

**DRAFT NUREG-1549: Using Decision Methods for Dose Assessment
to Comply With Radiological Criteria for License Termination**

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1.0 Introduction

1.1 Use of Decision-Making Framework for Complying with NRC Regulations on Radiological Criteria for License Termination

This NUREG contains an overall framework for dose assessment and decision making for site characterization, dose assessments, and remedial actions at sites licensed by the U.S. Nuclear Regulatory Commission (NRC). The framework can be used throughout the decommissioning and license termination process for sites ranging from the more simple sites to the most complex or contaminated sites. This document represents information for using the framework to step through the decommissioning and license termination process.

This framework is designed for coordinated and mutual use by the licensee, the NRC, and other stakeholders and is intended to streamline the process of coming to closure on decisions while providing a sound technical basis for decisionmaking. By doing so, the process allows the licensee to coordinate its planning efforts with the NRC's input, to conduct dose assessments and site characterization activities that are directly related to regulatory decisions, to optimize cost decisions related to site characterization, remediation, and land-use restrictions, to integrate analyses for As Low As Reasonably Achievable (ALARA) requirements; and to elicit other stakeholders' input at crucial points. The framework also provides a comprehensive approach for treating the uncertainty associated with contaminated sites, including quantification, propagation, and reduction of uncertainty.

1.2 Content of the NRC regulations on Radiological Criteria for License Termination

On July 21, 1997, the NRC published in the Federal Register (62 FR 39058) a final rule incorporating a new Subpart E into 10 CFR Part 20 that includes radiological criteria for license termination. Subpart E provides the regulatory basis for determining the extent to which lands and structures must be remediated before decommissioning of a site can be considered complete and the license terminated.

Subpart E of Part 20 includes requirements for unrestricted and restricted use of facilities after license termination in Sections 20.1402 and 20.1403, respectively. Subpart E also addresses public participation in the license termination process, the finality of license termination decisions, time periods for dose calculations, alternate dose criteria, and minimization of contamination.

The criteria for releasing a site for unrestricted or restricted use are listed here (and summarized in Table 1.1):

§ 20.1402 - Criteria for unrestricted use - a site is considered acceptable for unrestricted use if the residual radioactivity that is distinguishable from background radiation results in a Total Effective Dose Equivalent (TEDE) to an average member of the critical group that does not exceed 25 mrem/yr, including that from groundwater sources of drinking water, and the residual radioactivity has been reduced to levels that are as low as is reasonably achievable (ALARA).

§ 20.1403 - Criteria for license termination under restricted conditions - a site is considered acceptable for license termination under restricted conditions if:

- (a) A licensee can demonstrate that further reductions in residual radioactivity necessary to comply with the provisions of § 20.1402 would result in net public or environmental harm or were not made because the residual levels associated with restricted conditions are ALARA;
- (b) A licensee has made provisions for legally enforceable institutional controls that provide reasonable assurance that the TEDE from residual radioactivity distinguishable from background to the average member of the critical group will not exceed 25 mrem/yr;
- (c) A licensee has provided sufficient financial assurance to enable an independent third party to assume and carry out responsibilities for any necessary control and maintenance of the site.
- (d) A licensee has submitted a decommissioning plan or license termination plan specifying that the licensee intends to decommission by restricting use of the site and documenting how the advice of individuals and institutions in the community who may be affected by the decommissioning has been sought and incorporated into the plan.
- (e) Residual radioactivity at the site has been reduced so that if the institutional controls were no longer in effect, there is reasonable assurance that the TEDE from residual radioactivity distinguishable from background to the average member of the critical group is as low as is reasonably achievable and would not exceed either: (1) 100 mrem/yr; or (2) 500 mrem/yr provided the licensee: (a) demonstrates that further reductions in residual radioactivity necessary to comply with 100 mrem/y are not technically achievable, would be prohibitively expensive, or would result in net public or environmental harm; (b) makes provisions for durable institutional controls; and (c) provides sufficient financial assurance to enable an independent third party both to carry out periodic rechecks of the site every 5 years to assure that the institutional controls remain in place and to assume and carry out responsibilities for any necessary control and maintenance of those controls.

This NUREG provides information on demonstrating compliance with the dose criteria and ALARA provisions of the unrestricted and restricted use requirements in Sections 20.1402 and 20.1403. Other requirements described above (e.g., public participation) are covered in Regulatory Guide 1.xxx.

