10 DOSE AND RISK CALCULATIONS

10.1 Introduction

This chapter discusses the final step in obtaining estimates of doses and risks to the hypothetical receptors described in the scenarios. As indicated in Chapter 9, doses and risks are proportional to "intake of radionuclides by each ingestion and inhalation exposure pathway, and exposure to radionuclides from external exposure pathways."(1). The intakes, estimated according to the approaches outlined in Chapter 9, depend on the estimated concentrations of radionuclides in various environmental media: air, water, soil, plants, and animal products. Methods for estimating concentrations are presented in Chapter 5 for air, Chapter 7 for water, and Chapter 8 for the remaining media. Intakes also depend on the behaviors described in the scenario specifications (Chapter 3) that bring the receptors into contact with these contaminated environmental media. Because the doses and risks are proportional to intake, linear coefficients are used to relate intake to dose and risk. These coefficients have been developed over many decades by the health physics community through national and international radiation protection organizations.

10.2 Basic Radiation Concepts

Additional information about radiation assessment and protection principles, and terminology, can be obtained from Internet sites on radiation such as those established by EPA (http://www.epa.gov/radiation) and the University of Michigan (http://www.umich.edu/~nradinfo).

10.2.1 Types of Radiation

Radionuclides released by the SRS into the environment emit two basic kinds of radiation:

- Particle radiation - tiny fast-moving particles that have both energy and mass (weight).
- Electromagnetic radiation - pure energy with no weight.

Particle radiation includes alpha and beta particles. An alpha particle is the positively charged nucleus of a helium atom. Alpha particles lose energy quickly when they collide with matter; therefore, their ability to penetrate is slight. A sheet of paper or layer of skin may completely absorb such particles. However, if radionuclides emitting alpha particles are inside the body, the alpha particles may cause harm to body cells. Beta particles are free, mobile electrons. Beta particles have a greater ability to penetrate matter than alpha particles. Electromagnetic radiation emitted by radionuclides includes gamma rays and x-rays. This radiation has more ability to penetrate matter than most particle radiation. All the types of radiation emitted by radionuclides may damage living cells by ionizing atoms or molecules within the cells.

10.2.2 Radiation Dose

The term "dose" has several meanings, depending on how it is used. For this study, several different terms for "dose" are needed to describe the effects of radiation[1]. The most fundamental definition of dose is the *absorbed dose*, which a measure of the amount of energy imparted to matter (e.g. tissue) by the radiation. Units of the *absorbed dose* are the rad or gray; the gray, the SI unit of absorbed dose, is equivalent to one joule of energy absorbed by a kilogram of tissue (J/kg). One gray equals 100 rad.

[1] The terms discussed here are appropriate for the low doses and stochastic health effects usually associated with exposures to environmental radioactivity.

Although the amount of energy absorbed per unit mass, as measured by the absorbed dose, is fundamental to determining the adverse impact of radiation on the absorbing tissue and ultimately on the health of the exposed person, the adverse impact also depends upon the type of radiation absorbed. This is because different types of radiation are more or less efficient in producing damage in tissue, given the same amount of energy absorbed per unit mass. These differences are included in the concept of an *equivalent dose*,[2] which may be defined as:

$$H = D \cdot W_R \qquad (10\text{-}1)$$

Where, H is the equivalent dose (sievert);
D is the absorbed dose (Gray);
W_R is the weighting factor (dimensionless).

The SI unit of equivalent dose is called the *sievert* (Sv); another unit commonly used in the United States is the "*rem*," or "Roentgen equivalent man," which is one one-hundredth of a sievert. A *millirem* (mrem) is one one-thousandth of a rem. The weighting factor[3] accounts for differences in how energy is imparted to tissue by different types of radiation. X-rays, gamma rays, and beta particles are generally assigned weighting factors of one, while alpha particles are generally assigned weighting factors of twenty.

