7.20E+03
U 237	3.21E+03
NP237	3.94E+02
PA233	5.82E+03
U 233	7.10E+00
TH229	1.63E+03
RA225	1.51E+02

TABLE D.9. EXTDF Output for Volume Source Configuration (contd)

AC225	6.34E+03
U 238	4.93E+00
TH234	6.22E+02
PA234	5.48E+04
PU236	6.77E+00
PU237	1.12E+03
AM242M	1.98E+01
AM242	3.29E+02
CM242	5.64E+00
PU238	5.71E+00
PU242	4.55E+00
NP238	1.57E+04
PU238	5.71E+00
CM244	4.99E+00
PU244	3.83E+00
U 240	1.03E+04
PU240	5.48E+00
CM245	1.54E+03
PU241	1.41E-05
AM241	2.65E+02
CM246	4.40E+00
CM247	9.88E+03
PU243	3.92E+02
CM243	2.98E+03
AM243	7.62E+02
NP239	4.05E+03
PU239	3.44E+00
CM248	3.56E+00
CF252	3.62E+00

TABLE D.10. EXTDF Output for Soil Source Configuration

```

-----
                        EXTDF Dose Calculation Program
                        (Version 1.429 19-Dec-89)

Case title:  15 cm Infinite Slab Source, soil for Residual Radioactivity
Executed on: 12/21/89 at 08:50:36                               Page 1
-----

```

Shield composition (gm/cc):

	1	2	3	4	5
ORDCONC	1.8E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
AIR	0.0E+00	1.3E-03	0.0E+00	0.0E+00	0.0E+00

Shield thickness (cm):

1.5E+01	1.0E+02

Geometry index:

5

INFINITE SLAB source

SLAB shield

Distance to detector:

1.150E+02 cm

Angle:

0.0 degrees

Source thickness:

15.00 cm

Taylor buildup data for shield:

1

with effective atomic number:

10.0

Units are rem/hr per Ci/cm2 or cm3

H 3	4.38E-06
BE10	5.48E+01
C 14	9.39E-01
N 13	4.36E+05
F 18	4.22E+05
NA22	8.89E+05
NA24	1.72E+06
SI31	1.22E+03
P 32	1.22E+03
P 33	4.25E+00
S 35	1.13E+00
CL36	1.09E+02
K 40	6.46E+04
AR39	5.52E+01
AR41	4.93E+05
CA41	5.95E+00
CA45	4.51E+00
SC46	8.28E+05
CR51	1.46E+04
MN54	3.31E+05
MN56	7.14E+05
FE55	1.36E+01
FE59	4.57E+05

TABLE D.10. EXTDF Output for Soil Source Configuration (contd)

C057	3.15E+04
C058	4.01E+05
C060	9.93E+05
NI59	1.65E+01
NI63	2.39E-02
NI65	2.31E+05
CU64	8.05E+04
ZN65	2.58E+05
ZN69M	2.07E+05
ZN69	2.10E+02
GA72	1.13E+06
AS76	2.04E+05
SE75	1.22E+05
SE79	6.70E-01
BR82	1.13E+06
BR83	3.28E+03
KR83M	1.22E+01
BR84	7.21E+05
KR85M	4.54E+04
KR85	1.04E+03
KR87	3.60E+05
RB87	5.03E+00
KR88	7.85E+05
RB88	2.90E+05
KR89	7.66E+05
RB89	8.52E+05
SR89	8.83E+02
SR87M	1.22E+05
RB86	3.85E+04
SR85	2.17E+05
SR90	4.47E+01
Y 90	2.50E+03
SR91	2.81E+05
Y 91M	2.65E+05
Y 91	2.38E+03
SR92	5.81E+05
Y 92	1.20E+05
Y 93	4.05E+04
M093	3.18E+01
ZR93	1.68E-02
NB93M	6.60E+00
ZR95	3.05E+05
NB95M	2.07E+04
NB95	3.31E+05
ZR97	7.75E+04
NB97M	2.73E+05
NB97	2.82E+05
NB94	6.10E+05
M099	5.74E+04
TC99M	2.88E+04

TABLE D.10. EXTDF Output for Soil Source Configuration (contd)

TC99	6.33E+00
TC101	1.59E+05
RU103	2.13E+05
PD103	3.95E+02
RH103M	4.18E+01
RU105	3.27E+05
RH105	3.64E+04
RU106	9.57E+04
PD107	5.21E-04
PD109	1.22E+03
AG110M	1.15E+06
AG111	1.14E+04
CD109	3.30E+02
CD113M	5.41E+01
CD115M	1.04E+04
CD115	8.49E+04
IN115M	6.97E+04
IN111	1.07E+05
IN114M	4.63E+04
SN113	1.96E+03
IN113M	9.66E+04
SN117M	2.89E+04
SN119M	2.26E+02
SN121M	0.00E+00
SN121	0.00E+00
SN123	3.37E+03
I 125	1.20E+03
SN125	1.29E+05
SB125	1.94E+05
TE125M	1.10E+03
SN126	6.54E+03
SB126M	6.88E+05
SB126	1.16E+06
SB122	2.16E+05
SB124	8.10E+05
SB127	2.79E+05
TE127M	3.57E+02
TE127	2.49E+03
TE123M	2.75E+04
TE129M	1.31E+04
TE129	2.46E+04
I 129	6.98E+02
TE131M	5.93E+05
TE131	1.63E+05
I 131	1.54E+05
XE131M	1.06E+03
TE132	7.43E+04
I 132	9.72E+05
TE133M	9.58E+05
TE133	4.11E+05

TABLE D.10. EXTDF Output for Soil Source Configuration (contd)

I 133	2.48E+05
XE133M	8.89E+03
XE133	5.52E+03
TE134	3.57E+05
I 134	1.07E+06
CS134M	4.79E+03
CS134	6.85E+05
I 130	8.80E+05
I 135	6.53E+05
XE135M	1.77E+05
XE135	8.39E+04
CS135	1.82E+00
XE137	9.68E+04
CS137	2.38E+05
XE138	4.79E+05
CS138	1.00E+06
CS139	1.33E+05
BA139	1.02E+04
BA140	7.67E+04
LA140	9.14E+05
CS136	8.64E+05
BA141	3.49E+05
LA141	2.15E+04
CE141	1.60E+04
BA142	3.65E+05
LA142	1.14E+06
CE143	8.60E+04
PR143	2.11E+02
CE144	3.90E+03
PR144M	6.70E+02
PR144	1.75E+04
PR142	2.42E+04
ND147	4.58E+04
PM147	3.44E+00
SM147	0.00E+00
PM148M	9.02E+05
PM148	2.54E+05
PM149	4.02E+03
PM151	1.29E+05
SM151	2.44E-01
SM153	1.21E+04
EU152M	1.27E+05
EU152	4.72E+05
EU154	4.91E+05
EU155	1.13E+04
EU156	5.60E+05
GD153	1.61E+04
GD159	1.40E+04
TB160	4.25E+05
TB161	1.87E+03

TABLE D.10. EXTDF Output for Soil Source Configuration (contd)

DY165	8.67E+03
H0166M	6.10E+05
H0166	1.03E+04
ER169	1.07E+01
ER171	1.43E+05
TA182	5.18E+05
W 181	3.47E+03
W 185	2.69E+01
W 187	1.95E+05
RE187	0.00E+00
OS185	2.82E+05
OS191	1.24E+04
IR192	3.63E+05
HG203	6.50E+04
TH230	5.15E+01
RA226	1.15E+03
RN222	7.38E+05
PB210	1.31E+02
BI210	3.58E+02
PO210	3.51E+00
U 232	3.91E+01
TH232	2.68E+01
RA228	1.36E-03
AC228	4.01E+05
TH228	4.27E+02
RA224	3.55E+03
PB212	4.56E+04
BI212	5.99E+05
U 234	2.37E+01
U 236	1.23E+01
U 235	3.00E+04
TH231	1.84E+03
PA231	1.17E+04
AC227	3.23E+01
TH227	3.45E+04
FR223	1.23E+04
RA223	1.05E+05
U 237	3.83E+04
NP237	3.69E+03
PA233	8.84E+04
U 233	6.06E+01
TH229	1.73E+04
RA225	9.29E+02
AC225	9.89E+04
U 238	1.08E+01
TH234	8.18E+03
PA234	7.95E+05
PU236	1.18E+01
PU237	1.20E+04
AM242M	7.36E+01

TABLE D.10. EXTDF Output for Soil Source Configuration (contd)

AM242	3.45E+03
CM242	7.44E+00
PU238	7.88E+00
PU242	6.56E+00
NP238	2.33E+05
PU238	7.88E+00
CM244	6.35E+00
PU244	4.66E+00
U 240	1.53E+05
PU240	7.86E+00
CM245	1.67E+04
PU241	1.46E-05
AM241	1.79E+03
CM246	5.25E+00
CM247	1.66E+05
PU243	4.15E+03
CM243	3.69E+04
AM243	6.58E+03
NP239	5.06E+04
PU239	1.75E+01
CM248	4.78E+00
CF252	5.32E+00

TABLE D.11. GENEXT1.BAS Computer Program Listing

```

'-----
'
' GENEXT1
'
' GENII input file generator and batch file controller.
' Surface external dose factors for NRC Residual Radioactivity
'
' Utility program for the Hanford Environmental Dosimetry Software
' System
'
' Last Modification: 27-Jan-90 RAP
'-----

```

```

DEFINT i-n

CALL copyfile ("\\resid\\filext.sur", "\\resid\\filename.dat", errs)

' GENII input file--
fin$ = "GENII.IN" : fing$ = "\\GENII\\GENII.IN"

' Check if DOSEQA file exists, then delete--
filo$ = "\\GENII\\DOSEQA.OUT"
CALL exist (filo$, ifound)
IF ifound THEN SHELL "erase "+filo$

OPEN "I", #1, "RMDLIBDA.SHT"
LINE INPUT #1, dum$

' Process each record in batch control file--
WHILE NOT EOF(1)

' Read radionuclide record--
LINE INPUT #1, l$
rad$ = LEFT$ (l$, 6)

' Open new input file and write header--
OPEN "O", #2, fin$
PRINT #2, "NRC Residual Rad. Surface External Dose Factors"
PRINT #2, "Title: "+rad$ + " Sur Ext (pCi/m2)"

' Open, read, and write options file--
OPEN "I", #3, "EXTOPT.TPL"
WHILE NOT EOF(3)
    LINE INPUT #3, l$
    PRINT #2, l$
WEND
CLOSE 3

```

TABLE D.11. GENEXT1.BAS Computer Program Listing (contd)

```
' Write inventory lines--
PRINT #2, "      ";rad$; SPACE$(35); "      1.0"

' Open, read, and write parameters file--
OPEN "I", #3, "EXTPAR.TPL"
WHILE NOT EOF(3)
    LINE INPUT #3, 1$
    PRINT #2, 1$
WEND
CLOSE 3

' Close input file and copy to GENII subdirectory--
CLOSE 2
CALL copyfile (fin$, fing$, ecode)

' Execute GENII--
IF NOT ecode THEN
    SHELL "\genii\envin"
    SHELL "\genii\env"
    SHELL "\genii\dose"
ENDIF

WEND
CLOSE 1

CALL copyfile (fil0$, "ext1.df", errs)
CALL copyfile ("\genii\genii.in", "ext1.gin", errs)
CALL copyfile ("\genii\genii.out", "ext1.out", errs)
CALL copyfile ("\genii\dose.out", "ext1-2.out", errs)
```

TABLE D.12. EXTOPT.TPL GENII Input File Template

```

EXTOPT.TPL  25-Jan-90 RAP
OPTIONS===== Default =====
T  Near-field scenario?      (Far-field)    NEAR-FIELD: narrowly-focused
F  Population dose?          (Individual)  release, single site
F  Acute release?            (Chronic)     FAR-FIELD:  wide-scale release,
Maximum Individual data set used                multiple sites

                                Complete
TRANSPORT OPTIONS===== Section  EXPOSURE PATHWAY OPTIONS===== Section
F  Air Transport              1      F  Finite plume, external          5
F  Surface Water Transport    2      F  Infinite plume, external        5
F  Biotic Transport (near-field) 3    T  Ground, external                5

F  Waste Form Degradation (near) 4    F  Recreation, external           5

                                Complete
REPORT OPTIONS=====
T  Report AEDE only
T  Report by radionuclide
T  Report by exposure pathway
F  Debug report on screen
                                F  Inhalation uptake                6
                                F  Drinking water ingestion           7,8
                                F  Aquatic foods ingestion            7,8
                                F  Terrestrial foods ingestion        7,9
                                F  Animal product ingestion           7,10
                                F  Inadvertent soil ingestion

.

INVENTORY #####
1  Inventory input activity units: (1-pCi 2-uCi 3-mCi 4-Ci 5-Bq)
1  Surface soil source units (1- m2 2- m3 3- kg)
T  Equilibrium question goes here

```

Use when	----Release Terms----- transport selected			-----Basic Concentrations----- near-field scenario, optionally				
Release	Surface		Buried	Surface		Deep	Ground	Surface
Radio-nuclide	Air /yr	Water /yr	Waste /m3	Air /L	Soil /unit	Soil /m3	Water /L	Water /L

TABLE D.13. EXTPAR.TPL GENII Input File Template

-----	----Derived Concentrations----			
Use when	measured values are known			
-----	-----			
Release	Terres.	Animal	Drink	Aquatic
Radio-	Plant	Product	Water	Food
nuclide	/kg	/kg	/L	/kg
-----	-----			

TIME #####

1 Intake ends after (yr)
 50 Dose calc. ends after (yr)
 0 Release ends after (yr)
 0 No. of years of air deposition prior to the intake period
 0 No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) #####

0 Definition option: 1-Use population grid in file POP.IN
 0 2-Use total entered on this line

NEAR-FIELD SCENARIOS #####

Prior to the beginning of the intake period: (yr)
 0 When was the inventory disposed? (Package degradation starts)
 0 When was LOIC? (Biotic transport starts)
 1.0 Fraction of roots in upper soil (top 15 cm)
 0.0 Fraction of roots in deep soil
 0.0 Manual redistribution: deep soil/surface soil dilution factor

TRANSPORT #####
 ====AIR TRANSPORT=====SECTION 1=====

0 Calculate PM
 1 Option: 1-Use chi/Q or PM value F Stack release (T/F)
 2-Select MI dist & dir 0 Stack height (m)
 3-Specify MI dist & dir 0 Stack flow (m3/sec)
 0 Chi/Q or PM value 0 Stack radius (m)
 0 MI sector index (1=S) 0 Effluent temp. (C)
 0 MI distance from release point (m)
 T Use joint frequency data, otherwise chi/Q grid

====SURFACE WATER TRANSPORT=====SECTION 2=====

0 Mixing ratio model: 0-use value, 1-river, 2-lake, 3-river flow
 0 Mixing ratio, dimensionless
 0 Average river flow rate for: MIXFLG=0,3 (m3/s), MIXFLG=1,2 (m/s),
 0 Transit time to irrigation withdrawal location (hr)
 If mixing ratio model > 0:
 0 Rate of effluent discharge to receiving water body (m3/s)
 0 Longshore distance from release point to usage location (m)
 0 Offshore distance to the water intake (m)

