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Characterization, Survey, and Determination of Radiological Criteria

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Consolidated Decommissioning Guidance

Characterization, Survey, and Determination of Radiological Criteria

Final Report

U.S. Nuclear Regulatory Commission
Office of Nuclear Material Safety and Safeguards
Washington, DC 20555-0001

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Vol. 2, Rev. 1

Consolidated Decommissioning Guidance

Characterization, Survey, and Determination of Radiological Criteria

Final Report

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ABSTRACT

As part of its redesign of the materials license program, the U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Material Safety and Safeguards (NMSS) has consolidated and updated numerous decommissioning guidance documents into a three-volume NUREG. Specifically, the three volumes address the following topics:

(1) "Decommissioning Process for Materials Licensees";

(2) "Characterization, Survey, and Determination of Radiological Criteria"; and

(3) "Financial Assurance, Recordkeeping, and Timeliness."

This three-volume NUREG series replaces NUREG-1727 (NMSS Decommissioning Standard Review Plan) and NUREG/BR-0241 (NMSS Handbook for Decommissioning Fuel Cycle and Materials Licensees). This NUREG series is intended for use by NRC staff, licensees, and others.

Volume 2 of the NUREG series, entitled, "Consolidated Decommissioning Guidance: Characterization, Survey, and Determination of Radiological Criteria," provides guidance on compliance with the radiological criteria for license termination (License Termination Rule (LTR)) in 10 CFR Part 20, Subpart E. This guidance takes a risk-informed, performance-based approach to the demonstration of compliance. The approaches to license termination described in this guidance will help to identify the information (subject matter and level of detail) needed to terminate a license by considering the specific circumstances of the wide range of NRC licensees. Licensees should use this guidance in preparing decommissioning plans, license termination plans, final status surveys, and other technical decommissioning reports for NRC submittal. NRC staff will use the guidance in reviewing these documents and related license amendment requests.

Volume 2 is applicable to all licensees subject to the LTR.

PAPERWORK REDUCTION ACT STATEMENT

The information collections contained in this NUREG are covered by the requirements of 10 CFR Parts 19, 20, 30, 33, 34, 35, 36, 39, 40, 51, 60, 61, 63, 70, 72, and 150 which were approved by the Office of Management and Budget, approval numbers 3150–0044, 0014, 0017, 0015, 0007, 0010, 0158, 0130, 0020, 0021, 0127, 0135, 0199, 0009, 0132, and 0032.

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The majority of the information in this appendix is taken directly from the *Draft Branch Technical Position on Site Characterization for Decommissioning* (NRC 1994). The checklist in Section F.3 of this appendix regarding potential indicators for ground water contamination is taken directly from NUREG–1496. This chapter is applicable, either in total or in part, to Decommissioning Group 4 for surface water and Decommissioning Groups 5–7.

Characterization of surface and ground water is an essential component of the dose modeling used in the estimation of doses to demonstrate compliance with the license termination requirements in 10 CFR Part 20, Subpart E. If contaminated surface or ground water is identified, the screening DCGLs for soil are inappropriate since they are usually based on initially uncontaminated surface and ground water. Appendix I of this volume discusses the aspects of dose modeling that are specific to site hydrology.

F.1 Planning for Surface Water and Ground Water Characterization

Surface and ground water characterization should be planned in a manner that maximizes the utility of the information to be collected and optimizes its adequacy and quality during the characterization process. For example, a licensee may show for a particular site that the surface water pathway is not likely to be significant in terms of existing and potential future exposure to the public. In such a case, the need for detailed characterization of the surface water system is decreased. As an example of effective interactions during site characterization, identification of ground water contamination during preliminary scoping survey may warrant installation and sampling of additional monitoring wells to define the extent and migration status of the contamination.

In some instances, ground water may be unsuitable for specific uses, such as human and livestock consumption, but may be acceptable for crop irrigation. In addition, some aquifers may not have the yield to support crop irrigation but may produce enough water for human consumption. In some instances, EPA or a State agency may have declared that the aquifer in question is unfit for human or livestock use. Accordingly, this type of information needs to be addressed since it will be used to support site scenario development and dose modeling. Refer to Section I.3.3.3.2 from Appendix I of this volume for guidance on modification of waterborne exposure pathways.

NRC staff experience has shown that some decommissioning plans (DPs) have not adequately provided ground water characterization data. Additional environmental monitoring data may be needed because there may not be enough operational monitoring of ground water for adequate site characterization and dose assessment. Regulatory Issue Summary 2002–02 provides a detailed discussion of lessons learned regarding ground water characterization. The information contained in this RIS has been included in Section O.2.2 from Appendix O of this volume.

F.2 Ground Water Characterization

The need for surveys to characterize ground water should be determined from the historical site assessment (HSA). If the HSA indicates that residual radioactivity may have reached potable water, surveys of ground water would be appropriate. The nature of appropriate ground water surveys should be determined on a site-specific basis. In addition to that which is discussed below, MARSSIM (Sections 3.6.3.4 and 5.3.3.3) provides some guidance on evaluating the likelihood for release of radionuclides into ground water and on evaluating related concerns regarding characterization and sampling.

Characterization of ground water contamination, including all significant radiological constituents, along with inorganic and organic constituents and related parameters, should be adequate to determine the following:

- extent and concentration distribution of contaminants;
- source (known or postulated) of radioactive contaminants to ground water;
- background ground water quality;
- rate(s) and direction(s) of contaminated ground water migration;
- location of ground water plume and concentration profiles (i.e., maximum concentration in the vertical and lateral extent);
- assessment of present and potential future effects of ground water withdrawal on the migration of ground water contaminants;
- potential safety and environmental issues associated with remediating the surface and ground water;
- effect of the nonradiological constituents on the mobility of the radionuclides;
- whether the remediation activities and radiation control measures proposed by the licensee are appropriate for the type and amount of radioactive material present in the surface and ground water;
- whether the licensee's waste management practices are appropriate; and
- whether the licensee's cost estimates are plausible.

Besides licensee process discharges, there are other mechanisms that may affect ground water. For example, sumps that are used to capture infiltrating ground water may affect the local ground water elevation during pumping. In some situations, sumps are used to collect ground water at the lowest elevation of a building, with pumping going on continuously. Such pumping has been shown to affect the local ground water elevation (i.e., cone of depression).

Characterization of the nonradiological constituents and related parameters may also be required by other regulatory Agencies that have jurisdiction over the decommissioning effort. Therefore, licensees should contact Federal, State, or local government bodies responsible for regulating water. Typical analytical parameters include gross alpha particle activity, gross beta particle activity, specific radionuclide concentrations, gamma spectrum analysis for all gamma-emitting radionuclides suspected to be present, sulfate, chloride, carbonate, alkalinity, nitrate, TDS, Total Organic Carbon (TOC), Eh, pH, calcium, sodium, potassium, iron, and dissolved oxygen. Additional analytical parameters may be necessary to characterize any suspected contamination.

The extent of contamination and background ground water quality should be determined based on ground water monitoring data from a suitable monitoring well network. Guidance documents on acceptable ground water monitoring techniques are listed under References [Korte and Ealey (1983), Korte and Kearl (1984), NUREG–1383 and NUREG–1388, USGS (1977 and 1996), and EPA (1977, 1980, 1985, and 1986)]. The actual number, location, and design of monitoring wells depend on the size of the contaminated area, the type and extent of contaminants, the background ground water quality, the hydrogeologic system, and the objectives of the monitoring program. For example, if the objective of monitoring is only to indicate the presence of ground water contamination, relatively few downgradient and upgradient monitoring wells are needed. In contrast, if the objective is to develop a detailed characterization of the distribution of constituents within a complex aquifer as the design basis for a corrective action program, a large number of suitably designed and installed monitoring wells and well points may be necessary. Planned site characterization activities should be flexible enough to allow for the installation of additional monitoring wells during the characterization effort if either:
(a) preliminary characterization indicates contamination where previously unanticipated; or
(b) there is a need to delineate the vertical or lateral extent of contaminant plumes. Monitoring well locations, contaminant concentrations, and contaminant sources should be plotted on a map (or a series of maps for multiple contaminants) to show the relationship among contamination, sources, hydrogeologic features and boundary conditions, and property boundaries. At sites with significant vertical migration of contaminants, the DP should also provide hydrogeologic cross-sections that depict the vertical distribution of contaminants in ground water. The vertical exaggeration of the sections should not exceed 10 times.

The DP should also describe the ground water characterization program used to characterize the extent and distribution of contaminants in the ground water. Depending on the complexity of the site, the DP can include the detailed information as described below or can summarize this information and then reference the documents where the supporting details are contained. The description should provide monitoring well completion diagrams explaining elevation, internal and external dimensions, types of casings, type of backfill and seal, type of the screen and its location and size, borehole diameter and elevation and depth of hole, and type and dimension of riser pipe and other necessary information on the wells. An acceptable generic completion design is illustrated in Figure F.1.

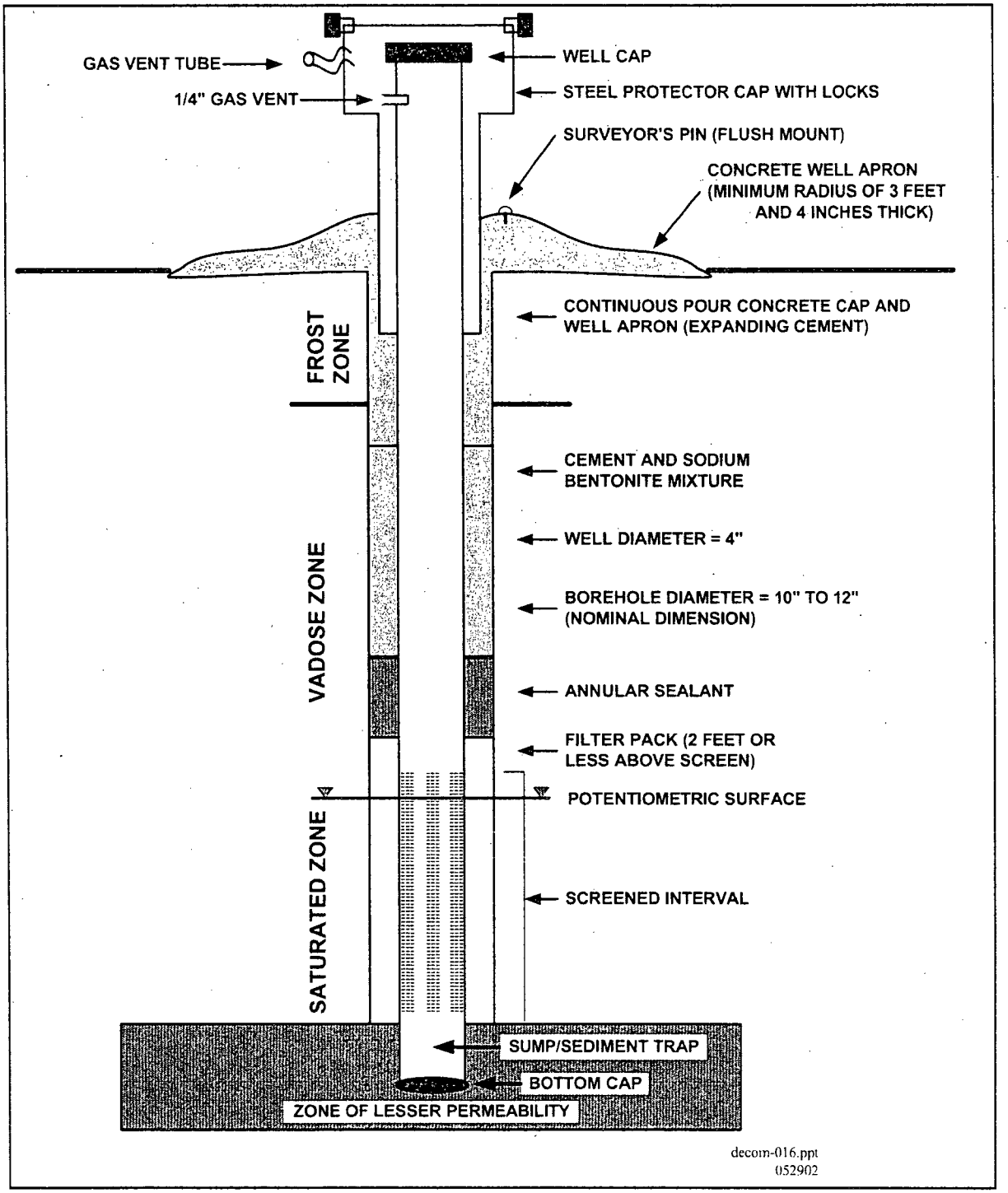

Figure F.1 General Monitoring Well Cross-Section.

Sampling techniques, methodology, and procedures should be documented or referenced in the DP. Site characterization procedures and methods should generally adhere to acceptable national practices and standards [e.g., American Society for Testing and Materials (ASTM), U.S. Geological Survey (USGS), U.S. Environmental Protection Agency (EPA), U.S. Department of Energy Environmental Monitoring Laboratory (DOE/EML), and National Institute of Standards and Technology (NIST)]. The DP should identify specific analytical methods that conform to generally accepted protocols and methods, such as those endorsed by NIST, DOE/EML, or other methods established through comprehensive peer review and recommendation process (e.g., ANSI/ASME 1986). Korte and Kearl (1984) provides forms for documenting well summary information, samples, chain of custody, quality assurance information for field chemical analyses, and sample location and identifier.

The site characterization program should include sufficient sampling and analysis of ground water samples collected upgradient from the site to develop a representative characterization of background ground water quality. Background ground water quality should not exhibit any influence from contaminants released by the site and should be representative of the quality of ground water that would exist if the site had not been contaminated. The site characterization should also assess any temporal or spatial variations in background ground water quality. If sources of contamination other than the site are present, the potential impact of such sources should be evaluated to determine the degree of ground water contamination caused by these sources.

F.3 Indicators for Potential Ground Water Contamination

When evaluating ground water contamination, it is especially necessary to consider the site-specific factors that permit radionuclides to migrate through the ground water pathway, and thus contribute to the dose to an individual from residual radioactivity.

As described in Table 1.1 of Volume 1 of this NUREG report, Decommissioning Groups 5–7 are sites that have the potential for residual radioactivity in ground water. Based on the experience gained from operational and decommissioning NRC–licensed sites, the following is a list of potential indicators for ground water contamination at decommissioning sites. The following are intended to be illustrative only and not intended to constitute a complete list:

- High Potential: if a site has a history of, or currently has:
  - — unlined lagoons, pits, canals, or surface-drainage ways that received radioactively contaminated liquid effluent;
  - — lined lagoons, pits, canals, or surface drainage ways that received radioactively contaminated liquid effluent, where the lining has leaked or ruptured, or where overflow has occurred;
  - — septic systems, dry wells, or injection wells that received radioactively contaminated liquid effluent;

- — storage tanks, waste tanks, and/or piping (above or below ground) that held or transported radioactively contaminated fluids and are known to have leaked;
- — liquid or wet radioactive waste buried onsite (i.e., burial under 10 CFR 20.302 or 20.304 (or the current 10 CFR 20.2002));
- — an accident or spill onsite where radioactive material was released exterior to a building;
- — wet bulk waste (e.g., sludge or tailings) stored exterior to buildings or used as backfill; and
- — containerized-liquid waste, stored exterior to buildings, that has leaked.

- Medium Potential: if a site has a history of or currently has:
  - — surface water or atmospheric discharge of radioactive effluents;
  - — radioactive contamination detected on the roof of a building;
  - — radioactive contamination detected in the floor cracks or sump of a building;
  - — an accident or spill onsite, where liquid radioactive material was released to the interior of a building;
  - — the presence of greater than 10-year-old underground storage tank or underground piping that held radioactively contaminated fluids, not known to have leaked, but never tested;
  - — a history of incineration of radioactive waste exterior to onsite buildings;
  - — dry bulk waste (e.g., sludge or tailings) stored exterior to buildings or used as backfill;
  - — solid containerized waste, stored exterior to buildings, that has leaked.
- Low Potential: if a site has a history of or currently has:
  - — less than 10-year-old underground storage tanks or underground piping that has held radioactively contaminated fluids and is known not to have leaked;
  - — dry bulk waste stored inside the buildings;
  - — a sealed-source-only license.

The potential for ground water contamination at any of these sites is conditioned by certain site characteristics such as depth of ground water, amount of yearly precipitation and hydraulic conductivity, and by certain source characteristics such as half-life, solubility, and distribution coefficient.

F.4 Monitoring Practices and Procedures

Depending on the complexity of the site, the DP can include the detailed information as described below, or the DP can summarize this information and then reference the documents where the supporting details are contained.

The site characterization should include a description of all surface and ground water characterization activities, methods, and monitoring installations sufficient to demonstrate that the methods and devices provided data that are representative of site conditions. Also included should be a description of the monitoring practices, procedures, and quality assurance programs used to collect water quality data. Monitoring well descriptions, for example, should include location, elevation, screened interval(s), depth, construction and completion details, and the hydrologic units monitored. Aquifer test descriptions should include testing configuration, test results, and a discussion of the assumptions, analytical techniques, test procedures, pretesting baseline conditions, limitations, errors in measurements, and final results. The description of the water quality sampling and analysis program should include or reference the procedures for sampling, preserving, storing, and analyzing the samples, including QA/QC protocols implemented. All methods used should be consistent with current standard methods and practices (e.g., ASTM, USGS, EPA, NIST, and ANSI/ASME). Some additional guidance on acceptable methods for sampling and analyzing water quality samples can be found in Korte and Ealey (1983); Korte and Kearl (1984); DOE (1988 and 1993); ANSI/ASME (1986); EPA (1977, 1985, 1986, 1987a, 1991); and NUREG–1293, NUREG–1383, and Regulatory Guide 4.15. Any deviations from standard methods should be appropriately justified.

F.5 Sampling Frequencies

Surface and ground water quality and water levels should be determined on a set frequency established based on site-specific considerations. For sites with extensive ground water contamination, a network of monitoring wells should be designed and installed to provide a high probability of detecting and characterizing existing contamination and determining background ground water quality. Ground water levels should be measured in piezometers and monitoring wells that provide a sufficiently accurate indication of hydraulic head to characterize the hydraulic gradient within the uppermost aquifer and adjacent units. Water levels should be measured on a quarterly basis for a minimum one year to determine temporal variations in the hydraulic gradient. After this period, the frequency of water level measurements should be adjusted to reflect anticipated temporal variation in hydraulic heads (e.g., tides, river bank storage, water year variations). Acceptable methods for ground water sampling and for measuring water levels are described in EPA and USGS documents (EPA 1977, 1985, 1986, and 1987a; USGS 1977) and in Korte and Kearl (1984).

The sampling frequency for determining variations in ground water quality should be determined based on the temporal variation in hydraulic gradients, as well as temporal variations in hydrochemistry and migration of radiological and associated nonradiological constituents. After an initial sampling round in which each monitoring well is sampled, representative samples should be collected and analyzed on a quarterly basis from key monitoring wells to estimate the temporal variation of water quality in the uppermost aquifer and adjacent units. After this initial period, sampling frequency should be adjusted to reflect variations in the hydraulic gradient and hydrochemistry. Concentrations of principal radiological constituents should not change by more than about 10–20 % between sampling events. If the concentrations change by more than 10–20 %, the frequency of sampling should be increased in an attempt to characterize the

temporal variability of ground water quality. For most sites, sampling on a quarterly basis (i.e., one sample per well per calendar quarter) should be sufficiently frequent to characterize temporal changes in water quality. More frequent sampling may be necessary, however, especially at sites involving offsite or potential offsite contamination of ground water resources. Acceptable methods for ground water sampling are described in Korte and Kearl (1984), USGS (1977) and the EPA references mentioned above.

Quarterly sampling of surface water and sediments should be sufficient at most sites. This sampling should be supplemented by additional sampling to characterize the surface system at representative low or high stage flow conditions (e.g., minimum annual, 7-day average low flow or maximum annual, 7-day average high flow). This information should be used to bound the existing and projected impacts of the release of contamination on adjacent surface water bodies.

F.6 Surface Water and Sediments

Surface water can include ponds, creeks, streams, rivers, lakes, coastal tidal waters, oceans, and other bodies of water. Note that certain ditches and intermittently flowing streams qualify as surface water. The need for surface water samples should be evaluated on a case-by-case basis. Surveys for water should be based on appropriate environmental standards for water sampling. If the body of water is included in a larger survey unit, then sediment samples should be taken at sample locations selected by the normal method without taking the body of water into consideration. In addition to that which is discussed below, MARSSIM (Sections 3.6.3.3 and 5.3.3.3) provides some guidance on evaluating the likelihood for release of radionuclides into surface water and sediments and on related concerns regarding characterization and sampling.

For sites that are located near surface water streams and could reasonably affect surface water pathways, the site characterization program should establish background surface water quality by sampling upstream of the site being studied or areas unaffected by any known activity at the site. Water should be collected as grab samples from the stream bank in a well-mixed zone. Depending on the significance and the potential for surface water contamination, it may be necessary for certain sites to collect stratified samples from the surface water to determine the distribution of contaminants within the water column. Surface water quality sampling should be accompanied by at least one round of stream sediment quality sampling to assess the relationship between the composition of the dissolved solids, the suspended sediment, and the bedload sediment fractions. Water levels and discharge rates of the stream should be determined at the time samples are collected. Licensees should also consider the effects of variability of the surface water flow rate. Based on the results of the HSA and/or preliminary investigation surveys, surface scans for gamma activity should be conducted in areas likely to contain residual activity (e.g., along the banks). Acceptable methods for surface water and sediment sampling are described in Korte and Kearl (1984) and USGS (1977). In addition, Fleishhauer and Engelder (1984) present suggested procedures for stream sediment sampling. The EPA guidance documents mentioned above are also applicable. In some cases, the Radiological Environmental Monitoring Program (REMP) data from a facilities operating period may provide useful

information to support the characterization program. Appendix O of this volume discusses the limitations of the use of REMP data to support site characterization.

Surface water sampling should be conducted in areas of runoff from active operations. In case of direct discharge into a stream, the outfall and the stream should be monitored and sampled upstream and downstream from the outfall. Preliminary characterization of the contamination levels should be conducted by measuring gross alpha and total beta particle activity (total and dissolved) and by obtaining a gamma spectrum for surface water samples. It should be noted that determination of gross alpha activity (and low energy beta emitters as well) may be of limited value for samples containing elevated total or dissolved solids concentrations because of sample attenuation. In such instances, gamma spectroscopy might be the only recourse. Specific radionuclide analysis may be needed depending on level of activities and type of radionuclides. Nonradiological parameters, such as specific conductance, pH, and total organic carbon, may be used as surrogate indicators of potential contamination, provided a clear relationship is established between radionuclide concentration and the level of the surrogate. Additional analysis for other parameters like volatile and semi-volatile compounds, chelating agents, pesticides, and polychlorinated biphenyls (PCBs) may also be necessary if they affect the mobility of radiological constituents and to evaluate potential environmental effects of the decommissioning.

Each of the surface water and sediment sampling locations should be carefully recorded on the appropriate survey form. Additionally, surface water flow models can be used to assist in estimating contaminant concentrations or migration rates.

F.7 Geochemical Conditions

Geochemical conditions at the site and their association with ground water and contaminants should also be described. Specifically, geochemical conditions that enhance or retard contaminant transport should be given special consideration. Geochemical data should include information on solid composition, buffering capacity, redox potential, sorption (represented as a range of distribution coefficients (K_d) for each radiological constituent), and other relevant geochemical data. Piper and Stiff diagrams may be useful for visualizing the geochemistry of the water. In general, licensees or responsible parties may estimate the values of K_d through laboratory column or batch sorption measurements [e.g., ASTM methods D4319 (ASTM 2002), D4646 (ASTM 2001), and D4874 (ASTM 2001)] or by using a conservative value to represent the values of K_d from available literature references [e.g., Sheppard and Thibault (1990) and NUREG/CR–5512, Volume 3]. If necessary, licensees (or responsible parties) may use appropriate geochemical codes to understand and quantify geochemical mechanisms that significantly affect transport of radiological and nonradiological contaminants and their potential fate (e.g., MINTEQ (EPA 1984); EQ3/6 (Daveler and Woolery 1992)). Additional information on ground water parameters necessary for dose modeling is discussed in Appendix I of this volume.

F.8 Surface Water and Ground Water Models

As a joint effort, EPA, NRC, and DOE have developed specific guidance on selecting and applying surface and ground water models (EPA 1994a, b, c). Supporting details may be found elsewhere (NUREG–3332 and NUREG/CR–5454, Volumes 1–5; NCRP 1985, 1996; DOE 1995; EPA 1987a, b, 1994a, b, c; NAS 1999).

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Appendix I

Technical Basis for Site-Specific Dose Modeling Evaluations

I.1 Introduction

This appendix consists of the technical guidance for the use of the site-specific dose modeling, applicable to Decommissioning Groups 4–7.

For guidance on lessons learned regarding use of site-specific dose modeling evaluations, refer to Question 4 from Section O.1 and Lesson 6 from Section O.2.2 from Appendix O of this volume.

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I.1.1 Background

On July 21, 1997, the U.S. Nuclear Regulatory Commission (NRC) published a final rule on "Radiological Criteria for License Termination," in the *Federal Register* (62 FR 39058), which was incorporated as Subpart E to 10 CFR Part 20. In 1998 NRC staff developed a draft regulatory guide, Demonstrating Compliance with the Radiological Criteria for License Termination (DG–4006) (NRC 1998), and a draft document Decision Methods for Dose Assessment to Comply With Radiological Criteria for License Termination (NUREG–1549) (NRC 1998a) in support of the final rule. In addition, staff developed a screening code "DandD" for demonstrating compliance with the dose criteria in Part 20, Subpart E.

On July 8, 1998, the Commission approved publication of the draft guidance, DG–4006, the draft NUREG–1549, and the DandD screening code for interim use for a 2-year period (i.e., from July 8, 1998, through July 7, 2000) (NRC 1998b). In addition, the Commission directed NRC staff to (a) develop a standard review plan (SRP) for decommissioning and provide the Commission with a timeline for developing the SRP; (b) maintain a dialogue with the public during the interim period; (c) address areas of excessive conservatism, particularly in the DandD screening code; (d) develop a more user-friendly format for the guidance; and (e) use a probabilistic approach to calculate the total effective dose equivalent (TEDE) to the average member of the critical group (NRC 1998b).