One difficulty of estimating radiation doses to humans is that human bodies are variable. To achieve agreement on standards for radiation protection, and to help comparisons of different radiation dose assessments, a concept was developed called a *standard man*, a surrogate human having organs of both sexes of reference radii and masses. Risk assessments are commonly performed using these standard physiological assumptions.

As discussed in previous chapters, especially Chapters 9, exposure to radiation may result from radionuclides inside or outside the body. Radionuclides were modeled as entering the body by inhalation and ingestion. Exposures to external radiation from radionuclides outside the body were modeled for:

- Immersion in a plume of air.
- Exposure to contaminated soil.
- Exposure to a contaminated shoreline.
- Exposure to contaminated water while swimming.
- Exposure to contaminated water while boating.

The radiation exposure from these external sources tends to be uniform throughout the body of the exposed person, because the sources are large compared to the human body. This is generally different from therapeutic and diagnostic medical exposures, where the radiation is focused on a particular body organ or region. Once the human is removed from proximity to the medium (air, water, and soil) contaminated by radionuclides, the external radiation exposure ceases.

Exposure resulting from radionuclides within the body is substantially different. First, a radionuclide may lodge in or migrate to a particular organ of the body, where it may produce most of its damage. Second, although some types of radiation (alpha and beta) travel short distances, gamma rays may irradiate body organs some distance from the location of the radionuclides. Third, although some radionuclides may lodge in a particular organ (e.g., the lung for inhaled particles), in time they may migrate to organs that have a biochemical affinity for them (e.g., Sr tends to migrate to bones). Fourth, even though the uptake of a radionuclide by inhalation or ingestion may be a short-term or even one-time event, the radionuclides inside the body may continue to irradiate body organs. Finally, radionuclides

[2] Except where noted, ICRP-60 terminology is used in this chapter.
[3] In ICRP-60 and other ICRP recommendations preceding ICRP-60, a weighting factor was called a quality factor (2).

inside the body may decay or be excreted over time, so their effect on the body lessens over time. To address this complex biological and physical situation, mathematical models are used to describe movement and retention of radioactive material in the body and the doses that are imparted to various organs. A radionuclide taken into the body will impart a dose to a person not only for the first year of intake, but in all the following years until the radionuclide decays or is eliminated. To account for this long-lasting effect, the time-varying equivalent dose rate from radioactive material uptake at a given time is integrated (added) over an appropriate time period. For this study, the time period used is 70 years, representing a typical lifetime.[4] This integral of equivalent dose rate for internal radionuclides produces a *committed equivalent dose*, which is measured in sieverts.

The models (sometimes called *biokinetic* models) used to describe the movement of radionuclides in the body and the resulting doses to various organs are quite complex, as indicated in the following summary:

> "The dosimetric methodology used in FGR-13 is that of the ICRP...The methodology considers two sets of anatomical regions within the body. A set of source regions is used to specify the location of radionuclide within the body. The set of target regions consists of those organs and tissues for which the radiation dose is of interest. For a specific radionuclide, the set of source regions consists of anatomical regions along the route of intake (respiratory and gastrointestinal tract), regions associated with the systemic behavior of the radionuclide, and regions along the routes of elimination of the radionuclide from the body. A region may consist of multiple compartments as necessary to represent the kinetics. Within each region the radionuclide is assumed to be uniformly distributed either by volume or, in some instances, by surface area. The mean absorbed dose to the target region is the fundamental dosimetric quantity.
>
> The energy deposition in the target regions is based on calculations of the radiation transport in an anthropomorphic phantom representing the newborn, 1 y, 5 y, 10 y, 15-y-old male, and adult male (with breasts, ovaries, and uterus added)." (3)

Somewhat simpler models are used to estimate the doses to various organs in the body from external radiation.