TABLE D.13. EXTPAR.TPL GENII Input File Template (contd)

```

0      Average water depth in surface water body (m)
0      Average river width (m), MIXFLG=1 only
0      Depth of effluent discharge point to surface water (m), lake only

====WASTE FORM AVAILABILITY=====SECTION 3=====
0      Waste form/package half life, (yr)
0.85   Waste thickness, (m)
0.15   Depth of soil overburden, m

====BIOTIC TRANSPORT OF BURIED SOURCE=====SECTION 4=====
T      Consider during inventory decay/buildup period (T/F)?
T      Consider during intake period (T/F)?      1-Arid non agricultural
0      Pre-Intake site condition.....          2-Humid non agricultural
                                              3-Agricultural

EXPOSURE #####

====EXTERNAL EXPOSURE=====SECTION 5=====
Exposure time:
0      Plume (hr)                                T      Residential irrigation:
1.0    Soil contamination (hr)                    0      Consider: (T/F)
0      Swimming (hr)                                Source: 1-ground water
0      Boating (hr)                                2-surface water
0      Shoreline activities (hr)                    0      Application rate (in/yr)
0      Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin)
0      Duration (mo/yr)
0      Transit time for release to reach aquatic recreation (hr)
0      Average fraction of time submersed in acute cloud (hr/person hr)

====INHALATION=====SECTION 6=====
1.0    Hours of exposure to contamination per year
2      0-No resus- 1-Use Mass Loading                2-Use Anspaugh model
1.0    pension      Mass loading factor (g/m3)      Top soil available (cm)

====INGESTION POPULATION=====SECTION 7=====
0      Atmospheric production definition (select option):
0      0-Use food-weighted chi/Q, (food-sec/m3), enter value on this line

        1-Use population-weighted chi/Q
        2-Use uniform production
        3-Use chi/Q and production grids (PRODUCTION will be overridden)
0      Population ingesting aquatic foods, 0 defaults to total (person)
0      Population ingesting drinking water, 0 defaults to total (person)
F      Consider dose from food exported out of region (default=F)

Note below: S* or Source: 0-none, 1-ground water, 2-surface water
              3-Derived concentration entered above
==== AQUATIC FOODS / DRINKING WATER INGESTION=====SECTION 8=====

F      Salt water? (default is fresh)

```

TABLE D.13. EXTPAR.TPL GENII Input File Template (contd)

USE ? T/F	FOOD TYPE	TRAN- SIT hr	PROD- UCTION kg/yr	-CONSUMPTION- HOLDUP da	RATE kg/yr	DRINKING WATER	
---	---	---	---	---	---	---	---
F	FISH	0.00	0.0E+00	0.00	0.0	0	Source (see above)
F	MOLLUS	0.00	0.0E+00	0.00	0.0	T	Treatment? T/F
F	CRUSTA	0.00	0.0E+00	0.00	0.0	0	Holdup/transit(da)
F	PLANTS	0.00	0.0E+00	0.00	0.0	0	Consumption (L/yr)

====TERRESTRIAL FOOD INGESTION=====SECTION 9=====

USE ?	FOOD T/F	TYPE	GROW TIME da	--IRRIGATION-- S RATE * in/yr		TIME mo/yr	YIELD kg/m2	PROD- UCTION kg/yr	--CONSUMPTION-- HOLDUP da	RATE kg/yr
---	---	---	---	---	---	---	---	---	---	---
T	LEAF	V	60.00	0	0.0	0.0	2.0	0.0E+00	1.0	9.8
T	ROOT	V	60.00	0	0.0	0.0	2.0	0.0E+00	14.0	91.4
T	FRUIT		60.00	0	0.0	0.0	2.0	0.0E+00	14.0	41.8
T	GRAIN		60.00	0	0.0	0.0	2.0	0.0E+00	14.0	46.9

====ANIMAL PRODUCTION CONSUMPTION=====SECTION 10=====

USE ? T/F	FOOD TYPE	---HUMAN---		TOTAL PROD- UCTION kg/yr	DRINK WATER CONTAM FRACT.	DIET		GROW TIME da	--IRRIGATION--		STORED FEED		STOR- AGE da
		CONSUMPTION RATE kg/yr	HOLDUP da			FRAC- TION	---		S RATE * in/yr	TIME mo/yr	YIELD kg/m3	---	
T	BEEF	95.0	20.0	0.00	0.00	1.00	60.0	0	0.0	0.00	2.00	90.0	
F	POULTR												
T	MILK	110.0	2.0	0.00	0.00								
F	EGG												
	BEEF												
	MILK					1.00	30.0	0	0.0	0.00	0.70	0.0	

#####

TABLE D.14 Control Program Usage for Generating Internal Dose Factors Contained in Files INTERNAL.DF and INTNODAU.DF

<u>Control Program</u>	<u>GENII Input File Templates</u>	<u>GENII DOSEQA.OUT Output File</u>	<u>Used In</u>	<u>Pathways Considered</u>
GENALL.BAS (Table D.11)	SOILOPT.TPL SOILPAR.TPL	SOILS.DF	INTERNAL.DF	Soil contribution from ingestion of food and food products
GENALL2.BAS (Table D.12)	DRINKOPT.TPL DRINKPAR.TPL	INHSD.DF	INTERNAL.DF	Inhalation and secondary ingestion
GENALL3.BAS (Table D.13)	SOILOPT.TPL SOILPAR.TPL	AIRS.DF	INTERNAL.DF	Air contribution from ingestion of food and food products
GENALL4.BAS (Table D.14)	DRINKOPT.TPL DRINKPAR.TPL	DW.DF	INTERNAL.DF	Drinking water critical organ and drinking water critical organ dose
GENALLN.BAS	SOILOPT.TPL SOILPAR.TPL	SOILSNO.DF	INTNODAU.DF	Soil contribution from ingestion of food and food products
GENALL2N.BAS	DRINKOPT.TPL DRINKPAR.TPL	INHSINO.DF	INTNODAU.DF	Inhalation and secondary ingestion
GENALL3N.BAS	SOILOPT.TPL SOILPAR.TPL	AIRSNO.DF	INTNODAU.DF	Air contribution from ingestion of food and food products
GENALL4N.BAS	DRINKOPT.TPL DRINKPAR.TPL	DWNO.DF	INTNODAU.DF	Drinking water critical organ and drinking water critical organ dose

TABLE D.15. GENALL.BAS Computer Program Listing

'
' GENALL

' GENII input file generator and batch file controller.
' Ingestion (soil contribution) dose factors for
' NRC Residual Radioactivity

' Utility program for the Hanford Environmental Dosimetry Software
' System

' Last Modification: 4-Oct-89 RAP

DEFINT i-n

CALL copyfile ("\\resid\\filename.sol", "\\genii\\filename.dat", errs)

' GENII input file--
fin\$ = "GENII.IN" : fing\$ = "\\GENII\\GENII.IN"

' Check if DOSEQA file exists, then delete--
filo\$ = "\\GENII\\DOSEQA.OUT"
CALL exist (filo\$, ifound)
IF ifound THEN SHELL "erase "+filo\$

OPEN "I", #1, "RMDLIBDA.SHT"
LINE INPUT #1, dum\$

' Process each record in batch control file--
WHILE NOT EOF(1)

' Read radionuclide record--
LINE INPUT #1, l\$
rad\$ = LEFT\$ (l\$, 6)

' Open new input file and write header--
OPEN "O", #2, fin\$
PRINT #2, "NRC Residual Radioactivity Ingestion Dose Factors (Soil)"
PRINT #2, "Title: "+rad\$ + " Soil (pCi/g)"

' Open, read, and write options file--
OPEN "I", #3, "SOIOPT.TPL"
WHILE NOT EOF(3)
LINE INPUT #3, l\$
PRINT #2, l\$
WEND
CLOSE 3

TABLE D.15. GENALL.BAS Computer Program Listing (contd)

```
'      Write inventory lines--
      PRINT #2, "      ";rad$; SPACE$(35); "1.0E+03"

'      Open, read, and write parameters file--
      OPEN "I", #3, "SOILPAR.TPL"
      WHILE NOT EOF(3)
        LINE INPUT #3, l$
        PRINT #2, l$
      WEND
      CLOSE 3

'      Close input file and copy to GENII subdirectory--
      CLOSE 2
      CALL copyfile (fin$, fing$, ecode)

'      Execute GENII--
      IF NOT ecode THEN
        SHELL "\genii\envin"
        SHELL "\genii\env"
        SHELL "\genii\dose"
      ENDIF

      WEND
      CLOSE 1

      CALL copyfile (fil0$, "soils.df", errs)
      CALL copyfile ("\genii\genii.in", "soils.in", errs)
      CALL copyfile ("\genii\genii.out", "soils.out", errs)
      CALL copyfile ("\genii\dose.out", "soils2.out", errs)
```

TABLE D.16. GENALL2.BAS Computer Program Listing

'
' GENALL2

' GENII input file generator and batch file controller for
' inhalation and secondary ingestion (NRC Residual Radioactivity)

' Utility program for the Hanford Environmental Dosimetry Software
' System

' Last Modification: 4-Oct-89 RAP
'

DEFINT i-n

CALL copyfile ("\\resid\\filename.sol", "\\genii\\filename.dat", errs)

' GENII input file--

fin\$ = "GENII.IN" : fing\$ = "\\GENII\\GENII.IN"

' Check if DOSEQA file exists, then delete--

filo\$ = "\\GENII\\DOSEQA.OUT"

CALL exist (filo\$, ifound)

IF ifound THEN SHELL "erase "+filo\$

OPEN "I", #1, "RMDLIBDA.SHT"

LINE INPUT #1, dum\$

' Process each record in batch control file--

WHILE NOT EOF(1)

' Read radionuclide record--

LINE INPUT #1, l\$

rad\$ = LEFT\$ (l\$, 6)

' Open new input file and write header--

OPEN "O", #2, fin\$

PRINT #2, "GENII Input File for Residual Radioactivity Facility"

PRINT #2, "Title: "+rad\$ + " Inh/SI (pCi/m3 or pCi)"

' Open, read, and write options file--

OPEN "I", #3, "FACIOPT.TPL"

WHILE NOT EOF(3)

LINE INPUT #3, l\$

PRINT #2, l\$

WEND

CLOSE 3

TABLE D.16. GENALL2.BAS Computer Program Listing (contd)

```

' Write inventory lines--
PRINT #2, " ";rad$; SPACE$(27); " 1.0" 'air

PRINT #2, " "
PRINT #2, " -----|-----Derived Concentrations-----|"
PRINT #2, " Use when measured values are known"|"
PRINT #2, " -----|-----"|"
PRINT #2, " Release Terres. Animal Drink Aquatic"|"
PRINT #2, " Radio- Plant Product Water Food"|"
PRINT #2, " nuclide /kg /kg /L /kg"|"
PRINT #2, " -----|-----|"
PRINT #2, " ";rad$; SPACE$(19); " 1.0" 'drinking water

' Open, read, and write parameters file--
OPEN "1", #3, "FACILPAR.TPL"
WHILE NOT EOF(3)
    LINE INPUT #3, 1$
    PRINT #2, 1$
WEND
CLOSE 3

' Close input file and copy to GENII subdirectory--
CLOSE 2
CALL copyfile (fin$, fing$, ecode)

' Execute GENII--
IF NOT ecode THEN
    SHELL "\genii\envin"
    SHELL "\genii\env"
    SHELL "\genii\dose"
ENDIF

WEND
CLOSE 1

CALL copyfile (fil0$, "inhsi.df", errs)
CALL copyfile ("\genii\genii.out","inhsi.out", errs)
CALL copyfile ("\genii\dose.out","inhsi2.out", errs)
' -----

```

TABLE D.17. GENALL3.BAS Computer Program Listing

'
' GENALL3
'

' GENII input file generator and batch file controller.
' Ingestion (air contribution) dose factors for
' NRC Residual Radioactivity
'

' Utility program for the Hanford Environmental Dosimetry Software
' System
'

' Last Modification: 5-Oct-89 RAP
'

DEFINT i-n

CALL copyfile ("\\resid\\filename.air", "\\genii\\filename.dat", errs)

' GENII input file--

fin\$ = "GENII.IN" : fing\$ = "\\GENII\\GENII.IN"

' Check if DOSEQA file exists, then delete--

filo\$ = "\\GENII\\DOSEQA.OUT"

CALL exist (filo\$, ifound)

IF ifound THEN SHELL "erase "+filo\$

OPEN "I", #1, "RMDLIBDA.SHT"

LINE INPUT #1, dum\$

' Process each record in batch control file--

WHILE NOT EOF(1)

' Read radionuclide record--

LINE INPUT #1, l\$

rad\$ = LEFT\$ (l\$, 6)

' Open new input file and write header--

OPEN "O", #2, fin\$

PRINT #2, "NRC Residual Radioactivity Ingestion Dose Factors (Air)"

PRINT #2, "Title: "+rad\$ + " Air (pCi/m3)"

' Open, read, and write options file (same as soil)--

OPEN "I", #3, "SOILOPT.TPL"

WHILE NOT EOF(3)

LINE INPUT #3, l\$

PRINT #2, l\$

WEND

CLOSE 3

TABLE D.17. GENALL3.BAS Computer Program Listing (contd)

```
' Write inventory lines--
PRINT #2, "      ";rad$; SPACE$(27); "      1.0"

' Open, read, and write parameters file (same as soil)
OPEN "I", #3, "SOILPAR.TPL"
WHILE NOT EOF(3)
  LINE INPUT #3, l$
  PRINT #2, l$
WEND
CLOSE 3

' Close input file and copy to GENII subdirectory--
CLOSE 2
CALL copyfile (fin$, fing$, ecode)

' Execute GENII--
IF NOT ecode THEN
  SHELL "\genii\envin"
  SHELL "\genii\env"
  SHELL "\genii\dose"
ENDIF

WEND
CLOSE 1

CALL copyfile (fil0$, "airs.df", errs)
CALL copyfile ("\genii\genii.in", "airs.in", errs)
CALL copyfile ("\genii\genii.out", "airs.out", errs)
CALL copyfile ("\genii\dose.out", "airs2.out", errs)
```

TABLE D.18. GENALL4.BAS Computer Program Listing

```
-----
GENALL4
```

```
GENII input file generator and batch file controller for
drinking water maximum organ (NRC Residual Radioactivity)
```

```
Utility program for the Hanford Environmental Dosimetry Software
System
```

```
Last Modification: 10-Oct-89  RAP
-----
```

```
DEFINT i-n
```

```
CALL copyfile ("\\resid\\filename.sol", "\\genii\\filename.dat", errs)
```

```
GENII input file--
```

```
fin$ = "GENII.IN" : fing$ = "\\GENII\\GENII.IN"
```

```
Check if DOSEQA file exists, then delete--
```

```
fil0$ = "\\GENII\\DOSEQA.OUT"
```

```
CALL exist (fil0$, ifound)
```

```
IF ifound THEN SHELL "erase "+fil0$
```

```
OPEN "I", #1, "RMDLIBDA.SHT"
```

```
LINE INPUT #1, dum$
```

```
Process each record in batch control file--
```

```
WHILE NOT EOF(1)
```

```
    Read radionuclide record--
```

```
    LINE INPUT #1, l$
```

```
    rad$ = LEFT$(l$, 6)
```

```
    Open new input file and write header--
```

```
    OPEN "O", #2, fin$
```

```
    PRINT #2, "GENII Input File for Residual Radioactivity Facility"
```

```
    PRINT #2, "Title: "+rad$ + " DW (pCi/L)"
```

```
    Open, read, and write options file--
```

```
    OPEN "I", #3, "FACIOPT.TPL"
```

```
    WHILE NOT EOF(3)
```

```
        LINE INPUT #3, l$
```

```
        PRINT #2, l$
```

```
    WEND
```

```
    CLOSE 3
```