NRC staff completed development of the SRP, and it was published in 2000 of September as NUREG–1727. Chapter 5 of the SRP (which is incorporated into Chapter 5 of this volume) addresses NRC staff review of licensee's dose modeling to demonstrate compliance with the criteria in 10 CFR Part 20, Subpart E. Appendix C of the SRP (Appendix I of this volume) was developed by NRC staff as a technical information support document for performing NRC staff evaluations of the licensee's dose modeling. It presents detailed technical approaches, methodologies, criteria, and guidance to staff reviewing dose modeling for compliance demonstration with the dose criteria in 10 CFR Part 20, Subpart E. Appendix C of the SRP was developed through an iterative process with the public including, licensees, Federal agencies, States, and other interested individuals. To support this process, NRC staff conducted seven public workshops and gave several presentations at national and international professional meetings, stakeholder meetings, Interagency Steering Committee on Radiation Standards (ISCORS) meetings, Conference of Radiation Control Program Directors (CRCPD) meetings, as well as presentations to NRC's Advisory Committee on Nuclear Waste (ACNW). In addition, NRC posted the draft Appendix C (formerly the Technical Basis Document) on NRC's Web site and requested interested individuals to provide NRC with comments.

Since the publication of the license termination rule (LTR), NRC staff has tested the DandD code for complex sites and addressed the issue of excessive conservatism in the DandD code. In addition, NRC staff developed a new probabilistic DandD code (i.e., DandD Version 2.1) to reduce the excessively conservative approach in the initial version of the DandD code. Further, NRC staff developed RESRAD and RESRAD–BUILD probabilistic codes for site-specific analysis. Development of the probabilistic DandD and RESRAD/RESRAD–BUILD codes also

responds to the Commission's direction to use a probabilistic approach to calculate the TEDE to the average member of the critical group.

Licensees using probabilistic dose modeling should use the "peak of the mean" dose distribution (see Section I.7.3.2.2 from Appendix I of this volume) for demonstrating compliance with the 10 CFR Part 20, Subpart E. Similar to all regulatory guidance, this NUREG report contains one approach for determining compliance with the regulations using probabilistic analyses. Other probabilistic approaches, such as, "mean of the peaks" or other methods, if justified, may also be acceptable for demonstrating compliance.

I.1.2 Brief Description and Scope

This section is divided into the following different topic areas, as summarized below.

- Section I.2 presents NRC approaches for reviewing the conceptual representation of the radioactive source term at the site. This section describes the areas of reviews pertaining to the existing radioactive material contamination and physical and chemical characteristics of the material. In addition, the section presents recommended approaches for source-term abstraction for the purpose of performing the dose analysis.
- Section I.3 focuses on areas of review and criteria for accepting modifications of pathways of the two generic critical group scenarios, the "resident farmer" and the "building occupancy" scenarios. Section I.3, also, along with Appendices L and M, discusses the information that should be provided for a licensee's justification for modifying default screening scenarios and associated pathways. It also presents approaches for establishing site-specific scenarios, critical groups, and/or sets of exposure pathways based on specific land use, site restrictions, and/or site-specific physical conditions.
- Section I.4 provides approaches for developing site-conceptual models for dose analysis. This section presents approaches—via the linkage of the source term with the critical group receptor and the use of applicable pathways and site-characterization data—for the assimilation of data to establish a site conceptual model. It also presents approaches for employing applicable mathematical models to simulate and calculate the release and transport of contaminants from the source to the receptor. This section also presents discussions of the typical conceptual models used in the DandD and RESRAD codes. Additionally, the section provides (a) information on the limitations of the DandD and RESRAD models and (b) review areas to ensure compatibility of the site conceptual model with the conceptual models embedded in the DandD and RESRAD codes.
- Section I.5 presents approaches and criteria for NRC staff acceptance of computer codes/models. This section discusses review aspects pertaining to specifications, testing, verification, documentation, and QA/QC of the licensee's codes/models. This section also addresses reviews applicable to embedded numerical models for the source term, the exposure

pathway models, the transport models, and the intakes or dose conversion models. In addition, the section provides a discussion of the development of and a description of the DandD code, particularly the excessive conservatism of the Version 1 of the DandD code. Section I.5 also presents a generic description of the RESRAD/RESRAD–BUILD codes.

- Section I.6 describes approaches for the selection and modification of input parameters for dose modeling analysis and includes the use of default parameters from the DandD code in other models.
- Section I.7 addresses the acceptable criteria for treating uncertainties in the dose modeling analysis. Issues pertaining to uncertainty and sensitivity are described, and NRC staff recommended approaches for the resolution of these issues are addressed. Policy positions are presented regarding approaches both to uncertainty/sensitivity treatments and to specific percentile dose-distribution selection for the screening and site-specific analysis. NRC staff review of input parameter distributions for Monte Carlo analysis and generic description of sensitivity analysis, including statistical techniques, are also described.
- Section I.8 compiles the references used throughout the appendix.
- Appendix J integrates the guidance in Appendix I and discusses methods that licensees may use in analyzing former burials with a very simple approach.

I.2 Source-Term Abstraction

I.2.1 Introduction

Source-term abstraction is the process of developing a conceptual representation of the radioactive source at a site. Typically, the radiological conditions at a site proposed for decommissioning are relatively complex. Source-term abstraction is necessary to allow the detailed radiological characterization of the site to be incorporated into the mathematical and computer models that are used to estimate radiological impacts (e.g., dose). The abstraction process involves generalizing the radiological characteristics across the site to produce a simplified representation, which should facilitate the modeling of radiological impacts. The conceptual representation of the source developed in the abstraction process, however, should not be simplified to the extent that radiological impacts are significantly underestimated or unrealistically overestimated.

As discussed in Chapter 5 of this volume, source-term abstraction serves as the starting point for the dose modeling process. The conceptual abstraction of the source term is combined with the physical characteristics of the site and characteristics of the critical group receptor to develop the conceptual model for the site. This conceptual model provides the basis for identifying applicable exposure scenarios, pathways, and selection of computer models. These other elements of dose modeling are discussed in subsequent sections of this document.

Volume 1 of NUREG–1757 and Chapter 4 of this volume discuss the information the licensee is expected to provide regarding the existing radiological characterization of the site. The licensee

should provide a description of the types, levels, and extent of radioactive material contaminated at the site. This should include residual radioactivity in all media (including buildings, systems and equipment that will remain after license termination, surface and subsurface soil, and surface and subsurface ground water). The source-term abstraction should be based on the characterization of the radiological status (e.g., process historical development, records of leakage or disposal). The licensee should explicitly relate the information provided in the discussion of radiological status of the site with the discussion of source-term abstraction. The reviewer should be able to clearly interpret the relationship.

Generally, in the source-term abstraction process, the licensee may focus on several specific elements of the source term, which include the following:

1. The licensee should identify the radionuclides of concern. This should be taken directly from the description of the site's radiological status. The radionuclides should be identified based on pre-remediation radiological status. All radionuclides potentially present at the site should be included, so that their presence or absence may be verified during the FSS, except as noted in Chapter 4 and Section 3.3 of this volume.

2. The licensee should describe the physical/chemical form(s) of the contaminated media *anticipated at the time of FSS and site release.* The licensee should indicate whether the residual radioactivity will be limited to building surfaces and/or surface soil, or whether the residual radioactivity will involve other media such as subsurface soil, debris or waste materials (e.g., sludge, slag, tailings), or ground and surface water.

3. The licensee should delineate the spatial extent of the residual radioactivity *anticipated at the time of FSS and site release.* The delineation of the spatial extent should include descriptions of (a) the areal extent of radionuclides throughout the site and (b) the vertical extent of soil residual radioactivity of radionuclides below the ground surface. The delineation of spatial extent and depth should establish the source areas and volumes. Depending on the presence of specific radionuclides, source areas and volumes may be radionuclide-specific.

4. The licensee should define the distribution of each radionuclide throughout the delineated source areas and volumes *anticipated at the time of FSS and site release.* The distribution of a radionuclide through the source should be defined in terms of representative volumetric or areal concentrations. In addition, for volumetrically contaminated soil, the licensee may provide an estimate of total radioactivity of each radionuclide.

5. The licensee should define sources in ground water or surface water, if any, based on environmental monitoring and sampling of aquifers and surface water bodies. A site with ground water or surface water contamination may be categorized as "complex" and may require more advanced dose modeling analysis (see Section 1.3 of this volume).

In the source-term abstraction process, the licensee should address the first two of these five elements. Whether the licensee needs to address the other elements depends on the objective of the licensee's dose modeling. This is discussed later in this section.

I.2.2 Issues Associated with Source-Term Abstraction

The level of effort that a licensee expends to develop a conceptualization of a source term should be commensurate with the licensee's approach to demonstrating compliance with the release criterion. Also, the focus should be on the source-term characteristics anticipated to exist at the site at the time of FSS and release, after any planned remediation.

If a licensee plans to use the screening DCGLs published by NRC in the *Federal Register*, a licensee should only have to identify the radionuclides that may be present at the site, and demonstrate that the conditions at the site meet the prerequisites for using the screening values [i.e., residual radioactivity is limited to building surfaces or the uppermost 15 to 30 cm (6 to 12 in) of surface soil and no contamination of ground water or surface water]. The licensee's source-term abstraction would not have to address issues such as existing radiological conditions, areal and volumetric extent of residual radioactivity, or spatial variability or radiological conditions for such sources. This is discussed further in Section I.2.3 of this appendix.

If a licensee anticipates that residual radioactivity will be limited to building surfaces or surface soils at the time of FSS, but considers the published DCGLs overly restrictive, the licensee may develop site-specific DCGLs. In this case, the licensee would most likely have to delineate the anticipated areal extent of residual radioactivity. However, the licensee would not have to discuss the anticipated spatial variability of radionuclide concentrations within the anticipated area of residual radioactivity.

A licensee should provide a site-specific dose assessment if the residual radioactivity is not limited to building surfaces or surface soil. In this case, the licensee would have to delineate the spatial extent (laterally and vertically) of the residual radioactivity, and the licensee would have to provide a discussion of the spatial variability of the physical, chemical, and radiological characteristics of the contaminated media.

Ideally, the source characteristics at a site would be relatively uniform, justifying simplified abstraction. However, this is generally not the case. Issues may arise when the residual radioactivity projected at a site at the time of release falls short of the ideal case. These issues may include the following:

1. Spatial extent
   - limited areal extent of residual radioactivity;
   - irregular areal shape; and
   - varying depth of residual radioactivity in soil.

2. Spatial variability
   — nonuniform distribution of radioactivity throughout a site;
   — limited areas of relatively elevated radionuclide concentrations;
   — multiple noncontiguous areas of residual radioactivity; and
   — nonuniform physical and chemical characteristics.

The following approach to source-term abstraction addresses most of these issues. Others (e.g., irregular areal shape) are best addressed by appropriate selection of computer codes.

I.2.3 Approach to Source-Term Abstraction

A licensee's approach to source-term abstraction will depend on the objective of the dose modeling presented in the decommissioning plan (DP). Generally, the licensee's dose modeling should have one of the following objectives:

- Develop DCGLs commensurate with demonstrating compliance with the dose-based release criterion, and then demonstrate through FSS that residual radioactivity concentrations at the site are equal to or below the DCGLs.
- Assess dose associated with actual concentrations of residual radioactivity distributed across the site to determine whether the concentrations will result in a dose that is not equal to or below the regulatory dose criterion.

In the first objective, the licensee intends to demonstrate at the time of FSS before release that residual radionuclide concentrations across the site are below a prespecified concentration limit with some prespecified degree of confidence. The design of the FSS would be based on the proposed DCGLs, in accordance with MARSSIM. The MARSSIM process does not require that the licensee incorporate information regarding the existing (i.e., pre-remediation or pre–FSS) spatial distribution of radioactivity into the source-term abstraction. The identification of DCGLs may involve site-specific model and parameter assumptions, or may use "screening" analyses.

In the second objective, the licensee intends to assess potential radiation doses that may result from specified levels of radioactive material. The contaminated material may not be limited to building surfaces or surface soils, but may include contaminated subsurface soil, debris, and waste. The licensee's dose modeling should demonstrate that the residual radioactivity should not result in radiation doses in excess of applicable regulatory limits. This modeling would likely be site-specific. Most likely, this modeling objective would require that the licensee incorporate information regarding both the spatial extent and spatial variability of radioactivity into the source-term abstraction.

Table I.1 summarizes the approach to source-term abstraction that the licensee should adopt, depending on the licensee's dose modeling objective and whether the licensee is providing screening or site-specific analyses. This table can serve as an index for the reviewer of the licensee's source-term abstraction.

Table I.1 Summary of Source-Term Abstraction Approaches Based on Dose-Modeling Objective

Objective	Screening	Site-Specific
Identify DCGLs.	No source-term abstraction is necessary beyond radionuclide identification. (Assume unit radionuclide concentrations.)	Delineate proposed lateral and vertical extent of residual contamination. (Assume unit radionuclide concentrations.)
Provide Dose Assessment.	Use actual concentrations with DandD v2.1 and assure that spatial variability is minimal.	Site-specific source-term abstraction incorporating spatial extent and variability.

I.2.3.1 Dose Modeling Objective One: Identify DCGLs

The MARSSIM approach, as documented in NUREG–1575 (NRC 1997) and discussed in Chapter 4 of this volume, requires that a licensee establish a set of DCGLs before conducting an FSS. In fact, the design of the FSS should be based on the identified DCGLs. DCGL is defined in MARSSIM as:

> "*...a derived, radionuclide-specific activity concentration within a survey unit corresponding to the release criterion.... DCGLs are derived from activity/dose relationships through various exposure pathway scenarios.*"

The $DCGL_W$ is the concentration of a radionuclide which, if distributed uniformly across a survey unit, would result in an estimated dose equal to the applicable dose limit. The $DCGL_{EMC}$ is the concentration of a radionuclide which, if distributed uniformly across a smaller limited area within a survey unit, would result in an estimated dose equal to the applicable dose limit.

Two approaches are possible for developing DCGLs: screening and site-specific analysis.

SCREENING DCGLs

NRC has published radionuclide-specific screening DCGLs in the *Federal Register* for residual building-surface radioactivity and residual surface-soil radioactivity. The DCGLs in the *Federal Register* are intended to be concentrations which, if distributed uniformly across a building or

soil surface, would individually result in a dose equal to the dose criterion. The licensee may adopt these screening DCGLs without additional dose modeling, if the site is suitable for screening analysis. Alternatively, the licensee may use the DandD computer code to develop screening DCGLs. The licensee would use the code to determine the dose attributable to a unit concentration of a radionuclide and scale the result to determine the $DCGL_W$ for the radionuclide. Either of these methods for identifying screening DCGLs requires the licensee (a) to identify the radionuclides of concern for the site and (b) to demonstrate that the source term and model screening assumptions are satisfied. Thus, this approach requires essentially no source-term abstraction. The screening process and the source-term screening assumptions are discussed in detail in Appendix H of this volume.

Before designing an FSS, the licensee may likely need to identify a $DCGL_{EMC}$ for each radionuclide over a range of smaller limited areas. Since the conservative screening models of DandD are not appropriate for modeling small limited areas of residual radioactivity, use of the DandD screening code would likely result in $DCGL_{EMC}$ values that are overly conservative. Therefore, licensees may likely use other codes or approaches to develop $DCGL_{EMC}$ values. These would be considered "site-specific" analyses in that they would not be using the DandD code with the default screening values. See Section I.3.3.3.5 of this appendix for more information.

SITE-SPECIFIC DCGLs

The licensee may choose to identify site-specific DCGLs if (a) the site conditions are not consistent with screening criteria or (b) the licensee believes the screening DCGLs are unnecessarily restrictive. As defined in MARSSIM, the site-specific DCGLs may be derived from activity/dose relationships through various exposure pathway scenarios. "Site-specific" in this context may refer to the selection of conceptual models/computer models, physical (site) input parameter values, or behavioral/metabolic input parameter values. These aspects of site-specific analyses are discussed in other sections of this document. "Site-specific" may also refer to the source-term abstraction.

From the MARSSIM perspective, identifying a site-specific $DCGL_W$ still begins with assuming a uniform radionuclide concentration across some source area (building surface) or volume (surface soil). The site-specific $DCGL_W$ for a particular radionuclide may be identified by evaluating the dose resulting from a unit concentration and then scaling the result. Spatial variability of the radionuclide concentration within the area or volume is not evaluated in identifying the DCGLs, but is taken into account in the statistical analysis of the data collected during the FSS. In identifying the site-specific DCGLs, the licensee may, however, take the spatial extent into account.

If the licensee is certain that the residual radionuclide concentration is limited to a specific lateral extent, the licensee may incorporate the "area of residual radioactivity" into the identification of DCGLs. Computer modeling codes, such as RESRAD or DandD, allow the user to directly specify the area of residual radioactivity. Through the FSS, the licensee would have to

demonstrate that the $DCGL_W$ is satisfied within the specified area of residual radioactivity, and would have to demonstrate that residual radioactivity is not present outside the specified area of residual radioactivity. In order to adequately design the FSS, the licensee should develop $DCGL_{EMC}$ values for smaller areas within the area of residual radioactivity.

In addition to specifying a limited area of residual radioactivity in developing the site-specific DCGLs for soil, the licensee should also appropriately represent the vertical extent of residual radioactivity within the area. The screening DCGLs and the DandD code assume that residual radioactivity is contained within the uppermost 15 to 30 cm (6 to 12 in) of soil. If the licensee intends to leave residual radioactivity at depths below 15 to 30 cm (6 to 12 in), this should be reflected in the calculation of the $DCGL_W$. Otherwise, leaving residual radioactivity below 15 to 30 cm (6 to 12 in) may not be acceptable.

For subsurface residual radioactivity [i.e., residual radioactivity at depths greater than 15 to 30 cm (6 to 12 in)], the NRC license reviewer should evaluate whether the licensee has reviewed existing historical site data (including previous processes or practices) and site characterization data to establish an adequate conceptual model of the subsurface source specifically regarding horizontal and vertical extent of residual radioactivity. Lateral and vertical trends of variation in concentration for each specific radionuclide should be evaluated. Since certain radionuclides have higher mobility than others, radionuclide ratios may not be maintained as constant across subsurface soil. In other words, radionuclide concentration within the unsaturated zone may vary depending on the original source location and the time since contamination existed. The NRC license reviewer should evaluate whether the licensee has reviewed the physical and chemical properties of the source and the surface/subsurface formation to assess potential for leaching or retardation within the natural physical system of the concerned site. In this context, the NRC license reviewer should evaluate the selected physical parameters and the physical conceptual model of the site versus actual subsurface geologic units or formation to ensure conservative selection of pertinent sensitive physical parameters. The NRC license reviewer should also consider (a) the physical variability in subsurface soil and the unsaturated zone and (b) the selected depth to the water table considering the lower boundary of the subsurface source term.

If the thickness of residual radioactivity that the licensee intends to leave at the site is generally uniform across the site, the licensee may choose to use an upper bounding value for modeling the thickness. Alternatively, the licensee may choose to adopt an area-weighted approach to calculate an representative thickness. The representative thickness may be the area-weighted average value, or may reflect a conservative upper-percentile value. The NRC license reviewer should ensure that the representative thickness value proposed by the licensee does not significantly underestimate localized thicknesses at sites where the thickness of the proposed residually contaminated soil varies greatly across the site.

If appropriate, the licensee should provide maps and cross-sections detailing the proposed lateral and vertical extent of residual radioactivity left on the site.

I.2.3.2 Dose Modeling Objective Two: Assess Dose

An alternative objective that a licensee may have for performing and submitting dose modeling may be to assess doses attributable to specific quantities of radioactive material. Although the development of DCGLs focuses on the determination of radionuclide concentrations corresponding to a specified dose, the dose assessment objective focuses on the determination of doses corresponding to specified radionuclide concentrations.

In this situation, the licensee should give much more attention to the source-term abstraction. The licensee should address all elements of the source-term abstraction:

- identify the radionuclides of concern;
- delineate the spatial extent of residual radioactivity;
- represent the spatial variability of residual radioactivity; and
- incorporate spatial variability of physical and chemical characteristics of the contaminated media.

The licensee should focus on the distribution of radioactive material expected to be present at the time of FSS and subsequent site release. The licensee may assess doses attributable to existing radiological conditions at the site if the licensee can demonstrate that the existing radiological conditions reasonably bound conditions expected at FSS, from a dose perspective.

The first two elements of source-term abstraction—radionuclides of concern and spatial extent — were considered in the discussion of source-term abstraction for development of DCGLs. Spatial variability was not considered since it is statistically evaluated after FSS. In dose assessment, however, spatial variability should be factored into the source-term abstraction before dose modeling.

Assuming that the licensee has identified the radionuclides of concern and delineated the spatial extent of residual radioactivity, the licensee should provide a projection of residual radionuclide concentration distribution and total residual radionuclide inventory across the site. This projection should be directly tied to the characterization of existing radiological conditions at the site. The site may then be divided into relatively large areas that are radiologically distinct, based on radionuclide concentration or depth of residual radioactivity. The licensee should statistically demonstrate that the radionuclide concentrations or depth within an area may be relatively uniform, taking into account the spatial distribution of the data. Similarly, within the larger areas, the licensee should statistically delineate relatively small areas of projected elevated radionuclide concentrations or increased depth. (The licensee should discuss the reason for leaving the elevated concentrations in place as residual radioactivity.)

When complete, the licensee's source-term abstraction should define a site divided into relatively large areas of statistically uniform radionuclide concentrations and residual radioactivity depth. Within these areas may be relatively small areas of elevated concentration

or increased depth. Assuming that the physical and chemical conditions across the site are relatively uniform, the licensee may use this source-term abstraction for modeling and proceed with the dose assessment. The following is a suggested approach:

- Consider each relatively large area independently, and initially ignore the relatively small elevated areas within each large area.
- Assess dose based on the properties of a large area, taking the areal extent into account.
- Repeat the dose assessment, but assume essentially infinite areal extent. The specific approach will depend on the computer modeling code used. This should quantify the impact of dividing the site into artificial modeling areas.
- Assess dose attributable to each limited area of elevated concentration, assuming no residual radioactivity exists outside the limited area. This may then be combined with the dose attributable to the surrounding larger area, to assess the impact of leaving the elevated concentrations.

In some cases, it may not be practical to separate a site into areas with relatively uniform radionuclide concentrations; sometimes areas to be evaluated will have non-uniform distributions of concentrations. In such cases, for performing the second step above, there may be a question about what statistical value best represents the radionuclide concentration for the large area. Log-normal distributions occur frequently in nature and are not unexpected when surveying contaminated sites. For log-normal distributions, the geometric mean is often used as a descriptor of the distribution. However, the geometric mean concentration should not be used as the average value for the source term for dose calculations. Arithmetic means reflect that (1) the dose rate is proportional to radionuclide concentration; (2) the dose receptor generally spends an equal amount of time in each area of the site; and (3) each characterization data point represents an equal area. If samples are not taken randomly or systematically (and thus data points represent unequal areas), weighted means may be appropriate, with application of weighting factors consistent with the assumptions of receptor exposures. Therefore, the arithmetic mean or weighted mean is the appropriate statistic to use for calculating source term average concentrations for the large areas (second step above) for dose modeling.

The above discussion does not specifically address the determination of relatively significant large or small areas. This designation will depend on the areal assumptions underlying the computer modeling code used. For example, the DandD code considers the area of cultivation to be uniformly contaminated and irrigated. The area of cultivation depends on the cultivation requirements defined by the specific exposure scenario. Conversely, the RESRAD code considers a range of exposure-pathway specific areas [e.g., 400 m^2 (4300 ft^2) for soil ingestion; 1000 m^2 (11,000 ft^2) for plant ingestion; and 20,000 m^2 (5 ac) for milk and meat ingestion]. Therefore, the licensee should discuss and justify the designation of relatively large and relatively small areas, based on the computer code used. However, by providing the additional assessments identified above, where alternative areas are evaluated, the sensitivity of the dose modeling results to the area designation can be determined.

The licensee may also have to consider the impact of multiple areas of elevated concentration within a single larger area. In general, modeling two small areas independently and combining the results of the two dose assessments should result in a higher dose than if the two areas were combined and modeled as a single area. The higher dose is unrealistic in that it assumes that the receptor location relative to each contaminated area is such that the dose is maximized from each contaminated area independently. For a more reasonable estimate of potential dose, these smaller areas may be combined into a single larger area if the concentrations within the smaller areas are comparable. If this is not the case, then the licensee may model each smaller area individually and modify the scenario and critical group assumptions for each area (e.g., time spent on each area) and combine the results.

I.3 Criteria for Selecting and Modifying Scenarios, Pathways, and Critical Groups

I.3.1 Introduction

After the source term has been evaluated, the question becomes: "How could humans be exposed either directly or indirectly to residual radioactivity?" or "What is the appropriate exposure scenario?" Each exposure scenario should address the following questions:

1. How does the residual radioactivity move through the environment?
2. Where can humans be exposed to the environmental concentrations?
3. What is the likely land use(s) in the future for these areas?
4. What are the exposure group's habits that will determine exposure? (e.g., what do they eat and where does it come from? How much? Where do they get water and how much? How much time do they spend on various activities? etc.)

The ultimate goal of dose modeling is to estimate the dose to a specific receptor. Broad generalizations of the direct or indirect interaction of the affected receptors with the residual radioactivity can be identified for ease of discussion between the licensee, regulator, public, and other interested parties. Scenarios are defined as reasonable sets of activities related to the future use of the site. Therefore, scenarios provide a description of future land uses, human activities, and behavior of the natural system.

In most situations, there are numerous possible scenarios of how future human exposure groups could interact with residual radioactivity. The compliance criteria in Part 20 for decommissioning does not require an investigation of all (or many) possible scenarios; its focus is on the dose to members of the critical group. The critical group is defined (at 10 CFR 20.1003) as "...the group of individuals reasonably expected to receive the greatest exposure to residual radioactivity for any applicable set of circumstances."

By combining knowledge about the answers to Questions 1 and 2, the licensee can develop exposure pathways. Exposure pathways are the routes that residual radioactivity travels, through the environment, from its source, until it interacts with a human. They can be fairly simple (e.g., surface-soil residual radioactivity emits gamma radiation, which results in direct exposure to the individual standing on the soil) or they can be fairly involved (e.g., the residual radioactivity in the surface soil leaches through the unsaturated soil layers into the underlying aquifer and the water from the aquifer is pumped out by the exposed individual for use as drinking water, which results in the exposed individual ingesting the environmental concentrations). Exposure pathways typically fall into three principal categories, identified by the manner in which the exposed individual interacts with the environmental concentrations resulting from the residual radioactivity: ingestion, inhalation, or external (i.e., direct) exposure pathways.