At one time, the usual practice was to calculate doses to individual bodily organs or tissues. But in 1977, the ICRP recommended in ICRP-26 the concept of a weighted mean whole-body dose (4). It provides a measure of the dose across multiple organs or tissues, and is determined by multiplying the dose received by each organ or tissue by a weighting factor, and then adding all of these weighted doses to arrive at a single representative dose. ICRP originally called this dose an *effective dose equivalent* (4). In a more recent recommendation (ICRP-60, issued in 1991), ICRP called this dose an *effective dose* (2). The effective dose may be defined as:

$$H_E = \sum_T W_T \cdot H_T \qquad (10\text{-}2)$$

Where,

H_E is effective dose (Sv);
W_T is a weighting factor representing the ratio of the stochastic risk (cancers and hereditary effects) from irradiation of tissue T to that for the whole body when irradiated uniformly;
H_T is the equivalent dose in tissue T.

[4] ICRP-26 recommended a 50-year time period for members of the public as well as radiation workers. ICRP-60 recommends a 70-year time period for members of the public and a 50-year time period for radiation workers.

Values for tissue weighting factors recommended by ICRP in 1977 (4) and 1991 (2) are listed in Table 10-1. As shown, the weighting factors recommended in ICRP-60 (2) are different from those recommended in ICRP-26 (4).[5] Additional information on these weighting factors may be found in original ICRP documents cited above and in the documentation for FGR-13 (3), (5), FGR-12 (6), and FGR-11 (7); information on how these are employed in the GENII-2 code may be found in Chapter 11 of the GENII SDD. Note that FGR-11 provides internal dose conversion factors and FGR-12 provides external dose conversion factors based on the ICRP-26 (4) and ICRP-30 (8) methodologies. FGR-13 provides internal risk coefficients based on the ICRP 60 (2) methodologies.

Table 10-1 ICRP-26 and ICRP-60 Tissue Weighting Factors

Organ or Tissue	ICRP-26 Weighting Factors	ICRP-60 Weighting Factors
Gonads	0.25	0.20
Breast	0.15	0.05
Colon		0.12
Red bond marrow	0.12	0.12
Lungs	0.12	0.12
Stomach		0.12
Urinary bladder		0.05
Liver		0.05
Esophagus		0.05
Thyroid	0.03	0.05
Bone surface	0.03	0.01
Skin		0.01
Remainder	0.30*	0.05†,‡

*The value 0.30 is applied to the average dose among the five remaining organs or tissues receiving the entire dose, excluding the skin, lens of the eye, and the extremities.
†The reminder consists of: adrenals, brain, small intestine, upper large intestine, kidney, muscle, pancreas, spleen, thymus, and uterus.
‡The value 0.05 is applied to the average dose to the remainder tissue group. However, if a member of the remainder receives a dose exceeding the highest dose in any of the 12 organs for which weighting factors are specified, a weighting factor of 0.025 is applied to that organ and weighting factor of 0.025 is applied to the average dose to the rest of the remainder.

The concept of effective dose is used for doses resulting from both external and internal exposures. Furthermore, for internal doses, the concept of effective dose is combined with the concept of committed dose, yielding the *committed effective dose*, which is sometimes shortened to *effective dose* and is the time integral of the effective dose rate. For both internal and external exposures, the effective dose depends on the age of the exposed individual. This is because the risk of cancer depends on the latency period over

[5] These weighting factors were calculated under somewhat different assumptions. ICRP-26 weighting factors are based on the risk of fatal cancers and hereditary defects in the first two generations. ICRP-60 weighting factors are based on risks for both fatal and non-fatal cancers, the risk of hereditary defects over all future generations, and the relative loss of life expectancy given a fatal cancer or a severe genetic disorder.

which cancer may develop. Persons exposed early in life have a higher risk of radiation-induced disease than persons exposed later in life, because these diseases have a greater time to develop and because other causes of mortality are less likely to arise. In addition, for internal exposures, the committed dose is higher for persons exposed earlier in life than those exposed later in life, because the residual radionuclides have a longer time to irradiate body organs. In addition, the models used to derive the organ doses from internal incorporate age-dependent factors into the models, e.g., the size of various organs, metabolic rates. For all these reasons, the coefficients used to relate effective doses to internal or external exposures are age-dependent. In this study these age-dependent dose coefficients were used to estimate doses, so the changing ages of children in the various scenarios would be accounted for.