TABLE D.18. GENALL4.BAS Computer Program Listing (contd)

```
'
Write inventory lines--
PRINT #2, " ";rad$; SPACE$(27); " 0.0" 'air

PRINT #2, " "
PRINT #2, " -----|----Derived Concentrations-----|"
PRINT #2, " Use when measured values are known |"
PRINT #2, " -----|-----|"
PRINT #2, " Release Terres. Animal Drink Aquatic |"
PRINT #2, " Radio- Plant Product Water Food |"
PRINT #2, " nuclide /kg /kg /L /kg |"
PRINT #2, " -----|-----|"
PRINT #2, " ";rad$; SPACE$(19); " 1.0" 'drinking water

'
Open, read, and write parameters file--
OPEN "1", #3, "FACILPAR.TPL"
WHILE NOT EOF(3)
  LINE INPUT #3, 1$
  PRINT #2, 1$
WEND
CLOSE 3

'
Close input file and copy to GENII subdirectory--
CLOSE 2
CALL copyfile (fin$, fing$, ecode)

'
Execute GENII--
IF NOT ecode THEN
  SHELL "\genii\envin"
  SHELL "\genii\env"
  SHELL "\genii\dose"
ENDIF

WEND
CLOSE 1

CALL copyfile (fil0$, "dw.df", errs)
CALL copyfile ("\genii\genii.out", "dw.out", errs)
CALL copyfile ("\genii\dose.out", "dw2.out", errs)
```

TABLE D.19. SOILOPT.TPL GENII Input File Template

```

SOILOPT.TPL 2-Oct-89 RAP
OPTIONS===== Default =====
T Near-field scenario?      (Far-field)    NEAR-FIELD: narrowly-focused
F Population dose?          (Individual)   release, single site
F Acute release?            (Chronic)      FAR-FIELD: wide-scale release,
Maximum Individual data set used           multiple sites
Complete
TRANSPORT OPTIONS===== Section EXPOSURE PATHWAY OPTIONS===== Section
F Air Transport             1 F Finite plume, external 5
F Surface Water Transport   2 F Infinite plume, external 5
F Biotic Transport (near-field) 3 F Ground, external 5
F Waste Form Degradation (near) 4 F Recreation, external 5
F Inhalation uptake 6
REPORT OPTIONS=====
T Report AEDE only F Drinking water ingestion 7,8
T Report by radionuclide F Aquatic foods ingestion 7,8
T Report by exposure pathway T Terrestrial foods ingestion 7,9
F Debug report on screen F Animal product ingestion 7,10
F Inadvertent soil ingestion
INVENTORY #####
1 Inventory input activity units: (1-pCi 2-uCi 3-mCi 4-Ci 5-Bq)
3 Surface soil source units (1- m2 2- m3 3- kg)
T Equilibrium question goes here

```

----- Use when -----	----Release Terms----- transport selected			-----Basic Concentrations----- near-field scenario, optionally				
Release Radio- nuclide	Air /yr	Surface Water /yr	Buried Waste /m3	Air /L	Surface Soil /unit	Deep Soil /m3	Ground Water /L	Surface Water /L
-----	-----	-----	-----	-----	-----	-----	-----	-----

TABLE D.20. SOILPAR.TPL GENII Input File Template

-----	----Derived Concentrations----			
Use when	measured values are known			
-----	-----			
Release	Terres.	Animal	Drink	Aquatic
Radio-	Plant	Product	Water	Food
nuclide	/kg	/kg	/L	/kg
-----	-----	-----	-----	-----

TIME #####

1 Intake ends after (yr)
 50 Dose calc. ends after (yr)
 0 Release ends after (yr)
 0 No. of years of air deposition prior to the intake period
 0 No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) #####

0 Definition option: 1-Use population grid in file POP.IN
 0 2-Use total entered on this line

NEAR-FIELD SCENARIOS #####

Prior to the beginning of the intake period: (yr)
 0 When was the inventory disposed? (Package degradation starts)
 0 When was LOIC? (Biotic transport starts)
 1.0 Fraction of roots in upper soil (top 15 cm)
 0.0 Fraction of roots in deep soil
 0.0 Manual redistribution: deep soil/surface soil dilution factor

TRANSPORT #####

====AIR TRANSPORT=====SECTION 1=====

	0-Calculate PM		
1	Option: 1-Use chi/Q or PM value	F	Stack release (T/F)
	2-Select MI dist & dir	0	Stack height (m)
	3-Specify MI dist & dir	0	Stack flow (m3/sec)
0	Chi/Q or PM value	0	Stack radius (m)
0	MI sector index (1=S)	0	Effluent temp. (C)
0	MI distance from release point (m)		
T	Use joint frequency data, otherwise chi/Q grid		

====SURFACE WATER TRANSPORT=====SECTION 2=====

0 Mixing ratio model: 0-use value, 1-river, 2-lake, 3-river flow
 0 Mixing ratio, dimensionless
 0 Average river flow rate for: MIXFLG=0,3 (m3/s), MIXFLG=1,2 (m/s),
 0 Transit time to irrigation withdrawal location (hr)
 If mixing ratio model > 0:
 0 Rate of effluent discharge to receiving water body (m3/s)
 0 Longshore distance from release point to usage location (m)
 0 Offshore distance to the water intake (m)

TABLE D.20. SOILPAR.TPL GENII Input File Template (contd)

```

0      Average water depth in surface water body (m)
0      Average river width (m), MIXFLG=1 only
0      Depth of effluent discharge point to surface water (m), lake only

====WASTE FORM AVAILABILITY=====SECTION 3=====
0      Waste form/package half life, (yr)
0.85   Waste thickness, (m)
0.15   Depth of soil overburden, m

====BIOTIC TRANSPORT OF BURIED SOURCE=====SECTION 4=====
T      Consider during inventory decay/buildup period (T/F)?
T      Consider during intake period (T/F)?
0      Pre-Intake site condition.....
      1-Arid non agricultural
      2-Humid non agricultural
      3-Agricultural

EXPOSURE #####

====EXTERNAL EXPOSURE=====SECTION 5=====
Exposure time:
0      Plume (hr)
1.0    Soil contamination (hr)
0      Swimming (hr)
0      Boating (hr)
0      Shoreline activities (hr)
0      Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin)
0      Transit time for release to reach aquatic recreation (hr)
0      Average fraction of time submersed in acute cloud (hr/person hr)

Residential irrigation:
T      Consider: (T/F)
0      Source: 1-ground water
      2-surface water
0      Application rate (in/yr)
0      Duration (mo/yr)

====INHALATION=====SECTION 6=====
1.0    Hours of exposure to contamination per year
2      0-No resus- 1-Use Mass Loading 2-Use Anspaugh model
1.0    pension    Mass loading factor (g/m3) Top soil available (cm)

====INGESTION POPULATION=====SECTION 7=====
0      Atmospheric production definition (select option):
0      0-Use food-weighted chi/Q, (food-sec/m3), enter value on this line
      1-Use population-weighted chi/Q
      2-Use uniform production
      3-Use chi/Q and production grids (PRODUCTION will be overridden)
0      Population ingesting aquatic foods, 0 defaults to total (person)
0      Population ingesting drinking water, 0 defaults to total (person)
F      Consider dose from food exported out of region (default=F)

Note below: S* or Source: 0-none, 1-ground water, 2-surface water
      3-Derived concentration entered above
==== AQUATIC FOODS / DRINKING WATER INGESTION=====SECTION 8=====
F      Salt water? (default is fresh)

```

TABLE D.20. SOILPAR.TPL GENII Input File Template (contd)

USE ? T/F	FOOD TYPE	TRAN- SIT hr	PROD- UCTION kg/yr	-CONSUMPTION- HOLDUP da	RATE kg/yr	DRINKING WATER	
F	FISH	0.00	0.0E+00	0.00	0.0	0	Source (see above)
F	MOLLUS	0.00	0.0E+00	0.00	0.0	T	Treatment? T/F
F	CRUSTA	0.00	0.0E+00	0.00	0.0	0	Holdup/transit(da)
F	PLANTS	0.00	0.0E+00	0.00	0.0	0	Consumption (L/yr)

====TERRESTRIAL FOOD INGESTION=====SECTION 9=====

USE ? T/F	FOOD TYPE	GROW TIME da	--IRRIGATION-- S RATE * in/yr			YIELD kg/m2	PROD- UCTION kg/yr	--CONSUMPTION-- HOLDUP da	RATE kg/yr
T	LEAF V	60.00	0	0.0	0.0	2.0	0.0E+00	1.0	9.8
T	ROOT V	60.00	0	0.0	0.0	2.0	0.0E+00	14.0	91.4
T	FRUIT	60.00	0	0.0	0.0	2.0	0.0E+00	14.0	41.8
T	GRAIN	60.00	0	0.0	0.0	2.0	0.0E+00	14.0	46.9

====ANIMAL PRODUCTION CONSUMPTION=====SECTION 10=====

		---HUMAN---		TOTAL	DRINK	---		STORED FEED---		---	
USE	FOOD	CONSUMPTION	HOLDUP	PROD-	WATER	DIET	GROW	-IRRIGATION--			STOR-
? T/F	TYPE	RATE	da	UCTION	CONTAM	FRAC-	TIME	S RATE	TIME	YIELD	AGE
		kg/yr		kg/yr	FRACT.	TION	da	* in/yr	mo/yr	kg/m3	da
T	BEEF	95.0	20.0	0.00	0.00	1.00	60.0	0	0.0	0.00	2.00
F	POULTR										90.0
T	MILK	110.0	2.0	0.00	0.00						
F	EGG										

#####

TABLE D.21. FACILOPT.TPL GENII Input File Template

FACILOPT.TPL 4-Oct-89 RAP

OPTIONS===== Default =====
T Near-field scenario? (Far-field) NEAR-FIELD: narrowly-focused
F Population dose? (Individual) release, single site
F Acute release? (Chronic) FAR-FIELD: wide-scale release,
Maximum Individual data set used multiple sites
Complete

TRANSPORT OPTIONS===== Section EXPOSURE PATHWAY OPTIONS===== Section
F Air Transport 1 F Finite plume, external 5
F Surface Water Transport 2 F Infinite plume, external 5
F Biotic Transport (near-field) 3 F Ground, external 5
F Waste Form Degradation (near) 4 F Recreation, external 5
T Inhalation uptake 6
REPORT OPTIONS===== T Drinking water ingestion 7,8
T Report AEDE only F Aquatic foods ingestion 7,8
F Report by radionuclide F Terrestrial foods ingestion 7,9
F Report by exposure pathway F Animal product ingestion 7,10
F Debug report on screen F Inadvertent soil ingestion

INVENTORY #####

- 1 Inventory input activity units: (1-pCi 2-uCi 3-mCi 4-Ci 5-Bq)
- 3 Surface soil source units (1- m2 2- m3 3- kg)
- T Equilibrium question goes here

Use when	----Release Terms----- transport selected			-----Basic Concentrations----- near-field scenario, optionally				
Release Radio- nuclide	Air /yr	Surface Water /yr	Buried Waste /m3	Air /L	Surface Soil /unit	Deep Soil /m3	Ground Water /L	Surface Water /L

TABLE D.22. FACILPAR.TPL GENII Input File Template

```

TIME #####

1   Intake ends after (yr)
50  Dose calc. ends after (yr)
0   Release ends after (yr)
0   No. of years of air deposition prior to the intake period
0   No. of years of irrigation water deposition prior to the intake period

FAR-FIELD SCENARIOS (IF POPULATION DOSE) #####

0           Definition option: 1-Use population grid in file POP.IN
0           2-Use total entered on this line

NEAR-FIELD SCENARIOS #####

           Prior to the beginning of the intake period: (yr)
0           When was the inventory disposed? (Package degradation starts)
0           When was LOIC? (Biotic transport starts)
1.0        Fraction of roots in upper soil (top 15 cm)
0.0        Fraction of roots in deep soil
0.0        Manual redistribution: deep soil/surface soil dilution factor

TRANSPORT #####
=====AIR TRANSPORT=====SECTION 1=====
           0-Calculate PM
1   Option: 1-Use chi/Q or PM value | F           Stack release (T/F)
           2-Select MI dist & dir   | 0           Stack height (m)
           3-Specify MI dist & dir   | 0           Stack flow (m3/sec)
0   Chi/Q or PM value               | 0           Stack radius (m)
0   MI sector index (1=S)            | 0           Effluent temp. (C)
0   MI distance from release point (m)
T   Use joint frequency data, otherwise chi/Q grid

=====SURFACE WATER TRANSPORT=====SECTION 2=====
0   Mixing ratio model: 0-use value, 1-river, 2-lake, 3-river flow
0   Mixing ratio, dimensionless
0   Average river flow rate for: MIXFLG=0,3 (m3/s), MIXFLG=1,2 (m/s),
0   Transit time to irrigation withdrawal location (hr)
    If mixing ratio model > 0:
0   Rate of effluent discharge to receiving water body (m3/s)
0   Longshore distance from release point to usage location (m)
0   Offshore distance to the water intake (m)
0   Average water depth in surface water body (m)
0   Average river width (m), MIXFLG=1 only
0   Depth of effluent discharge point to surface water (m), lake only

=====WASTE FORM AVAILABILITY=====SECTION 3=====
0   Waste form/package half life, (yr)
0.85 Waste thickness, (m)
0.15 Depth of soil overburden, m