As required under Subpart E, the dose from residual radioactivity is evaluated for the average member of the critical group, which is not necessarily the same as the maximally exposed individual. This is not a reduction in the level of protection provided to the public, but an attempt to emphasize the uncertainty and assumptions needed in calculating potential future doses, while limiting boundless speculation on possible future exposure scenarios. Although it is possible to actually identify with confidence the most exposed member of the public in some operational situations (through monitoring, time studies, distance from the facility, etc.), identification of the specific individual who may receive the highest dose some time (up to 1000 years) in the future is impractical, if not impossible. Speculation on his or her habits, characteristics, age, or metabolism could be endless. The use of the "average member of the critical group" acknowledges that any hypothetical "individual" used in the performance assessment is based, in some manner, on the statistical results from data sets (e.g., the breathing rate is based on the range of possible breathing rates) gathered from groups of individuals. Although bounding assumptions could be used to select values for each of the parameters (i.e., the maximum amount of meat, milk, vegetables, possible exposure time, etc.), the result could be an extremely conservative calculation of an unrealistic scenario and may lead to excessively low allowable residual radioactivity levels, compared to the actual risk.

Calculating the dose to the critical group is intended to bound the individual dose to other possible exposure groups because the critical group is a relatively small group of individuals, because of their habits, actions, and characteristics, who could receive among the highest potential dose at some time in the future. By using the hypothetical critical group as the dose receptor, coupled with prudently conservative models, it is highly unlikely that any individual would actually receive doses in excess of that calculated for the average member of the critical group. The description of a critical group's habits, actions, and characteristics should be based on credible assumptions and the information or data ranges used to support the assumptions should be limited in scope to reduce the possibility of adding members of less exposed groups to the critical group.

ALARA analyses should use the dose based on the reasonably foreseeable land use for any cost-benefit calculations performed.

I.3.2 Issues in Selecting and Modifying Scenarios, Pathways, and Critical Groups

The definition of scenarios, identification of a critical group with its associated exposure pathways, and the dose assessment based on that definition can be generic or site specific. Licensees might:

- Use screening scenarios, screening groups, and pathway parameters as described in NUREG–1549 (NRC 1998a) and the NUREG/CR–5512 series. This can be used for either screening or site-specific analyses.
- Use the default screening scenarios as a starting point to develop more site-specific pathway analyses or critical group habits.
- Develop site-specific scenarios, critical groups, and identify associated exposure pathways from scratch.

To establish either site-specific scenarios, critical groups, and/or sets of exposure pathways, the licensee may need to provide justifications defending its selections. For some licensees, this may require minimum amounts of site-specific data to support the assumptions inherent in the existing default screening scenarios or for removing specific exposure pathways. For others, the licensee may need to thoroughly investigate and justify the appropriateness of the selected scenarios and/or critical groups, which may include evaluation of alternate scenarios and/or critical groups. If a licensee creates the exposure scenario and associated critical group based on site-specific conditions (e.g., at a site that is grossly different than the assumptions inherent in the default scenarios), the licensee should provide documentation that provides a transparent and traceable audit trail for each of the assumptions used in developing the exposure scenario and critical group [e.g., justify the inclusion (or exclusion) of a particular exposure pathway].

I.3.3 Recommended Approaches

I.3.3.1 Screening Analyses

In the case of screening, the decisions involved in identifying the appropriate scenario and critical group, with their corresponding exposure pathways, have already been made. Scenario descriptions acceptable to NRC staff for use in generic screening are developed and contained in NUREG/CR–5512, Volume 1. NUREG/CR–5512, Volume 3, and NUREG–1549, provide the rationale for applicability of the generic scenarios, critical groups, and pathways at a site; the rationale and assumptions for scenarios and pathways included (and excluded); and the associated parameter values or ranges (only from NUREG/CR–5512, Volume 3). A summary of the scenarios is in Table I.2. The latest version of the DandD computer code should contain the latest default data values for the critical group's habits and characteristics.

Table I.2 Pathways for Generic Scenarios

Building Occupancy Scenario
This scenario accounts for exposure to fixed and removable residual radioactivity on the walls, floor, and ceiling of a decommissioned facility. It assumes that the building may be used for commercial or light industrial activities (e.g., an office building or warehouse). Pathways include: • external exposure from building surfaces; • inhalation of (re)suspended removable residual radioactivity; and • inadvertent ingestion of removable residual radioactivity.
Resident Farmer Scenario
This scenario accounts for exposure involving residual radioactivity that is initially in the surficial soil. A farmer moves onto the site and grows some of his or her diet and uses water tapped from the aquifer under the site. Pathways include: • external exposure from soil; • inhalation to (re)suspended soil; • ingestion of soil; • ingestion of drinking water from aquifer; • ingestion of plant products grown in contaminated soil and using aquifer to supply irrigation needs; • ingestion of animal products grown onsite (using feed and water derived from potentially contaminated sources); and • ingestion of fish from a pond filled with water from the aquifer.

I.3.3.2 Site-Specific Analyses

Site-specific analyses give licensees greater flexibility in developing the compliance scenario. The licensee should justify its selection of the compliance scenario based on reasonably foreseeable land use at the site. The compliance scenario should result in an exposure to the public, such that no other scenario, using reasonably foreseeable land use assumptions, will result in higher doses to its exposure group(s). The level of justification and analysis provided

by the licensee will be depend on the how close the analysis is to the "real" dose. The more realistic the analysis, greater degrees of justification and, potentially ancillary analyses, will be required. For example, a site is currently zoned industrial and the local area is a mix of suburban, commercial, and industrial. Rural uses of the property are less likely but plausible for the foreseeable future. If the licensee chose to use the generic screening scenario, the licensee would need to provide limited justification for the bounding scenario. If the licensee proposed to use a maintenance worker scenario assuming industrial land use as the compliance scenario, the licensee would need to provide quantitative analyses of or a qualitative argument discounting the need to analyze other competing scenarios (based on industrial land use and on suburban or commercial land use) to justify the selection of the compliance scenario. In addition, the licensee would need to provide analyses of the rural use of the land to show what impacts would occur from this less likely but plausible situation.

Site-specific analyses can use the generic screening scenario(s) with a little justification. The licensee may need to justify that the site contains no physical features nor locations of residual radioactivity, other than those assumed in the screening analyses, that would invalidate the assumptions made in developing the scenarios. The NRC license reviewer should evaluate the justification to provide reasonable assurance that the generic scenario would still be appropriate for the site. A site can fail to meet the requirements of the conceptual model (see Section I.4 of this appendix) without invalidating the generic scenario, and situations can arise where the default scenario is no longer the limiting case. For example, the site may have pre-existing ground water contamination, which is counter to the assumptions in the conceptual model inherent in the screening models, but this may not require any change in the exposure scenario because the residential farmer scenario may still be an appropriate scenario, as it contains all of the appropriate exposure pathways, including ground water use for drinking, irrigation, and for animals. Alternately, if the residual radioactivity were a volumetric source in the walls of a building, rather than on the building surfaces, the generic exposure scenario of an office worker may not be the scenario leading to the critical group. For certain sets of radionuclides, a building renovation scenario may be more limiting because of the exposure to airborne concentration of material as the walls are modified.

Site-specific scenarios, critical groups, and pathways can be developed, for any situation, and would occur in cases where, for example:

1. Major pathways (e.g., the ground water pathway, or agricultural pathways) associated with the default screening scenarios could be eliminated, either because of physical reasons or site-use reasons.
2. The location of the residual radioactivity and the physical features of the site are outside the major assumptions used in defining the default critical group and/or scenarios.
3. Restricted use was proposed for a site.

The second situation listed above can be ambiguous, as a number of assumptions key to the development of the DandD screening tool do not affect the scenario description, and may require an NRC reviewer to evaluate whether the initial generic scenario would still be appropriate for the site.

Modifying scenarios or developing a site-specific critical group requires information regarding plausible uses of the site and demographic information. Such information might include considerations of the prevailing (and future) uses of the land, and physical characteristics of the site that may constrain site use. Potential land uses should be categorized as reasonably foreseeable, less likely but plausible, or implausible. Any land uses that similar property in the region currently has, or may have in the near future (e.g., approximately 100 years), should be characterized as reasonably foreseeable. Consideration should be given to trends and area land use plans in determining the likelihood of potential land use. Land uses that are plausible, generally because similar land historically was used for the purpose, but are counter to the current trends or regional experience could be characterized as less likely but plausible (e.g., rural use of property currently in an urban setting). Implausible land uses are those that because of physical limitations could not occur (e.g., residential land use for an underwater plot of land). It may be necessary to evaluate several potential critical groups, based on different combinations of site-specific scenarios developed from expected land use, pathways and demographics, to determine the group receiving the highest exposure.

Depending on the resulting exposure scenarios, considerations of offsite exposure by either transport (e.g., through ground water) or material transfer (e.g., soil being taken from the site and used elsewhere) may be necessary to identify the critical group. Thus, the licensee should consider if offsite uses are reasonably foreseeable. If they are, such offsite uses should also be analyzed to determine if the critical group might be an offsite user instead of an onsite user.

Similar considerations apply for restricted release. Thus, when analyzing the dose under restricted conditions, the nature of the critical group is likely to change because of these restrictions and controls. Site restrictions and institutional controls can restrict certain kinds of activities and land or water uses associated with the physical features of the site. The detailed definition of the scenarios considered for restricted release need to include the impact of the control provisions on the location and behavior of the average member of the appropriate critical group.

For restricted use, licensees must also evaluate doses assuming the loss of institutional controls. This evaluation should address: (a) the associated degradation of engineered barriers without active maintenance; and (b) inadvertent intruder scenarios. See Section 3.5.2 of this volume for additional information.

The NRC license reviewer should evaluate the justifications provided by the licensee on its scenarios using the following appropriate guidance. The guidance is characterized by the general approach used in development of the scenarios: (a) modifying existing generic exposure scenarios or (b) developing site-specific scenarios from "scratch."

I.3.3.2.1 Modification of Generic Scenarios

First, the NRC license reviewer should evaluate whether the generic scenario was applicable to the site before modification. If the scenario was applicable before the licensee started modifying the scenario based on physical features or restrictions, go to the next step and evaluate the justifications for the various modifications performed by the licensee. If the scenario was not initially applicable, that does not mean that a final modified scenario is inappropriate for the site conditions. It just means that the review may be more complex than a simple modification of a scenario and that the NRC license reviewer should evaluate whether it may be more appropriate to evaluate the scenario using the guidance below.

The NRC license reviewer should identify the modifications done by the licensee to the scenario and evaluate the licensee's justification for those changes. Table I.3 lists some common exposure scenarios, but is by no means comprehensive. The Sandia Letter Report, "Process for Developing Alternate Scenarios at NRC Sites Involved in D&D and License Termination" (Thomas, et al., 2000), which is included in this volume as Appendix M, provides a series of flow charts and sources of information to assist a licensee or reviewer in modifying the default scenarios using site-specific information. See below for specific guidance on acceptable justifications using different types of site-specific information, which was adapted from the letter report. Additionally, if the licensee's intent is restricted release, the final scenario should be reviewed looking at the effect of site restrictions. The licensee's justifications should support, based on either site restrictions or site-specific data, the elimination of scenarios and pathways from the analysis. The NRC license reviewer should focus the review on the pathways, and models associated with those pathways, that have the highest likelihood of significant exposures to the critical group.

Table I.3 Potential Scenarios for Use in Dose Assessments

General Scenario Classification
• Building occupancy (Generic screening – NUREG/CR–5512-based).
• Residential farmer (Generic screening – NUREG/CR–5512-based).
• Urban construction (contaminated soil, no suburban or agricultural uses). This scenario is meant for small urban sites cleared of all original buildings; only contaminated land and/or buried waste remains.
• Residential (a more restricted subset of the residential farmer scenario, for those urban or suburban sites where farming is not a realistic projected future use of the site).
• Recreational User (where the site is preserved for recreational uses only).
• Maintenance Worker (tied to the Recreational User scenario but involves the grounds keepers maintaining or building on the site).
• Hybrid industrial building occupancy (adds contaminated soil, building may or may not be contaminated).
• Drinking water (e.g., no onsite use of ground water; offsite impacts from the contaminated plume).

The licensee may need to evaluate whether the final modified scenario is still the limiting reasonable representation of the critical group at the site. This may involve investigation of exposure pathways not covered in the default scenarios.

I.3.3.2.2 Development of Alternate Scenarios

In some decommissioning cases, either the location of the residual radioactivity, the physical characteristics of the site, and/or planned institutional restrictions may make the default scenarios inappropriate. In other cases, the licensee may wish to provide a transparent and traceable development of the compliance and other exposure scenarios, starting with the potential land use and the site conditions. Development (and review) of alternate scenarios may involve iterative steps involving the development of the conceptual model of the site. For example, the licensee may (a) develop a generic list of exposure pathways, (b) develop the site conceptual model to screen the generic list, (c) aggregate or reduce the remaining exposure pathways to the major exposure pathways, and (d) re-evaluate the conceptual model to verify that all the necessary processes are included.

A brief summary of the NRC–recommended pathway analysis process follows. An example development of exposure scenarios, while developed for partial site release, is listed in Appendix K.

- The licensee compiles a list of exposure pathways applicable to any contaminated site. There are a number of existing sources of information that can be used. One source is NUREG/CR–5512, Volume 1 (NRC 1992), and the list is summarized in Appendix C.1 of NUREG–1549 (NRC 1998a). Another source, although the guidance is more focused on offsite exposures, is NUREG/CR–5453, Volumes 1 and 2, "Background Information for the Development of a Low-Level Waste Performance Assessment Methodology" (Shipers 1989; Shipers and Harlan 1989). Another potential source is the international "Features, Events and Processes," list which is an expansive generic list that does not strictly deal with decommissioning issues (SSI 1996).
- Categorize the general types of residual radioactivity at the site (e.g., sediment or soil, deposits in buildings, surface residual radioactivity, surface water, ground water, industrial products such as slag).
- Screen out pathways, for each contaminant type, that do not apply to the site.
- Identify the physical processes pertinent to the remaining pathways for the site.
- Separate the list of exposure pathways into unique pairs of exposure media (e.g., source to ground water, ground water to surface water, etc.). Determine the physical processes that are relevant for each exposure media pair and combine the processes with the pathway links.
- Reassemble exposure pathways for each source type, using the exposure media pairs as building blocks, thus associating all the physical processes identified with the individual pairs with the complete pathway.

The licensee's documentation of the decisions made regarding inclusion (or exclusion) of the various pathways should be transparent and traceable. An international working group of Biospheric Model Validation Study, Phase II (BIOMOVS II) (SSI 1996), established a methodology for developing models to analyze radionuclide behavior in the biosphere and associated radiological exposure pathways (i.e., the Reference Biospheres Methodology). BIOMOVS II published the methodology in its Technical Report No.6, "Development of a Reference Biospheres Methodology for Radioactive Waste Disposal" (SSI 1996), and it may be useful as a guide for additional information on a logical method to complete the pathway analysis sets above and include proper justification. Generally, the Reference Biospheres Methodology is more useful for complex sites that may have numerous physical processes that interact in such as a way that a number of different exposure groups may need to be investigated to identify the critical group. Additional work has been done on implementing the Reference Biospheres Methodology by a working group of the International Atomic Energy Agency's Biosphere Modeling and Assessment (BIOMASS) program (IAEA 1999a). Specifically, IAEA Working Document BIOMASS/T1/WD03, "Guidance on the Definition of Critical and Other Hypothetical Exposed Groups for Solid Radioactive Waste Disposal," may provide additional information on developing a site-specific critical group for situations where the generic critical group is inappropriate.

I.3.3.3 Guidance on Specific Issues

I.3.3.3.1 Land Use

A licensee's assumptions for land use should focus on current practice in the region. The region of concern can be as large as an 80-kilometer (50-mile) radius. To narrow the focus of current land practices, the licensees can use information on how land use has been changing in the region, and more weight should be given to land-use practices either close to the site or in similar physical settings. This can be very important for semi-rural sites that are being encroached by suburban residential development. Reviewers may wish to involve State and local land-use planning agencies in discussions, if the licensee has not already requested their involvement.

Potential land uses should be categorized as reasonably foreseeable, less likely but plausible, or implausible. Any land uses that similar properties in the region currently have, or may have in the near future (e.g., approximately 100 years), should be characterized as reasonably foreseeable. Consideration should be given to trends and area land use plans in determining the likelihood of potential land use. The time frame of interest for scenario development could be less than 100 years in certain cases and would depend on such factors as the rate of change in land use patterns in the area, radionuclides of interest and the time of peak dose. For example, a site with residual Cobalt-60, which has approximately a 5 year half-life, would not likely need to explore possible land uses that may exist at the site beyond a few decades, because of the natural decay of the residual material. Note that the 100-year timeframe described here is only for estimating future land uses; the licensee must evaluate doses that could occur over the 1000-year time period specified in the LTR.

Land use that are plausible, generally because similar land historically was used for the purpose, but are counter to the current trends or regional experience should be characterized as less likely but plausible (e.g., rural use of property currently in an urban setting).

Implausible land uses are those that because of generally physical limitations could not occur (e.g., residential land use for an underwater plot of land).

Land use justifications by licensees often rely on State or local codes, in building or well development to constrain future use. In general, licensees requesting unrestricted release should not rely solely on these factors as reasons to remove pathways or justify the scenario unless (a) the radionuclides have a relatively short-half life (approximately 10 years or less) or (b) the dose from long-lived radionuclides reaches its peak before 100 years. Similarly, licensees requesting unrestricted release should not limit land use scenarios based on commitments, or require the enforcement of limitations by the licensee or another party (e.g., a licensee states that the land will remain industrial because the licensee states that the land will not be sold by the licensee after the license is terminated).

Licensees should base justifications of land use on (1) the nature of the land and reasonable predictions based on its physical and geologic characteristics, and (2) societal uses of the land based on past historical information, current uses of it and similar properties, and what is reasonably foreseeable in the near future. The societal uses of the site in the future should be based on advice from local land planners and other stakeholders on what possible land uses are likely within a time period of around a hundred years. The level of justification for the final land uses is inversely proportional to the level of realism assumed by the licensee. Limited justification may be required for bounding analyses while much more detailed justification including alternate reasonably foreseeable and less likely but plausible scenario analyses may be needed for a situation with a smaller degree of conservatism in the analyses.

Additional guidance is available on potential sources of land use information in Appendix M.5.

I.3.3.3.2 Waterborne Exposure Pathways

Removal of waterborne exposure pathways can range from being global (e.g., all ground water pathways) to being specific (e.g., no drinking water but still have agricultural/fish pond use). Acceptable justifications are generally based on physical conditions at the site rather than local codes. Justification of water quality and quantity of the saturated zone should be based on the classification systems used by the U.S. Environmental Protection Agency (EPA) or the State, as appropriate. Arguments involving depth to water table, or well production capacity, should have supporting documentation from either the U.S. Geological Survey (USGS), an appropriate State agency, or an independent consultant.

NRC license reviewers should evaluate the reasons for the classification. Tables M.5–M.12 in Appendix M provide details regarding water quality standards. For example, where the aquifer is classified as not being a source of drinking water, but is adequate for stock watering and irrigation, the licensee can eliminate the drinking water pathway, but should still maintain the irrigation and meat/milk pathways. Aquifers may exceed certain constituents and still be able to be used for various purposes because those constituents may easily be treatable (e.g., turbidity). In cases where the water may be treatable or because the degree of connection between the aquifer and surface water may make the use of the aquifer questionable, the NRC license reviewer should involve the EPA and/or the State, as appropriate, in discussions on reasonable assumptions for the aquifer use.

I.3.3.3.3 Agricultural Pathways

Agricultural pathways may be removed or modified for various reasons: (a) land use patterns, (b) poor-quality soil, (c) topography, and (d) size of contaminated area. Many justifications may result in modification of the pathways, rather than complete elimination. For example, the soil may of inappropriate quality to support intensive farming activities, but residential gardening may still be reasonable.

Licensees using poor-quality soil as a justification for modifying the agricultural pathways should provide the reviewer with supporting documentation from the Soil Conservation Service, appropriate State or local agency, or an independent consultant. Reviewers should carefully consider whether the state of the soil would reasonably preclude all activities (e.g., because of high salinity of soil) or only certain activities. In most cases, soil quality can reasonably preclude activities such as intensive farming, but could allow grazing or small gardens.

When reviewing justifications involving topography, the NRC license reviewer should limit speculation of future topographical changes from civil engineering projects. The NRC license reviewer should evaluate the reasonableness of the critical group performing its activities on the current topography, for example, a slope. Supporting documentation should be provided by the licensee in the form of pictures, USGS or similar topographic maps, hand-drawn maps, or a detailed description of how the topography would limit farming. NRC reviewers may wish to perform a site visit to evaluate the topography firsthand.

I.3.3.3.4 Age-Dependent Critical Groups

Use the definitions in Part 20 when calculating for compliance with the requirements of Subpart E. Use the Federal Guidance Report No. 11 when calculating internal exposures by using the intake-to-dose conversion factors, which are based primarily on adults. As stated in the Environmental Protection Agency's *Federal Register* notice (59 FR 66414, Dec. 23, 1994) on "Federal Radiation Protection Draft Guidance for Exposure of the General Public," which proposes a public dose limit of 1.0 mSv/y (100 mrem/y) from all sources:

> "These dose conversion factors are appropriate for application to any population adequately characterized by the set of values for physiological parameters developed by the [International Committee on Radiological Protection] and collectively known as "Reference Man." The actual dose to a particular individual from a given intake is dependent upon age and sex, as well as other characteristics. As noted earlier, implementing limits for the general public expressed as age and sex dependent would be difficult.... More importantly, the variability in dose due to these factors is comparable in magnitude to the uncertainty in our estimates of the risks which provide the basis for our choice of the [public dose limit]. For this reason EPA believes that, for the purpose of providing radiation protection under the conditions addressed by these recommendations, the assumptions exemplified by Reference Man adequately characterize the general public, and a detailed consideration of age and sex is not generally necessary." (59 FR 66423, Dec. 23, 1994) [sic]

Since age-based dose conversion factors are not being used, the same dose conversion factors are applied to all individuals. Only in rare scenarios will a non-adult individual receive a higher dose (i.e., intake more radioactive material) than an adult individual in a similar exposure scenario. One example is the milk pathway, children generally drink more milk annually than adults. If milk was the only pathway that would expose the individual to a dose, then the child would have a slightly higher dose than the adult. But in most situations, especially ones involving multiple pathways, the total intake of the adult is greater than that of a child.

Therefore, for most multiple pathway scenarios, such as screening analyses, the average member of the critical group should usually be assumed to be an adult, with the proper habits and characteristics of an adult. As the licensee eliminates pathways or modifies the scenario, the behavior and dietary habits of children may become important. In such cases, the licensees should consult with NRC staff for guidance.

I.3.3.3.5 Area Factors

The $DCGL_W$ is the average concentration across the site that is calculated to result in the average member of the critical group receiving a dose at the appropriate dose limit [e.g., 0.25 mSv/y (25 mrem/y) for unrestricted release]. The general assumption is that the concentration of the radionuclides in the source are fairly homogenous. The degree to which any single localized area can be elevated above the average, assuming the average is at the $DCGL_W$, and not invalidate the homogenous assumption is characterized by the $DCGL_{EMC}$ (see Chapter 4 of this volume and MARSSIM). One method for determining values for the $DCGL_{EMC}$ is to modify the $DCGL_W$ using a correction factor that accounts for the difference in area and the resulting change in dose. The area factor is then the magnitude by which the concentration within the small area of elevated activity can exceed $DCGL_W$ while maintaining compliance with the release criterion.

The area factor works by taking into consideration how a smaller area would affect the dose to the average member of the critical group. For example, a smaller area could mean that external dose is more limited because it is not reasonable to expect the individual to be exposed the same amount of time as the individual would be to a larger area.

The default scenario for surface soil assumes large areas of homogeneous surface residual radioactivity. If the area of residual radioactivity is smaller than the defaults [e.g., 2400 m^2 (0.6 ac) for DandD], the licensee may propose modifying the exposure pathways to account for the effect on the critical group's activities. The licensee can follow either of two methods:

- Reduce the calculated dose by modifying the exposure time or usage parameters accordingly.
- Modify the exposure scenario and pathways and/or modify the calculational method to account for the size of the residual radioactivity.

These methods may be built into some dose assessment codes for surficial soil, but the user should verify proper use of the method. When the user changes the size of the contaminated area, the code will modify the appropriate usage factors and remove pathways if they are no longer viable.

When the extent of residual radioactivity becomes smaller, some of the activities are no longer viable as reasonable assumptions for exposure. Generally, the first pathways affected are animal husbandry activities, because of the larger area needs for grazing and growing fodder. As a general rule, as the area gets smaller, the more the scenario transforms into a residential gardener scenario, so long as the initial residual radioactivity begins in the surface soil. For cases where

the residual radioactivity is not in the surficial soil, the original area of residual radioactivity may not be as important in scenario development, because some of the primary transport mechanisms result in redistribution of the radionuclides over larger areas (i.e., ground water used as irrigation).

One common mistake in licensee submittals is that area factors are typically not provided for residual radioactivity on building surfaces. The primary reason for this is that such factors could not be calculated by using the DandD, Version 1. Therefore, when the screening $DCGL_W$ values were published in the *Federal Register* (see Appendix H), which were derived from an improved DandD, Version 1, the associated area factors were not published. An alternative approach should be used to calculate area factors for residual radioactivity on building surfaces.

One approach is to use DandD, Version 2.1, to calculate the area factors, although it models area factors conservatively. Another approach that has been successfully used is to develop the area factors by using the RESRAD–BUILD computer code and adjusting these derived area factors to account for the fact that RESRAD–BUILD typically gives less conservative dose estimates. With this approach, the screening DCGL values are converted into the appropriate concentration unit for RESRAD–BUILD [i.e., from (dpm per 100 cm^2) to (pCi/m^2)]. Area factors calculated by RESRAD–BUILD can then be adjusted by the ratio of the dose from RESRAD–BUILD to 0.25 mSv/y (25 mrem/y) (i.e., the equivalent dose from DandD).

I.3.3.3.6 Offsite Scenarios

In rare situations, the scenario resulting in the highest exposures from the residual radioactivity will be offsite use scenarios. For these evaluations, the dose limit remains that of 10 CFR 20, Subpart E, even though the situation may seem similar to the clearance of materials prior to license termination (see also Section G.1.1 of this volume). In these scenarios, the exposure to the radioactive material will occur because it has been removed from the current location, and this results in either new or enhanced exposure pathways. For example, a site has poor ground water characteristics (thereby, allowing the licensee to remove the ground water pathway from any applicable scenarios) and the reasonably foreseeable land use is either commercial or industrial. The primary contaminant is Tc-99, which primarily results in dose through either the ground water or vegetable pathways, both of which are not applicable to the physical characteristics of the site or land use assumptions. The residual radioactivity is present in the site's top soil. A possible offsite scenario is that during construction of any commercial interest on the site after license termination, the removed topsoil is sold for use in a residential setting. In this case, it is likely that the topsoil with residual radioactivity will be unintentionally mixed with other topsoil at the offsite location. Licensees can use generic analyses to screen the importance of offsite uses with such sources as NUREG-1640, "Radiological Assessments for Clearance of Materials from Nuclear Facilities." (NRC 2003)

Even if offsite use is not considered reasonably foreseeable, offsite scenarios may be less likely but plausible scenarios and should be analyzed as scenarios, to understand the robustness of the analysis.