10.2.3 Risk from Radiation Exposure

As discussed in the preceding section, the concept of effective dose accounts for the different sensitivities of different body tissues to cancer and hereditary effects and is essentially a risk weighted equivalent dose. One way to express risks is the probability of cancer *fatality* (*mortality*) occurring over a lifetime from exposure to radioactive material. Fatality (mortality) is the risk of dying of cancer. Another way to express risks is the probability of cancer *incidence (morbidity)* occurring over a lifetime from exposure to radioactive material. Incidence (morbidity) is the risk of getting radiation-related cancer whether or not the cancer is fatal. For the point estimate calculations described in Chapter 11, the effective dose equivalent, the individual organ doses, the cancer incidence risk, and the cancer fatality risk were all calculated and recorded on an annual basis for each receptor in each scenario. For the uncertainty analysis described in Chapter 12, only the effective dose equivalent over the 39-years studied, not the risk, was recorded for each receptor in each scenario, because of the large amount of data involved.

10.3 Calculation of Dose or Risk

Doses and risks are proportional to the intakes calculated according to the methods outlined in Chapter 9. The constant of proportionality (dose coefficient, dose conversion factor, or risk coefficient) depends on the type of exposure; i.e., whether the exposure is external, inhalation, or ingestion. For external exposure the dose coefficient depends on the geometry of the contaminated medium relative to the receptor; for example, the dose coefficient depends on whether the receptor is immersed in a plume of radioactive contaminants, is standing on the surface of contaminated ground, or is on a contaminated body of water. For internal exposure the dose coefficient depends upon whether the radioactive material was inhaled or ingested. In addition, for inhaled radionuclides, the dose coefficient depends upon the inhalation solubility class. The solubility class is important because in the metabolic models used to determine dose, the solubility of the nuclide determines how long it stays in the lungs and its ability to migrate to other organs in the body. The dose coefficient also depends on the age of the receptor for the reasons described at the end of Section 10.2.2. Finally, the dose coefficient depends on the identity of the particular radionuclide causing the exposure. Because different radionuclides emit different types of radiation (particles and electromagnetic waves) of different energies as they decay, the doses produced from internal or external exposure are unique for each radionuclide.

The constants of proportionality, the dose coefficients or dose conversion factors, have been compiled for a large number of radionuclides by assuming a unit concentration in the appropriate contaminated medium (Bq/m^3 for immersion or Bq/m^2 for ground plane) or a unit uptake (Bq for inhalation and ingestion). These dosimetric models and the resulting dose coefficients have been developed over many years and are promulgated by international standards organizations (e.g., ICRP), national standards organizations (e.g., NCRP), and federal agencies (e.g., EPA). For this report, the dose and risk

coefficients are almost all based on EPA's April 2002[6] Update (5) to Federal Guidance Report No.13 (3). These coefficients are almost, but not quite, identical to those used by the ICRP:

> "The age-specific dose coefficients [in FGR13]…were calculated using the biokinetic and dosimetric models used in the calculations of the risk coefficients. These models are consistent with those used by the ICRP in its recent series of publications tabulating dose coefficients for the general public, which is similar ICRP-60, but may be slightly different." (3)

However, for most radionuclides and organs, these differences are negligible, especially considering other uncertainties. These minor differences may be revealed by comparing the documentation for FGR-13 (3) and ICRP-60 (2).

Dose conversion factors are derived using models that represent the physics and biology of the interaction of the human body with radiation or radioactive material. For external exposure the models consider the geometry and physics of the exposure (immersion in air or water, exposure to a contaminated ground plane, exposure to shoreline strips of contamination) coupled with a representation of a standard human body absorbing the radiation. For internal exposure from inhaled or ingested radionuclides, the dose conversion factors are based on models representing the complex interactions of the radionuclide's physical and chemical attributes with human physiology. Once the dose conversion factors are developed, they may be applied to any dose assessment, thereby avoiding the need to repeat the complex modeling for every dose assessment. Conversion of doses to risks of cancer incidence and fatality are based on epidemiological data that relate radiation exposures to the incidence of cancer at various organ sites in exposed individuals and the subsequent mortality among those individuals.