```

TABLE D.22. FACILPAR.TPL GENII Input File Template (contd)

```

=====BIOTIC TRANSPORT OF BURIED SOURCE=====SECTION 4=====
T Consider during inventory decay/buildup period (T/F)?
T Consider during intake period (T/F)? | 1-Arid non agricultural
0 Pre-Intake site condition..... | 2-Humid non agricultural
                                     | 3-Agricultural

EXPOSURE #####

=====EXTERNAL EXPOSURE=====SECTION 5=====
Exposure time: | Residential irrigation:
0 Plume (hr) | F Consider: (T/F)
1.0 Soil contamination (hr) | 0 Source: 1-ground water
0 Swimming (hr) | | 2-surface water
0 Boating (hr) | 0 Application rate (in/yr)
0 Shoreline activities (hr) | 0 Duration (mo/yr)
0 Shoreline type: (1-river, 2-lake, 3-ocean, 4-tidal basin)
0 Transit time for release to reach aquatic recreation (hr)
0 Average fraction of time submersed in acute cloud (hr/person hr)

=====INHALATION=====SECTION 6=====
1.0 Hours of exposure to contamination per year
1 0-No resus- 1-Use Mass Loading 2-Use Anspaugh model
1.0E-4 pension Mass loading factor (g/m3) Top soil available (cm)

=====INGESTION POPULATION=====SECTION 7=====
0 Atmospheric production definition (select option):
0 0-Use food-weighted chi/Q, (food-sec/m3), enter value on this line
  1-Use population-weighted chi/Q
  2-Use uniform production
  3-Use chi/Q and production grids (PRODUCTION will be overridden)
0 Population ingesting aquatic foods, 0 defaults to total (person)
0 Population ingesting drinking water, 0 defaults to total (person)
F Consider dose from food exported out of region (default=F)

Note below: S* or Source: 0-none, 1-ground water, 2-surface water
              3-Derived concentration entered above
===== AQUATIC FOODS / DRINKING WATER INGESTION=====SECTION 8=====

F Salt water? (default is fresh)

USE      TRAN-  PROD-  -CONSUMPTION-
?  FOOD  SIT   UCTION  HOLDUP  RATE
T/F TYPE hr   kg/yr   da      kg/yr

-----
F  FISH   0.00  0.0E+00  0.00    0.0    3    Source (see above)
F  MOLLUS 0.00  0.0E+00  0.00    0.0    F    Treatment? T/F
F  CRUSTA 0.00  0.0E+00  0.00    0.0    0    Holdup/transit(da)
F  PLANTS 0.00  0.0E+00  0.00    0.0    1.0  Consumption (L/yr)

```

TABLE D.22. FACILPAR.TPL GENII Input File Template (contd)

====TERRESTRIAL FOOD INGESTION=====SECTION 9=====

USE ?	FOOD T/F	TYPE	GROW TIME da	--IRRIGATION-- S RATE * in/yr	TIME mo/yr	YIELD kg/m2	PROD- UCTION kg/yr	--CONSUMPTION-- HOLDUP da	RATE kg/yr	
T	LEAF	V	90.00	0	0.0	0.0	1.5	0.0E+00	1.0	2.4
T	ROOT	V	90.00	0	0.0	0.0	4.0	0.0E+00	5.0	21.4
T	FRUIT		90.00	0	0.0	0.0	2.0	0.0E+00	5.0	10.5
T	GRAIN		90.00	0	0.0	0.0	0.8	0.0E+00	180.0	12.8

====ANIMAL PRODUCTION CONSUMPTION=====SECTION 10=====

USE ?	FOOD T/F	TYPE	---HUMAN--- CONSUMPTION RATE kg/yr	---HUMAN--- HOLDUP da	TOTAL PROD- UCTION kg/yr	DRINK WATER CONTAM FRACT.	DIET FRAC- TION	GROW TIME da	---STORED FEED--- --IRRIGATION-- S RATE * in/yr	TIME mo/yr	YIELD kg/m3	STOR- AGE da	
T	BEEF		17.1	15.0	0.00	0.00	0.25	90.0	0	0.0	0.00	0.80	180.0
T	POULTR		2.1	1.0	0.00	0.00	1.00	90.0	0	0.0	0.00	0.80	180.0
T	MILK		27.5	1.0	0.00	0.00	0.25	45.0	0	0.0	0.00	2.00	100.0
T	EGG		4.8	1.0	0.00	0.00	1.00	90.0	0	0.0	0.00	0.80	180.0
	BEEF						0.75	45.0	0	0.0	0.00	2.00	100.0
	MILK						0.75	30.0	0	0.0	0.00	1.50	0.0

#####

TABLE D.23. Radionuclide Master Library - Radionuclide Chains in Equilibrium (RMDLIB.DAT)

RMDLIB.NRC - for NRC Residual Radioactivity (19-Dec-89 RAP)

H 3	4.49E+3	1	0	0.0000	0	0.0000	1	ND
BE10	5.84E+8	1	0	0.0000	0	0.0000	4	VY
C 14	2.09E+6	1	0	0.0000	0	0.0000	6	ND
N 13	6.92E-3	1	0	0.0000	0	0.0000	7	ND
F 18	7.62E-2	1	0	0.0000	0	0.0000	9	SD
NA22	9.50E+2	1	0	0.0000	0	0.0000	11	VD
NA24	6.25E-1	1	0	0.0000	0	0.0000	11	VD
SI31	1.09E-1	1	0	0.0000	0	0.0000	14	NW
P 32	1.43E+1	1	0	0.0000	0	0.0000	15	SD
P 33	2.54E+1	1	0	0.0000	0	0.0000	15	VD
S 35	8.74E+1	1	0	0.0000	0	0.0000	16	NW
CL36	1.1E+8	1	0	0.0000	0	0.0000	17	ND
K 40	4.67E11	1	0	0.0000	0	0.0000	19	ND
AR39	9.83E+4	1	0	0.0000	0	0.0000	18	ND
AR41	7.61E-2	1	0	0.0000	0	0.0000	18	ND
CA41	3.67E+7	1	0	0.0000	0	0.0000	20	1 VW
CA45	1.63E+2	1	0	0.0000	0	0.0000	20	1 VW
SC46	8.38E+1	1	0	0.0000	0	0.0000	21	VY
CR51	2.77E+1	1	0	0.0000	0	0.0000	24	VY
MN54	3.13E+2	1	0	0.0000	0	0.0000	25	SW
MN56	1.07E-1	1	0	0.0000	0	0.0000	25	SW
FE55	9.86E+2	1	0	0.0000	0	0.0000	26	NW
FE59	4.46E+1	1	0	0.0000	0	0.0000	26	NW
C057	2.71E+2	1	0	0.0000	0	0.0000	27	NY
C058	7.08E+1	1	0	0.0000	0	0.0000	27	NY
C060	1.92E+3	1	0	0.0000	0	0.0000	27	T NY
NI59	2.74E+7	1	0	0.0000	0	0.0000	28	NW
NI63	3.65E+4	1	0	0.0000	0	0.0000	28	NW
NI65	1.05E-1	1	0	0.0000	0	0.0000	28	NW
CU64	5.29E-1	1	0	0.0000	0	0.0000	29	ND
ZN65	2.44E+2	1	0	0.0000	0	0.0000	30	T VY
ZN69M	5.73E-1	1	0	0.0000	0	0.0000	30	SY
ZN69	3.86E-2	2	1	1.0000	0	0.0000	30	SY
GA72	5.87E-1	1	0	0.0000	0	0.0000	31	SW
AS76	1.10E+0	1	0	0.0000	0	0.0000	33	NW
SE75	1.2E+2	1	0	0.0000	0	0.0000	34	NW
SE79	2.37E+7	1	0	0.0000	0	0.0000	34	NW
BR82	1.47E+0	1	0	0.0000	0	0.0000	35	ND
BR83	9.96E-2	1	0	0.0000	0	0.0000	35	ND
KR83M	7.63E-2	2	1	1.0000	0	0.0000	36	ND
BR84	2.21E-2	1	0	0.0000	0	0.0000	35	ND
KR85M	1.87E-1	1	0	0.0000	0	0.0000	36	ND
KR85	3.91E+3	2	1	0.2110	0	0.0000	36	ND
KR87	5.30E-2	1	0	0.0000	0	0.0000	36	ND
RB87	1.73E13	2	1	1.0000	0	0.0000	37	VD
KR88	1.18E-1	1	0	0.0000	0	0.0000	36	ND
RB88	1.24E-2	2	1	1.0000	0	0.0000	37	VD
KR89	2.20E-3	1	0	0.0000	0	0.0000	36	ND

TABLE D.23. Radionuclide Master Library - Radionuclide Chains in Equilibrium (RMDLIB.DAT) (contd)

RB89	1.07E-2	2	1	1.0000	0	0.0000	37	VD			
SR89	5.06E+1	3	2	1.0000	0	0.0000	38	1	VD		
SR87M	1.17E-1	1	0	0.0000	0	0.0000	38	1	SD		
RB86	1.87E+1	1	0	0.0000	0	0.0000	37		VD		
SR85	6.5E+1	1	0	0.0000	0	0.0000	38	1	VD		
SR90	1.04E+4	1	0	0.0000	0	0.0000	38	T	1	VD	
Y 90	2.67E+0	2	1	1.0000	0	0.0000	39	T		SY	
SR91	3.96E-1	1	0	0.0000	0	0.0000	38	1	SD		
Y 91M	3.45E-2	2	1	0.5740	0	0.0000	39			SY	
Y 91	5.85E+1	3	2	1.0000	1	0.4260	39			SY	
SR92	1.13E-1	1	0	0.0000	0	0.0000	38	1	SD		
Y 92	1.48E-1	2	1	1.0000	0	0.0000	39			SY	
Y 93	4.21E-1	1	0	0.0000	0	0.0000	39			SY	
M093	1.28E+6	1	0	0.0000	0	0.0000	42			SD	
ZR93	5.58E+8	2	0	0.0000	0	0.0000	40			SW	
NB93M	5.33E+3	3	2	1.0000	1	1.0000	41			VY	
ZR95	6.40E+1	1	0	0.0000	0	0.0000	40			SW	
NB95M	3.61E+0	2	1	0.0080	0	0.0000	41			SY	
NB95	3.51E+1	3	2	0.9450	1	0.9922	41			SY	
ZR97	7.04E-1	1	0	0.0000	0	0.0000	40			SW	
NB97M	6.94E-4	2	1	0.9470	0	0.0000	41			SY	
NB97	5.01E-2	3	2	1.0000	1	0.0530	41			SY	
NB94	7.41E+6	1	0	0.0000	0	0.0000	41			VY	
M099	2.75E+0	1	0	0.0000	0	0.0000	42			SD	
TC99M	2.51E-1	2	1	0.8860	0	0.0000	43			NW	
TC99	7.77E+7	1	0	0.0000	0	0.0000	43	T		NW	
TC101	9.86E-3	1	0	0.0000	0	0.0000	43			NW	
RU103	3.94E+1	1	0	0.0000	0	0.0000	44			NY	
PD103	1.70E+1	2	0	0.0000	0	0.0000	46			VY	
RH103M	3.90E-2	3	1	0.9974	2	0.9997	45			NY	
RU105	1.85E-1	1	0	0.0000	0	0.0000	44		NY	1	RH105M 1.000
RH105	1.47E+0	2	1	1.0000	0	0.0000	45		NY		
RU106	3.68E+2	1	0	0.0000	0	0.0000	44	T	NY	1	RH106 1.000
PD107	2.37E+9	1	0	0.0000	0	0.0000	46			VY	
PD109	5.61E-1	1	0	0.0000	0	0.0000	46		VY	1	AG109M 1.000
AG110M	2.50E+2	1	0	0.0000	0	0.0000	47		ND	1	AG110 0.985
AG111	7.46E+0	1	0	0.0000	0	0.0000	47			ND	
CD109	4.64E+2	1	0	0.0000	0	0.0000	48			ND	
CD113M	5.00E+3	1	0	0.0000	0	0.0000	48			ND	
CD115M	4.46E+1	1	0	0.0000	0	0.0000	48			ND	
CD115	2.23E+0	2	0	0.0000	0	0.0000	48			ND	
IN115M	1.82E-1	3	2	1.0000	0	0.0000	49			VD	
IN111	2.8E+0	1	0	0.0000	0	0.0000	49			VD	
IN114M	5.00E+1	1	0	0.0000	0	0.0000	49		VD	1	IN114 0.957
SN113	1.15E+2	1	0	0.0000	0	0.0000	50			VW	
IN113M	6.91E-2	2	1	1.0000	0	0.0000	49			VD	
SN117M	1.40E+1	1	0	0.0000	0	0.0000	50			SW	
SN119M	2.93E+2	1	0	0.0000	0	0.0000	50			VW	
SN121M	2.01E+4	1	0	0.0000	0	0.0000	50			VW	

TABLE D.23. Radionuclide Master Library - Radionuclide Chains in Equilibrium (RMDLIB.DAT) (contd)

SN121	1.13E+0	2	1	0.776	0	0.0000	50		VW
SN123	1.29E+2	1	0	0.0000	0	0.0000	50		VW
I 125	6.01E+1	1	0	0.0000	0	0.0000	53	2	ND
SN125	9.64E+0	1	0	0.0000	0	0.0000	50		SW
SB125	1.01E+3	2	1	1.0000	0	0.0000	51		SW
TE125M	5.80E+1	3	2	0.2310	0	0.0000	52		SW
SN126	3.65E+7	1	0	0.0000	0	0.0000	50		VW
SB126M	1.32E-2	2	1	1.0000	0	0.0000	51		SW
SB126	1.24E+1	3	2	0.1400	0	0.0000	51		SW
SB122	2.70E+0	1	0	0.0000	0	0.0000	51		SW
SB124	6.02E+1	1	0	0.0000	0	0.0000	51		SW
SB127	3.85E+0	1	0	0.0000	0	0.0000	51		SW
TE127M	1.09E+2	2	1	0.1690	0	0.0000	52		SW
TE127	3.90E-1	3	2	0.9820	1	0.8310	52		SW
TE123M	1.20E+2	1	0	0.0000	0	0.0000	52		SW
TE129M	3.36E+1	1	0	0.0000	0	0.0000	52		SW
TE129	4.83E-2	2	1	0.6290	0	0.0000	52		SW
I 129	5.73E+9	1	0	0.0000	0	0.0000	53	T 2	ND
TE131M	1.25E+0	1	0	0.0000	0	0.0000	52		SW
TE131	1.74E-2	2	1	0.2220	0	0.0000	52	T	SW
I 131	8.04E+0	3	2	1.0000	1	0.7780	53	T 2	ND
XE131M	1.18E+1	4	3	0.0109	0	0.0000	54		ND
TE132	3.26E+0	1	0	0.0000	0	0.0000	52		SW
I 132	9.58E-2	2	1	1.0000	0	0.0000	53	2	ND
TE133M	3.85E-2	1	0	0.0000	0	0.0000	52		SW
TE133	8.65E-3	2	1	0.1300	0	0.0000	52		SW
I 133	8.67E-1	3	2	1.0000	1	0.8700	53	2	ND
XE133M	2.19E+0	4	3	0.0288	0	0.0000	54		ND
XE133	5.25E+0	5	4	1.0000	3	0.9712	54		ND
TE134	2.90E-2	1	0	0.0000	0	0.0000	52		SW
I 134	3.65E-2	2	1	1.0000	0	0.0000	53	2	ND
CS134M	1.21E-1	1	0	0.0000	0	0.0000	55		ND
CS134	7.53E+2	1	1	1.0000	0	0.0000	55		ND
I 130	5.15E-1	1	0	0.0000	0	0.0000	53	2	ND
I 135	2.75E-1	1	0	0.0000	0	0.0000	53	2	ND
XE135M	1.07E-2	2	1	0.1650	0	0.0000	54		ND
XE135	3.80E-1	3	2	1.0000	1	0.8350	54		ND
CS135	8.40E+8	1	0	0.0000	0	0.0000	55		ND
XE137	2.66E-3	1	0	0.0000	0	0.0000	54		ND
CS137	1.10E+4	2	1	1.0000	0	0.0000	55	T	ND 1 BA137M 0.946
XE138	9.81E-3	1	0	0.0000	0	0.0000	54		ND
CS138	2.24E-2	2	1	1.0000	0	0.0000	55		ND
CS139	6.53E-3	1	0	0.0000	0	0.0000	55		ND
BA139	5.77E-2	2	1	1.0000	0	0.0000	56	1	SD
BA140	1.28E+1	1	0	0.0000	0	0.0000	56	T 1	SD
LA140	1.68E+0	2	1	1.0000	0	0.0000	57	T	SD
CS136	1.32E+1	1	0	0.0000	0	0.0000	55		ND
BA141	1.27E-2	1	0	0.0000	0	0.0000	56	1	SD
LA141	1.64E-1	2	1	1.0000	0	0.0000	57		SD