I.3.3.3.7 Determining the Compliance Scenario

In many situations a licensee will be faced with selecting a compliance scenario from potentially a large suite of scenarios and exposure groups. The licensee is expected to base their demonstration of compliance on the exposure to the highest group, consistent with the definition of the critical group. Licensees may find it advantageous to use an iterative approach to screen all the potential scenarios. This will allow the licensees to focus their more detailed analyses on the important scenarios. Licensees may be able to use information from NUREG/CR-5512, NUREG-1640, and NUREG-1717, as well as other licensees' analyses to screen their potential scenarios with quantitative methods. Licensees also may be able to provide qualitative arguments to demonstrate that the dose from certain scenarios are bounded by the dose of higher level scenarios (e.g., a residential gardening scenario will bound the dose for the residential non-gardening scenario). The licensees should provide justifications on the basis, method, and results of their scenario screening in their DP.

Even after screening the scenarios, a licensee will likely be left with a few scenarios that may require detailed analyses to determine which will result in the critical group. For licensees with multiple radionuclides, commonly, determining the compliance scenario depends on the final mixture of radionuclides. This can provide a dilemma for licensees creating DCGLs. The licensee must show that the final concentrations at the site meet the dose criteria of 10 CFR Part 20, Subpart E. Three possible approaches that the licensee may use to show compliance are, but are not limited to the following:

1. Use the most limiting DCGL for each radionuclide, regardless of the scenario, and use the sum of fractions, ignoring the scenario basis for each DCGL. This approach requires limited justification. It will always either estimate the same dose as the individual scenarios or overestimate the dose. Generally, it will greatly overestimate the dose for the individual scenarios.

2. Use a surrogate approach to limit the number of radionuclides of importance. A surrogate approach relies on different radionuclides having relatively fixed ratios. For example, assume that at a site with cesium-137 and strontium-90 can show that for every 37 Bq/kg (1 pCi/g) of Cs-137, there will be a 18 Bq/kg (0.5 pCi/g) of Sr-90. By using this relationship, an effective DCGL for combined Cs-137 and Sr-90 can be created. The licensee may be able to reduce the number of critical scenarios, specifically those driven by exposure to Sr-90. This approach requires that the licensee have the necessary information on relative ratios of the radionuclides.

3. Commit to demonstrating the final dose for each of the important scenarios in the final status survey reports. This approach will require the licensee to establish operational DCGLs to fully utilize MARSSIM (see Section 2.5).

The licensee needs to provide either quantitative analysis of or a qualitative argument discounting the need to analyze all the scenarios generated from the less likely but plausible land uses. The results of these analyses will be used by the staff to evaluate the degree of sensitivity of dose to overall scenario assumptions (and the associated parameter assumptions). Analyses of less likely but plausible scenarios are not meant to be 'worst-case' analyses and should not utilize a set of 'worst-case' parameters. Selection of parameters for less likely but plausible scenarios should be consistent with the guidance in this Appendix. The reviewer will consider both the magnitude and time of the peak dose from these scenarios. If peak dose from the less likely but plausible land use scenarios is significant, the licensee would need to provide greater assurance that the scenario is unlikely to occur, especially during the period of peak dose. The licensee may be able to show that the compliance scenario bounds the results of all or many of the scenarios associated with the less likely but plausible land uses.

I.3.4 Generic Examples

The following examples are provided as situations where the default pathways may be removed or modified. Note, the examples assume that an adequate level of justification has been provided by the licensee.

I.3.4.1 Removal of Ground Water Pathways

A licensee has extensive contamination of the upper soil horizon and the upper aquifer, which is unconsolidated and the licensee wishes to remove the ground water pathway because the upper aquifer would not be used as a water source. The aquifer shows relatively high levels of microbial activity, turbidity, and nitrates. In addition, adjacent to the site is a small patch of wetlands that shows a great deal of communication with the upper aquifer. The potential yield rate of the upper aquifer is sufficient for domestic use, but there is a better-quality, confined aquifer, whose horizon is at a depth of approximately 30 meters (100 feet). The licensee has also demonstrated that the deeper aquifer will not become contaminated from the upper aquifer. Considering all of these reasons in combination, it is questionable whether the upper aquifer would actually be used. Although it may be possible for someone to treat the contaminants and use the aquifer, there are better sources of water easily available. After consultation with the EPA and the State, it is agreed that it would be unreasonable to assume someone would use the upper aquifer as a water source. Therefore, the licensee is allowed to remove the ground water pathway from the scenario.

I.3.4.2 Scenario Development for Buried Residual Radioactivity

I.3.4.2.1 Example 1: Subsurface Soil

A site has residual radioactivity buried at a few feet below the surface and the licensee is requesting unrestricted release. The residual radioactivity does not have enough highly energetic gamma-emitters to result in an external dose in the current configuration. Two exposure

scenarios can be developed (without any other site-specific information): (1) leaching of the radionuclides to the ground water, which is then used by a residential farmer; and (2) inadvertent intrusion into the buried residual radioactivity by house construction for a resident farmer with the displaced soil, which includes part of the residual radioactivity, spread across the surface. Exposure scenario 2 encompasses all the exposure pathways and, although not all of the source term is in the original position, leaching may occur both from the remaining buried residual radioactivity and the surface soil. Except for cases where an additional 0.6 m (2 ft) of unsaturated zone may make a tremendous difference in travel time to the aquifer, the ground water concentrations should be similar and, therefore, analysis of the second exposure scenario appears to be the appropriate scenario for the critical group exposure. This example is described in greater detail and integrated with the other guidance in Appendix J of this volume.

I.3.4.2.2 Example 2: Embedded Piping

At another site, the licensee is requesting unrestricted release of its site. It is removing the buildings, but is evaluating the need to remove the concrete pads, which have embedded piping that contains the residual radioactivity. Two scenarios can be reasonably envisioned. The first scenario involves a resident farmer onsite. The farmer builds a house on the concrete pad, without disturbing the embedded piping. Possible exposure pathways would be external dose from the piping and exposure to leached materials from the piping through ground water use (e.g., drinking, irrigation, etc.). The second scenario is similar to the building renovation scenario, where the concrete pad and piping are removed from the site. The licensee should investigate both to find the limiting scenario.

I.3.4.3 Scenario Development for Restricted Release

The site restrictions planned for an alternate site include a restriction, for this example, on the deed, on the use of the property for only parkland, and an engineered cover is placed over the residual radioactivity. The engineered cover is contoured for use as parkland and has a vegetative cover (i.e., not a mound covered in rip-rap). Three scenarios are easily envisioned for the restricted release analysis. The first is recreational use of the property as a city park or golf course, which would limit exposure scenarios to possible external exposure. The second would involve offsite use of ground water that contains radionuclides leached from the buried residual radioactivity. The default offsite user would be a resident farmer using the ground water for all water needs. The third scenario would be a worker maintaining the park.

The doses assuming the loss of the institutional control (i.e., the deed restriction) and degradation of the engineered cover also must be evaluated. Again, two main scenarios can be envisioned.

The first scenario is similar to the default exposure and would involve a residential farmer that uses ground water from the aquifer under the site. The engineered cover may have been compromised by the placement of the buildings, but the cover may still work in some degraded

function (e.g., the water infiltration rate would increase from the design rate to some higher rate, but probably not as high as the infiltration rate would have been if the cover had never been constructed). Whether buried residual radioactivity had been transported to the surface by the construction of a basement under the resident farmer's house would depend on the thickness of the engineered cover. If typical basement depth were deeper than the engineered cover's thickness, some portion of residual radioactivity would be transported to the surface, mixed with the "clean" cover material, and spread over the site.

The second scenario would involve possible erosion of the cover and subsequent exposure of an onsite resident to the buried radionuclides or radionuclides redistributed by surface water. The exposure scenario would still be a resident farmer. The reasonableness of this scenario would depend on the thickness and erosion-resistence of the engineered cover.

I.4 Criteria to Establish Conceptual Models

I.4.1 Introduction

Analyzing the release and migration of radionuclides through the natural environment and/or engineered systems, at a specific site, requires the licensee to interpret the nature and features of the site so that the site can be represented by mathematical equations (i.e., mathematical models). This simplified representation of the site, including the associated mathematical models, is commonly referred to as the conceptual model of the site.

Figure I.1 depicts the process of conceptual model development. In dose assessments, developing a conceptual model involves making an abstraction of site data into a form that is capable of being modeled. This development should generally involve making simplifying assumptions, including simplification of the appropriate governing equations, to reflect the physical setting. These simplifying assumptions are usually made in describing the geometry of the system, spatial and temporal variability of parameters, isotropy of the system, and the influence of the surrounding. The conceptual model should provide an illustration, or description, of site conditions, which shows, or explains, contaminant distributions, release mechanisms, exposure pathways and migration routes, and potential receptors. In other words, the conceptual model should explain or illustrate how radionuclides enter, move through, and/or are retained in, and leave, the environment.

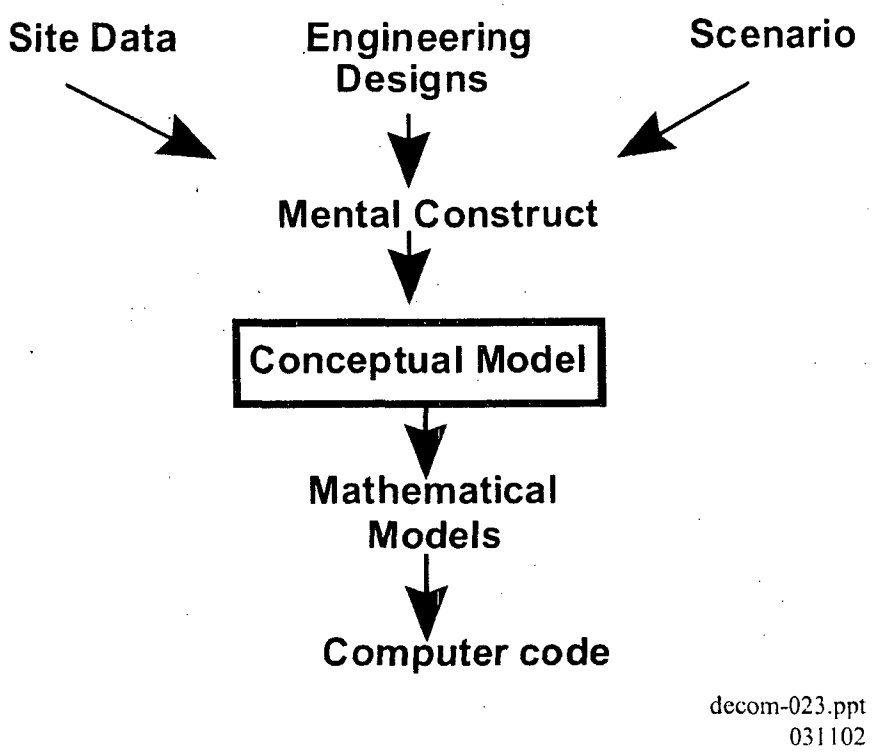

Figure I.1 Conceptual Model Development.

As shown in Figure I.2, developing a conceptual model at a site is Step 3 of the Decommissioning Decision Framework (see Section 2.6 of this volume). Conceptual model development follows after assimilation of site data (Step 1) and definition of scenarios (Step 2), because information from these two steps feeds into its development. In other words, the conceptual model should be based on what is known about the site from data and information gathered as part of Step 1, and how the site evolves during the period covered by the analysis based on the assumed land-use defined under Step 2.

Mathematical models are a quantitative representation of the conceptual model. Because the conceptual model provides the linkage between site conditions and features (Steps 1 and 2) and the computer code(s) (with its associated mathematical models) used in the dose analysis (Step 4 of the Decommissioning Framework), it is a key step in a dose assessment and should not be taken lightly.

exposed) and when they might get there (thus, the radionuclide concentration when it arrives). On the other hand, an overly complex conceptual model may introduce unnecessary uncertainty and costs into the analyses. As a broad example, simple models contained in screening codes may oversimplify features and processes at a specific site. The licensee also should ensure that the appropriate level of detail is provided in the conceptual model. It is important that the conceptual model have sufficient detail and scope for a license reviewer to be able to assess the appropriateness of the computer codes used in the analysis and the defensibility of the assumptions made. In summary, key issues in developing and presenting the conceptual model are: (a) identifying the important site features and processes that need to be included in the conceptual model; (b) deciding among possible competing interpretations of the site data; and (c) determining the level of detail needed to describe those features and processes.

I.4.3 Recommended Approach

I.4.3.1 Screening

An acceptable dose assessment analysis need not incorporate all the physical, chemical, and biological processes at the site. The scope of the analysis, and accordingly the level of sophistication of the conceptual model, should be based on the overall objective of the analysis. A performance assessment conceptual model can be simple if it still provides satisfactory confidence in site performance. For an initial screening analysis, little may be known about the site from which to develop a conceptual model. Computer codes used for screening analyses are generally intended to provide a generic and conservative representation of processes and conditions expected for a wide array of sites. Accordingly, the generic conceptual model in such codes may not provide a close representation of conditions and processes at a specific site. Such a generic representation is still acceptable as long as it provides a conservative assessment of the performance of the site.

The DandD code has two default land-use scenarios; a building occupancy and a resident farmer scenario. The building occupancy scenario is intended to account for exposure to both fixed and removable residual radioactivity within a building. Exposure pathways included in the building occupancy scenario include external exposure to penetrating radiation, inhalation of resuspended surface residual radioactivity, and inadvertent ingestion of surface residual radioactivity. The resident farmer scenario is intended to account for exposure to residual radioactivity in soil. Exposure pathways included in the resident farmer scenario include: external exposure to penetrating radiation; inhalation exposure to resuspended soil; ingestion of soil; and ingestion of contaminated drinking water, plant products, animal products, and fish. The predefined conceptual models within DandD are geared at assessing releases of radioactivity, transport to, and exposure along, these pathways.

For the building occupancy scenario, DandD models external exposure to penetrating radiation as an infinite area source, using surface source dose rate factors from Federal Guidance Report No. 12 (EPA, 1993). Exposure to inhalation of resuspended surface residual radioactivity is

modeled as a linear static relationship between surface residual radioactivity and airborne concentrations. The model accounts for ingrowth and decay. Exposure to incidental ingestion of surface residual radioactivity is modeled with a constant transfer rate.

The generic conceptual models for the resident farmer scenario are more complicated because of the large number of exposure pathways and considerations of release of radioactivity from the source area and transport of radionuclides in the environment. DandD models external exposure from volume soil sources when the person is outside as an infinite slab of residual radioactivity 15 cm (6 in) thick, using dose rate factors from Federal Guidance Report No. 12, for volume residual radioactivity. When the person is indoors, exposure from external radiation is modeled in a similar manner, except the exposure is assumed to be attenuated through the use of a shielding factor (note: the higher the shielding factor, the lower the assumed attenuation). Exposure through ingestion of contaminated animal and plant products is modeled simply through the use of transfer factors. Instantaneous equilibrium is assumed to occur between radionuclide concentration in the soil and the concentration in plants, and between animal feed and animal products.

The generic source-term conceptual model in DandD assumes a constant release rate of radionuclides into the water and air pathways. Release of radionuclides by water is assumed to be downward and a function of a constant infiltration rate, constant contaminant zone thickness, constant moisture content, and equilibrium adsorption. DandD assumes that there are no radioactive gas or vapor releases. Release of radioactive particulates is assumed to be upward, instantaneous, uniform, and a function of a constant particulate concentration in the air and the radioactivity within the soil. Radionuclides in the contaminant zone are assumed to be uniformly distributed in a single soil layer, 15 cm (6 in) thick. No transport is assumed to occur within the source zone, but radioactive decay is taken into account. In terms of containment, DandD assumes that there are no containers (or that they have failed), and that there is no cover over the contaminated zone.

The DandD generic conceptual model for the ground water pathway assumes a single hydrostratigraphic layer for each of the unsaturated and saturated zones. The unsaturated zone (vadose zone) can be broken into multiple layers within DandD; however, each layer is assumed to have the same properties. For radionuclides entering the vadose zone, DandD accounts for adsorption-limited leaching by considering the vadose zone to behave as a well-mixed chemical reactor with a constant water inlet and outlet rate set at the infiltration rate. Accordingly, it is assumed that the vertical saturated hydraulic conductivity of the unsaturated zone is greater than or equal to the infiltration rate (i.e., there is neither ponding nor runoff on the surface). The outlet concentration from one unsaturated zone layer to another is assumed to be a function of the constant infiltration rate, equilibrium partitioning, the thickness of the layer, a constant moisture content, and radioactive decay. Radionuclides entering the saturated zone are assumed to be instantaneously and uniformly distributed over a constant volume of water equivalent to the larger of either the volume of infiltrating water (i.e., the infiltration rate times the contaminated area) or the sum of the water assumed to be removed for domestic use and irrigation. Based on the default parameters in DandD, dilution in the ground water pathway is based on the water use.

No retardation is assumed to occur in the aquifer; however, radioactive decay is taken into account. A volume of contaminated water equivalent to the irrigation volume is assumed to be returned annually to the source zone. The concentration of radionuclides in the irrigation water is assumed to remain constant during the year. Radionuclides deposited on the vegetation are assumed to be removed at a constant rate. The DandD ground-water model should generally provide a conservative representation of the ground water system because it allows very little dilution and nominal attenuation.

The generic surface-water conceptual model in DandD assumes that radionuclides are uniformly mixed within a finite volume of water representing a pond. Radionuclides are assumed to enter the pond at the same time and concentration as they enter the ground water. Accordingly, there is assumed to be no transport of radionuclides through the ground water to the pond and thus no additional attenuation (besides the initial ground water dilution) is assumed for transport in the ground water. The surface-water model within DandD should provide a conservative dose estimate as long as a small volume is assumed for the surface-water pond. Because the parameters in DandD are selected to provide a conservative dose estimate, the generic conceptualization of the surface-water pathway should generally provide a conservative representation of transport of radionuclides through the surface-water pathway. Figure I.3 shows the generic ground-water and surface-water conceptual model within DandD.

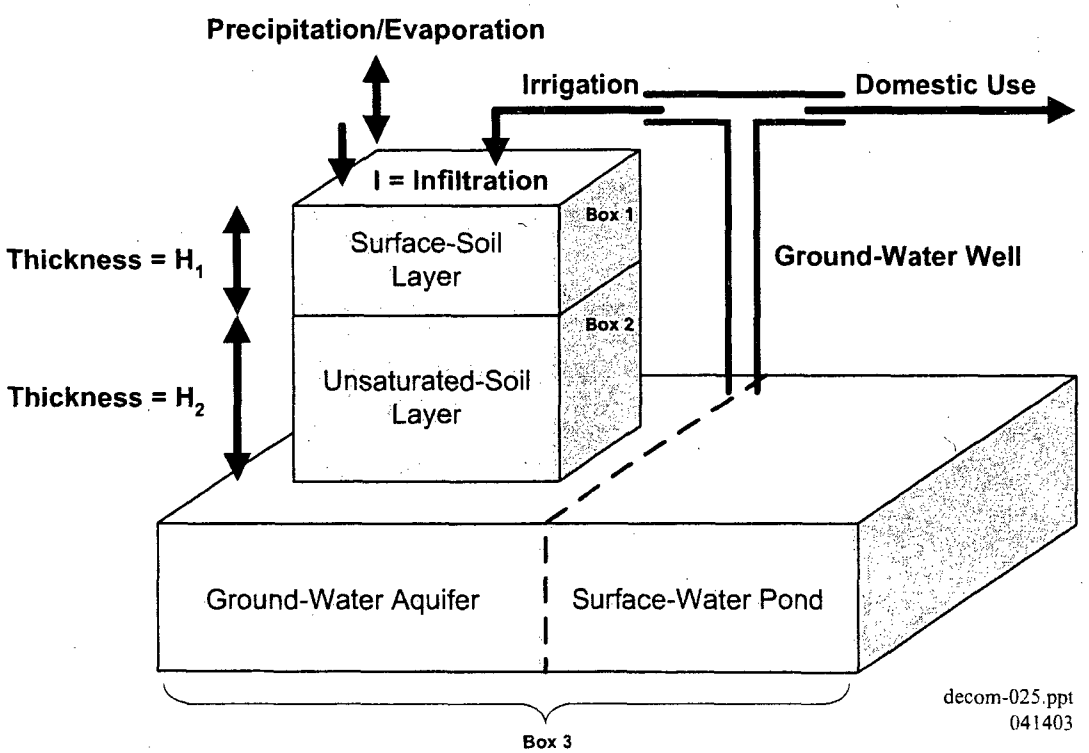

Figure I.3 DandD Conceptual Model of the Ground-Water and Surface-Water Systems (from NUREG/CR–5621).

The generic conceptual model of the air pathway in DandD assumes an equilibrium distribution between radionuclides in the air and soil. The concentration in air is assumed to be a function of the soil concentration and a constant dust loading in the air. Accordingly, all radionuclides in the air are assumed to be in a particulate form. The air pathway model within DandD is very simple and should generally allow a conservative dose estimate as long as a conservative particulate concentration is assumed. Because the default parameters in DandD are geared to be conservative, in general the air pathway in DandD should allow a conservative dose estimate.

In general, the conceptual models within DandD are expected to provide a conservative representation of site features and conditions. Therefore, for screening analyses, NRC staff should consider such generic conceptual models to be acceptable provided it is acceptable to assume that the initial radioactivity is contained in the top layer (building surface or soil) and the remainder of the unsaturated zone and ground water are initially free of residual radioactivity. In using DandD for site-specific analyses, it is important to ensure that a more realistic representation of the site that is consistent with what is known about the site would not lead to higher doses. Some site features and conditions that may be incompatible with the generic conceptual models within DandD are listed in Table I.4. The relative importance of the incompatibilities varies with the scenario and radionuclides involved. More information on the assumptions of the model available in the development documentation (e.g., the NUREG/CR–5512 series).

For any site where it is known that one or more of these conditions or features are present, the licensee should provide an appropriate rationale on why the use of the DandD should not result in an underestimation of potential doses at the specific site.

Table I.4 Site Features and Conditions that May be Incompatible with Those Assumed in DandD

- Sites with highly heterogeneous radioactivity
- Sites with wastes other than soils (e.g., slags and equipment)
- Sites that have multiple source areas
- Sites that have contaminated zones thicker than 15 cm (6 in.)
- Sites with chemicals or a chemical environment that could facilitate radionuclide releases (e.g., colloids)
- Sites with soils that have preferential flow conditions that could lead to enhanced infiltration
- Sites with a perched water table, surface ponding, or no unsaturated zone
- Sites where the ground water discharges to springs or surface seeps
- Sites with existing ground water contamination
- Sites where the potential ground water use is not expected to be located immediately below the contaminated zone
- Sites with significant transient flow conditions
- Sites with significant heterogeneity in subsurface properties
- Sites with fractured or karst formations
- Sites where the ground water dilution would be less than 2000 m^3 (70,000 ft^3)
- Sites where overland transport of contaminants is of potential concern
- Sites with radionuclides that may generate gases
- Sites with stacks or other features that could transport radionuclides to result in a higher concentration offsite than onsite

As example, it may be possible to demonstrate the acceptable use of DandD for analyzing sites that contain H-3 and C-14, although both radionuclides may be occur as a gas. The following approach can be used to demonstrate the acceptable use of DandD for analyzing sites that contain either H-3 or C-14 (NRC 1999a): (1) determine the area of the contaminated zone; (2) run DandD for the site with only H-3 or C-14; (3) read the associated activity ratio factor for the given area from Figure I.4; and (4) estimate the potential missed dose by multiplying the inhalation dose calculated from DandD by the activity ratio factor.

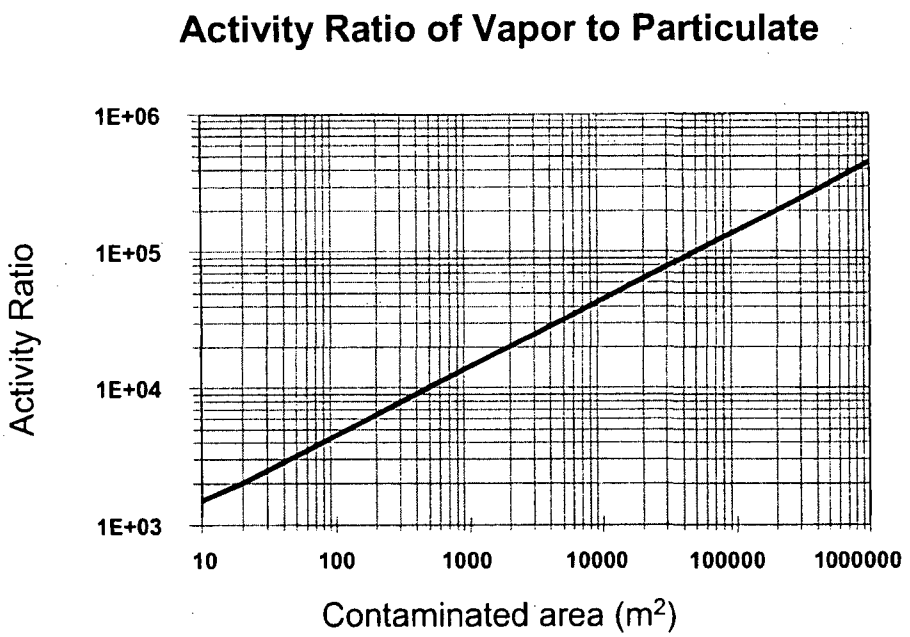

Figure I.4 Activity Ratio of Vapor to Particulate as a Function of Contaminated Area.

I.4.3.2 Site-Specific

For site-specific analyses, the intent is to provide a more realistic assessment of doses based on more site-specific information and/or data. Presumably for such analyses, more is known about the site from which to develop a conceptual model. For site-specific analyses, the licensee should provide a schematic or verbal description of the problem that it is attempting to analyze. Even when using a computer code that has a predefined conceptual model, it is important for the licensee to identify any site features or conditions that may differ from those assumed in the code. In developing a site-specific conceptual model or identifying potential limitations with a predefined conceptual model, the issues listed in Table I.5 should be considered.