Given the preceding discussion, the simple formula that relates dose to intake, stated in Chapter 9,

$$\text{Dose} = \text{Intake} * \text{Dose Conversion Factor} \qquad (9\text{-}1)$$

may be stated in a more general form:

$$ED_{iae} = I_{ie} \cdot DC_{iaec} \qquad (10\text{-}3)$$

Where,

ED_{iae} = Incremental equivalent dose from radionuclide i for age group a and exposure route e;
I_{ie} = Intake of radionuclide i through exposure route e;
DC_{iaec} = Dose conversion factor for radionuclide i for age group a exposure route e and inhalation class c inhalation class.

Equation (10-3) recognizes the explicit dependence of the dose conversion factor, DC_{iaec}, on the radionuclide, age of the receptor, exposure route, and inhalation class; however, equation (10-1) still retains the linear relationship between dose and intake. Similar equations can be used to generate risks of cancer incidence and fatality, by replacing the term ED_{iae}, by a cancer incidence term, RI_{iae}, or a cancer fatality term, RF_{iae}; in both cases the conversion factor, DC_{iaec}, must be appropriately adjusted. Doses and risks can be further disaggregated into contributions from specific organs. Intakes, as discussed in Chapter 9, are based on radioactive material inhaled or ingested or direct exposure to external penetrating radiation.

[6] A supplement was first issued in 2000, but this supplement contained errors in the viewer and was replaced by the April 2002 version. The interactive viewer is entitled "Federal Guidance Report 13 CD Supplement, Cancer Risk Coefficients for Environmental Exposure to Radionuclides" EPA, rev 1 April 2002 and is available from the Office of Air and Radiation.

For exposures of persons from inhaling or ingesting radionuclides, the study used the following coefficients from FGR-13U (5):

- Age-dependent dose coefficients for 23 organs and bodily tissues, plus effective dose based on ICRP-60 weighting factors (see Table 10.2).
- Age-dependent cancer risk coefficients (fatality and incidence) for 15 cancer sites, plus the sum of cancers across all cancer sites.

Table 10-2 lists the organs and bodily tissues considered in the dose coefficients, and the cancer sites considered in the risk coefficients. Table 10-3 lists the age categories considered for the dose and risk coefficients. (Note that the age categories are different for the dose and risk coefficients.)

Table 10-2 Organs, Tissues, and Lung-Compartments, and Cancer Sites, Addressed in Dose and Risk Conversion Factors in the FGR-13 Update

Organs, Tissues and Lung-Compartments Addressed in Dose Conversion Factors			Cancer Sites Addressed in Risk Conversion Factors	
Adrenals	Kidneys	Skin	Esophagus	Breast
Bone Surface	Liver	Spleen	Stomach	Ovary
Brain	Extra-thoracic Region	Testes	Colon	Bladder
Breast	Lung	Thymus	Liver	Kidneys
Stomach Wall	Muscle	Thyroid	Lung	Thyroid
Small Intestine Wall	Ovaries	Uterus	Bone	Leukemia
Upper Lower Intestine Wall	Pancreas	Urinary Bladder Wall	Skin	Residual*
Lower Lower Intestine Wall	Red Bone Marrow	Effective Dose		Total

*Residual cancer sites.

Table 10-3 Age Categories Addressed in Dose and Risk Conversion Factors Presented in the FGR-13 Update

Dose Conversion Factors	Risk Conversion Factors
Infant	0-5 Years
1-Year Old	5-15 Years
5-Year Old	15-25 Years
10-year Old	25-70 Years
15-Year Old	0-110 Years
Adult	

For doses and risks from inhalation, the physical and chemical form of some radionuclides is specified; this is denoted by the subscript "c" in equation (10-1). The radionuclide "class" is important for some radionuclides, because the radionuclide's chemical and physical form affects the rate at which the radionuclide is removed from the lungs and subsequently migrates elsewhere in the body or is excreted. The study assumed that most radionuclides were particulates assigned to one of three absorption types:

- Type F: Fast dissolution and a high level of absorption to blood.