Table 1.1 - Summary of 10 CFR Part 20 Subpart E

	Unrestricted Release	Restricted Release	
Dose Criterion	25 mrem TEDE per year peak annual dose to the average member of the critical group	25 mrem TEDE per year peak annual dose to the average member of the critical group while controls are in place	100 mrem or 500 mrem TEDE per year peak annual dose to the average member of the critical group upon failure of controls
Time Frame	1000 years	1000 years	1000 years
Other Requirements	ALARA	ALARA, financial assurance, public participation	ALARA, financial assurance, public participation

2.0 Overview of the decision framework

2.1 Rationale for the decision framework

The NRC is responsible for evaluating requests from licensees for the termination of the NRC license for their facilities. As part of the regulatory process, these facilities must demonstrate that they meet the radiological criteria for license termination in Subpart E of 10 CFR 20 (summarized in Table 1.1).

A logical, consistent decision process is viewed as a useful tool that will support licensee planning of decommissioning activities and NRC review of license termination requests. To support this process, this NUREG describes a decision methodology, or "framework," to support implementation of the dose assessment requirements in Subpart E.

Dose assessments of facilities are typically used to demonstrate compliance with the criteria of Subpart E and generally rely on the use of site characterization and modeling and analytical tools. The principal components of the dose assessments are: (a) models for transport of radionuclides through the environment to a receptor, and (b) the parameters used in those models. In these dose assessments, a reasonable treatment of uncertainty is needed to provide the regulator with the confidence that the actions taken and the decisions made to terminate the facility license are consistent with the regulations.

The steps and decision points of the decision framework support assessment of the entire range of dose modeling options from which a licensee may choose, whether it involves using generic screening, parameters, changing parameters, or modifying pathways or models. The decision framework, including its steps and decision points, is illustrated in Figure 1.

2.2 Phased approach in using the decision framework

2.2.1 Contents of the phased approach in using the decision framework

To facilitate the preparation and evaluation of the dose assessments, this NUREG describes a phased approach to decision making for license termination. A phased approach is necessary because of the very wide range of levels of contamination and complexity of analysis and potential remediation necessary at NRC-licensed sites. The phased approach consists of generic screening and of making use of site specific information as appropriate. These phases are described in broad terms below:

- 1) Generic screening: In this phase, licensees would demonstrate compliance with the dose criteria of the rule by using: (a) pre-defined models, and (b) generic screening parameters.

Pre-defined models which use generic exposure scenarios and pathways are based on the NUREG/CR-5512 methodology and can be used with minimal justification by licensees who are applying generic screening scenarios and parameters using the DandD software. The minimum justification for the use of the default scenarios and parameters consists of a statement by the licensee that no conditions exist at the site,

outside those incorporated in the default scenarios and modeling assumptions, that would cause the calculated dose to increase. Examples of site-specific features that may require modeling beyond the defaults include (but are not limited to) known groundwater contamination, large quantities of contaminated material (such as slag piles), or buried wastes. The generic scenarios and pathways of the pre-defined models provide the licensee with a simple method to demonstrate compliance using little or no site-specific information other than the source term.

The pre-defined models and generic screening parameters are intended to approximate the upper range of the dose that the average member of the critical group could receive. The default screening parameters were selected probabilistically to control the regulatory risk associated with releasing a site based on source term data alone. Uncertainty in site conditions across sites is treated by the NRC through their use of a systematic quantification of the uncertainty that assures the regulator will not make an incorrect decision.

In generic screening, the licensee need only provide site specific residual contamination information which is combined with NRC's pre-defined models and generic screening parameter values. If compliance is demonstrated using NRC's screening models and parameter values, then progression to more site specific analysis is unnecessary.

It is anticipated that the majority of NRC's licensees will be able to use generic screening to demonstrate that their site is acceptable for license termination. Use of the framework for facilities using generic screening will be relatively simple and straightforward and generally results in use of only Steps 1 - 7 of Figure 1.

- 2) Use of site specific information as appropriate: If compliance cannot be demonstrated with generic screening, then there can be progression to a later phase in which defensible site specific values are obtained and applied. Depending on the complexity of the site contamination, the licensee can use site specific information by:
 - (a) using the NRC's pre-defined models but replacing generic screening parameters with site-specific parameter values to allow site specific factors to be taken into account. Thus, the dose estimates would be more realistic, but will still be conservative for a particular site based on the use of the pre-defined models. or
 - (b) using both site-specific parameter values and site-specific model assumptions;
 - (c) using some combination of a and b and also remediating the site;
 - (d) using some combination of a, b, and c, and also restricting use of the site

In any of the cases a - d, site specific data are used to support modifying or eliminating a particular scenario or pathway, or to demonstrate that a parameter or group of parameters can be better represented by site specific values. Alternative exposure scenarios may be appropriate based on site-specific factors that affect the likelihood

and extent of potential future exposure to residual radioactivity. In cases a - d, the licensee would have to provide justification for the site specific parameter values or for the alternative model, as appropriate.