Because conceptual models are developed based on limited data, in most cases more than one possible interpretation of the site can be justified based on the existing data. This uncertainty should be addressed by developing multiple alternative conceptual models and proceeding forward with the conceptual model(s) that provides the most conservative estimate of the dose and *yet is consistent with the available data.* Consideration of unrealistic and highly speculative conceptual models should be avoided. Consistent with the overall dose modeling framework of starting with simple analyses and progressing to more complex modeling, as warranted, it may be advisable for the analyst to begin with a simple, conservative analysis that incorporates the key site features and processes and progress to more complexity only as merited by site data. It is important to stress that a simple representation, of the site, in itself does not mean that the analysis is conservative. It is incumbent on the licensee to demonstrate that its simplification is

justified, based on what is known about the site and the likelihood that alternative representations of the site would not lead to higher calculated doses.

Table I.5 Issues To Be Considered in Developing a Site-Specific Conceptual Model

- Whether a more realistic representation of the site would lead to higher doses
- Whether the conceptual model accounts for the most important physical, chemical, and biological processes at the site
- Whether the conceptual model adequately represents responses to changes in stresses
- Whether the conceptual model includes consistent and defensible assumptions

In general, there are two primary areas of the dose analysis where the conceptual model is expected to change from one site to another; these are related to the source term and environmental transport. Aspects of the analysis related to the exposure pathways in the biosphere and dosimetry are largely determined by the scenario and the assumed behavior of the critical group. Accordingly, models related to the exposure pathways in the biosphere and dosimetry should not change from one site to another unless there is a significant change in the scenario and associated critical group. The principal environmental transport pathways that should have to be considered in a dose assessment are ground water (including transport through the unsaturated zone), surface water, and air.

The conceptual model of the source area should describe the contaminants and how they are likely to be released into the environment. Specifically, it should describe key features and processes such as the infiltration of water into the source area, the geometry of the source zone, the distribution of contaminants, release mechanisms, the physical form of the contaminants, near-field transport processes, and containment failure. If the contaminants are assumed to be uniformly distributed, this is an important assumption that needs to be justified because in general contaminants may not be uniformly distributed (see discussion under Section I.2 of this appendix). The source description should clearly identify how the contaminants are assumed to be released from the media. Common release mechanisms are diffusion, dissolution, surface release, and gas generation. The source description should also identify key processes and features that may retain or limit the release of contaminants from the source area (e.g., solubility and sorption). In addition, the description of near-field transport should state assumptions made regarding the dimensionality. In general, the assumption of one-dimensional vertical flow should be appropriate, unless there is some type of barrier present that may hinder flow in the vertical direction. The description of the source term should also describe failure mechanisms for any containment (e.g., corrosion, concrete degradation, or cover degradation) if containers or other forms of containment are present.

The conceptual model of the ground water pathway should describe how contaminants could migrate through the unsaturated and saturated zones to potential receptors (e.g., a well, spring, or surface-water bodies). Essential features that should be included in the conceptual model include hydrostratigraphic units; information on the geometry of the pathway (i.e., boundaries and boundary conditions); the physical form of the contaminants (i.e., dissolved, suspended sediment, gas, etc.); structural features of the geology (i.e., those that influence contaminant transport such as fractures, faults, and intrusions); and physical and chemical properties. Important processes that should be characterized include the dimensions and state conditions (e.g., steady-state) of flow; dimensions and state conditions of transport (e.g., dispersion); chemical and mass transfer processes (e.g., sorption, precipitation, complexation); and transformation processes (e.g., radioactive ingrowth and decay). Although contaminant migration through both the unsaturated and saturated zones is best represented in three dimensions, it may be appropriate to assume only one or two dimensions, if this provides a more conservative representation of contaminant migration, and/or if it can be demonstrated that migration in one or more other directions is not expected to result in exposure to potential receptors.

The conceptual model of the surface-water pathway should describe potential contaminant migration through surface-water bodies such as lakes, streams, channels, or ponds to potential receptors. Essential features that should be included in the conceptual model include: the geometry of the surface-water body (i.e., boundaries and boundary conditions); the physical form of the contaminants (e.g., dissolved or solid); and physical and chemical properties. Key processes that should be described include: the dimensions and state conditions of flow and transport; chemical and mass transfer processes (e.g., sorption, precipitation, volatization); and transformation. One key boundary condition that should be described is how the contaminants are expected to initially mix or interact with the surface water.

The conceptual model of the air pathway should describe potential contaminant migration through the air to potential receptors. Essential features that should be included in the conceptual model are similar to those for the other environmental pathways—namely, the geometry (i.e., boundaries and boundary conditions); form of contaminants (e.g., particulates or gases); and physical and chemical properties. Key processes that should be described include the dimensions and state conditions of flow and transport, and transformation processes.

I.4.3.2.1 Site-Specific Computer Codes

Two common computer codes used for site-specific analyses are RESRAD and RESRAD–BUILD. Both these computer codes have predefined conceptual models. Therefore, in using these codes, it is important for the licensee to demonstrate that key site features and conditions are consistent with the modeling assumptions within the codes or, where they are not consistent, the analysis may not result in an underestimation of potential doses.

I.4.3.2.1.1 RESRAD–BUILD

The RESRAD–BUILD code can be used to evaluate doses for the building occupancy scenario.

It considers exposure from external radiation at the source and air submersion, inhalation of airborne material, and inadvertent ingestion of radioactive material. Exposure to direct radiation at the source is calculated using surface source dose rate factors from Federal Guidance Report No. 12. RESRAD–BUILD incorporates correction factors to account for a finite area source, for any offset of the receptor from the axis of the disk of residual radioactivity, and for shielding by material covering the residual radioactivity. Exposure to external radiation from air submersion is calculated as an infinite cloud of material using dose rate conversion factors for an infinite cloud. RESRAD–BUILD models airborne concentration of radionuclides using a dynamic model that accounts for the kinetic introduction and removal of radioactive material to and from indoor air. Exposure to incidental ingestion of radioactive material is modeled using a constant transfer rate.

I.4.3.2.1.2 RESRAD

RESRAD can be used for analyzing the resident farmer scenario. As with the generic conceptual models used by DandD for analyzing the resident farmer scenario, the conceptual models in RESRAD (see Figure I.5) are more complex than those in RESRAD–BUILD. RESRAD models external exposure from volume soil sources when the person is outside, using volume dose rate factors from Federal Guidance Report No. 12. Correction factors are used to account for soil density, areal extent of residual radioactivity, thickness of residual radioactivity, and cover attenuation. When the person is indoors, exposure from external radiation is modeled in a similar manner except that additional attenuation is included to account for the building. Exposure through ingestion of contaminated animal and plant products is modeled simply through the use of transfer factors.

The generic source-term conceptual model in RESRAD assumes a time-varying release rate of radionuclides into the water and air pathways. Radionuclides in the contaminant zone are assumed to be uniformly distributed. No transport is assumed to occur within the source zone, but radioactive decay is accounted for. In terms of containment, the radioactive material is not assumed to be contained (or containers are assumed to have failed). RESRAD does allow inclusion of a cover over the contaminated area. However, the cover is not assumed to limit infiltration of water, and is assumed to function only in terms of providing shielding from gamma radiation. Release of radionuclides by water is assumed to be a function of a constant infiltration rate, time-varying contaminant zone thickness, constant moisture content, and equilibrium adsorption. The contaminant zone is assumed to decrease over time from a constant erosion rate. RESRAD assumes a uniform release of tritium and C-14 gases, based on a constant evasion loss rate. Particulates are assumed to be instantaneously and uniformly released into the air as a function of the concentration of particulates in the air, based on a constant mass loading rate.

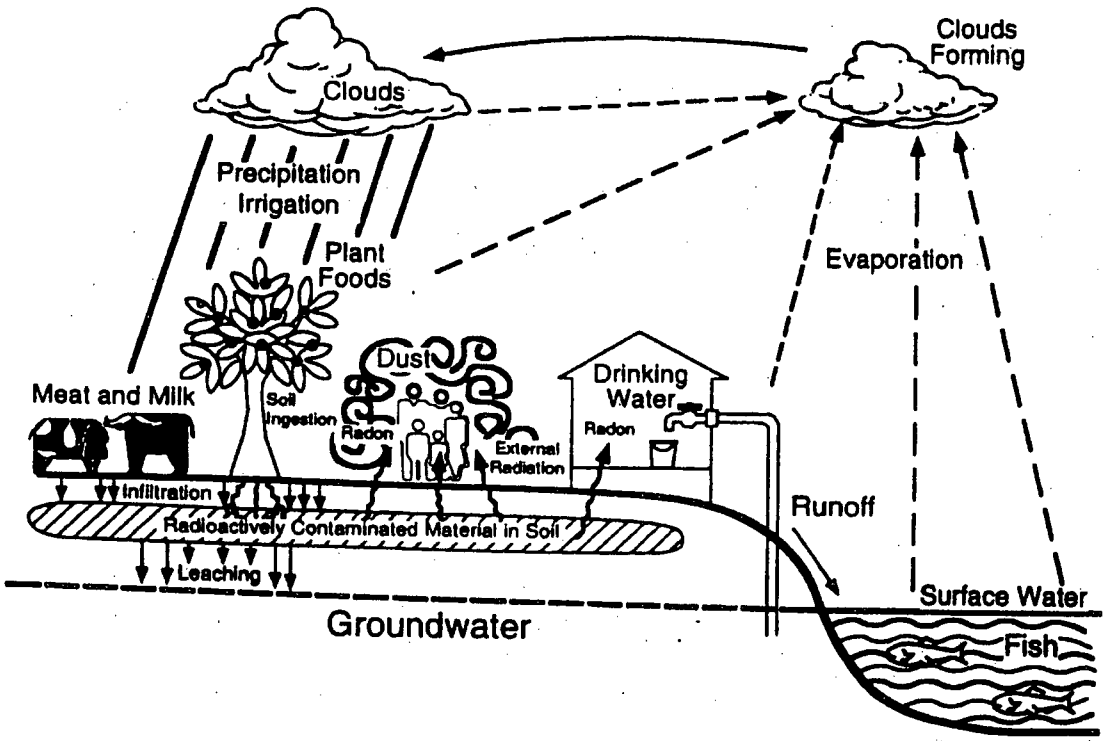

Figure I.5 Conceptualization Modeled by RESRAD (from ANL/EAD/LD–2).

The RESRAD generic conceptual ground-water model assumes one or more horizontal homogeneous strata for the unsaturated zone. Transport in the unsaturated zone is assumed to result from steady-state, constant vertical flow, with equilibrium adsorption, and decay, but no dispersion. RESRAD has two different ways of modeling radionuclides once they reach the saturated zone. In the mass-balance approach, radionuclides entering the saturated zone are assumed to be instantaneously and uniformly distributed over a constant volume equivalent to the volume of water removed by the hypothetical well (as long as the pumping rate is larger than the rate of leachate entering the ground water—if not, no dilution is assumed to occur in the ground water). For the mass-balance approach, radionuclides are assumed to enter a well pumping immediately beneath the contamination zone. The mass-balance approach is very similar to the ground-water modeling approach in DandD. In the nondispersion approach, transport in the saturated zone is assumed to occur in a single homogeneous stratum, under steady-state, unidirectional flow, with a constant velocity, equilibrium adsorption, and decay. It assumes no dispersion; however, radionuclides are assumed to be diluted by clean water as a function of the assumed capture zone of the hypothetical well, in relation to the width of residual radioactivity and the depth of residual radioactivity, in relation to the depth of the hypothetical well. Radioactive decay and equilibrium adsorption are assumed to occur for the nondispersion approach. Radionuclides are assumed to enter a well located at the immediate downgradient

edge of the contamination zone. For the nondispersion model, the calculated width of the effective pumping zone could be a factor of 2 larger than what one would predict from a steady-state capture zone analysis; this could lead to a slight overestimation in the amount of dilution (NRC 1999a).

In determining which of these two conceptual models to use, consideration should be given to where the hypothetical well may be located (i.e., either at the center of the residual radioactivity or at the edge of the residual radioactivity); the relative half-life of the radioactivity; and the potential capture zone of the hypothetical well. Use of the nondispersion model will generally result in lower estimated doses. Both models assume that radionuclides enter the well as soon as they reach the water table. However, the nondispersion model, unlike the mass-balance model, calculates the time it takes for the peak concentration to occur after the initial breakthrough. Accordingly, the nondispersion model accounts for radioactive decay during the interval between the initial breakthrough and arrival of the peak concentration. Generally, the amount of decay should be small unless the radionuclides have short half-lives and are retarded. In addition, unlike with the mass-balance model, for the nondispersion model no assumption is made that all radionuclides released from the contaminated zone are withdrawn through the well. Therefore, the nondispersion model may include dilution. The only way that dilution is not considered is if the expected capture zone of the hypothetical well is small in relation to the width and thickness of the residual radioactivity. Because the nondispersion model will generally give a lower estimated dose than the mass-balance model, it is important for the licensee to justify the use of this model for the specific analysis. Use of the mass-balance approach should always be acceptable. In Equations I–1 and I–2, use of the nondispersion model should be acceptable, without additional justification, for modeling long-lived radionuclides (i.e., where radioactive decay is not important) when either one of the following conditions are met:

$$\frac{U_w}{v \bullet d_w} > \frac{A}{len} \quad \text{and}$$

$$\left(\frac{I}{v}\right) len < d_w \qquad \textbf{(I–1)}$$

or

$$\frac{U_w}{v \cdot d_w} \leq \frac{A}{len} \quad \text{and}$$

$$\left(\frac{I}{v}\right) len \geq d_w \qquad \textbf{(I–2)}$$

where U_w = pumpage rate from the well (m^3/y);
v = ground-water darcy velocity (m/y);
A = area of residual radioactivity (m^2);
d_W = depth of well intake below water table (m);
len = length of residual radioactivity parallel to ground water flow (m); and
I = infiltration rate (m/y).

As a general rule, use of the nondispersion approach should be acceptable when the area of residual radioactivity is known to be larger than the assumed capture area of the hypothetical well. Assuming an essentially flat water table and steady-state conditions, the capture area of the hypothetical well can be calculated in Equation I–3 as follows:

$$A_w = \left(\frac{U_w}{I}\right) \qquad \textbf{(I–3)}$$

where A_W = area of well capture (m^2);
U_W = pumpage rate from the well (m^3/y); and
I = infiltration rate (m/y).

The generic conceptual model of the surface-water pathway in RESRAD assumes that radionuclides are uniformly distributed in a finite volume of water within a watershed. For example, the default watershed area in RESRAD Version 5.91 is 1×10^6 m^2 (250 ac). Radionuclides are assumed to enter the watershed at the same time and concentration as in the ground water. Accordingly, no additional attenuation is considered as radionuclides are transported to the watershed. In the surface water, radionuclides are assumed to be diluted as a function of the size of the contaminated area in relation to the size of the watershed. The RESRAD surface-water conceptual model assumes that all radionuclides reaching the surface water are derived from the ground water pathway. Thus, transport of radionuclides overland from runoff is not considered. In addition, additional dilution from overland runoff is not considered.

The generic conceptual model of the air pathway in RESRAD uses a constant mass loading factor and area factor to model radionuclide transport. The area factor, which is used to estimate the amount of dilution, relates the concentration of radionuclides from a finite area source to the concentration of radionuclides from an infinite area source. It is calculated as a function of particle diameter, wind speed, and the side length of a square-area source. The conceptual model assumes a fixed particle density, constant annual rainfall rate, and constant atmospheric stability. No radioactive decay is considered. See Chang, et al., (1998) for more detail. Tritium and C-14 gases are assumed to be uniformly mixed in a constant volume of air above the contaminated zone. RESRAD does not model the transport of tritium and C-14 as particulates in the air.

I.4.3.2.2 Limitations of Site-Specific Computer Codes

In general, the conceptual models within RESRAD and RESRAD–BUILD are expected to provide an acceptable generic representation of site features and conditions. Some specific site features and conditions that may be incompatible with this generic representation are listed in Table I.6. At any site where it is known that one or more of these conditions or features are present, the licensee should provide appropriate justification for use of the computer code.

Table I.6 Site Features and Conditions that May be Incompatible with the Assumptions in RESRAD

- Sites with highly heterogeneous radioactivity
- Sites with wastes other than soils (e.g., slags and equipment)
- Sites with multiple source areas
- Sites that have chemicals or a chemical environment that could facilitate radionuclide releases
- Sites with soils that have preferential flow conditions that could lead to enhanced infiltration
- Sites where the ground water discharges to springs or surface seeps
- Sites where the potential ground water use is not expected to be located in the immediate vicinity of the contaminated zone
- Sites with significant transient flow conditions
- Sites with significant heterogeneity in subsurface properties
- Sites with fractured or karst formations
- Sites where overland transport of contaminants is of potential concern
- Sites with stacks or other features that could transport radionuclides off the site at a higher concentration than onsite

I.4.4 Generic Examples

I.4.4.1 Screening

A hypothetical research and development (R&D) facility is authorized to use radiological chemicals through an NRC license. Because the R&D facility plans to discontinue its use of radioactive material, it wants to decommission the facility and terminate its license. A historical site assessment (HSA) reveals that use of radioactive material were limited to a single building

within the facility. The floor area of the facility is estimated to be 560 m^2 (6000 ft^2). The wall area is 430 m^2 (4600 ft^2). In addition, an outside area of roughly 930 m^2 (10,000 ft^2) was used for dry storage of chemicals. A preliminary characterization program has determined that approximately 10 % of the building floor area and 5 % of the wall area are contaminated with Cs-137 and Co-60. Surficial soils covering an area of approximately 2500 m^2 (27,000 ft^2) are contaminated from windblown dust and runoff from spills in the storage area. The soils are also contaminated with Cs-137 and Co-60.

The licensee proposes to use a screening analysis, using DandD, to demonstrate compliance with the LTR. A building occupancy scenario is assumed for the building and a residential farmer scenario is assumed for the contaminated soils. Based on what is known about the site, the licensee certifies that the use of the generic conceptual models within DandD is appropriate for the analysis.

I.4.4.2 Site-Specific

A hypothetical manufacturing facility has a former radioactive waste burial area that may be decommissioned for unrestricted release. Radioactively contaminated trash was previously buried in 0.2 cubic meter (55-gallon) drums, in trenches covering an area of roughly 2000 m^2 (22,000 ft^2). The trenches, which are roughly 0.9 m (3 ft) deep are covered with 1.2 m (4 ft) of native soil. A review of site operating records show that the radionuclides of concern are natural uranium, enriched uranium, and natural thorium.

Based on information from the local county agricultural extension office and published reports, the geology and hydrogeology at the site are described as follows. This description shows that none of the site features or conditions in Table I.6 are present at this site.

> "The surface geology at the site contains 14 to 27 m (46 to 89 ft) of till consisting primarily of fine, silty sand to sandy silt with narrow, discontinuous sand lenses. Sandstone bedrock underlies the unconsolidated till. A shallow unconfined aquifer occurs in the unconsolidated till. The average depth to the water table ranges between three to four meters below the land surface. The mean horizontal hydraulic conductivity is roughly 60 m/y (197 ft/y). The average vertical hydraulic conductivity of the till is estimated to be an order of magnitude less. The hydraulic gradient is estimated to range between 0.006 to 0.021. The mean precipitation at the site is roughly 0.8 m/y (30 in/y). The site is located in the reach of a surface water drainage basin that has a drainage area of approximately 500,000 m^2 (5.4 million ft^2)."

A residential farmer scenario is assumed as a reasonable future land use. The licensee proposes to use the RESRAD computer code for the dose analysis. Because the contaminated media is trash, an assumption is made that the trash degrades and becomes indistinguishable from soil. In addition, the metal drums are assumed to have degraded away. Given the relative short lifespan for metal drums and the long half-life of the radionuclides, this should be a reasonable assumption. The cover is also assumed to be breached through the construction of a basement

for the house. The contaminated soil is assumed to be uniformly mixed with the excavated cover. Because the trash is assumed to be indistinguishable from soil, it is also assumed that once the cover is breached the future hypothetical farmer may not recognize the contaminated material as contaminated. The licensee also assumes that the hypothetical future well is located at the center of the residual radioactivity because of limited bases for assuming otherwise.

The licensee determines that the other aspects of conceptual models within RESRAD are acceptable for analyzing the problem.

I.5 Criteria for Selecting Computer Codes/Models

I.5.1 Introduction

Dose assessment commonly involves the execution of numerical model(s) that mathematically represent the conceptual model of the contaminated site. The numerical models used to implement the mathematical equations are usually linked via the conceptual model and codified in a software package known as "the code." The words "code" and "model" are frequently used to express the software package, including the embedded numerical models or the specific models contained in the code. For example, "DandD code" may refer to the software package, including the associated exposure models (e.g., the water-use model, food-ingestion pathway model, inhalation-exposure model, etc.) embedded in the code. The "DandD model" may also refer to DandD software, the DandD conceptual model, or to any of the numerical models, or the group of models used in the code (e.g., DandD ground water model). Within the context of this volume, the word "code" will refer to the software package and the associated numerical models. However, the word "model" will refer to the mathematical representation of the conceptual model, including representation of the specific exposure scenario and pathways. This section describes the process and criteria used in selection of codes and models for the dose assessment.

The codes and models used in the dose assessment can be either generic screening codes/models or site-specific codes/models. Regardless of the intent of the use of the code/model (e.g., for screening or site-specific analysis), NRC staff should ensure that the dose assessment codes/models and the associated databases are properly documented and verified in accordance with a rigorous QA/QC criteria which is acceptable to NRC staff. Currently, the only acceptable generic screening code is DandD Version 2. If site-specific models/codes are used, a justification of the conceptual model should be provided (see Section I.4.3.2 of this appendix). NRC staff should also review the source-term model(s), the transport models, the exposure models, and the overall dose models. NRC staff should assess the QA/QC documentation and the level of conservatism of any alternate code/model.

This section describes the generic issues associated with the selection of the screening and site-specific codes/models that NRC staff may encounter, and recommends approaches and criteria, for NRC staff acceptance of the codes/models. In addition, this section presents as

generic description of the two common dose assessment codes, DandD Screen and RESRAD/RESRAD–BUILD. NRC staff developed or modified these codes. In addition, these codes have been used by NRC staff and licensees for demonstrating compliance with the dose criteria in Subpart E.

I.5.2 Issues in Selection of Computer Codes/Models

The major issues associated with the selection of computer codes/models include:

1. **Generic criteria for the selection of computer codes/models**: This issue pertains to NRC staff's review criteria of code aspects related to QA/QC requirements, specifications, testing, verification, documentation, interfacing, and other features related to uncertainty treatment approaches.

2. **Acceptance criteria for selection of site-specific codes/models**: This issue pertains to NRC staff's review of additional specific requirements for the justification of the use of the conceptual model, the numerical mathematical models, the source-term model and its abstraction, and the transport and exposure pathway models.

3. **Options for selection of deterministic or probabilistic site-specific codes**: This issue pertains to NRC staff's review of the justification to support the decision to use either of these two approaches.

A generic description of the DandD Version 2 is presented below to familiarize users with this code. Further, the rationale for development of DandD Version 2 and the issue of excessive conservatism in DandD Version 1 are also addressed. A description of the inherent excessive conservatism in DandD model and approaches to minimize such excessive conservatism, using DandD Version 2, site-specific input data, or use of other models/codes is included.

For site-specific analysis, NRC staff should accept any model or code that meets the criteria described below in "Generic Criteria for Selection of Codes/Models." However, NRC staff is expected to conduct a more detailed and thorough review of less common codes/models (e.g., codes other than DandD, and RESRAD), specifically those developed by licensees. NRC sponsored development of the probabilistic RESRAD (Version 6) and RESRAD–BUILD (Version 3) codes for site-specific analysis. These have already been reviewed for QA/QC and are acceptable.

Selection of appropriate models/codes for complex sites may also present challenges. For example, sites with multiple source terms, with significant ground water/surface water contamination, or sites with existing offsite releases, may require more advanced codes/models than common codes such as DandD or RESRAD. Complex sites may also include sites with engineered barrier(s), or with complex geological conditions like highly fractured geologic formations. Because of site complexity and variability, there is no standard dose analysis review criteria for these sites.

I.5.3 Recommended Approach

I.5.3.1 Generic Criteria for Selection of Codes/Models

The generic criteria under this subsection pertain to NRC staff review of codes/models other than commonly used codes, specifically, those developed or modified by NRC staff (i.e., other than DandD and RESRAD/RESRAD–BUILD). NRC staff should use the generic criteria when the codes/models have no readily available documentation of testing, verification, and QA/QC review. In this context, NRC staff should use the following generic criteria in reviewing the codes/models selected for the dose assessment:

- NRC staff should review the adequacy and completeness of the database available regarding QA/QC aspects of the code/model. The QA/QC database should be comparable to NRC's QA/QC requirements [NUREG/BR–0167 (Douglas 1993) and NUREG–0856 (NRC 1983)]. The QA/QC should include information regarding mathematical formulation, code/model assumptions, consistency of the pathways with the assumed conceptual model(s) used in the code, and accuracy of the software to reflect the model's mathematical formulation and correct representation of the process or system for which it is intended.
- NRC staff should ensure that the software used for the code are in conformance with the recommendations of IEEE Standard 830–1984, IEEE Guide for Software Requirement Specifications.
- NRC staff should review the adequacy and appropriateness of the code/model documentation with regard to: (a) software requirements and intended use; (b) software design and development; (c) software design verification; (d) software installation and testing; (e) configuration control; (f) software problems and resolution; and (g) software validation.
- For uncommon codes/models, NRC staff should review code data including: (a) a software summary form; (b) a software problem/change form; (c) a software release notice form; and (d) a code/model user's manual, which covers code technical description, software source code, functional requirements, and external interface requirements (e.g., user interface, hardware interface, software interface, and communication interface), if necessary.
- NRC staff should review the conceptual model of the selected code to ensure compatibility with the specific site conceptual model, including the pathways and the exposure scenario. The source-term assumptions of the selected code should also be compatible with site-specific source term. NRC staff may accommodate minor modifications in the source-term conceptual model, as long as the basic model assumptions are not violated.
- NRC staff should review the selected code to verify that the exposure scenario of the selected code is compatible with the intended scenario for the site. For example, models/codes designed for the onsite exposure scenario may not be appropriate for assessment of an offsite receptor scenario or a scenario to estimate an offsite collective public dose.

- NRC staff should review the selected model/code formulation to account for radionuclide decay and progenies. The code should have proper and timely formulation, as well as linkages of decay products with the receptor location and the transport pathways, via corresponding environmental media;
- NRC staff should examine documentation of the selected code/model performance; specifically, test and evaluation, as well as code comparison with commonly used (accepted) codes and models (e.g., DandD and RESRAD codes). NRC staff should also review documentation on code/model verification, if available, to support decisions for code acceptance.
- NRC staff should review code/model features regarding sensitivity/uncertainty analysis to account for variability in selection of input parameters and uncertainty in the conceptual model and multiple options for interpretation of the system.