- Type M: Intermediate rates of dissolution and levels of absorption to blood.
- Type S: Slow dissolution and a low level of absorption to blood.

It was assumed that some radionuclides existed as a gas or vapor, based on the Phase II information regarding releases. The assumptions for the lung absorption types used in this report are listed in Table 10-4 (3), (9).

Table 10-4 Assumptions for Lung Absorption Classes by Element

Element	Absorption Class*	Comments†
Americium (Am)	M	Default absorption type recommended in ICRP-72.
Argon (Ar)	NA	No absorption occurs for noble gases.
Carbon (C)	G	Type G was assumed because it was recommended in FGR-13 for CO_2.
Cesium (Cs)	F	Default absorption type recommended in ICRP-72.
Hydrogen (^3H - tritium)	HT: G HTO: V OBT‡: V	Type G was assumed for tritium released as a gas (HT) in accordance with FGR-13. Type G is also appropriate for tritium released as an organic. Type V is assumed for tritium released as water vapor (HTO) in accordance with FGR-13.
Iodine (I)	G	Iodine was released in several forms. Type G was assumed because it resulted in dose and risk conversion factors between those for a particulate and elemental I.
Plutonium (Pu)	M	Default absorption type recommended in ICRP-72.
Sulfur (S)	V	FGR-13 recommends Type V for sulfur dioxide. (Note that if S is released as a particulate, ICRP-72 recommends Type M.)
Strontium (Sr)	M	Default absorption type recommended in ICRP-72.
Thorium (Th)	S	Default absorption type recommended in ICRP-72.
Uranium (U)	M	Default absorption type recommended in ICRP-72

*F: fast; M: medium; S: slow; G: gas; V: vapor; NA: not applicable.
†Lung absorption classes are not listed for radioactive isotopes of elements released only into surface waters. Although GENII requires that lung absorption class assumptions be input for these isotopes, the assumed values are not used in the dose and risk calculations because inhalation exposure is not assessed for the surface water pathways considered in this report.
‡OBT: organic bound tritium.

For external exposures resulting from 1) immersion in a "cloud" of radionuclides in air, and 2) proximity to a contaminated ground surface, the study used the following coefficients from FGR-13U (5):

- Adult dose coefficients for 23 organs and bodily tissues, plus effective dose based on ICRP-60 weighting factors (see Table 10-1).
- Age-specific cancer risk coefficients (fatality and incidence) for 15 cancer sites, plus the sum of cancers across all cancer sites.

As noted, FGR-13U (5) provides only adult dose conversion factors for these types of external exposures. Hence, these adult dose conversion factors were used in this study. Although the error involved in using the adult dose conversion factors for all ages is difficult to quantify, FGR-13, p. 167 (3) states:

Although there is expected to be some age dependence in organ dose rates from external exposures, comprehensive tabulations of age-specific external dose coefficients are not yet available. Therefore, the tabulations for the reference adult in Federal Guidance Report No. 12 are applied to all age groups. As discussed in Appendix D to this report, the application of these external dose coefficients to other age groups appears to result in relatively small errors (usually <30%) in most cases. In extreme cases, such as for external irradiation of deep organs (e.g., ovaries or colon) of infants at energies less than 100 keV energies, 2-to 3-fold errors may arise. In applications of the derived risk coefficients, however, errors arising from application of age-independent external dose rates are likely to be negligible compared with errors associated with the simplified exposure scenarios used here (e.g., constant placement and position, no shielding, and infinite or semi-infinite source regions). Simplified exposure scenarios are used because it is not feasible to develop an external dosimetric methodology that applies to arbitrary distributions of contamination or to differences in life styles.