TABLE D.23. Radionuclide Master Library - Radionuclide
Chains in Equilibrium (RMDLIB.DAT) (contd)

CE141	3.25E+1	3	2	1.0000	0	0.0000	58		SY										
BA142	7.43E-3	1	0	0.0000	0	0.0000	56	1	SD										
LA142	6.63E-2	2	1	1.0000	0	0.0000	57		SD										
CE143	1.38E+0	1	0	0.0000	0	0.0000	58		SY										
PR143	1.36E+1	2	1	1.0000	0	0.0000	59		SY										
CE144	2.84E+2	1	0	0.0000	0	0.0000	58	T	SY										
PR144M	5.00E-3	2	1	0.0143	0	0.0000	59		SY										
PR144	1.20E-2	3	2	1.0000	1	0.9857	59	T	SY										
PR142	7.97E-1	1	0	0.0000	0	0.0000	59		SY										
ND147	1.10E+1	1	0	0.0000	0	0.0000	60		SY										
PM147	9.58E+2	2	1	1.0000	0	0.0000	61		SY										
SM147	3.87E13	1	0	0.0000	0	0.0000	62		SW										
PM148M	4.13E+1	1	0	0.0000	0	0.0000	61		SY										
PM148	5.37E+0	2	1	0.0420	0	0.0000	61		SY										
PM149	2.21E+0	1	0	0.0000	0	0.0000	61		SY										
PM151	1.18E+0	1	0	0.0000	0	0.0000	61		SY										
SM151	3.29E+4	1	0	0.0000	0	0.0000	62		SW										
SM153	1.95E+0	1	0	0.0000	0	0.0000	62		SW										
EU152M	3.88E-1	1	0	0.0000	0	0.0000	63		SW										
EU152	4.96E+3	1	0	0.0000	0	0.0000	63		SW										
EU154	3.21E+3	1	0	0.0000	0	0.0000	63		SW										
EU155	1.81E+3	1	0	0.0000	0	0.0000	63		SW										
EU156	1.52E+1	1	0	0.0000	0	0.0000	63		SW										
GD153	2.42E+2	1	0	0.0000	0	0.0000	64		SD										
GD159	7.73E-1	1	0	0.0000	0	0.0000	64		SD										
TB160	7.23E+1	1	0	0.0000	0	0.0000	65		SW										
TB161	6.91E+0	1	0	0.0000	0	0.0000	65		SW										
DY165	9.73E-2	1	0	0.0000	0	0.0000	66		SW										
HO166M	4.38E+5	1	0	0.0000	0	0.0000	67		SW										
HO166	1.12E+0	1	0	0.0000	0	0.0000	67		SW										
ER169	9.40E+0	1	0	0.0000	0	0.0000	68		SW										
ER171	3.13E-1	1	0	0.0000	0	0.0000	68		SW										
TA182	1.15E+2	1	0	0.0000	0	0.0000	73		VY										
W 181	1.21E+2	1	0	0.0000	0	0.0000	74		VD										
W 185	7.51E+1	1	0	0.0000	0	0.0000	74		VD										
W 187	9.93E-1	1	0	0.0000	0	0.0000	74		SD										
RE187	1.72E13	1	0	0.0000	0	0.0000	75		NW										
OS185	9.36E+1	1	0	0.0000	0	0.0000	76		ND										
OS191	1.5E+1	1	0	0.0000	0	0.0000	76		ND										
IR192	7.40E+1	1	0	0.0000	0	0.0000	77		NY										
HG203	4.66E+1	1	0	0.0000	0	0.0000	80		ND										
TH230	2.81E+7	1	0	0.0000	0	0.0000	90		SY										
RA226	5.84E+5	2	1	1.0000	0	0.0000	88	T	1	VW									
RN222	3.82E+0	3	2	1.0000	0	0.0000	86	T	ND	4	P0218	1.000	PB214	1.000					
											BI214	1.000	P0214	1.000					
PB210	8.12E+3	4	3	1.0000	0	0.0000	82	T	VD										
BI210	5.01E+0	5	4	1.0000	0	0.0000	83	T	NW										
P0210	1.38E+2	6	5	1.0000	0	0.0000	84	T	NW										
U 232	2.36E+4	1	0	0.0000	0	0.0000	92		VY										

TABLE D.23. Radionuclide Master Library - Radionuclide Chains in Equilibrium (RMDLIB.DAT) (contd)

TH232	5.13E12	1	0	0.0000	0	0.0000	90	SY					
RA228	2.10E+3	2	1	1.0000	0	0.0000	88	1	VW				
AC228	2.55E-1	3	2	1.0000	0	0.0000	89		SY				
TH228	6.98E+2	4	3	1.0000	0	0.0000	90		SY				
RA224	3.62E+0	5	4	1.0000	0	0.0000	88	1	SW	2	RN220	1.000	P0216 1.000
PB212	4.43E-1	6	5	1.0000	0	0.0000	82		SD				
BI212	4.20E-2	7	6	1.0000	0	0.0000	83		NW	2	P0212	.6407	TL208 .3593
U 234	8.29E+7	1	0	0.0000	0	0.0000	92		VY				
U 236	8.55E+9	1	0	0.0000	0	0.0000	92		VY				
U 235	2.57E11	1	0	0.0000	0	0.0000	92		VY				
TH231	1.06E+0	2	1	1.0000	0	0.0000	90		SY				
PA231	1.36E+7	1	0	0.0000	0	0.0000	91		SY				
AC227	7.95E+3	2	1	1.0000	0	0.0000	89		SY				
TH227	1.87E+1	3	2	0.9862	0	0.0000	90		SY				
FR223	1.51E-2	4	2	0.0138	0	0.0000	87		ND				
RA223	1.14E+1	5	3	1.0000	4	1.0000	88	1	SW	5	RN219	1.000	P0215 1.000
											PB211	1.000	BI211 1.000
											TL207	1.000	
U 237	6.75E+0	1	0	0.0000	0	0.0000	92		SY				
NP237	7.81E+8	1	0	0.0000	0	0.0000	93		SW				
PA233	2.70E+1	2	1	1.0000	0	0.0000	91		SY				
U 233	5.58E+7	1	0	0.0000	0	0.0000	92		VY				
TH229	2.68E+6	2	1	1.0000	0	0.0000	90		SY				
RA225	1.48E+1	3	2	1.0000	0	0.0000	88	1	SW				
AC225	1.00E+1	4	3	1.0000	0	0.0000	89		SY	6	FR221	1.000	AT217 1.000
											BI213	1.000	P0213 .9784
											TL209	.0216	PB209 1.000
U 238	1.63E12	1	0	0.0000	0	0.0000	92		VY				
TH234	2.41E+1	2	1	1.0000	0	0.0000	90		SY	1	PA234M	0.998	
PA234	2.79E-1	3	2	0.0016	0	0.0000	91		SY				
PU236	1.04E+3	1	0	0.0000	0	0.0000	94		SY				
PU237	4.53E+1	1	0	0.0000	0	0.0000	94		SY				
AM242M	5.55E+4	1	0	0.0000	0	0.0000	95		SW				
AM242	6.68E-1	2	1	1.0000	0	0.0000	95		SW				
CM242	1.63E+2	3	2	0.8270	0	0.0000	96		SW				
PU238	3.20E+4	4	3	1.0000	0	0.0000	94		SY				
PU242	1.37E+8	1	0	0.0000	0	0.0000	94		SY				
NP238	2.12E+0	1	0	0.0000	0	0.0000	93		SW				
PU238	3.20E+4	2	1	1.0000	0	0.0000	94		SY				
CM244	6.61E+3	1	0	0.0000	0	0.0000	96		SW				
PU244	3.01E10	1	0	0.0000	0	0.0000	94		SY				
U 240	5.88E-1	2	1	0.9988	0	0.0000	92		SY	1	NP240M	1.000	
PU240	2.40E+6	1	0	0.0000	0	0.0000	94		SY				
CM245	3.10E+6	1	0	0.0000	0	0.0000	96		SW				
PU241	5.26E+3	2	1	1.0000	0	0.0000	94		SY				
AM241	1.58E+5	3	2	1.0000	0	0.0000	95	T	SW				
CM246	1.73E+6	1	0	0.0000	0	0.0000	96		SW				
CM247	5.69E+9	1	0	0.0000	0	0.0000	96		SW				
PU243	1.92E-1	2	1	1.0000	0	0.0000	94		SY				

TABLE D.23. Radionuclide Master Library - Radionuclide
Chains in Equilibrium (RMDLIB.DAT) (contd)

CM243	1.04E+4	1	0	0.0000	0	0.0000	96	SW
AM243	2.69E+6	2	1	0.0024	0	0.0000	95	SW
NP239	2.36E+0	3	2	1.0000	0	0.0000	93	SW
PU239	8.81E+6	4	1	0.9976	0	0.0000	94 T	SY
CM248	1.24E+8	1	0	0.0000	0	0.0000	96	SW
CF252	9.63E+2	1	0	0.0000	0	0.0000	98	SW
		0	0	0.0000	0	0.0000		

TABLE D.24. Radionuclide Master Library - Radionuclides
without Explicit Daughters

RMDLIBNO.DAU - Radionuclide Master Library - No Daughters (25-Oct-89 RAP)

H 3	4.49E+3	1	0	0.0000	0	0.0000	1	ND
BE10	5.84E+8	1	0	0.0000	0	0.0000	4	VY
C 14	2.09E+6	1	0	0.0000	0	0.0000	6	ND
N 13	6.92E-3	1	0	0.0000	0	0.0000	7	ND
F 18	7.62E-2	1	0	0.0000	0	0.0000	9	SD
NA22	9.50E+2	1	0	0.0000	0	0.0000	11	VD
NA24	6.25E-1	1	0	0.0000	0	0.0000	11	VD
SI31	1.09E-1	1	0	0.0000	0	0.0000	14	NW
P 32	1.43E+1	1	0	0.0000	0	0.0000	15	SD
P 33	2.54E+1	1	0	0.0000	0	0.0000	15	VD
S 35	8.74E+1	1	0	0.0000	0	0.0000	16	NW
CL36	1.1E+8	1	0	0.0000	0	0.0000	17	ND
K 40	4.67E11	1	0	0.0000	0	0.0000	19	ND
AR39	9.83E+4	1	0	0.0000	0	0.0000	18	ND
AR41	7.61E-2	1	0	0.0000	0	0.0000	18	ND
CA41	3.67E+7	1	0	0.0000	0	0.0000	20	1 VW
CA45	1.63E+2	1	0	0.0000	0	0.0000	20	1 VW
SC46	8.38E+1	1	0	0.0000	0	0.0000	21	VY
CR51	2.77E+1	1	0	0.0000	0	0.0000	24	VY
MN54	3.13E+2	1	0	0.0000	0	0.0000	25	SW
MN56	1.07E-1	1	0	0.0000	0	0.0000	25	SW
FE55	9.86E+2	1	0	0.0000	0	0.0000	26	NW
FE59	4.46E+1	1	0	0.0000	0	0.0000	26	NW
CO57	2.71E+2	1	0	0.0000	0	0.0000	27	NY
CO58	7.08E+1	1	0	0.0000	0	0.0000	27	NY
CO60	1.92E+3	1	0	0.0000	0	0.0000	27	T NY
NI59	2.74E+7	1	0	0.0000	0	0.0000	28	NW
NI63	3.65E+4	1	0	0.0000	0	0.0000	28	NW
NI65	1.05E-1	1	0	0.0000	0	0.0000	28	NW
CU64	5.29E-1	1	0	0.0000	0	0.0000	29	ND
ZN65	2.44E+2	1	0	0.0000	0	0.0000	30	T VY
ZN69M	5.73E-1	1	0	0.0000	0	0.0000	30	SY
ZN69	3.86E-2	1	1	1.0000	0	0.0000	30	SY
GA72	5.87E-1	1	0	0.0000	0	0.0000	31	SW
AS76	1.10E+0	1	0	0.0000	0	0.0000	33	NW
SE75	1.2E+2	1	0	0.0000	0	0.0000	34	NW
SE79	2.37E+7	1	0	0.0000	0	0.0000	34	NW
BR82	1.47E+0	1	0	0.0000	0	0.0000	35	ND
BR83	9.96E-2	1	0	0.0000	0	0.0000	35	ND
KR83M	7.63E-2	1	1	1.0000	0	0.0000	36	ND
BR84	2.21E-2	1	0	0.0000	0	0.0000	35	ND
KR85M	1.87E-1	1	0	0.0000	0	0.0000	36	ND
KR85	3.91E+3	1	1	0.2110	0	0.0000	36	ND
KR87	5.30E-2	1	0	0.0000	0	0.0000	36	ND
RB87	1.73E13	1	1	1.0000	0	0.0000	37	VD
KR88	1.18E-1	1	0	0.0000	0	0.0000	36	ND
RB88	1.24E-2	1	1	1.0000	0	0.0000	37	VD
KR89	2.20E-3	1	0	0.0000	0	0.0000	36	ND

TABLE D.24. Radionuclide Master Library - Radionuclides without Explicit Daughters (contd)