I.5.3.2 Acceptance Criteria for Selection of Site-Specific Codes/Models

This issue involves NRC staff's review of additional requirements supporting the justification for using the conceptual model, the numerical mathematical models, the source-term model and its abstraction, and the transport- and exposure-pathway models.

CONCEPTUAL MODELS

NRC staff review should compare the conceptual model for the site with the conceptual model(s) in the selected code, to ensure compatibility with site-specific physical conditions and pathway assumptions for the critical group receptor.

NUMERICAL MATHEMATICAL MODELS

NRC staff should review the equations used in the code to implement the conceptual model and the numerical links between mathematical models to ensure correctness and consistency. For codes developed or modified by NRC staff (e.g., DandD, RESRAD & RESRAD–BUILD), NRC staff review would be minimal because these codes were revised by NRC staff and examined early for consistency with NRC's QA/QC requirements. For less commonly used codes, or codes developed locally by user(s), NRC staff should verify the numerical mathematical models, including the numerical links between these models. In this context, NRC staff may examine, if necessary, each mathematical model used for the specific transport-exposure pathway, to ensure that the code is designed for its intended use.

SOURCE-TERM MODELS

NRC staff should review the source-term model(s) used for the specific site. In this context, NRC staff review should include the following source-term aspects:

- **Building Occupancy Scenario Source Term**: NRC staff should review the HSA and other relevant data regarding extent of the source term and its depth [e.g., within 1 to 10 mm (0.04 to 0.39 in) deep into the building surface or more]. Based on this review, NRC staff should identify the source term as surficial or volumetric source. In addition, NRC staff should examine assumptions made for the loose/fixed fractions of the source. Sources of residual radioactivity on surfaces that are not integral parts of the building (e.g., equipment, pipes, and sewer lines) should be addressed separately, because the applicable model and exposure scenario could be different. Therefore, source-term model assumptions for such surfaces should be reviewed on a case-by-case basis.

  NRC staff should also review the source term regarding radionuclide mixture and if a constant ratio is assumed in the dose analysis. NRC staff should determine if surrogate radionuclides are used in the source-term model assumption. The latter two situations may require additional NRC staff verification of the source-term model and review of consistency with the intended final survey methodology.

  NRC staff should also review the use of multiple sources (e.g., multiple rooms). Certain codes may use advanced source-term assumptions, such as two to three rooms, with multiple-story buildings. The source term under these conditions allows for source depletion due open air circulation and common ventilation. For example, the RESRAD–BUILD code model uses two- or three-room models with two- or three-story buildings, allowing for air exchange within the rooms, and source-term depletion. The indoor air-quality model (e.g., building ventilation and infiltration), and the indoor air-concentration model, as well as the adaptation of the air-quality model in RESRAD–BUILD code should be reviewed, to ensure consistency with the site-specific condition. Input parameters associated with these models should be verified. NRC staff may accept such site-specific source-term models after an assessment of the compatibility of the source-term model with the conceptual model of the site. NRC staff should also review the physical parameters defining the source term, to ensure consistency with site-specific conditions, and the occupancy parameters, to ensure consistency with the exposure scenario.

- **Resident Farmer Scenario Source Term**: NRC staff should examine the source-term information to identify the source as surficial or volumetric, to ensure consistency with the model in the selected code. NRC staff should also review the vertical and horizontal extent of residual radioactivity, to verify the model assumed for the contaminated zone (CZ), and to determine if there is subsurface and/or ground water contamination at the site. For surficial source terms, DandD model and other codes like RESRAD (assuming appropriate thickness) may be used. For volumetric sources, DandD cannot be used directly before simulation of the volumetric source into a surficial source. The source-term model should also be

reviewed, to examine the contaminated area and its shape, to check for possible correction for the area and/or for geometry of the source. NRC staff should also determine if a cover or a barrier is assumed at the top of the CZ, and the justification for such an assumption. The cover and/or barrier issue should be examined within the context of the institutional control assumptions, if appropriate, and the physical performance of the cover or the barrier within the compliance period (e.g., 1000 years).

NRC staff should also review the physical and chemical form of the source term to evaluate the soil leaching model assumption and the two components, sorbed mass and leached mass of the source. This review should help assess the source mass-balance model and the transport model within the concerned environmental media. In addition, NRC staff review of these source-term aspects would help establish consistencies for the selection of relevant parameters. NRC staff should also review source-term horizontal distribution and homogeneity, and variation of source concentration with depth. NRC staff should use either an upper-bounding value for modeling the thickness or an area-weighted approach to calculate the representative thickness. In certain cases, NRC staff may evaluate the need for modeling of multiple sources and the need for more advanced subsurface source-term modeling.

TRANSPORT MODELS

The transport models simulate transport mechanisms of contaminants from the source to the receptor. NRC staff should review transport models for consistency and compatibility with respect to (a) the source term; (b) the exposure scenario defined for the critical group receptor; and (c) the simplified conceptual model, which describes site-specific physical conditions. The transport models may include diffusive and advective transport of contaminants via air, surface water, and ground water. The transport models can be overly simplified, using simple conservative assumptions such that minimal characterization data would be required to execute the model(s). Transport models can also be very complex, requiring advanced mathematical derivation and extensive site-specific, or surrogate, data about the site.

For the building occupancy scenario, the associated transport models (e.g., transport models for ingestion, inhalation, and direct exposure pathways) of DandD code are simple and conservative. For example, the ingestion pathway depends on the effective transfer rate of the removable surface residual radioactivity from surfaces to hands and from hands to mouth. The inhalation transport model depends largely on mechanical disturbance of the contaminated surface, resuspension of residual radioactivity in the air, and subsequent breathing of contaminated air. The external dose formulation assumes exposure from a nonuniform source of residual radioactivity on the walls, ceiling, and floor of a room. This model was found to be comparable to the infinite plane source for the building occupancy scenario (NRC 1992).

For the resident farmer scenario, the associated DandD transport models include models of contaminants transport to ground water, to surface water (e.g., three-box model that relies on transfer of contaminate through leaching), and to air (e.g., through dust mass loading and indoor

resuspension). Transport models of contaminants via the air include dust loading, resuspension of contaminated soil, and use of mass loading factor for deposition. Transfer of contaminants from the soil/water to plants, fish, animals, and animal products are calculated using a water-use model, along with transfer factors, translocation factors, and bio-accumulation factors. For carbon and tritium, separate models were used, as described in NUREG/CR–5512, Volumes 1, 2, and 3. The RESRAD model assumes a volumetric source, with an idealized cylindrical shape of the contaminated zone, and allows for a cover at the top of the contaminated zone, if appropriate.

In general, NRC staff should conduct a review of the selected code, with respect to transport models and appropriateness of such models with respect to the site-specific conditions (e.g., area, source, unsaturated zone, and aquifer conditions). In addition, NRC staff should review, for compatibility and consistency, the transport model assumptions and the generic formulation pertaining to the applicable pathways of the critical group exposure scenario. The extent of transport model review depends on the familiarity of NRC staff with these models. Because certain codes/models were commonly used and were developed or modified by NRC staff (e.g., DandD, RESRAD, and RESRAD–BUILD), NRC staff is more familiar with such common codes. Therefore, NRC staff review of these common codes/models, would be less than NRC staff review of a less common codes/model developed by users or other parties. NRC staff review should also include updated new models or code versions and studies regarding code/models testing, comparison, and verifications.

RESRAD–BUILD is a more advanced code than DandD, because it employs multiple sources and more advanced particulate air transport models. In other words, each contaminated location may be considered a distinct source. Depending on its geometric appearance, the source can be defined either as a volume, area, or as a point source. RESRAD–BUILD depends on erosion of the source and transport of part of its mass into the indoor air environment, resulting in airborne residual radioactivity. The RESRAD–BUILD model differs from DandD because it assumes air exchange among all compartments of the building. In other words, the model assumes that the airborne particulates are being loaded into the indoor air of the compartment and then transported to the indoor air of all compartments of the building. In addition to air exchange between compartments, the indoor air model also simulates air exchange between compartments and the outdoor air. Descriptions of models pertaining to indoor air quality, air particulate deposition, inhalation of airborne dust, and ingestion of removable materials and deposited dust, were documented in Argonne National Laboratory report "ANL/EAD/LD–3," (ANL 1994). The exposure pathways in the RESRAD–BUILD code include (a) the external exposure to radiation emitted directly from the source and from radioactive particulates deposited on the floors, and exposure caused by submersion from radioactive particulates; (b) inhalation of airborne radioactive particulates; and (c) ingestion of contaminated material directly from the source, and airborne particulates deposited onto the surface of the building.

EXPOSURE PATHWAY MODELS

The exposure pathway models pertain to the formulation of the links between the radiological source, the transport of contaminants within environmental media, the critical group receptor location, and behaviors of the receptor that lead to its exposure to residual radioactivity through direct exposure, inhalation, and ingestion of contaminated water, soil, plants, crops, fish, meat, milk, and other dairy products. NRC staff should review the conceptual model(s) that describe the human behaviors that lead, or control, the amount of receptor exposure. Therefore, the occupational, behavioral, and metabolic parameters describing these models should be reviewed and compared with the default model scenarios and associated parameters. NRC staff should review exposure model(s) and associated parameters to ensure conservatism, consistency, and comparability with site-specific conditions and scenario assumptions. NUREG/CR–5512, Volumes 1, 2, and 3 provide detailed information regarding default parameters and approaches for changing parameters in dose modeling analysis.

INTERNAL AND DIRECT EXPOSURE DOSE CONVERSION FACTORS

In general, NRC staff should review the dose conversion factors for inhalation and ingestion, to ensure that the factors used are those developed by EPA, published in Federal Guidance Report No. 11 (EPA, 1988). Similarly, NRC staff review should ensure that EPA's external dose factors, although they may correct for actual area, published in Federal Guidance Report No. 12 (EPA, 1993) were used or another appropriate code such as Microshield. These dose factors were selected to ensure consistency of the dosimetry models used in deriving these factors with NRC's regulations in Part 20. The default parameter sets for DandD and the RESRAD family of codes are based on Federal Guidance Reports No. 11 and No. 12.

Licensees may request an exemption from Part 20 to use the latest dose conversion factors (e.g., ICRP 72). Scenarios and critical group assumptions should be revisited to look at age-based considerations. Licensees may not "pick and choose" dosimetry methods for radionuclides (e.g., Federal Guidance Report No.11 for six radionuclides and current International dose conversion factors for three radionuclides).

I.5.3.3 Option for Selection of Deterministic or Probabilistic Site-Specific Codes

Licensees may select either a deterministic analysis approach or a probabilistic approach for demonstrating compliance with the dose criteria in 10 CFR Part 20, Subpart E. A deterministic analysis uses single parameter values for every variable in the code. By contrast, a probabilistic approach assigns parameter ranges to certain variables, and the code randomly selects the values for each variable from the parameter range each time it calculates the dose. While a deterministic analysis will calculate the results from a single solution of the equations each time the user runs the code, a probabilistic analysis will calculate hundreds of solutions to the equations, using different values for the parameters from the parameter ranges. The

deterministic analysis gives no indication of the sensitivity to certain parameters or of the uncertainty in the value of the parameters. Therefore, the deterministic approach may require more elaborate justification of code input parameter values and may require further analysis of doses using upper or lower bounding conditions.

NRC–approved data sets for both DandD and RESRAD are for the probabilistic calculation and not the deterministic mode.

Section I.7.3.2 of this appendix provides a detailed description of a NRC staff review for deterministic and probabilistic analysis.

I.5.3.4 Modeling of Subsurface Source-Term Residual Radioactivity

For subsurface residual radioactivity (residual radioactivity at depths >15–30 cm (6–12 in)), NRC staff should review existing historical site data (including previous processes or practices) and site characterization data, to establish an adequate conceptual model of the subsurface source, specifically the horizontal and vertical extent of residual radioactivity. Section I.2.3.1 describes approaches for subsurface source-term abstraction for dose modeling analysis.

I.5.3.5 Generic Description and Development of DandD

Two scenarios are implemented in DandD, the building occupancy and the residential scenario. The building occupancy scenario relates volume and surface residual radioactivity levels in existing buildings (presumably released after decommissioning for unrestricted commercial or light-industrial use) to estimates of the TEDE received during a year of exposure, with the conditions defined in the scenario. The exposure pathways for this scenario include external exposure, inhalation exposure, and secondary ingestion pathways.

The more complex and generalized residential scenario is meant to address sites with residual radioactivity in soils and ground water. The exposure pathways include external exposure, inhalation, and ingestion of contaminated crops, meat, soil, plants, fish, and drinking water (NRC 1992). A generic water-use model was developed to permit the evaluation of the annual TEDE from drinking water from wells and from multiple pathways associated with contaminated soil. Section I.4.3.1 describes the three-box water-use model of the DandD code.

I.5.3.5.1 Excessive Conservatism in DandD Version 1 Methodology and Parameters

DandD, Version 1.0, was a deterministic screening code, with a single set of default parameters, which is an acceptable screening tool to calculate the screening values to demonstrate compliance with the dose limit in Part 20, Subpart E. NRC staff used this code to develop the screening numbers published in the *Federal Register* (see Section 5.1 and Appendix H of this

volume). NRC staff examined several areas where the DandD code may be overly conservative. These areas include (a) reevaluation of the resuspension factor (RF); (b) reevaluation of default parameter selection; (c) model comparison study (NRC 1999a); and (d) ground water model comparison study (NRC 1998a). A technical basis document for revision of the RF is still under review and development.

Version 1.0 of the DandD code used a deterministic set of default parameters. These deterministic values, however, were selected from a range of possible values, rather than by establishing single bounding values. A probability density function (PDF) was established for the range of values for each parameter in the DandD code. A single set of default parameters was selected by probabilistically sampling the PDFs for each of the parameters, to maintain a 90% confidence level that doses would not exceed the dose limit for a combination of all radionuclides. A detailed discussion of the way the default parameters were selected is contained in NUREG/CR–5512, Volume 3.

This method of selecting the default parameter set tends to overestimate the dose. That is, if the default parameter set were selected for a single radionuclide rather than for all radionuclides, the dose calculated using DandD with the single radionuclide default parameter set would, in most cases, be lower than with the "all radionuclides" default parameter set in DandD, Version 1.0. For example, the $DCGL_W$ corresponding to 0.25 mSv/y (25 mrem/y) for Cs-137 using the "all radionuclide" default parameter set is approximately 37 Bq/kg (1 pCi/g); while the $DCGL_W$ using the "single radionuclide" default parameter set is approximately 407 Bq/kg (11 pCi/g). The results from DandD, Version 1.0 using the two default parameter sets are discussed in a Letter Report from Sandia National Laboratories, dated January 30, 1998. To improve this area, Version 2 of the code was developed (and replaced Version 1) to calculate a unique default parameter set based on the specific radionuclides in the source term.

To evaluate the overall conservatism in DandD, a study was conducted to compare the DandD code with the RESRAD and RESRAD–BUILD codes for both the residential and building occupancy scenarios, respectively. This comparison is documented in NUREG/CR–5512, Volume 4 (NRC 1999a). In summary, the models in the DandD codes appeared appropriate for screening (e.g., simplistic, and defensible with minimal data). The default soil mass loading factor for foliar deposition for DandD appears to be too high. The soil-to-plant transfer factors, distribution coefficients, and bio-accumulation factors for certain radionuclides appear to be too conservative. This conservatism is mainly caused by the DandD Version 1.0 approach for selection of the solution vector, to generate a single set of default parameters for all radionuclides. Therefore, the deterministic DandD code in Version 1.0 has been revised as a probabilistic code, DandD, Version 2. An arithmetic error was also found in the default parameter value of the S-35 radionuclide. Also, the code did not model tritium and carbon-14 realistically. This could lead to an underestimation of doses where ground water is not a predominate pathway. It was also determined that RESRAD and RESRAD–BUILD may be better suited to deal with "hot spots."

Another area where NRC staff evaluated the excess conservatism in the DandD code was the ground water model. The basic conceptual ground water model in DandD was described in NUREG/CR–5512, Volume 1. This ground water model was compared to two more realistic ground water models in NUREG/CR–5621 (NRC 1998a). These two models are the STOMP code, as the realistic vadose zone model, and the CFEST code, as the realistic aquifer compartment model. The study concluded that the maximum ground water concentration increased with the number of vadose zone compartments for the DandD model, and that it exaggerated vadose zone dispersion. The study recommended that the maximum vadose zone compartment (layer) thickness in the DandD code should be set to 1 m (3.3 ft). This could be a problem where the vadose zone is thicker than 10 m (33 ft), because the DandD code only allows 10 vadose zone compartments. In general, the study concluded that the DandD model described realistic and conservative representations, of an aquifer and vadose zone, that are appropriate for site assessment. However, it was indicated that, for radionuclides with short half-lives compared to the vadose zone transit time, the DandD model may not be adequate.

I.5.3.5.2 Probabilistic DandD Version 2

Because of the overly conservative approach resulting from the artifact in the way the single default parameter set was selected in DandD Version 1.0, NRC staff has developed a probabilistic DandD, Version 2. DandD, Version 2, updates, improves, replaces and significantly enhances the capabilities of Version 1.0. In particular, Version 2 allows full probabilistic treatment of dose assessments, whereas Version 1.0 embodied constant default parameter values and only allowed deterministic analyses. DandD implements the methodology and information contained in NUREG/CR–5512, Volume 1, as well as the parameter analysis in Volume 3, that established the probability distribution functions (PDFs) for all of the parameters associated with the scenarios, exposure pathways, and models embodied in DandD.

Finally, DandD Version 2 includes a sensitivity analysis module that assists licensees and NRC staff to identify those parameters in the screening analysis that have the greatest impact on the results of the dose assessment. Armed with this information and the guidance available in NUREG–1549, licensees are able to make informed decisions regarding the allocation of resources needed to gather site-specific information related to the sensitive parameters. When cost and the likelihood of success associated with acquisition of this new knowledge are considered, licensees are better able to optimize the costs to acquire site data that allow more realistic dose assessments that, in turn, may lead to demonstrated and defensible compliance with the dose criteria for license termination.

I.5.3.6 Generic Description of RESRAD/RESRAD–BUILD Codes

The RESRAD and RESRAD–BUILD computer codes were developed by Argonne National Laboratory under the sponsorship of the U.S. Department of Energy, and other Agencies, such as NRC. These two codes are pathway analysis models designed to evaluate potential radiological doses to an average member of the specific critical group. RESRAD code uses a residential

farmer scenario (ANL 1993a) with nearly identical exposure pathways as the DandD residential scenario described in NUREG/CR–5512, Volume 1 (NRC 1992). The RESRAD–BUILD code uses a building occupancy scenario that covers all exposure pathways in the DandD building occupancy scenario, plus pathways corresponding to external exposures from air submersion and deposited material, and to ingestion of deposited material. Brief descriptions of RESRAD and RESRAD–BUILD codes and conceptual models were presented in previous sections (see Section I.4.3.2 in this appendix). For detailed descriptions of these two codes, the user is referred to ANL/EAD/LD–2 (ANL 1993a), ANL/EAD/LD–3 (ANL 1994), and NUREG/CR–6697 (NRC 2000b). The deterministic versions of these codes were widely used by NRC staff and licensees, prior to the LTR, to estimate doses from radioactively contaminated sites and structures. NRC sponsored development of the probabilistic versions (RESRAD Version 6 and RESRAD–Build Version 3) and their default probabilistic data sets. These two codes were selected because they possess all three of the following attributes:

1. The software has been widely accepted and there is already a large user base among NRC staff and licensees.
2. The models in the software were designed, and have been applied successfully, to more complex physical and residual radioactivity conditions than DandD code.
3. Verification and validation of these two codes are well-documented (Yu 1999; NRC 1998a).

It should be noted that the RESRAD code has been widely used and tested by national and international agencies and has gone through verification (HNUS 1994), dose model comparison (NRC 1999a; EPRI 1999) and benchmarking (DOE 1995). Therefore, RESRAD and RESRAD–BUILD codes are continuously developed and updated with new code versions. Licensees should strive to use the latest version of the RESRAD and RESRAD–BUILD codes and should document in their DP the version used.

I.5.4 Use of Codes and Models Other than DandD and RESRAD

NRC staff should provide flexibility for possible use of other codes and models selected by licensees. However, less common codes, specifically those developed by users, may require more extensive NRC staff review and verifications. In this context, NRC staff may review the following pertinent aspects when using other less common codes:

- scope of code application and applicability to the concerned site;
- extensive review of the generic code selection criteria listed previously;
- review of the mathematical formulation of the associated models and the selected dose conversion factors;
- review of the conceptual model, including the source-term model, used in the code, and compatibility with site conditions;
- review of code performance and comparison with commonly used and verified codes;

- review of code capability regarding handling of default pathways and consistency in selection of default parameters (e.g., occupancy, behavioral, and metabolic parameters); and
- detailed review of codes/models documentation and updates for code/model modifications, including QA/QC reviews.

I.6 Criteria for Selecting or Modifying Input Parameter Values

I.6.1 Introduction

Any analytical approach to dose assessment should involve the selection of appropriate values for input parameters. Each computer modeling code or other analytical methods that a licensee may use should have its own suite of input parameters. Also, unless the licensee is performing a screening analysis, each site should likely have its own defining characteristics that should be incorporated into the dose assessment through the selection of input parameter values.

This section provides general guidelines for NRC staff to consider in evaluating a licensee's selection of values for input parameters. This section addresses three aspects of parameter value selection:

- selection of parameter values or range of values;
- technical justification to support value selection; and
- evaluation of the impact of parameter selection on dose assessment results.

NUREG/CR–5512, Volume 1, and the deterministic parameter set from DandD, Version 1, have been superseded by NUREG/CR–5512, Volume 3, and DandD, Version 2, respectively. Therefore, a licensee should not refer to NUREG/CR–5512, Volume 1, as a primary source for a default deterministic parameter set. Similarly, DandD Version 1, which did not support probabilistic analyses, provided a default deterministic input parameter set. DandD Version 2 has replaced Version 1 and the DandD, Version 1 default deterministic parameter set should not be used as a reference data set for any parameters. This is especially important for the Version 1 defaults, as all the defaults in the code were selected by a method that made them highly interdependent. Each single value in the default deterministic data set was selected based on the values of the other parameters. Thus, if a single parameter is changed in DandD Version 1, the appropriateness of all of the other parameters in the code may be questionable.

I.6.2 Issues in Modifying Parameters

In addressing the three aspects of parameter value selection identified above, several issues should be discussed. First is the distinction between screening analysis and site-specific analysis, with respect to parameter value modification. Second is the appropriateness of accepting default input parameter values in site-specific analyses. Third is the level of

justification expected to support the selection of site-specific input parameter values. NRC staff should consider these issues in evaluating a licensee's dose assessment.

I.6.2.1 Screening Analyses Versus Site-Specific Analyses

A licensee may perform a screening analysis to demonstrate compliance with the radiological criteria for license termination specified in Part 20, Subpart E. The screening analysis described in Chapter 16 of this volume requires that the licensee either (a) refer to radionuclide-specific screening values listed in the *Federal Register* (63 FR 64132 and 64 FR 68395) or (b) use the latest DandD computer code. A licensee pursuing the screening option may find that implementation of the DandD code is necessary if radionuclides not included in the *Federal Register* listings should be considered.

NRC staff should ensure that a licensee performing a screening analysis using the DandD code limits parameter modification to identifying radionuclides of interest and specifying the radionuclide concentrations. NRC staff should verify that the licensee has not modified any other input parameter values. The output file generated by DandD identifies all parameter values that have been modified. Modifying any input parameter value from a default value will constitute a site-specific analysis.

I.6.2.2 Default Values Versus Site-Specific Values

DandD and many other computer codes used for dose assessment provide the user with default values for the input parameters. Often, the user only needs to select radionuclides to execute the code. This allows the user to quickly obtain results with very little time expended in developing input data sets. This is basically how DandD, Version 2 was envisioned to be used for screening analyses.

Codes with default parameters, while developed to be run with little user-input or thought, require several considerations that should be made and justified to NRC staff. In actuality, they may be inappropriate for site conditions, scenario, time period, etc. Basically, in using an off-the-shelf computer code and its default parameters, the user agrees with (a) the conceptual model used by the computer code, (b) the exposure scenario, and (c) the process used to select the default parameters so that they are appropriate for the site being modeled.

Users of computer codes should have an understanding of the conceptual and numerical modeling approaches of the code through the process of developing or justifying data input sets. If default parameter values are unavailable or inappropriate, the user should address each and every input parameter by (a) determining what characteristics of the modeled system the parameter represents and how the parameter is used in the code and (b) developing a value for the input parameter that is appropriate for both the system being modeled and for the conceptual and numerical models implemented by the code. In fact, many default data values in the computer code may be simply "placeholders" for site data.

NRC staff realizes that the theoretical approach is quite intensive and probably inappropriate, based on the risk from some sites. Experience has shown that the availability of default values for input parameters can result in the user performing a "site-specific" analysis to modify values for parameters for which site data are readily available and accept the default values as appropriate for the remaining parameters, without an adequate understanding of the parameters and the implications of accepting the default values. Therefore, for site-specific analyses, NRC staff requests that the licensee provide justification for using both the model and the default parameters, along with any justification for site-specific modifications. The level of justification appropriate for the parameter value is not, necessarily, constant for all parameters. This is why Section I.7 of this appendix discusses uncertainty and sensitivity analyses to provide a means to focus both licensees and NRC staff resources on the important parameters.

NRC staff have reviewed, and considered appropriate for dose assessments using these codes, default parameter ranges for both DandD, Version 2 and RESRAD, Version 6. This supports decommissioning by (a) promoting consistency among analyses (where appropriate); (b) focusing licensee and NRC staff resources on parameters considered significant with respect to the dose assessment results; and (c) facilitating review of the licensee's dose assessment by NRC staff. Therefore, most licensees could use the code and its default parameter ranges with little justification. If parameters have been modified, the licensee may need to provide some more justification for default parameters associated with the site-specific parameters. While these are default data for the associated computer code, that does not mean that they can be transferred to another computer code for use in it without justification.

To benefit from the advantages while minimizing the disadvantages, NRC staff should ensure that the licensee employs default parameter values or ranges in a manner consistent with the guidance provided in this section.

I.6.2.3 Justifying Site-Specific Parameter Values

The NRC reviewer should evaluate whether a licensee submitting a site-specific dose assessment has demonstrated that all parameter input values are appropriate for the site being modeled. However, this does not require the licensee to submit a detailed analysis to support the values selected for each and every input parameter. Instead, the level of justification required should be based on the parameter classification and should be commensurate with the significance of the parameter relative to the dose assessment results, as evaluated through sensitivity analyses. The sensitivity analyses should reflect the relative significance of exposure pathways. Note that the relative significance of exposure pathways may change as parameters are modified.