The risk coefficients for these types of external exposures use the same age ranges as those listed in Table 10-3.

For external exposures while swimming in water or while boating, dose and risk coefficients from FGR-12 (6) were used because coefficients for immersion in contaminated water are not included in FGR-13U (5). These (adult) dose coefficients are provided for fewer organs than those in the FGR-13 update (5), and the weighting factors used to calculate effective dose equivalent are from ICRP-26 (4) (because they are based on FGR-12) rather than ICRP-60 (2) (see Table 10-1). Risk was estimated by multiplying the calculated doses for water immersion and boating by the following health effects conversion factors:

- Fatality: 0.05 Sv^{-1}
- Incidence: 0.06 Sv^{-1}

Finally, the dose and risk coefficients were grouped into four age groups: 0 to 5 years, 5 to 15 years, 15 to 25 years, and 25 to 70 years. This assumption allowed for better correlation between the doses and risks calculated as a function of age group. Dose and risk conversion factors for these calculations were determined by interpolating between appropriate dose and risk conversion factors obtained from the update to FGR-13 (3) and from FGR-12 (6). The three combined age groups are summarized in Table 10-5. Also listed is the exposure duration used for each age group.

Table 10-5 Exposure Groupings and Corresponding Combined Dose and Risk Factor Age Groups

Age / Gender	Exposure Group [Duration (years)]	Dose and Risk Factor Age Group
<1 male	Infant (male only) [1]	0 – 5
1 – 4 male	Preschool (male only) [4]	0 – 5
5 – 11 male	School age (male only) [7]	5 – 15
12 – 17 male	Teenage (male only) [6]	15 - 25
18 – 70 male	Adult male [varies] *	25 – 70
18 – 70 female	Adult female [varies] *	25 – 70

*The exposure duration of the adult age groups depends on the year that the individual reaches age 18. Exposure duration lasts from the year of the 18th birthday until the end of 1992, when one child would be 38 and the other 29.

10.4 References

1. Napier, B.A., et al. (2002, November). GENII Version II Software Design Document. PNNL for U.S. Environmental Protection Agency.

2. International Commission on Radiation Protection (ICRP) (1991). Recommendations of the International Commission on Radiation Protection. ICRP Publication 60. Pergamon Press. Oxford, England.

3. Eckerman, K. F., et al. (1999, September). Cancer Risk Coefficients for Environmental Exposure to Radionuclides. Federal Guidance Report No. 13. EPA 402-R-99-001. Oak Ridge National Laboratory and U.S. EPA Office of Radiation and Indoor Air.

4. International Commission on Radiation Protection (ICRP (1977). Recommendations of the International Commission on Radiation Protection. ICRP Publication 26. Pergamon Press. Oxford, England.

5. U.S. Environmental Protection Agency (EPA) (2002, April). Federal Guidance Report 13 Cancer Risk Coefficients for Environmental Exposure to Radionuclides: CD Supplement. EPA 402-C-99-001, Rev. 1. Oak Ridge National Laboratory and U.S. EPA.

6. Eckerman, K.F.& J.C. Ryman (1993, September). External Exposure to Radionuclides in Air, Water, and Soil. Federal Guidance Report No. 12. EPA 402-R-93-081. Oak Ridge National Laboratory and EPA Office of Radiation Programs.

7. Eckerman, K. F., et al. (1988, September). Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion. Federal Guidance Report No. 11. EPA-520/1-88-020. Oak Ridge National Laboratory and EPA Office of Radiation Programs.

8. International Commission on Radiation Protection (ICRP) (1979). Limits for Intakes of Radionuclides by Workers. ICRP Publication 30. Pergamon Press. Oxford, England.

9. International Commission on Radiation Protection (ICRP) (1996). Age-Dependent Doses to Members of the Public from Intake of Radionuclides, Part 5. Compilation of Ingestion and Inhalation Dose Coefficients. ICRP Publication 72. Pergamon Press. Oxford, England.