Thus use of the framework for these situations can range from fairly simple site assessments to fairly complex analyses. In either case, use of all 12 steps of the framework in Figure 1 are likely used in these cases, although the range of options analyzed in Step 8 can be fairly simple (e.g. modification of parameters) to fairly complicated (e.g., use of restrictions on site use).

2.2.2 General concepts regarding the phased approach

The following general concepts apply to using the phased approach with the decision framework:

- a) The approach provides a logical, iterative process for screening sites and for directing additional data collection efforts where necessary. It provides the licensee with a variety of options for performing dose assessments from simple screening to more detailed site specific analyses.

The framework is designed such that the level of complexity and rigor of analysis conducted for a given site should be commensurate with the level of risk that the site poses. Although all sites are expected to step through Steps 1 through 5, and steps 6 and 7, the amount of work that goes into each of these steps should be based on the expected levels of contamination and the health risks they pose. Note that in this framework, all sites may start at the same level of very simple analyses (not a requirement for successful implementation), but it is expected that only certain sites would progress to very complex dose assessment and options analyses. Some sites may not need to conduct any options analyses (Step 8) and some sites may need to evaluate a limited set of relatively simple and inexpensive options. For example, a site with a contained source of contamination that is obviously simple to remove would not spend time analyzing large suites of alternative data collection and remediation options. On the other hand, a site with high levels of contamination that are widely distributed may use this process to analyze a variety of simple and complex options to define the best decontamination and decommissioning strategy.

Thus, the approach ensures that the NRC's, the licensee's, and other affected parties' efforts and expenses are commensurate with the level of risk posed by the site;

- b) The licensee need not start the process with generic screening but can move directly to use of site specific information, as appropriate
- c) Consideration of risk is implicit in the methodology in that the likelihood of receiving less than the simulated dose is accomplished through the use of probabilistic treatment of parameter uncertainty (implicitly and/or explicitly). The NRC will not require licensees to conduct probabilistic analyses in their evaluation of compliance; however, a robust treatment of uncertainty will be needed to lend credibility to the results and confidence

to regulatory decision making when site specific information is used. Data collection activities can be tied directly to the regulatory dose-based performance objectives

A key point in implementing this framework is that, as new data is collected or the site is remediated, the simulated dose should decrease with each subsequent dose assessment.

- d) For the process to work correctly and efficiently, the licensee is encouraged to involve the NRC from the very first step through the end of the decision making process.

Chapters 3, 4 and 5 of this NUREG describe how to apply the decision framework of Figure 1 to the wide range of NRC licensees, from those with relatively simple decommissioning situations, to those with intermediate levels of contamination, and to those with more complex contamination patterns, respectively. Chapters 3, 4 and 5 provide descriptions of each of the framework steps (see Figure 1) in some detail, and how they integrate to define a process for moving through the framework to treat uncertainty and define a license termination strategy. It is important to note that these chapters and the process of considering them by any particular licensee should be fluid, that is a licensee may, in considering options for dose assessment and license termination, use any one of the chapters or all of them.

Detail on each step is provided in Chapter 3 for sites that use the generic screening approach developed by NRC, in Chapter 4 for sites that use an approach of incorporating site specific information because they have intermediate situations, and in Chapter 5 for more complex situations. Licensees using codes and modeling approaches other than generic screening should use Chapters 4 and 5. Chapter 4 is presented separately from Chapter 5 because of the large differences in the level of analysis and evaluation necessary for the wide range of NRC licensees that use site specific information. This may cause some repetition but it is expected to be most useful to licensees to be presented in this manner.