Dose assessment input parameters may be generally classified as behavioral, metabolic, or physical. Behavioral parameters (B) collectively describe the receptor—the exposed individual for whom the dose received is being assessed. The values selected for these input parameters should depend on the behavior hypothesized for the exposed individual. Metabolic parameters (M) also describe the exposed individual, but generally address involuntary characteristics of the individual. Physical parameters (P) collectively describe the physical characteristics of the site

being modeled. These would include the geohydrological, geochemical, and meteorological characteristics of the site. The characteristics of atmospheric and biospheric transport up to, but not including, uptake by, or exposure of, the dose receptor, would also be considered physical input parameters.

There is always uncertainty associated with the behavior of a hypothetical receptor. For this reason, the licensee may accept a generically defined receptor for its analysis. The generically defined receptor is the "average member of the critical group." The characteristics of this exposed individual and the criteria for modifying the characteristics for a site-specific analysis are discussed in Section I.3 of this appendix. The licensee may use default values for the behavioral and metabolic parameters, with limited justification, if the values are consistent with the generic definition of the average member of the critical group, and the screening group is reflective of the scenario.

In site-specific analyses, all efforts should be made by the licensee to use site-specific information for important physical parameters. "Site-specific" in this context includes (a) information directly related to the site; (b) information, characterizing the region, that is consistent with site conditions; and (c) generic information that is consistent with the specific geohydrologic conditions at the site (e.g., consistent with the surface-soil unsaturated-zone soil classifications). The justification for site-specific physical parameter values should demonstrate that the site-specific values selected are not inconsistent with the known or expected characteristics of the physical site being modeled. The level of justification should be based on the significance of the parameter to the results of the dose assessment. The licensee should evaluate the significance through sensitivity analyses (see Section I.7 of this appendix). Because of the importance of groundwater, NRC staff should verify that the licensee used site-specific values for all physical parameters (or parameter ranges) related to geohydrologic conditions. If a licensee relies on the DandD default parameter ranges for the physical parameters describing other geochemical conditions (i.e., partition coefficients) and biosphere transport (e.g., crop yields, soil-to-plant concentration factors), NRC staff should evaluate whether the default parameter ranges are inconsistent with known or expected conditions at the site.

I.6.3 Input Parameter Data Sets

I.6.3.1 DandD Default Probabilistic Parameter Set

Probabilistic analyses using the DandD computer code were performed to establish the screening values for building and surface-soil residual radioactivity that were published in the *Federal Register* in November 1998 and December 1999 (63 FR 64132 and 64 FR 68395). In performing these screening analyses, data were compiled for over 600 input parameters and reviewed by NRC staff. These data are discussed in great detail in NUREG/CR–5512, Volume 3, and are directly incorporated into DandD. These data form the reference input parameter set for probabilistic analyses using DandD. The user is referred to NUREG/CR–5512, Volume 3, and the current version of the DandD computer code for the current default parameter ranges and basis.

The DandD computer code may be used to evaluate radiological doses for two exposure scenarios: (1) the building occupancy scenario and (2) the residential scenario. These exposure scenarios and the associated exposure pathways are discussed in detail in NUREG–1549 and NUREG–CR/5512, Volume 1.

A licensee may use the default deterministic behavioral and metabolic parameters from NUREG/CR–5512, Volume 3, or the current version of the DandD computer code, with limited justification. The justification should examine how the licensee's scenario is consistent with the generic scenario from DandD. Similarly, a licensee may use the parameter range for a physical parameter, provided they justify why the parameter range is consistent with the site conditions.

Note that deterministic physical parameter values may not be used without substantial justification (including sensitivity and uncertainty analyses).

I.6.3.2 DandD Default Deterministic Parameter Set

Several default parameter sets have been developed to support deterministic analyses with the DandD code. NUREG/CR–5512, Volume 1, initially presented the conceptual and mathematical foundation of the DandD code, and deterministic values for many input parameters were presented in the document. Volume 3 of NUREG/CR–5512 incorporated much of the parameter information from Volume 1 in developing the default probabilistic input parameter set, making corrections and updating values as necessary. Therefore, a licensee should not refer to NUREG/CR–5512, Volume 1, as a primary source for a default deterministic parameter set.

Similarly, DandD Version 1, which did not support probabilistic analyses, provided a default deterministic input parameter set. DandD Version 2 has replaced Version 1, the DandD Version 1 default parameter set should not be used as a reference data set for any parameters.

Licensees may perform deterministic analyses using DandD (Version 2 or later). This would require licensees change all parameter distribution types to "constant" and specify a single value for each parameter. However, NRC staff does not intend to provide a default deterministic input parameter set to be used in conjunction with DandD. Also, a licensee intending to support decommissioning activities with deterministic dose assessments should ensure that the deterministic approach should provide the information necessary to demonstrate compliance (e.g., support necessary sensitivity analyses, as described in Section I.7 of this appendix).

I.6.3.3 RESRAD Default Probabilistic Parameter Set

The most recent versions of the RESRAD and RESRAD–BUILD computer codes include the option to perform probabilistic dose assessments. The RESRAD team at Argonne National Laboratory worked with NRC staff to develop a default input parameter set that may be used to perform probabilistic dose assessments with the RESRAD and RESRAD–BUILD codes. These

default probabilistic input parameter sets are documented in NUREG/CR–6697, "Development of Probabilistic RESRAD 6.0 and RESRAD–BUILD 3.0 Computer Codes" (NRC 2000b).

I.6.3.4 RESRAD Default Deterministic Parameter Set

Versions of RESRAD (e.g., Versions 5.82, 6.0, 6.1) and RESRAD–BUILD (Version 2.37) include default parameter values that support the RESRAD and RESRAD–BUILD deterministic analyses. Many of these default parameters are documented in "Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil" (ANL 1993b). As a set, these are not considered to be acceptable default input parameter values for performing dose assessments in support of decommissioning. Instead, a licensee may use the parameter set described in the preceding section as a starting point for its analyses. NRC staff should ensure that a licensee justifies the selected values and that the values are consistent with existing or expected conditions at the site.

I.6.3.5 Input Data Sets for Other Computer Codes

A licensee may choose to use a computer code or analytical approach other than DandD or RESRAD/RESRAD–BUILD to perform the dose assessment in support of decommissioning. Each code or analytical approach should have a unique set of input parameters. However, there will likely be some input parameters that are also included in the DandD input parameter set.

NRC staff should verify that a licensee provides a listing of all input parameters required in its analysis. For each parameter, the licensee should provide a discussion similar to that provided in NUREG/CR–5512, Volume 3, Chapters 5 and 6. The discussion should include the parameter name, a description of the parameter, a discussion of how the parameter is used in the dose assessment model, and the licensee's classification of the input parameter (i.e., behavioral, metabolic or physical). For the parameters being represented by constant values, the licensee should provide the range of appropriate values for the parameter, the single value selected for the parameter, and the basis for the range and selected value, including references. The level of justification to be provided in the basis should be based on the classification of the parameter (i.e., behavioral, metabolic or physical) and the relative significance of the parameter in the dose assessment.

For input parameters classified as "behavioral" or "metabolic," NRC staff should verify that the licensee specifies values that are consistent with the default screening values specified for the DandD behavioral and metabolic parameters, as long as the definition of the critical group has not been modified. Consistency may depend on the conceptual and numerical models underlying the code being used and the manner in which the parameters are used in the models. Using consistent behavioral and metabolic parameter values for the default critical group may support a relatively standardized definition of the average member of the critical group among analyses. The basis the licensee provides for these parameters should identify the comparable

DandD parameters and discuss any adjustments necessary to accommodate differences between DandD and the code or analytical method being used.

For the input parameters the licensee classifies as physical, other than those related to geochemical conditions and atmospheric and biospheric transport, NRC staff should verify that the licensee uses site-specific values whenever available. The licensee should provide the soil classification for all soil units and specify consistent values for all geohydrologic parameters. For geochemical parameters, such as partition coefficients, the licensee may rely on DandD default probabilistic ranges, as long as justification is provided to demonstrate that the ranges are consistent with geochemical conditions at the site. Site conditions may require that the licensee modify the default parameters to ensure consistency. Additionally, it is important to note that the distributions may not be applicable to codes other than DandD. For meteorological parameters, the licensee should use values that are based on applicable site or regional data. For physical parameters related to atmospheric and biospheric transport, the licensee may accept DandD default parameter ranges with minimal justification, using NUREG/CR–5512, Volume 3, as a starting reference point. Physical parameters related to biosphere transport would include parameters such as crop yields, animal ingestion rates, transfer factors, and crop growing times. NRC staff should evaluate whether the justification provided by the licensee demonstrates that the default values are consistent with conditions at the site.

I.6.3.6 Internal and Direct Exposure Dose Conversion Factors

NRC staff should review the dose conversion factors for inhalation and ingestion, to ensure that the factors used are those developed by EPA, published in Federal Guidance Report No. 11 (EPA 1988). Similarly, NRC staff review should ensure that EPA's external dose factors, although they may correct for actual area, published in Federal Guidance Report No. 12 (EPA 1993) were used or another appropriate code such as Microshield. These dose factors were selected to ensure consistency of the dosimetry models used in deriving these factors with NRC regulations in Part 20.

Licensees may request an exemption from Part 20 to use the latest dose conversion factors. Scenarios and critical group assumptions should be revisited, and justified, to explore at age-based considerations. Licensees may not "pick and choose" dosimetry methods for radionuclides (e.g., Federal Guidance Report No.11 for six radionuclides and current International dose conversion factors for three radionuclides).

I.6.4 Recommended Approach to Parameter Modification

Any analysis that does not meet the conditions of a screening analysis may be considered a site-specific analysis. This will include all analyses using the DandD computer code where one or more input parameters values have been modified from default ranges (or values for behavioral and metabolic parameters), as well as analyses using analytical methods or computer codes other than DandD.

I.6.4.1 Modifying the DandD Default Probabilistic Parameter Set

A reviewer should expect that a licensee who is modifying parameter values for a site-specific analysis using DandD is cognizant of the following:

- what the parameter represents,
- how the parameter is used in the DandD code,
- the basis for the default parameter value, and
- which parameters are physically or numerically correlated.

NUREG/CR–5512, Volumes 1–3, describes in detail what each parameter is intended to represent. Volume 1 provides the original parameter definitions but has been superceded by Volume 3 for parameter values. Volume 1 also provides the mathematical formulations, underlying the DandD code, that should allow the user to (a) understand how each parameter is used and the implication of parameter modification on the resulting calculated dose; and (b) identify numerical correlations among parameters. Volume 2 (the DandD user's manual) redefines several of the input parameters and mathematical formulations based on implementation of the Volume 1 methodology in the DandD computer code. Finally, Volume 3 provides a detailed discussion of most input parameters, allowing the user to fully understand the basis for the default ranges. Volume 3 provides a parameter description and a discussion of how parameters are used in the code, a review of the information sources on which the default values are based, a discussion of uncertainty in the default parameter values, and insight into the selection of alternative parameter values. The DandD user performing site-specific analyses with DandD should be cognizant of the information provided in the three volumes of NUREG/CR–5512.

A licensee may modify DandD behavioral (B) and metabolic (M) input parameter values for the building occupancy and residential scenarios to reflect the characteristics of the average member of a *site-specific* critical group. NUREG/CR–5512, Volume 3, provides the basis for the default value for each behavioral and metabolic parameter. If the licensee modifies the values for these parameters, NRC staff should verify that the licensee has defined a *site-specific* critical group. The licensee may provide site-specific parameter distributions that reflect the variability of the behavior of the average member of the site-specific critical group, or the licensee may use the mean of the site-specific information as a constant-value input for these parameters, consistent with the concept of the "average member" of the critical group. The level of justification required to support modification of behavioral and metabolic parameter values should be consistent with the sensitivity of the parameter.

For the DandD building occupancy scenario, there are only three physical parameters: the resuspension factor (Rfo*), which is derived from the loose fraction (Fl) and the loose resuspension factor (Rfo). Unless the licensee has site-specific information to indicate that the default values are inconsistent with the default values, NRC staff should verify that the licensee has used the default values for these physical parameters in its calculations.

There are many more physical parameters for the DandD residential scenario. The physical parameters may be considered in several groups. The following physical parameters address the geohydrologic conditions:

Unsaturated Zone Thickness (H2)
Soil Classification (SCSST)
Porosity Probability (NDEV)
Permeability Probability (KSDEV)
Parameter "b" Probability (BDEV)
Water Application Rate (AP)
Surface Soil Porosity (N1)
Unsaturated Zone Porosity (N2)
Surface Soil Saturation (F1)
Unsaturated Zone Saturation (F2)
Infiltration Rate (INFIL)
Surface Soil Density (RHO1)
Unsaturated Zone Density (RHO2)
Surface Soil Permeability (Ksat1)
Soil Moisture Content (sh)

For these physical parameters, the licensee should use site-specific distributions and values. [As stated previously, "site-specific" in this context includes (a) information directly related to the site; (b) information characterizing the region that is consistent with site conditions; and (c) generic information that is consistent with the specific geohydrologic conditions at the site (e.g., consistent with the unsaturated zone soil classification)].

NRC staff should verify that the licensee has provided site-specific information for the thickness of the unsaturated zone and the soil classification. In addition, the licensee should ensure that the water application rate is consistent with the irrigation rate (behavioral parameter) if the licensee modifies the irrigation rate. Alternatively, the licensee may demonstrate, through sensitivity analyses, that the dose assessment results are insensitive to these parameters, and use the default ranges.

Values for the derived parameters will be generated internally according to the soil classification indicated and the uniform distributions defined for the porosity probability (NDEV), the permeability probability (KSDEV), and the parameter "b" probability (BDEV). NRC staff should verify that the licensee has not modified the uniform distributions for these three parameters. If site-specific data are available, the licensee may proceed to modify the derived geohydrologic parameters, consistent with the information presented in NUREG/CR–5512, Volume 3.

The only geochemical parameter used in DandD is the element-specific partition coefficient. As documented in NUREG/CR–5512, Volume 3, the partition coefficients at a site are generally dependent on geochemical conditions and are generally independent of soil classification. If the

licensee has used the default distributions, NRC staff should evaluate whether the defaults are inconsistent with known or expected conditions at the site.

The following physical parameters address radionuclide transport through the atmosphere and exposure to direct radiation:

Outdoor Shielding Factor (SFO)
Flood dust loading (PD)
Indoor Resuspension Factor (RFR)
Outdoor Dust Loading (CDO)
Indoor Dust Loading (CDI)
Indoor/Outdoor Penetration Factor (PF)
Gardening Dust Loading (CDG)

The remaining physical parameters address characteristics of transport through the biosphere:

Growing Periods (produce, forage, grain, hay) [TG_(#)]
Animal Product Specific Activity (SATac)
Livestock Feeding Periods [TF_(#)]
Animal Product Yields [YA(#)]
Interception Fractions [R_(#)]
Translocation factors [T_(#)]
Contaminated Fractions [x_(#)]
Crop Yields [Y_(#)]
Wet-to-dry conversion factors [W_(#)]
Animal Ingestion Rates [Q_(#)]
Mass-Loading factors [ML_(#)]
Carbon Fractions [fc_(#)]
Hydrogen Fractions [fh_(#)]
Hydrogen Fraction: Soil (fhd016)
Tritium Equivalence: Plant/Soil (sasvh)
Tritium Equivalence: Plant/Water (sawvh)
Tritium Equivalence: Animal Products (satah)

These two groups of physical parameters describe characteristics of the transport of radionuclides through the atmosphere or biosphere up to the point of ingestion or inhalation by, or external exposure to, the receptor. The licensee may accept the default distributions for these parameters as long as the default distributions are consistent with conditions that may exist at the site in the future. The licensee should review the basis given in NUREG/CR–5512, Volume 3, for the default distributions, to determine whether the basis is inconsistent with conditions hypothesized for the site. If so, the licensee should modify the input values accordingly. NRC staff should ensure that the licensee documents this assessment for each of the physical parameters. Note that modifying several of these parameters (e.g., crop yields, animal product yields) should affect the derived behavioral parameters (e.g., area of land cultivated).

For the physical parameters, the licensee may use representative distributions or values. A representative distribution should take into account spatial and temporal variation of the parameter at the site. A representative distribution, for example, would be a precipitation rate based on the historical precipitation data for the site, if available, or from surrounding defensibly relevant monitoring locations. The arithmetic or geometric mean value is often used in defining a representative value. However, the calculation of a mean value should be weighted to account for nonuniform sampling or other nonuniform parameters (e.g., material volume) and parameter sensitivity and uncertainty. The licensee is not required to routinely adopt worst-case, bounding, upper- or lower-percentile, or other overly conservative values in defining distributions.

NRC staff review of this information should be facilitated if the licensee presents the information in a tabular or list format. NRC staff should verify that the licensee has listed every DandD input parameter with the default screening distributions or value (for behavioral or metabolic parameters). For those parameters for which the licensee is using site-specific values (e.g., the physical parameters), the licensee should provide the range of plausible values for the site, the selected distribution or value, and supporting justification, including references.

I.6.4.2 Modifying the RESRAD Default Probabilistic Parameter Set

A licensee using the RESRAD or RESRAD–BUILD codes may change parameters from the default values to reflect a site-specific critical group or site-specific conditions, or to incorporate site-specific data. As discussed in the preceding section, NRC staff should expect that a licensee who is modifying parameter values for a site-specific analysis using RESRAD or RESRAD–BUILD is cognizant of the following:

- what the parameter represents;
- how the parameter is used in the code;
- the basis for the default parameter value; and
- which parameters are physically or numerically correlated.

The licensee should refer to the current code documentation to determine the basis for and how the parameter distributions are used in the code. References to the documentation should be provided. With respect to the basis for the default parameter distributions and values, the licensee should refer to Yu, et al. (2000).

When modifying parameter distributions and values, the licensee should consider whether the parameters are classified as behavioral, metabolic or physical. For behavioral and metabolic parameters for which probability distributions have been developed, the licensee may adopt the DandD default distribution, or the mean of the DandD default distribution, as long as the licensee has not modified the definition of the critical group. For behavioral and metabolic parameters for which distributions have not been developed, the licensee should use values or distributions that are consistent with the DandD default distributions, as applicable.

A licensee may modify behavioral and metabolic default input parameter values to reflect the characteristics of the average member of a *site-specific* critical group. The licensee may modify the values for these parameters if the licensee has defined a *site-specific* critical group. The licensee may provide site-specific parameter distributions that reflect the variability of the behavior of the average member of the site-specific critical group, or the licensee may use the mean of the site-specific information as a constant-value input for these parameters, consistent with the concept of the "average member" of the critical group. The level of justification required to support modification of behavioral and metabolic parameter values should be consistent with the sensitivity of the parameter.

For the physical parameters, the licensee should use site-specific information for the physical parameters addressing geohydrologic and meteorologic conditions. The level of justification for the parameter values should be based on sensitivity analyses. Alternatively, sensitivity analyses may be used to support the use of default distributions or representative values.

For the physical parameters describing geochemical conditions (i.e., distribution coefficients), the licensee should use values that are consistent with the RESRAD default distributions, as long as the values are consistent with known or expected site conditions. Justification supporting the values should be based on sensitivity analyses.

For the remaining physical parameters (atmospheric and biospheric transport), the licensee may use distributions or representative values that are consistent with the RESRAD default distributions, as applicable, as long as the default distributions are consistent with known or expected site conditions.

I.6.4.3 Sensitivity Analyses

The level of justification required to support site-specific parameter values should be commensurate with the sensitivity of the results of the dose assessment to the selected values. Sensitivity analyses are discussed in detail in Section I.7 of this appendix.

I.6.4.4 Site-Specific Distribution Coefficients for Soil or Concrete

The following describes an acceptable approach for the developing input distribution coefficient (K_d) values for soil or concrete for use in site-specific dose modeling codes. This guidance is from Question 4 of Appendix O.

It is noted that K_d values commonly reported in the literature may vary by as much as six orders of magnitude for a specific radionuclide. Generally, no single set of ancillary parameters, such as pH and soil texture, is universally appropriate in all cases for determining appropriate K_d values. Although K_d values are intended to represent adsorption, they are in most cases a lumped parameter representing a myriad of processes. Given the above, the proper selection of a range of K_d values, for either soils or concrete, from the literature will require judicious selection.

The licensee is encouraged to use sensitivity analyses to identify the importance of the K_d parameter on the resulting dose either (1) to demonstrate that a specific value used in the analysis is conservative or (2) to identify whether site-specific data should be obtained (if the licensee feels K_d is overly conservative). The sensitivity analysis should encompass an appropriate range of K_d values. As noted above, the input range for the sensitivity analysis may be obtained from literature, DandD default distribution, or RESRAD probabilistic default distribution.

The licensee should use sensitivity analyses, which include an appropriate range of K_d values, to identify the importance of the K_d to the dose assessment and how the change in K_d impacts the dose (i.e., how dose changes as K_d increases or decreases). The range of K_d values that bound the sensitivity analysis may be obtained from (a) the literature, (b) the default distribution in DandD, or (c) the default distribution in the probabilistic code of RESRAD.

Using the results of the sensitivity analysis, the licensee can choose a conservative K_d value, depending on how it affects the dose. For example, if higher K_d values result in the larger dose, an input K_d value should be selected from the upper quartile of the distribution, or if lower K_d values result in the larger dose, an input K_d value should be selected from the lower quartile of the distribution. For those isotopes where the K_d does not have a significant impact on the dose assessment (i.e., K_d is not a sensitive parameter), the median value within the range is an acceptable input parameter.

If the licensee feels that the K_d value is overly conservative, the licensee is encouraged to perform a site-specific K_d determination, so that the dose assessment reflects true site conditions.

DandD

The use of the default K_d values from DandD Version 1.0 outside of the scope of DandD may not be justified, since the single set of default parameters derived for DandD was developed assuming a specific set of exposure pathways and a specific source term. Any single parameter value taken from the default set of parameters outside of the context of the given exposure scenario, source term, and other parameters will have no meaning in terms of the original prescribed probability; therefore there is no basis to conclude that any default K_d value will give a conservative result. However, the distribution of K_d values, used in DandD (which can be found in NUREG/CR–5512, Volume 3, "Residual Radioactive Contamination From Decommissioning —Parameter Analysis," Table 6.86), can be used as the range of K_d values for the sensitivity analysis.

RESRAD

RESRAD default parameter values (including K_d values) should not be used. The defaults were included in the code primarily as place holders that enable the code to be run; it was assumed that site-specific values would be developed. However, it is appropriate to use the default parameter distribution, developed for RESRAD Version 6.0, as the range for use in the sensitivity analysis.

After performing sensitivity analysis with the appropriate K_d ranges, the K_d value at the upper or lower quartile of the distribution, resulting in the highest derived dose, is an acceptable value to input into the dose code, and no further justification is required. For those K_d values that are overly conservative, a site-specific K_d value may be determined by the direct measurement of site samples. Appropriate techniques for K_d determination include American Society for Testing and Materials (ASTM) and U.S. Environmental Protection Agency (EPA) Methods 9–83, "Distribution Ratios by the Short-Term Batch Method"; ASTM D 4646–87, "24-h Batch-Type Measurement of Contaminant Sorption by Soils and Sediments"; and "Understanding Variation in Partition Coefficient, K_d Values, Volumes I and II, EPA 402–R–99–004A, 8/99" available at http://www.epa.gov/radiation/technology/partition.htm#voli.

I.7 Uncertainty/Sensitivity Analyses

I.7.1 Introduction

Uncertainty is inherent in all dose assessment calculations and should be considered in regulatory decision making. In general, there are three primary sources of uncertainty in a dose assessment; (1) uncertainty in the models, (2) uncertainty in scenarios, and (3) uncertainty in the parameters (NRC 1988a, DOE 1991). As stated in Section I.4 of this appendix, models are simplifications of reality and, in general, several alternative models may be consistent with available data. Uncertainty in scenarios is the result of our lack of knowledge about the future of the site. Parameter uncertainty results from incomplete knowledge of the model coefficients.

NRC's risk-informed approach to regulatory decision making suggests that an assessment of uncertainty be included in estimating doses. Specifically, the Probabilistic Risk Assessment (PRA) Policy Statement (60 FR 42622, August 16, 1995) states, in part, "The use of PRA technology should be increased in all regulatory matters to the extent supported by the state of the art in PRA methods and data, and in a manner that complements NRC's deterministic approach...." In the past, dose assessments in support of NRC decommissioning requirements have primarily included the use of deterministic analyses. The deterministic approach has the advantage of being simple to implement and easy to communicate to a nonspecialist audience. However, it has a significant drawback in not allowing consideration of the effects of unusual combinations of input parameters and by not providing information on uncertainty in the results, which would be helpful to the decision-maker. Furthermore, a deterministic analysis that had a high assurance of not being exceeded would have to rely on the use of pessimistic estimates of each parameter of the model, often leading to overly conservative evaluations. Even with the use of probabilistic analyses, it is generally recognized that not all sources of uncertainty can be considered in a dose assessment, nor need to be considered. The primary emphasis in uncertainty analysis should be to identify the important assumptions and parameter values that, when altered, could change the decision.

Sensitivity analysis performed in conjunction with the uncertainty analysis can be used to identify parameters and assumptions that have the largest effect on the result. Sensitivity

analysis provides a tool for understanding and explaining the influence of these key assumptions and parameter values on the variability of the estimated dose.

I.7.2 Issues in Uncertainty/Sensitivity Analyses

Uncertainty analysis imparts more information to the decision-maker than deterministic analysis. It characterizes a range of potential doses and the likelihood that a particular dose may be exceeded.

An important issue in uncertainty and sensitivity analysis is that not all sources of uncertainty can be easily quantified. Of the three primary sources of uncertainty in dose assessment analyses, parameter uncertainty analysis is most mature. However, approaches for quantifying conceptual model and scenario uncertainty are less well-developed. Difficulties in predicting the characteristics of future society, especially those influencing exposure, can lead to large uncertainties. At most, one is able to assert that an acceptably complete suite of scenarios has been considered in the assessment (Flavelle 1992). For these reasons, we make no attempt to quantify formally model or scenario uncertainty, although to a certain extent, these are captured in parameter uncertainty analyses. Choices of the scenarios and conceptual model(s) to be used for the site are discussed in Sections I.3 and I.4, of this appendix, respectively.

Uncertainty analyses frequently use the Monte Carlo method. Input variables for the models are selected randomly from probability distribution functions, which may be either independent or correlated to other input variable distributions. Critics of formal uncertainty analysis have often pointed out that limitations of knowledge about the nature and extent of correlation among variables fundamentally limit our ability to make meaningful statements about the degree of uncertainty in dose assessments (Smith et al., 1992).