RB89	1.07E-2	1	1	1.0000	0	0.0000	37	VD			
SR89	5.06E+1	1	2	1.0000	0	0.0000	38	1	VD		
SR87M	1.17E-1	1	0	0.0000	0	0.0000	38	1	SD		
RB86	1.87E+1	1	0	0.0000	0	0.0000	37		VD		
SR85	6.5E+1	1	0	0.0000	0	0.0000	38	1	VD		
SR90	1.04E+4	1	0	0.0000	0	0.0000	38	T	1	VD	
Y 90	2.67E+0	1	1	1.0000	0	0.0000	39	T		SY	
SR91	3.96E-1	1	0	0.0000	0	0.0000	38	1	SD		
Y 91M	3.45E-2	1	1	0.5740	0	0.0000	39			SY	
Y 91	5.85E+1	1	2	1.0000	1	0.4260	39			SY	
SR92	1.13E-1	1	0	0.0000	0	0.0000	38	1	SD		
Y 92	1.48E-1	1	1	1.0000	0	0.0000	39			SY	
Y 93	4.21E-1	1	0	0.0000	0	0.0000	39			SY	
MO93	1.28E+6	1	0	0.0000	0	0.0000	42			SD	
ZR93	5.58E+8	1	1	1.0000	0	0.0000	40			SW	
NB93M	5.33E+3	1	3	1.0000	2	1.0000	41			VY	
ZR95	6.40E+1	1	0	0.0000	0	0.0000	40			SW	
NB95M	3.61E+0	1	1	0.0080	0	0.0000	41			SY	
NB95	3.51E+1	1	2	0.9450	1	0.9922	41			SY	
ZR97	7.04E-1	1	0	0.0000	0	0.0000	40			SW	
NB97M	6.94E-4	1	1	0.9470	0	0.0000	41			SY	
NB97	5.01E-2	1	2	1.0000	1	0.0530	41			SY	
NB94	7.41E+6	1	0	0.0000	0	0.0000	41			VY	
MO99	2.75E+0	1	0	0.0000	0	0.0000	42			SD	
TC99M	2.51E-1	1	1	0.8860	0	0.0000	43			NW	
TC99	7.77E+7	1	2	1.0000	1	0.1140	43	T		NW	
TC101	9.86E-3	1	0	0.0000	0	0.0000	43			NW	
RU103	3.94E+1	1	0	0.0000	0	0.0000	44			NY	
PD103	1.70E+1	1	0	0.0000	0	0.0000	46			VY	
RH103M	3.90E-2	1	1	0.9974	2	0.9997	45			NY	
RU105	1.85E-1	1	0	0.0000	0	0.0000	44		NY	1	RH105M 1.000
RH105	1.47E+0	1	1	1.0000	0	0.0000	45		NY		
RU106	3.68E+2	1	0	0.0000	0	0.0000	44	T	NY	1	RH106 1.000
PD107	2.37E+9	1	0	0.0000	0	0.0000	46		VY		
PD109	5.61E-1	1	0	0.0000	0	0.0000	46		VY	1	AG109M 1.000
AG110M	2.50E+2	1	0	0.0000	0	0.0000	47		ND	1	AG110 0.985
AG111	7.46E+0	1	0	0.0000	0	0.0000	47		ND		
CD109	4.64E+2	1	0	0.0000	0	0.0000	48		ND		
CD113M	5.00E+3	1	0	0.0000	0	0.0000	48		ND		
CD115M	4.46E+1	1	0	0.0000	0	0.0000	48		ND		
CD115	2.23E+0	1	0	0.0000	0	0.0000	48		ND		
IN115M	1.82E-1	1	2	1.0000	0	0.0000	49		VD		
IN111	2.8E+0	1	0	0.0000	0	0.0000	49		VD		
IN114M	5.00E+1	1	0	0.0000	0	0.0000	49		VD	1	IN114 0.957
SN113	1.15E+2	1	0	0.0000	0	0.0000	50		VW		
IN113M	6.91E-2	1	1	1.0000	0	0.0000	49		VD		
SN117M	1.40E+1	1	0	0.0000	0	0.0000	50		SW		
SN119M	2.93E+2	1	0	0.0000	0	0.0000	50		VW		
SN121M	2.01E+4	1	0	0.0000	0	0.0000	50		VW		

TABLE D.24. Radionuclide Master Library - Radionuclides
without Explicit Daughters (contd)

SN121	1.13E+0	1	1	0.776	0	0.0000	50	VW	
SN123	1.29E+2	1	0	0.0000	0	0.0000	50	VW	
I 125	6.01E+1	1	0	0.0000	0	0.0000	53	2	ND
SN125	9.64E+0	1	0	0.0000	0	0.0000	50	SW	
SB125	1.01E+3	1	1	1.0000	0	0.0000	51	SW	
TE125M	5.80E+1	1	2	0.2310	0	0.0000	52	SW	
SN126	3.65E+7	1	0	0.0000	0	0.0000	50	VW	
SB126M	1.32E-2	1	1	1.0000	0	0.0000	51	SW	
SB126	1.24E+1	1	2	0.1400	0	0.0000	51	SW	
SB122	2.70E+0	1	0	0.0000	0	0.0000	51	SW	
SB124	6.02E+1	1	0	0.0000	0	0.0000	51	SW	
SB127	3.85E+0	1	0	0.0000	0	0.0000	51	SW	
TE127M	1.09E+2	1	1	0.1690	0	0.0000	52	SW	
TE127	3.90E-1	1	2	0.9820	1	0.8310	52	SW	
TE123M	1.20E+2	1	0	0.0000	0	0.0000	52	SW	
TE129M	3.36E+1	1	0	0.0000	0	0.0000	52	SW	
TE129	4.83E-2	1	1	0.6290	0	0.0000	52	SW	
I 129	5.73E+9	1	2	1.0000	1	0.3710	53	T 2	ND
TE131M	1.25E+0	1	0	0.0000	0	0.0000	52	SW	
TE131	1.74E-2	1	1	0.2220	0	0.0000	52	T	SW
I 131	8.04E+0	1	2	1.0000	1	0.7780	53	T 2	ND
XE131M	1.18E+1	1	3	0.0109	0	0.0000	54	ND	
TE132	3.26E+0	1	0	0.0000	0	0.0000	52	SW	
I 132	9.58E-2	1	1	1.0000	0	0.0000	53	2	ND
TE133M	3.85E-2	1	0	0.0000	0	0.0000	52	SW	
TE133	8.65E-3	1	1	0.1300	0	0.0000	52	SW	
I 133	8.67E-1	1	2	1.0000	1	0.8700	53	2	ND
XE133M	2.19E+0	1	3	0.0288	0	0.0000	54	ND	
XE133	5.25E+0	1	4	1.0000	3	0.9712	54	ND	
TE134	2.90E-2	1	0	0.0000	0	0.0000	52	SW	
I 134	3.65E-2	1	1	1.0000	0	0.0000	53	2	ND
CS134M	1.21E-1	1	0	0.0000	0	0.0000	55	ND	
CS134	7.53E+2	1	1	1.0000	0	0.0000	55	ND	
I 130	5.15E-1	1	0	0.0000	0	0.0000	53	2	ND
I 135	2.75E-1	1	0	0.0000	0	0.0000	53	2	ND
XE135M	1.07E-2	1	1	0.1650	0	0.0000	54	ND	
XE135	3.80E-1	1	2	1.0000	1	0.8350	54	ND	
CS135	8.40E+8	1	3	1.0000	0	0.0000	55	ND	
XE137	2.66E-3	1	0	0.0000	0	0.0000	54	ND	
CS137	1.10E+4	1	1	1.0000	0	0.0000	55	T	ND 1 BA137M 0.946
XE138	9.81E-3	1	0	0.0000	0	0.0000	54	ND	
CS138	2.24E-2	1	1	1.0000	0	0.0000	55	ND	
CS139	6.53E-3	1	0	0.0000	0	0.0000	55	ND	
BA139	5.77E-2	1	1	1.0000	0	0.0000	56	1	SD
BA140	1.28E+1	1	0	0.0000	0	0.0000	56	T 1	SD
LA140	1.68E+0	1	1	1.0000	0	0.0000	57	T	SD
CS136	1.32E+1	1	0	0.0000	0	0.0000	55	ND	
BA141	1.27E-2	1	0	0.0000	0	0.0000	56	1	SD
LA141	1.64E-1	1	1	1.0000	0	0.0000	57	SD	

TABLE D.24. Radionuclide Master Library - Radionuclides
without Explicit Daughters (contd)

CE141	3.25E+1	1	2	1.0000	0	0.0000	58		SY										
BA142	7.43E-3	1	0	0.0000	0	0.0000	56	1	SD										
LA142	6.63E-2	1	1	1.0000	0	0.0000	57		SD										
CE143	1.38E+0	1	0	0.0000	0	0.0000	58		SY										
PR143	1.36E+1	1	1	1.0000	0	0.0000	59		SY										
CE144	2.84E+2	1	0	0.0000	0	0.0000	58	T	SY										
PR144M	5.00E-3	1	1	0.0143	0	0.0000	59		SY										
PR144	1.20E-2	1	2	1.0000	1	0.9857	59	T	SY										
PR142	7.97E-1	1	0	0.0000	0	0.0000	59		SY										
ND147	1.10E+1	1	0	0.0000	0	0.0000	60		SY										
PM147	9.58E+2	1	1	1.0000	0	0.0000	61		SY										
SM147	3.87E13	1	2	1.0000	0	0.0000	62		SW										
PM148M	4.13E+1	1	0	0.0000	0	0.0000	61		SY										
PM148	5.37E+0	1	1	0.0420	0	0.0000	61		SY										
PM149	2.21E+0	1	0	0.0000	0	0.0000	61		SY										
PM151	1.18E+0	1	0	0.0000	0	0.0000	61		SY										
SM151	3.29E+4	1	1	1.0000	0	0.0000	62		SW										
SM153	1.95E+0	1	0	0.0000	0	0.0000	62		SW										
EU152M	3.88E-1	1	0	0.0000	0	0.0000	63		SW										
EU152	4.96E+3	1	0	0.0000	0	0.0000	63		SW										
EU154	3.21E+3	1	0	0.0000	0	0.0000	63		SW										
EU155	1.81E+3	1	0	0.0000	0	0.0000	63		SW										
EU156	1.52E+1	1	0	0.0000	0	0.0000	63		SW										
GD153	2.42E+2	1	0	0.0000	0	0.0000	64		SD										
GD159	7.73E-1	1	0	0.0000	0	0.0000	64		SD										
TB160	7.23E+1	1	0	0.0000	0	0.0000	65		SW										
TB161	6.91E+0	1	0	0.0000	0	0.0000	65		SW										
DY165	9.73E-2	1	0	0.0000	0	0.0000	66		SW										
HO166M	4.38E+5	1	0	0.0000	0	0.0000	67		SW										
HO166	1.12E+0	1	0	0.0000	0	0.0000	67		SW										
ER169	9.40E+0	1	0	0.0000	0	0.0000	68		SW										
ER171	3.13E-1	1	0	0.0000	0	0.0000	68		SW										
TA182	1.15E+2	1	0	0.0000	0	0.0000	73		VY										
W 181	1.21E+2	1	0	0.0000	0	0.0000	74		VD										
W 185	7.51E+1	1	0	0.0000	0	0.0000	74		VD										
W 187	9.93E-1	1	0	0.0000	0	0.0000	74		SD										
RE187	1.72E13	1	1	1.0000	0	0.0000	75		NW										
OS185	9.36E+1	1	0	0.0000	0	0.0000	76		ND										
OS191	1.5E+1	1	0	0.0000	0	0.0000	76		ND										
IR192	7.40E+1	1	0	0.0000	0	0.0000	77		NY										
HG203	4.66E+1	1	0	0.0000	0	0.0000	80		ND										
TH230	2.81E+7	1	0	0.0000	0	0.0000	90		SY										
RA226	5.84E+5	1	1	1.0000	0	0.0000	88	T	1	VW									
RN222	3.82E+0	1	2	1.0000	0	0.0000	86	T		ND	4	P0218	1.000	PB214	1.000				
												BI214	1.000	P0214	1.000				
PB210	8.12E+3	1	3	1.0000	0	0.0000	82	T		VD									
BI210	5.01E+0	1	4	1.0000	0	0.0000	83	T		NW									
P0210	1.38E+2	1	5	1.0000	0	0.0000	84	T		NW									
U 232	2.36E+4	1	0	0.0000	0	0.0000	92			VY									

TABLE D.24. Radionuclide Master Library - Radionuclides without Explicit Daughters (contd)

TH232	5.13E12	1	0	0.0000	0	0.0000	90	SY					
RA228	2.10E+3	1	2	1.0000	0	0.0000	88	1	VW				
AC228	2.55E-1	1	3	1.0000	0	0.0000	89		SY				
TH228	6.98E+2	1	4	1.0000	1	1.0000	90		SY				
RA224	3.62E+0	1	5	1.0000	0	0.0000	88	1	SW	2	RN220	1.000	P0216 1.000
PB212	4.43E-1	1	6	1.0000	0	0.0000	82		SD				
BI212	4.20E-2	1	7	1.0000	0	0.0000	83		NW	2	P0212	.6407	TL208 .3593
U 234	8.29E+7	1	0	0.0000	0	0.0000	92		VY				
U 236	8.55E+9	1	0	0.0000	0	0.0000	92		VY				
U 235	2.57E11	1	0	0.0000	0	0.0000	92		VY				
TH231	1.06E+0	1	1	1.0000	0	0.0000	90		SY				
PA231	1.36E+7	1	2	1.0000	0	0.0000	91		SY				
AC227	7.95E+3	1	3	1.0000	0	0.0000	89		SY				
TH227	1.87E+1	1	4	0.9862	0	0.0000	90		SY				
FR223	1.51E-2	1	4	0.0138	0	0.0000	87		ND				
RA223	1.14E+1	1	5	1.0000	6	1.0000	88	1	SW	5	RN219	1.000	P0215 1.000
											PB211	1.000	BI211 1.000
											TL207	1.000	
U 237	6.75E+0	1	0	0.0000	0	0.0000	92		SY				
NP237	7.81E+8	1	1	1.0000	0	0.0000	93		SW				
PA233	2.70E+1	1	2	1.0000	0	0.0000	91		SY				
U 233	5.58E+7	1	3	1.0000	0	0.0000	92		VY				
TH229	2.68E+6	1	4	1.0000	0	0.0000	90		SY				
RA225	1.48E+1	1	5	1.0000	0	0.0000	88	1	SW				
AC225	1.00E+1	1	6	1.0000	0	0.0000	89		SY	6	FR221	1.000	AT217 1.000
											BI213	1.000	P0213 .9784
											TL209	.0216	PB209 1.000
U 238	1.63E12	1	0	0.0000	0	0.0000	92		VY				
TH234	2.41E+1	1	1	1.0000	0	0.0000	90		SY	1	PA234M	0.998	
PA234	2.79E-1	1	2	0.0016	0	0.0000	91		SY				
PU236	1.04E+3	1	0	0.0000	0	0.0000	94		SY				
PU237	4.53E+1	1	0	0.0000	0	0.0000	94		SY				
AM242M	5.55E+4	1	0	0.0000	0	0.0000	95		SW				
AM242	6.68E-1	1	1	1.0000	0	0.0000	95		SW				
CM242	1.63E+2	1	2	0.8270	0	0.0000	96		SW				
PU242	1.37E+8	1	2	0.1730	0	0.0000	94		SY				
NP238	2.12E+0	1	0	0.0000	0	0.0000	93		SW				
PU238	3.20E+4	1	5	1.0000	3	1.0000	94		SY				
CM244	6.61E+3	1	0	0.0000	0	0.0000	96		SW				
PU244	3.01E10	1	0	0.0000	0	0.0000	94		SY				
U 240	5.88E-1	1	2	0.9988	0	0.0000	92		SY	1	NP240M	1.000	
PU240	2.40E+6	1	3	1.0000	1	1.0000	94		SY				
CM245	3.10E+6	1	0	0.0000	0	0.0000	96		SW				
PU241	5.26E+3	1	1	1.0000	0	0.0000	94		SY				
AM241	1.58E+5	1	2	1.0000	0	0.0000	95	T	SW				
CM246	1.73E+6	1	0	0.0000	0	0.0000	96		SW				
CM247	5.69E+9	1	0	0.0000	0	0.0000	96		SW				
CM243	1.04E+4	1	0	0.0000	0	0.0000	96		SW				
PU243	1.92E-1	1	1	1.0000	0	0.0000	94		SY				

TABLE D.24. Radionuclide Master Library - Radionuclides
without Explicit Daughters (contd)

AM243	2.69E+6	1	3	1.0000	2	0.0024	95	SW
NP239	2.36E+0	1	4	1.0000	0	0.0000	93	SW
PU239	8.81E+6	1	5	1.0000	2	0.9976	94 T	SY
CM248	1.24E+8	1	0	0.0000	0	0.0000	96	SW
CF252	9.63E+2	1	0	0.0000	0	0.0000	98	SW
		0	0	0.0000	0	0.0000		

**TABLE D.25. Food Transfer Coefficient Data for Soil
Contribution to Food Product Ingestion**

10 CFR 61 Transfer Factors when Available, then Reg Guide 1/109 (5-Oct-89 RAP)											
Element	Dep Vel m/sec	Leafy Veg	Root Veg	Fruit --	Grain --	Beef day/kg	Poultry day/kg	Milk day/L	Egg day/kg	Leaching Factor	
AC	8.0E-4	1.0E-2	1.0E-2	3.0E-3	3.0E-4	4.0E-4	4.0E-3	2.0E-5	2.0E-3	1.3E-03	
AM	8.0E-4	5.6E-2	2.2E-2	3.1E-2	3.1E-2	3.9E-3	2.0E-4	5.0E-6	9.0E-3	1.3E-03	
SB	8.0E-4	5.0E-2	5.0E-2	5.0E-2	5.0E-2	1.0E-3	6.0E-3	7.5E-4	7.0E-2	4.2E-02	
AR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	
BA	8.0E-4	5.0E-2	2.0E-2	2.8E-2	2.8E-2	3.2E-3	8.1E-4	4.0E-4	1.5E+0	9.5E-05	
BE	8.0E-4	4.2E-3	1.7E-3	2.3E-3	2.3E-3	1.0E-3	4.0E-1	9.1E-7	2.0E-2	1.9E-04	
BI	8.0E-4	1.5E+0	6.0E-1	8.3E-1	8.3E-1	1.3E-2	9.9E-4	5.0E-4	9.9E-4	2.7E-05	
CD	8.0E-4	2.0E+0	2.0E+0	2.0E+0	6.0E-1	4.0E-4	8.4E-1	1.2E-4	1.0E-1	6.3E-04	
CA	8.0E-4	3.7E-1	1.5E-1	2.1E-1	2.1E-1	4.0E-2	4.4E-2	1.1E-2	4.4E-1	1.9E-04	
C	0.0	5.5E+1	2.2E+1	3.1E+1	3.1E+1	3.1E-2	0.0	1.2E-2	0.0	8.0E-01	
CS	8.0E-4	9.3E-2	3.7E-2	5.2E-2	5.2E-2	1.4E-2	4.4E+0	5.6E-3	4.9E-1	1.1E-03	
CE	8.0E-4	2.5E-2	1.0E-2	1.4E-2	1.4E-2	1.2E-3	1.0E-2	1.0E-4	5.0E-3	5.0E-04	
CL	8.0E-4	5.0E+1	2.0E+1	2.8E+1	2.8E+1	8.0E-2	3.0E-2	1.7E-2	9.9E-4	8.0E-01	
CR	8.0E-4	2.5E-3	1.0E-3	1.4E-3	1.4E-3	2.4E-3	9.9E-4	2.2E-3	9.9E-4	4.7E-03	
CO	8.0E-4	9.4E-2	3.8E-2	5.2E-2	5.2E-2	1.3E-2	5.0E-1	1.0E-3	1.0E-1	3.0E-02	
CU	8.0E-4	1.2E+0	4.8E-1	6.7E-1	6.7E-1	8.0E-3	5.1E-1	1.4E-2	4.9E-1	2.9E-03	
CM	8.0E-4	2.5E-2	1.0E-2	1.4E-2	1.4E-2	2.0E-4	4.0E-3	5.0E-6	2.0E-3	1.3E-04	
EU	8.0E-4	2.5E-2	1.0E-2	1.4E-2	1.4E-2	4.8E-3	4.0E-3	2.0E-5	7.0E-3	5.0E-04	
GD	8.0E-4	5.0E-2	5.0E-2	5.0E-2	5.0E-3	2.0E-3	9.9E-4	6.0E-5	9.9E-4	4.1E-04	
GA	8.0E-4	1.0E-2	1.0E-2	1.0E-2	1.0E-3	3.0E-4	9.9E-4	1.0E-5	9.9E-4	1.8E-04	
AU	8.0E-4	4.0E-1	4.0E-1	4.0E-1	4.0E-2	5.0E-3	9.9E-4	1.0E-5	9.9E-4	1.1E-02	
HF	8.0E-4	1.0E-2	1.0E-2	1.0E-2	2.0E-3	4.0E-4	9.9E-4	2.0E-5	9.9E-4	1.8E-04	
HO	8.0E-4	1.0E-2	2.0E-2	1.0E-2	2.7E-3	5.0E-3	4.0E-3	2.5E-6	7.0E-3	4.1E-04	
IN	8.0E-4	1.0E-2	1.0E-2	1.0E-2	1.0E-3	4.0E-3	9.9E-4	2.0E-4	9.9E-4	1.8E-04	
I	1.0E-2	5.5E-1	2.2E-1	3.1E-1	3.1E-1	7.0E-3	1.8E-2	1.0E-2	2.8E+0	0.8	
IR	8.0E-4	1.0E-1	1.0E-1	1.0E-1	4.0E-3	2.0E-3	9.9E-4	2.0E-6	9.9E-4	1.8E-03	
FE	8.0E-4	6.6E-3	2.6E-3	3.7E-3	3.7E-3	4.0E-2	1.5E+0	5.9E-5	1.3E+0	1.8E-02	
KR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	
LA	8.0E-4	2.5E-2	1.0E-2	1.4E-2	1.4E-2	2.0E-4	1.0E-1	5.0E-6	9.0E-3	4.1E-04	
PB	8.0E-4	4.0E-2	1.6E-2	2.2E-2	2.2E-2	7.1E-4	9.9E-4	1.2E-4	9.9E-4	4.5E-04	
MN	8.0E-4	2.9E-1	1.2E-1	1.6E-1	1.6E-1	8.0E-4	5.0E-2	2.5E-4	6.5E-2	1.1E-02	
HG	8.0E-4	1.0E+0	1.0E+0	1.0E+0	1.0E-1	1.0E-1	1.1E-2	4.0E-4	9.9E-4	4.6E-04	
MO	8.0E-4	1.2E+0	4.8E-1	6.7E-1	6.7E-1	8.0E-3	1.9E-1	1.4E-3	7.8E-1	0.8	
ND	8.0E-4	2.4E-2	9.6E-3	1.3E-2	1.3E-2	3.3E-3	4.0E-3	5.0E-6	2.0E-4	4.1E-04	
NP	8.0E-4	2.5E-2	1.0E-2	1.4E-2	1.4E-2	2.0E-4	4.0E-3	5.0E-6	2.0E-3	3.3E-03	
NI	8.0E-4	1.9E-1	7.6E-2	1.1E-1	1.1E-1	5.3E-2	1.0E-3	6.7E-3	1.0E-1	4.6E-03	
NB	8.0E-4	9.4E-2	3.8E-2	5.2E-2	5.2E-2	2.8E-1	3.1E-4	2.5E-3	1.3E-3	2.7E-03	
PD	8.0E-4	3.0E-1	3.0E-1	3.0E-1	5.0E-2	1.0E-3	3.0E-4	5.0E-3	4.0E-3	4.6E-03	
P	8.0E-4	1.1E+1	4.4E+0	6.1E+0	6.1E+0	4.6E-2	1.9E-1	2.5E-2	1.0E+1	0.8	
PU	8.0E-4	5.6E-3	2.2E-3	3.1E-3	3.1E-3	3.9E-4	1.5E-4	2.0E-6	8.0E-3	1.3E-03	
PO	8.0E-4	1.0E-2	1.0E-2	1.0E-2	1.0E-3	4.5E-3	9.9E-4	1.2E-4	9.9E-4	2.7E-05	
K	8.0E-4	3.0E+0	3.0E+0	3.0E+0	3.0E+0	1.8E-2	9.9E-4	7.0E-3	9.9E-4	0.5	
PR	8.0E-4	2.5E-2	1.0E-2	1.4E-2	1.4E-2	4.7E-3	3.0E-2	5.0E-6	5.0E-3	5.0E-04	
PM	8.0E-4	1.0E-2	1.0E-2	1.0E-2	1.0E-3	5.0E-3	2.0E-3	2.5E-6	2.0E-2	5.0E-04	
PA	8.0E-4	5.0E-2	5.0E-2	5.0E-2	2.0E-2	5.0E-3	4.0E-3	2.5E-6	2.0E-3	1.3E-03	
RA	8.0E-4	1.4E-1	5.6E-2	7.8E-2	7.8E-2	5.1E-4	9.9E-4	5.9E-4	2.0E-5	5.9E-04	

TABLE D.25. Food Transfer Coefficient Data for Soil
Contribution to Food Product Ingestion (contd)

RH	8.0E-4	2.5E+0	1.0	1.4	1.4	8.0E-3	3.0E-4	1.3E-3	4.0E-3	4.4E-03
RB	8.0E-4	1.3E+0	5.2E-1	7.2E-1	7.2E-1	3.1E-2	2.0E+0	3.0E-2	3.0E+0	4.4E-03
RU	8.0E-4	5.0E-1	2.0E-1	2.8E-1	2.8E-1	4.0E-1	7.0E-3	1.0E-6	6.0E-3	7.6E-04
SM	8.0E-4	1.0E-2	1.0E-2	1.0E-2	1.0E-2	5.0E-3	4.0E-3	2.0E-5	7.0E-3	4.1E-04
SC	8.0E-4	1.0E-2	1.0E-2	1.0E-2	1.0E-2	6.0E-3	4.0E-3	2.5E-6	9.9E-4	2.7E-04
AG	8.0E-4	1.5E+0	6.0E-1	8.3E-1	8.3E-1	1.7E-2	9.9E-4	5.0E-2	9.9E-4	2.7E-01
SE	8.0E-4	5.0E-1	5.0E-1	5.0E-1	5.0E-2	1.0E+0	8.5E+0	2.3E-2	9.3E+0	1.7E-02
NA	8.0E-4	5.2E-1	2.1E-1	2.9E-1	2.9E-1	3.0E-2	1.0E-2	4.0E-2	2.0E-1	0.5
SR	8.0E-4	2.9E+0	1.2E+0	1.6E+0	1.6E+0	3.0E-4	3.5E-2	2.4E-3	3.0E-1	2.7E-03
S	8.0E-4	2.0E+0	2.0E+0	2.0E+0	2.0E+0	2.0E-1	9.9E-4	1.5E-2	9.9E-4	3.4E-02
TC	8.0E-4	1.1E+1	4.4E+0	6.1E+0	6.1E+0	8.7E-3	3.0E-2	9.9E-3	3.0E+0	0.8
TE	8.0E-4	1.3E+1	5.2E+0	7.2E+0	7.2E+0	7.7E-2	8.5E-2	1.0E-3	5.2E+0	0.8
TH	8.0E-4	4.2E-2	1.7E-2	2.3E-2	2.3E-2	2.0E-4	4.0E-3	5.0E-6	2.0E-3	5.3E-04
SN	8.0E-4	1.0E-1	1.0E-1	1.0E-1	1.0E-2	1.0E-2	9.9E-4	1.0E-3	9.9E-4	2.7E-03
W	8.0E-4	1.8E-1	7.2E-2	1.0E-1	1.0E-1	1.3E-3	9.9E-4	5.0E-4	9.9E-4	1.8E-03
U	8.0E-4	2.5E-2	1.0E-2	1.4E-2	1.4E-2	3.4E-4	1.2E+0	6.1E-4	9.9E-1	1.3E-03
XE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
Y	8.0E-4	2.6E-2	1.0E-2	1.4E-2	1.4E-2	4.6E-3	1.0E-2	1.0E-5	2.0E-3	5.0E-04
ZN	8.0E-4	4.0E+0	1.6E+0	2.2E+0	2.2E+0	3.0E-2	6.5E+0	3.9E-2	2.6E+0	2.8E-04
ZR	8.0E-4	1.7E-3	6.8E-4	9.4E-4	9.4E-4	3.4E-2	6.4E-5	5.0E-6	1.9E-4	5.3E-04
H	0.0	4.8E+1	1.9E+1	2.7E+1	2.7E+1	1.2E-2	0.0	1.0E-2	0.0	8.0E-01
N	8.0E-4	7.5E+0	7.5E+0	7.5E+0	7.5E+0	9.9E-4	9.9E-4	1.1E-2	9.9E-4	0.8
F	8.0E-4	2.0E-2	2.0E-2	2.0E-2	2.0E-2	2.0E-2	9.9E-4	7.0E-3	9.9E-4	0.8
AS	8.0E-4	1.0E-2	1.0E-2	1.0E-2	1.0E-2	1.5E-3	8.3E-1	8.0E-5	9.9E-4	1.3E-03
BR	8.0E-4	7.6E-1	7.6E-1	7.6E-1	7.6E-1	2.0E-2	4.0E-3	2.0E-2	1.6E+0	1.1E-01
TB	8.0E-4	2.6E-3	2.6E-3	2.6E-3	2.6E-3	5.0E-3	4.0E-3	2.5E-6	7.0E-3	4.1E-04
RN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
CF	8.0E-4	2.5E-3	2.5E-3	2.5E-3	2.5E-3	5.0E-3	4.0E-3	7.5E-7	2.0E-3	4.1E-04
DY	8.0E-4	9.9E-4	9.9E-4	9.9E-4	9.9E-4	5.3E-3	9.9E-4	5.0E-6	9.9E-4	4.1E-04
MG	8.0E-4	9.9E-4	9.9E-4	9.9E-4	9.9E-4	1.8E-2	9.9E-4	9.9E-4	1.6E+0	1.9E-04
RE	8.0E-4	9.9E-4	9.9E-4	9.9E-4	9.9E-4	9.9E-4	9.9E-4	1.0E-3	9.9E-4	3.3E-02
TA	8.0E-4	9.9E-4	9.9E-4	9.9E-4	9.9E-4	9.9E-4	9.9E-4	3.0E-6	9.9E-4	4.1E-04
TL	8.0E-4	9.9E-4	9.9E-4	9.9E-4	9.9E-4	9.9E-4	9.9E-4	2.0E-3	9.9E-4	0.5
SI	8.0E-4	3.5E-1	3.5E-1	3.5E-1	3.5E-1	4.0E-5	9.9E-4	2.0E-5	9.9E-4	8.8E-03
ER	8.0E-4	1.0E-2	1.0E-2	1.0E-2	1.0E-2	4.0E-3	9.9E-4	2.0E-5	9.9E-4	4.1E-04

TABLE D.26. Food Transfer Coefficient Data for Air Contribution to Food Product Ingestion