Because the results of an uncertainty analysis provide a distribution of doses, it should be recognized that some percentage of the calculated doses may exceed the regulatory limit. A key issue that should be addressed in the treatment of uncertainty is specifying how to interpret the results from an uncertainty analysis in the context of a deterministic regulatory limit. Agency practice has not been to require absolute assurance that the regulatory limit will be met, so regulatory compliance could be stated in terms of a metric of the distribution such as the mean, or a percentage of calculated doses allowed to exceed the limit. Even for a deterministic analysis, it is recognized that the reported dose is simply one of a range of possible doses that could be calculated for the site; therefore, there is still an issue of where this calculated dose should lie in terms of the unquantified spectrum of possible doses.

In summary, the key issues in addressing uncertainty are (a) incorporating alternative conceptual models and scenarios to identify a complete suite of possibilities; (b) determining how to select appropriate parameter distribution and ranges, along with the associated correlation between parameters for the analysis; and (c) specifying the metric of the dose distribution to use in determining compliance with the dose limit.

I.7.3 Recommended Approach

I.7.3.1 Screening Analyses

Often the first step in evaluating site compliance should be a screening analysis. At preliminary stages of the evaluation, there may be little information available about the site. Therefore, NRC's screening approach is designed to ensure that there is high confidence that the dose should not be underestimated. As discussed in Sections I.3 and I.4 of this appendix, the models and scenarios used in screening were selected to represent generic conditions and are intended to be "prudently conservative." The screening analysis assumes that all that is known about a site is the source term. Accordingly, the default parameters were selected to make it unlikely for the dose that would be calculated using site-specific information to exceed the screening dose.

NRC published a screening table for building-surface residual radioactivity and surface soil (see Appendix J). NRC staff performed a Monte Carlo analysis, using the DandD code, with values of the input parameters sampled from wide ranges selected to represent the variability in those parameters across the United States. The default values of input parameters for the DandD code (i.e., the values that the code would use without specification by the user) were then chosen from distributions of those parameters that would never cause the 90th percentile of the output dose distribution from the Monte Carlo analysis to be exceeded for any radionuclide, as illustrated in Figure I.6 (NRC 1999a).

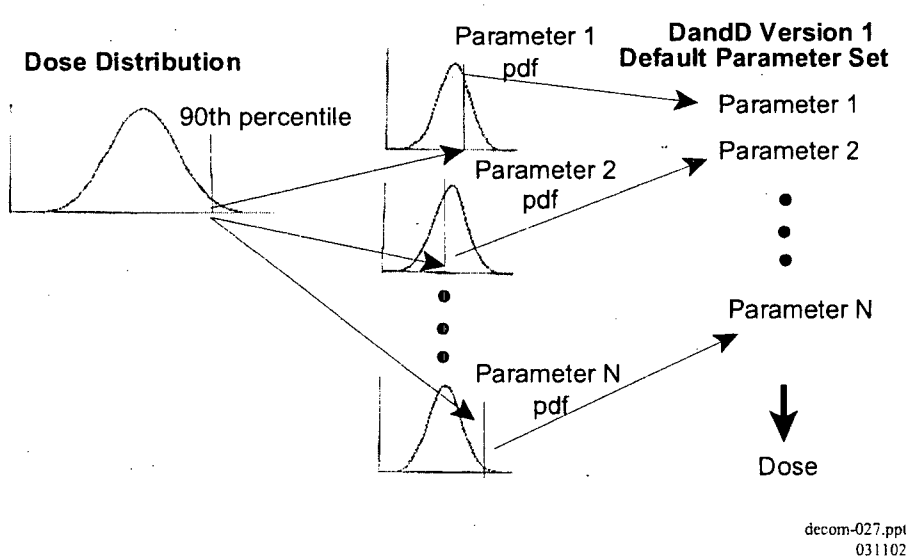

Figure I.6 Treatment of Parameter Uncertainty in DandD Version 1.

The intent of the specification of default parameter values, scenario, and conceptual models in the DandD code was to ensure that there should be less than a 10 % probability that the calculated dose using site-specific information may exceed the dose limit. Because the default parameters, scenarios, and conceptual models in DandD Version 1.0 were designed to provide high confidence that the dose should not be underestimated, an licensee using the screening criteria does not need to quantify the uncertainty in the dose analysis. The calculated results may be considered to represent a "prudently conservative" estimate of the dose (i.e., the calculated dose is likely an overestimation of the true dose). In many cases, however, the default parameter values chosen were highly conservative, making the outcome of the deterministic analysis overly stringent.

DandD Version 2 is designed to allow Monte Carlo analyses which give a distribution of doses as illustrated in Figure I.7. The code automatically performs the probabilistic analyses and aggregates the results for the user. To maintain consistency in approaches used for Versions 1 and 2, and previously published screening tables, the 90th percentile of the dose distribution should be used to determine compliance with the Subpart E when used for screening analysis. Default parameter probability density functions have been incorporated into the code for screening analyses; therefore, for screening analyses, the license reviewer may only need to ensure that these aforementioned default parameters were used.

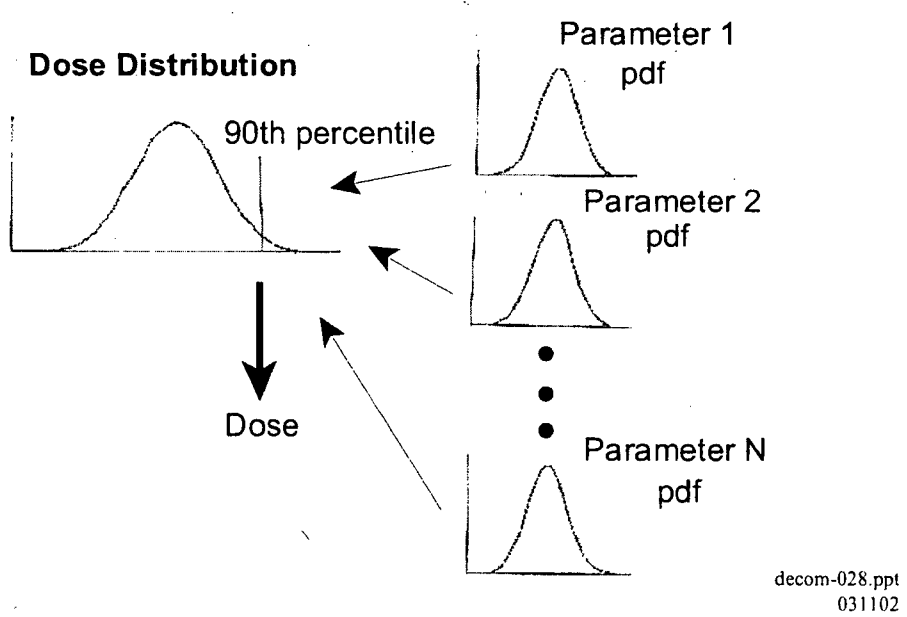

Figure I.7 Treatment of Parameter Uncertainty in DandD Version 2.

I.7.3.2 Site-Specific Analyses

I.7.3.2.1 Deterministic Analysis

For site-specific analyses, the treatment of uncertainty in deterministic and probabilistic analyses should be handled differently. NRC's risk-informed approach to regulatory decision making suggests that an assessment of uncertainty should be included in dose analyses. However, in some cases such analyses may not be needed (e.g., bounding type analyses). Because no information is provided on the uncertainty in bounding analyses, it is important for the licensee to demonstrate that the single reported estimate of the peak dose is likely to be an overestimation of the actual peak dose. Use of conservatism in only some aspects of the analysis may not necessarily result in a conservative estimate of the dose. Uncertainties in the conceptual model may be larger than uncertainties in parameters used in the analysis; therefore, use of conservative parameter values do not necessarily ensure a conservative estimate of the dose. To ensure that the results from a deterministic analysis are unlikely to underestimate the dose, it is recommended that the licensee use the approaches discussed in Sections I.3 and I.4, of this appendix, for developing land-use scenarios and conceptual models. In addition, the licensee should use conservative values for key parameters. The approaches discussed below on performing sensitivity analyses should be used in identifying key parameters in the analysis.

I.7.3.2.2 Probabilistic Analysis

Although bounding analyses are a good starting point for determining regulatory compliance, the demonstration that a single, deterministic result is bounding may be too difficult to prove. For site-specific probabilistic analysis, it is only necessary to demonstrate that the mean dose does not exceed the regulatory criterion.

A single deterministic calculation using the mean values of parameters is unlikely to result in the mean dose.

Parameter uncertainty analysis provides a quantitative method for estimating the uncertainty in calculated doses, assuming the structure of the model is an adequate representation of the real world, and the exposure scenario is an appropriate reflection of potential future land-use at the site. Several methods have been developed for quantifying parameter uncertainty, including (a) analytical methods, (b) Monte Carlo methods, (c) response surface methods, and (d) differential methods (DOE 1990). In addition, alternative approaches, such as the first-order reliability method, have recently been applied on a wide variety of environmental problems (DOE 1998). Of these methods, the Monte Carlo methods are recommended because they are easy to implement and provide significant versatility.

Monte Carlo methods can be applied to either linear or nonlinear models, and analytical or numerical models. Input parameter uncertainties are represented as probability density

functions. Parameter values randomly sampled from probability density functions are used as inputs to multiple runs or "realizations" of the model.

For probabilistic analyses, the peak of the plot of mean dose over time should be compared with the regulatory standard to determine compliance. Equation I–4 shows how the mean dose as a function of time can be derived. For Monte Carlo Runs:

$$Mean(t_i) = \frac{\sum_{k=1}^{N} Dose_k(t_i)}{N} \qquad \textbf{(I–4)}$$

where $Mean(t_i)$ = mean dose at time t_i
$Dose_k(t_i)$ = dose at time t_i for run k
t_i = time in years
i = time steps (1 to 1000)

Essentially, a mean dose is determined at each discrete time in the analysis. A plot is then made of these means over time. The mean dose provides the "best estimate" of dose at each discrete time. The overall peak of these best estimates is then used to determine compliance with the rule. Figure I.8 shows how such a plot would be used to determine compliance with the regulations.

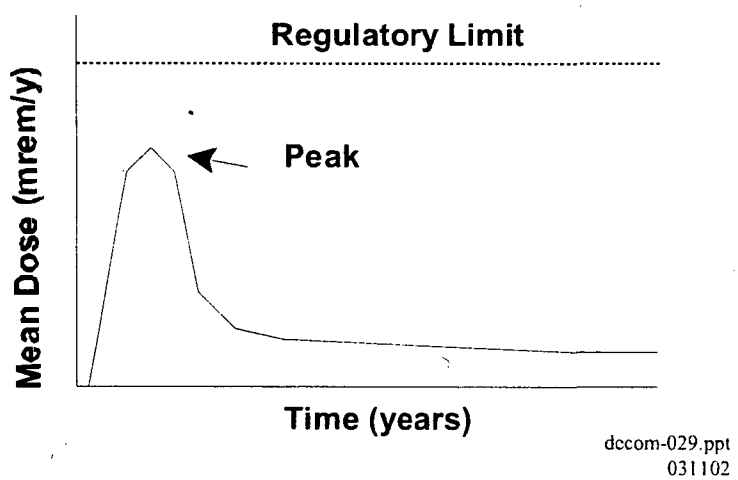

Figure I.8 Application of "Peak of the Mean" Dose.

Licensees using probabilistic dose modeling should use the "peak of the mean" dose distribution for demonstrating compliance with 10 CFR Part 20, Subpart E. The "peak of the means" approach is one method for determining compliance with the regulations using probabilistic analyses. Other probabilistic approaches, such as "mean of the peaks," if justified, may also be acceptable for demonstrating compliance. If the licensee intends to use any probabilistic approach to calculate DCGLs, the licensee should discuss their planned approach with NRC staff.

I.7.4 Input Parameter Distributions for Monte Carlo Analysis

A key aspect of any Monte Carlo analysis is defining the ranges and statistical distribution of parameters treated as uncertain in the analysis. It is important for the licensee to avoid assigning overly restrictive ranges that suggest an unwarranted precision in the state of knowledge. On the other hand, the specification of unreasonably large ranges may not account for what is known about a parameter and also may lead to "risk dilution." The distributions used in the analysis should characterize the degree of belief that the true but unknown value of a parameter lie within a specified range of values for that parameter.

Sensitivity results are generally less dependent on the actual distributions assigned to the input parameters than they are on the ranges chosen for the parameters. However, distributional assumptions can have a large impact on the dose distribution (SNL 1993). Resources can often be used most effectively by performing a Monte Carlo analysis in an iterative manner. Initially, rather crude ranges and distribution assumptions can be used to determine which input variables dominate the behavior of the calculated dose. Often, most of the variation in the calculated dose is caused by a relatively small subset of input parameters. Once the most important input parameters are identified, resources can be concentrated on characterizing their uncertainty. This avoids spending a large effort characterizing the uncertainty in parameters that have little impact on the dose (SNL 1993).

A reasonable strategy for assigning distributions for parameters used in Monte Carlo analyses is summarized below (NRC 2000):

- **Select parameters to be assigned distributions**—Not all parameters of the system under study require specification of a distribution. Those parameters that may well be distributed, but have little impact ultimately on the results, can be assigned constant values. Even if a parameter is known to have a significant effect on the results, its value may be specified at a constant value if it can be demonstrated that the choice leads to a conservative result.
- **Assign distributions for important parameters**—The assignment of parameter distributions usually is a matter of the quantity of available data.
- **Ample data available**—Where there are ample data, empirical distributions of a parameter can be generated directly.

- **Sufficient data available**—Data plotted as histograms or in probability coordinates can be used to identify standard distributional forms (e.g., normal, lognormal, and uniform).
- **Parameters with some data**—Where there are insufficient data to estimate the shape of an empirical distribution, data may be supplemented by other soft information. For example, if there were a mechanistic basis for assigning a given distribution, or if a distribution were well-known for the parameter, on a regional basis, this information could be used to estimate the likely shape of the distribution. Alternatively, the new data can be used to supplement a prior, non-site-specific parameter distribution (e.g., Bayesian updating).
- **Parameters with insufficient information**—If sufficient data are not available, but there were other kinds of data that imply the likely behavior of a parameter, then it may be possible to supplement the desired data indirectly. An example of such a procedure is the use of root uptake factors to infer distribution coefficients in soil (ORNL 1984). If only incomplete information is known about the parameter (e.g., its mean, or its range), and no correlations to other types of data are available, then the choice of the parameter distribution should reflect the uncertainty. The distribution should have the least-biased value, which is generally a wide distribution encompassing all the possible values. One procedure to assure that the distribution has the least bias is known as the "maximum entropy formalism," based on Shannon's informational entropy (Harr 1987). This formalism allows the investigator to pick the distribution based on the kinds of information available on the parameter to assure that the result is least-biased; for example, if only the range of the data is known, a uniform distribution between the range is least-biased. Table I.7 describes the maximum entropy solutions for several classes of data (Harr 1987). Other, empirical sources of guidance for choosing parameter distributions can be found in several other references (IAEA 1989; NCRP 1996a).
- **Parameter correlations**—Many of the parameters used in the probabilistic analyses may be correlated to other parameters. Some parameter distributions may in fact be used to derive other distributions (e.g., root uptake factors may be used to derive soil distribution coefficients). Also, correlations are expected on physical grounds, such as the relationship between hydraulic gradient and permeability. Where available, these correlation coefficients can then be used to generate correlated values of distributed parameters. This may help to avoid the situation where two correlated quantities are treated as uncorrelated, leading to unlikely combinations of parameters (e.g., high gradient and high-hydraulic conductivity). The effects of assumed minimum versus assumed maximum levels of correlation can be investigated to evaluate the importance of including an explicit estimate of dependency between model parameters. In some cases, explicit modeling of the dependency between model parameters is possible, based on knowledge about the explicit mechanistic reasons for the dependencies. In general, it is more important to consider the effect of dependency when correlations are strong among the model's most sensitive parameters (see discussion below on identifying sensitive parameters); weak correlations between sensitive parameters and strong correlations among insensitive parameters will generally have very little impact on the overall calculated dose (NCRP 1996a).

Table I.7 Maximum Entropy Probability Distributions (Adapted from Harr 1987)

Given Constraints on Data	Assigned Probability Density
Minimum and maximum only	Uniform
Expected value only	Exponential
Expected value and standard deviation	Normal
Expected value, standard deviation, minimum and maximum	Beta
Mean occurrence rate between arrival of independent events	Poisson

I.7.5 Sensitivity Analysis

Uncertainty and sensitivity analyses are closely linked, and ideally, they should be considered together. The primary aim of a sensitivity analysis is to identify the input parameters that are the major contributors to the variation or uncertainty in the calculated dose. Identifying these key parameters is essential for building a defensible case in support of the assessment. It is very important for the licensee to justify the value or range of values used in the assessment to represent these key parameters. Several of the more-popular sensitivity methods used in other performance assessments conducted at NRC are presented, very briefly, below (NRC 1999). It may be necessary for the licensee to use more than one approach in identifying the key parameters.

The licensee should focus on the pathways and radionuclides that are providing the greatest dose. If these pathways are modified or eliminated, a re-evaluation of the sensitivity analysis should be done to verify the important parameters for the analysis, consistent with the iterative nature of the "Decommissioning and License Termination Framework" (see Section 1.5 of this volume). For sites with a suite of radionuclides, the licensee may use expected concentrations or relative ratios of radionuclides to focus resources on the overall critical pathways and parameters. In addition, the licensee also should evaluate the effects of uncertainty on the relative ratios.

I.7.5.1 Deterministic Sensitivity Analysis

Two types of sensitivity analysis techniques are widely used: deterministic and Monte Carlo. The first, deterministic sensitivity analysis, calculates the change in the output result (i.e., peak dose) with respect to a small change in the independent variables, one at a time. The following formula illustrates the normalized sensitivity coefficient calculated from a deterministic analysis.

$$S_i = \left[\frac{\overline{X}_i}{d(\overline{X}_i)}\right]\left(\frac{\partial d}{\partial \overline{X}_i}\right) \qquad \textbf{(I–5)}$$

where S_i = sensitivity coefficient
$\overline{X}_i$ = baseline value of the ith parameter
$d(\overline{X}_i)$ = peak dose for the baseline case
∂d = change in peak dose
∂X_i = change in i^{th} parameter

Variable transformations, such as *normalization,* used in this example, are described further below.

The advantage of the deterministic technique is that it is unambiguous in terms of demonstrating a cause and effect for the given conceptual model. The disadvantages are that at least one evaluation of the model should be performed for every independent variable, and the sensitivity result applies only locally (i.e., for one location in the space of all of the independent variables).

I.7.5.2 Statistical Sensitivity Analysis Techniques

The techniques used herein (except deterministic analysis) rely on the use of the Monte Carlo method for probabilistically determining system performance. Statistical analyses of Monte Carlo results starts with a large pool of realizations (hundreds to thousands). These techniques determine sensitivities of the dependent variable (dose) to changes in the independent variables. The main advantage of these techniques is that they allow sensitivity to be determined over wide ranges of the independent variables, as opposed to the deterministic techniques that apply to only one point within the ranges. The disadvantage of statistical techniques is that it is often difficult to extract useful information on sensitivity except for a small set of the most important variables, because smaller sensitivities are obscured. A compilation of some of the more popular techniques for analyzing sensitivity from Monte Carlo results is presented below.

Usually, statistical sensitivity techniques have been applied to the set of peak doses drawn from the realizations. Sensitivity information from the ensemble of the peak doses provides useful information, and would be the correct approach if one were pursuing the "mean of the peaks"

dose. However, this approach is not as meaningful for the "peak of the mean" dose. For the latter, the statistical techniques should be applied to the set of doses drawn from the Monte Carlo runs at the time of the "peak of the mean" dose.

I.7.5.2.1 Scatter Plot and Linear Regression on One Variable

In the scatter plot/single linear regression technique, peak TEDE is plotted versus each of the sampled input variables. This is often a good starting point for examining Monte Carlo results because strong relationships between peak dose and the independent variables are often obvious. Single linear regression of Monte Carlo results may fail to show unambiguous correlation since other sampled parameters that affect the output are varying at the same time.

I.7.5.2.2 Use of the T-Statistic to Determine Significance of Single Linear Regression Parameters

The t-test estimates the confidence that an estimated parameter value differs from another value. In this case, it is used to determine if there is a specified (e.g., 95-%) confidence that the slope (m_i) of a single linear regression is different from zero (Benjamin and Cornell 1970).

The t statistic of the slope of the regression line is defined:

$$t_i = m_i \sqrt{n \frac{S_{i,x}^2}{S^2}} \qquad \text{(I–6)}$$

where t_i = t-statistic for regression coefficient i
m_i = estimated value of regression coefficient (i.e., slope of the best-fit line for dose versus the independent variable i)
S = estimated standard deviation of dose
$S_{i,x}$ = estimated standard deviation of independent variable x_i
n = number of samples

When the number of realizations is large, the t distribution may be represented by the normal distribution. The critical value to ensure 95-% confidence that m_i differs from zero under these conditions is 1.96. Equation I–6 is used therefore to determine whether the absolute value of the t statistic for each independent variable is greater than 1.96. If not, then the hypothesis that the independent variable is significant is rejected.

I.7.5.2.3 Partial Rank Correlation

The partial rank correlation coefficient measures the strength of the relationship between variables after any confounding influences of other variables have been removed. The partial rank correlation coefficient between X_1 and Y, with the influence of X_2 removed, is given by:

$$\rho(X_1 Y X_2) = \frac{\rho_{X_1 Y} - (\rho_{X_1 X_2})(\rho_{Y X_2})}{\left[(1 - \rho_{X_1 X_2}{}^2)(1 - \rho_{Y X_2}{}^2)\right]^{1/2}} \qquad \textbf{(I–7)}$$

where $\rho(X_1 Y X_2)$ = partial rank correlation coefficeient between X_1 and Y, with the influence of X_2 removed

ρ_{X1Y} = rank correlation coefficient between X_1 and Y

ρ_{X1X2} = rank correlation coefficient between X_1 and X_2

ρ_{YX2} = rank correlation coefficient between Y and X_2

I.7.5.2.4 Stepwise Multiple Linear Regression

Stepwise multiple linear regression (stepwise regression) determines the most influential independent variables on output uncertainty according to how much each reduces the residual sum of squares (RSS) (SNL 1991). The form of the regression equation is:

$$y = m_1 x_1 + m_2 x_2 + \ldots + m_n x_n + b \qquad \textbf{(I–8)}$$

where y = dependent variable (i.e., peak dose)

x_i = independent variables

m_i = regression coefficients

b = intercept

The variables may be the raw variables, transformed variables (e.g., logarithms), or ranks (see Section I.7.5.3.2 of this appendix). The stepwise algorithm calculates the reduction in RSS for the independent variables in the order that gives the greatest reduction first. The regression coefficients m_i are the partial derivatives of the dependent variable with respect to each of the independent variables; therefore, m_i provides a measure of the relative change in output with respect to a change in the input variable, given that the other input variables are held constant.

I.7.5.2.5 Nonparametric Tests

Nonparametric tests differ from regression and differential analyses in that they do not require fitting the data to prespecified functional form. The Kolmogorov–Smirnov (KS) test is one such test that determines whether a set of samples has been drawn from a specific distribution (NRC 1988). It is used to determine whether an independent variable is important by comparing a subset of the independent variable composed of the values from the highest category (e.g., 10 %) of the peak TEDE realizations to the theoretical distribution of that independent variable. If the distributions are equivalent, then peak TEDE is not sensitive to the variable in question. Conversely, if the distributions are different, then the variable in question does have an effect on peak TEDE.

I.7.5.3 Variable Transformations and Their Attributes

Demonstrating the relationship among input and output variables can be enhanced by transforming the variables. This section describes some common variable transformations used in sensitivity analysis.

I.7.5.3.1 Normalization

In normalization, the input variable x_i is transformed by dividing by its mean value (or another baseline such as the median, 90th percentile, etc.):

$$x_i^* = \frac{x_i}{\overline{x}_i} \qquad \textbf{(I–9)}$$

Normalized variables are dimensionless and are scalar multiples of their baseline values. Dimensionless variables allow the comparison of sensitivities to other independent variables with different dimensions. Normalized variables are a natural outcome of sensitivity derived from regression of log-transformed variables. Such sensitivity measures describe only the relative change in the dependent variable (peak TEDE) to changes in the independent variables. Sensitivities calculated from normalized variables do not take into account the uncertainty in the independent variables.

I.7.5.3.2 Rank Transformation

Rank transformation, a dimensionless transform, replaces the value of a variable by its rank (i.e., the position in a list that has been sorted from largest to smallest values) (Iman and Conover 1979). Analyses with ranks tend to show a greater sensitivity than results with untransformed variables, and diminish the influence of the tails in highly skewed distributions.

I.7.5.3.3 Logarithmic Transformation

For situations in which input and output variables range over many orders of magnitude, it may be advantageous or even necessary to perform analyses on the logarithm of the variables instead of the variable values themselves. The log transformation is also valuable for creating regression equations, where the subprocesses of the model multiply each other to form the output variable. For the present situation, in which the dose calculation results from radionuclide releases from the waste form, transport through the geosphere, and uptake by humans, the processes are indeed largely multiplicative rather than additive. Log transforms therefore tend to give better fits to the Monte Carlo results than untransformed variables. The log transformation is generally used in conjunction with normalization.

I.7.5.3.4 Standardization

The independent and dependent variables can be standardized by subtracting the mean and dividing by the standard deviation, that is,

$$x_i^* = \frac{x_i - \bar{x}}{\sigma_x} \qquad \textbf{(I–10)}$$

The advantage of standardization over normalization is that it inserts the approximate range of the variables into the sensitivity analyses. Therefore a variable that has a large per-unit sensitivity, but is well-known and has a narrow range, will have an increased sensitivity when standardized. Conversely, independent variables with wide ranges may show a reduced sensitivity when standardized.

Sensitivity measures based on standardized variables (standardized sensitivities) have the advantage of taking into account the uncertainty (in terms of the standard deviation) of the independent variable. This technique decreases the sensitivity if the range of the independent variable is large. Furthermore, the standardized sensitivities preserve the absolute values of peak TEDE since the derivatives are divided by the standard deviation for the entire set of calculations, rather than the mean peak TEDE at the evaluation point.

I.7.6 Conclusions

Sensitivity analyses should be used to identify parameters of the models and assumptions that have the largest effect on the results. These sensitivity results should be used to determine if more information on key parameters is warranted to make a convincing case for the acceptability of the site. The sensitivity techniques discussed here portray sensitivity in different ways, and all have their strengths and weaknesses. A useful way to use sensitivity results is to employ several different techniques, and then to determine if a common set of parameters regularly turns out to be important.

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