10 CFR 61 Element	Transfer Factors (NO root uptake), then Reg Guide 1/109 (4-Oct-89 RAP)	Leafy Veg	Root Veg	Fruit --	Grain --	Beef day/kg	Poultry day/kg	Milk day/L	Egg day/kg	Leaching Factor
AC	8.0E-4					4.0E-4	4.0E-3	2.0E-5	2.0E-3	1.3E-03
AM	8.0E-4					3.9E-3	2.0E-4	5.0E-6	9.0E-3	1.3E-03
SB	8.0E-4					1.0E-3	6.0E-3	7.5E-4	7.0E-2	4.2E-02
AR	0.0					0.0	0.0	0.0	0.0	0.8
BA	8.0E-4					3.2E-3	8.1E-4	4.0E-4	1.5E+0	9.5E-05
BE	8.0E-4					1.0E-3	4.0E-1	9.1E-7	2.0E-2	1.9E-04
BI	8.0E-4					1.3E-2	9.9E-4	5.0E-4	9.9E-4	2.7E-05
CD	8.0E-4					4.0E-4	8.4E-1	1.2E-4	1.0E-1	6.3E-04
CA	8.0E-4					4.0E-2	4.4E-2	1.1E-2	4.4E-1	1.9E-04
C	0.0					3.1E-2	0.0	1.2E-2	0.0	8.0E-01
CS	8.0E-4					1.4E-2	4.4E+0	5.6E-3	4.9E-1	1.1E-03
CE	8.0E-4					1.2E-3	1.0E-2	1.0E-4	5.0E-3	5.0E-04
CL	8.0E-4					8.0E-2	3.0E-2	1.7E-2	9.9E-4	8.0E-01
CR	8.0E-4					2.4E-3	9.9E-4	2.2E-3	9.9E-4	4.7E-03
CO	8.0E-4					1.3E-2	5.0E-1	1.0E-3	1.0E-1	3.0E-02
CU	8.0E-4					8.0E-3	5.1E-1	1.4E-2	4.9E-1	2.9E-03
CM	8.0E-4					2.0E-4	4.0E-3	5.0E-6	2.0E-3	1.3E-04
EU	8.0E-4					4.8E-3	4.0E-3	2.0E-5	7.0E-3	5.0E-04
GD	8.0E-4					2.0E-3	9.9E-4	6.0E-5	9.9E-4	4.1E-04
GA	8.0E-4					3.0E-4	9.9E-4	1.0E-5	9.9E-4	1.8E-04
AU	8.0E-4					5.0E-3	9.9E-4	1.0E-5	9.9E-4	1.1E-02
HF	8.0E-4					4.0E-4	9.9E-4	2.0E-5	9.9E-4	1.8E-04
HO	8.0E-4					5.0E-3	4.0E-3	2.5E-6	7.0E-3	4.1E-04
IN	8.0E-4					4.0E-3	9.9E-4	2.0E-4	9.9E-4	1.8E-04
I	1.0E-2					7.0E-3	1.8E-2	1.0E-2	2.8E+0	0.8
IR	8.0E-4					2.0E-3	9.9E-4	2.0E-6	9.9E-4	1.8E-03
FE	8.0E-4					4.0E-2	1.5E+0	5.9E-5	1.3E+0	1.8E-02
KR	0.0					0.0	0.0	0.0	0.0	0.8
LA	8.0E-4					2.0E-4	1.0E-1	5.0E-6	9.0E-3	4.1E-04
PB	8.0E-4					7.1E-4	9.9E-4	1.2E-4	9.9E-4	4.5E-04
MN	8.0E-4					8.0E-4	5.0E-2	2.5E-4	6.5E-2	1.1E-02
HG	8.0E-4					1.0E-1	1.1E-2	4.0E-4	9.9E-4	4.6E-04
MO	8.0E-4					8.0E-3	1.9E-1	1.4E-3	7.8E-1	0.8
ND	8.0E-4					3.3E-3	4.0E-3	5.0E-6	2.0E-4	4.1E-04
NP	8.0E-4					2.0E-4	4.0E-3	5.0E-6	2.0E-3	3.3E-03
NI	8.0E-4					5.3E-2	1.0E-3	6.7E-3	1.0E-1	4.6E-03
NB	8.0E-4					2.8E-1	3.1E-4	2.5E-3	1.3E-3	2.7E-03
PD	8.0E-4					1.0E-3	3.0E-4	5.0E-3	4.0E-3	4.6E-03
P	8.0E-4					4.6E-2	1.9E-1	2.5E-2	1.0E+1	0.8
PU	8.0E-4					3.9E-4	1.5E-4	2.0E-6	8.0E-3	1.3E-03
PO	8.0E-4					4.5E-3	9.9E-4	1.2E-4	9.9E-4	2.7E-05
K	8.0E-4					1.8E-2	9.9E-4	7.0E-3	9.9E-4	0.5
PR	8.0E-4					4.7E-3	3.0E-2	5.0E-6	5.0E-3	5.0E-04
PM	8.0E-4					5.0E-3	2.0E-3	2.5E-6	2.0E-2	5.0E-04
PA	8.0E-4					5.0E-3	4.0E-3	2.5E-6	2.0E-3	1.3E-03
RA	8.0E-4					5.1E-4	9.9E-4	5.9E-4	2.0E-5	5.9E-04

TABLE D.22. Food Transfer Coefficient Data for Air Contribution to Food Product Ingestion (contd)

RH	8.0E-4	8.0E-3	3.0E-4	1.3E-3	4.0E-3	4.4E-01
RB	8.0E-4	3.1E-2	2.0E+0	3.0E-2	3.0E+0	4.4E-01
RU	8.0E-4	4.0E-1	7.0E-3	1.0E-6	6.0E-3	7.6E-01
SM	8.0E-4	5.0E-3	4.0E-3	2.0E-5	7.0E-3	4.1E-01
SC	8.0E-4	6.0E-3	4.0E-3	2.5E-6	9.9E-4	2.7E-01
AG	8.0E-4	1.7E-2	9.9E-4	5.0E-2	9.9E-4	2.7E-01
SE	8.0E-4	1.0E+0	8.5E+0	2.3E-2	9.3E+0	1.7E-01
NA	8.0E-4	3.0E-2	1.0E-2	4.0E-2	2.0E-1	0.5
SR	8.0E-4	3.0E-4	3.5E-2	2.4E-3	3.0E-1	2.7E-01
S	8.0E-4	2.0E-1	9.9E-4	1.5E-2	9.9E-4	3.4E-01
TC	8.0E-4	8.7E-3	3.0E-2	9.9E-3	3.0E+0	0.8
TE	8.0E-4	7.7E-2	8.5E-2	1.0E-3	5.2E+0	0.8
TH	8.0E-4	2.0E-4	4.0E-3	5.0E-6	2.0E-3	5.3E-01
SN	8.0E-4	1.0E-2	9.9E-4	1.0E-3	9.9E-4	2.7E-01
W	8.0E-4	1.3E-3	9.9E-4	5.0E-4	9.9E-4	1.8E-01
U	8.0E-4	3.4E-4	1.2E+0	6.1E-4	9.9E-1	1.3E-01
XE	0.0	0.0	0.0	0.0	0.0	0.8
Y	8.0E-4	4.6E-3	1.0E-2	1.0E-5	2.0E-3	5.0E-01
ZN	8.0E-4	3.0E-2	6.5E+0	3.9E-2	2.6E+0	2.8E-01
ZR	8.0E-4	3.4E-2	6.4E-5	5.0E-6	1.9E-4	5.3E-01
H	0.0	1.2E-2	0.0	1.0E-2	0.0	8.0E-01
N	8.0E-4	9.9E-4	9.9E-4	1.1E-2	9.9E-4	0.8
F	8.0E-4	2.0E-2	9.9E-4	7.0E-3	9.9E-4	0.8
AS	8.0E-4	1.5E-3	8.3E-1	8.0E-5	9.9E-4	1.3E-01
BR	8.0E-4	2.0E-2	4.0E-3	2.0E-2	1.6E+0	1.1E-01
TB	8.0E-4	5.0E-3	4.0E-3	2.5E-6	7.0E-3	4.1E-01
RN	0.0	0.0	0.0	0.0	0.0	0.8
CF	8.0E-4	5.0E-3	4.0E-3	7.5E-7	2.0E-3	4.1E-01
DY	8.0E-4	5.3E-3	9.9E-4	5.0E-6	9.9E-4	4.1E-01
MG	8.0E-4	1.8E-2	9.9E-4	9.9E-4	1.6E+0	1.9E-01
RE	8.0E-4	9.9E-4	9.9E-4	1.0E-3	9.9E-4	3.3E-02
TA	8.0E-4	9.9E-4	9.9E-4	3.0E-6	9.9E-4	4.1E-01
TL	8.0E-4	9.9E-4	9.9E-4	2.0E-3	9.9E-4	0.5
SI	8.0E-4	4.0E-5	9.9E-4	2.0E-5	9.9E-4	8.8E-03
ER	8.0E-4	4.0E-3	9.9E-4	2.0E-5	9.9E-4	4.1E-01

APPENDIX E

GLOSSARY

APPENDIX E

GLOSSARY

"Absorbed dose" means the energy imparted by ionizing radiation per unit mass of irradiated material. The units of absorbed dose are the rad and the gray (Gy).

"Activity" is the rate of disintegration (transformation), or decay of radioactive material. The units of activity are the curie (Ci) and the becquerel (Bq).

"Airborne radioactive material" means radioactive material dispersed in the air in the form of dusts, fumes, particulates, mists, vapors, or gases.

"Annual Dose" means an accounting for external exposure during a year plus the effective committed dose equivalent from intake by inhalation and ingestion during a year. The duration of exposure for each pathway is determined by the scenario considered and need not be 8760 h/yr. For example, an individual may reside or work at a contaminated site for a fraction of the year.

"Class" (or "lung class" or "inhalation class") means a classification scheme for inhaled material according to its rate of clearance from the pulmonary region of the lung. Materials are classified as D, W, or Y which applies to a range of clearance half-times for D(Days) of less than 10 days, for W(Weeks) from 10 to 100 days, and for Y(Years) of greater than 100 days.

"Collective dose" is the sum of the individual doses received in a given period of time by a specified population from exposure to a specified source of radiation.

"Commission" means the Nuclear Regulatory Commission (NRC) or its duly authorized representatives.

"Committed dose equivalent" ($H_{T,50}$) means the dose equivalent to organs or tissues of reference (T) that will be received from an intake of radioactive material by an individual during the 50-year period following the intake.

"Committed effective dose equivalent" ($H_{E,50}$) is the sum of the products of the weighting factors applicable to each of the body organs or tissues which are irradiated and the committed dose equivalent to these organs or tissues ($H_{E,50} = \sum W_T H_{T,50}$).

"Conservative" means the application of a cautious approach to a dose analysis that is likely to produce an overestimate of the expected result. A conservative analysis involves the deliberate selection of parameter values that maximize the expected result.

"Deep dose equivalent" (H_d), which applies to external whole body exposure, is the dose equivalent at a tissue depth of 1 cm (1000 mg/cm²).

"Dose" or "radiation dose" is a generic term which means absorbed dose, dose equivalent, effective dose equivalent, committed dose equivalent, committed effective dose equivalent, or total effective dose equivalent, as defined in other paragraphs of this section.

"Dose equivalent" (H_T) means the product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest. The units of dose equivalent are the rem and sievert (Sv).

"Effective dose equivalent" (H_E) is the sum of the products of the dose equivalent to the organ or tissue (H_T) and the weight factors (w_T) applicable to each of the body organs or tissues which are irradiated ($H_E = \sum w_T H_T$).

"Exposure" means being exposed to ionizing radiation or to radioactive material.

"External dose" means that portion of the dose equivalent received from radiation sources outside of the body.

"Gray" (Gy) is the SI unit of absorbed dose. One gray is equal to an absorbed dose of 1 joule/kilogram (100 rad).

"Individual" means any human being.

"Internal dose" means that portion of the dose equivalent received from radioactive material taken into the body.

"License" means a license issued under the regulations in Parts 30 through 35, 39, 40, 50, 60, 61, 70, or 72 of this chapter.

"Licensee" means the holder of a license.

"Licensed material" means source material, special nuclear material, or byproduct material received, possessed, used, or transferred under a general or specific license issued by the Commission.

"Member of the public" means an individual in a controlled or unrestricted area. However, an individual is not a member of the public during any period in which the individual receives an occupational dose.

"NRC" means the Nuclear Regulatory Commission or its duly authorized representatives.

"Pathway" means the potential routes through which people may be exposed to radiation or radioactive materials. Typical radiation exposure pathways include external exposure to penetrating radiation, inhalation of airborne materials, and ingestion of materials contained in surface contamination, food products, or drinking water.

"Public dose" means the dose received by a member of the public from exposure to radiation and to radioactive material released by a licensee, or to another source of radiation either within a licensee's controlled area or in unrestricted areas. It does not include occupational dose, or dose received from natural background, as a patient from medical practices, or from voluntary participation in medical research programs.

"Rad" is the special unit of absorbed dose. One rad is equal to an absorbed dose of 100 ergs/gram or 0.01 joule/kilogram (0.01 gray).

"Radiation" (ionizing radiation) means alpha particles, beta particles, gamma rays, x-rays, neutrons, high-speed electrons, high-speed protons, and other particles capable of producing ions. Radiation, as used in this part, does not include nonionizing radiation, such as sound, radio, or microwaves, or visible, infrared, or ultraviolet light.

"Reference man" means a hypothetical aggregation of human physical and physiological characteristics arrived at by international consensus. These characteristics may be used by researchers and public health workers to standardize results of experiments and to relate biological insult to a common base.

"Rem" is the special unit of dose equivalent. The dose equivalent in rem is equal to the absorbed dose in rad multiplied by the quality factor (1 rem = 0.01 sieverts).

"Scenario" means a combination of radiation exposure pathways in an effort to conceptually model the potential conditions, events, and processes that result in radiation exposure to individuals or groups of people.

"Sievert" is the SI unit of dose equivalent. The dose equivalent is sieverts is equal to the absorbed dose in grays multiplied by the quality factor (1 Sv = 100 rem).

"Total Effective Dose Equivalent" means the sum of the deep dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures).

"Uranium fuel cycle" means the operations of milling of uranium ore, chemical conversion of uranium, isotopic enrichment of uranium, fabrication of uranium fuel, generation of electricity by a light-water-cooled nuclear power plant using uranium fuel, and reprocessing of spent uranium fuel, to the extent that these activities directly support the production of electrical power for public use. Uranium fuel cycle does not include mining operations, operations at waste disposal sites, transportation of radioactive material in support of these operations, and the reuse of recovered non-uranium special nuclear and byproduct materials from the cycle.

"Weight factor," w_T , for an organ or tissue (T) is the proportion of the risk of stochastic effects resulting from irradiation of that organ or tissue to the total risk of stochastic effects when the whole body is irradiated uniformly. For calculating the effective dose equivalent, the values of w_T are:

Organ or Tissue	w_T
Gonads	0.25
Breast	0.15
Red bone marrow	0.12
Lung	0.12
Thyroid	0.03
Bone surfaces	0.03
Remainder	0.30(a)
Whole body	1.0(b)

- (a) 0.30 results from 0.06 for each of 5 "remainder organs" (excluding the skin and the lens of the eye) that receive the highest doses).
- (b) For the purpose of weighting the external whole body dose (for adding it to the internal dose), a single weight factor, $w_T = 1.0$, has been specified. The use of other weighting factors for external exposure will be approved on a case-by-case basis until such time as specific guidance is issued.

"Whole body" means, for purposes of external exposure, head, trunk (including male gonads), arms above the elbow, or legs above the knee.