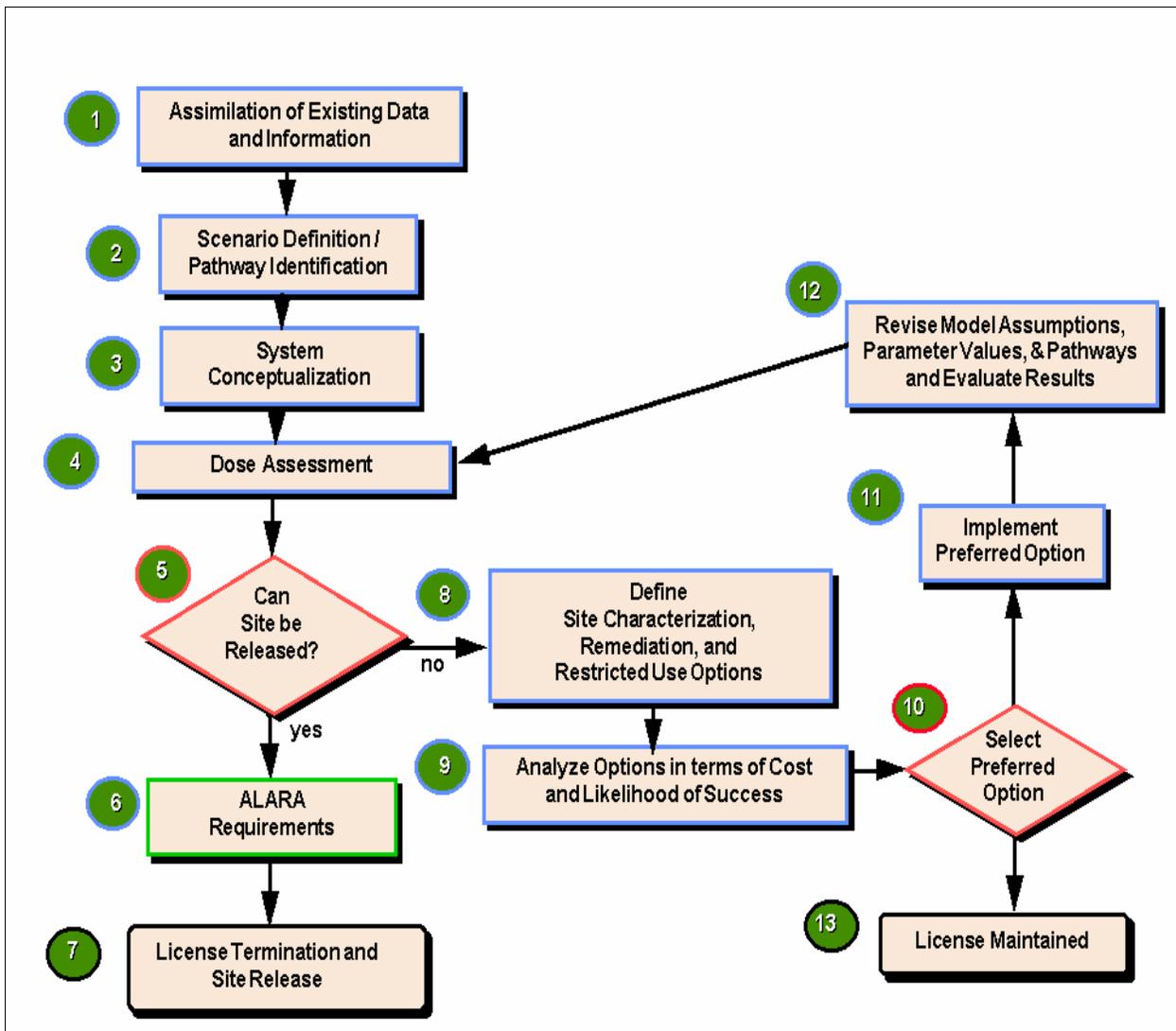


Figure 1 Decommissioning and License Termination Framework

3.0 Use of the Framework for Licensees That Use Generic Screening

As noted above, this chapter describes the use of the framework for licensees that use the generic screening approach described in Section 2.2.1 (as noted in Section 2.2.2, licensees may use other models or codes but should use the steps in Chapters 4 or 5 of this NUREG with those approaches). In general, a licensee with a relatively simple decommissioning situation would follow Steps 1 through 7 of the framework of Figure 1. Such licensees would likely include those NRC licensees with contained or short-lived radionuclide sources that have small amounts of building or soil contamination. An example of the use of the framework for such a situation is given in Appendix G as Case 1. Licensees of this type would step through the framework as follows:

3.1 Step 1:

This step involves gathering and evaluating existing data and information. Licensees should check their records to determine the types and amounts of radioactive material they possessed on their site. They should also gather information about any surveys and leak tests that had been performed, as well as any records that would support their ability to terminate the license under 10 CFR Parts 30, 40, 50, 70, or 72, as appropriate. For example, Part 30 licensees should gather information sufficient to "Certify the disposition of all licensed material, including accumulated wastes, by submitting a completed NRC Form 314 or equivalent information" [10 CFR 30.36(j)(1)].

Licensees using generic screening would be making use of the NRC developed DandD models and generic screening concentration values, and therefore only site-specific source term data quantifying the amount of contamination present would need to be gathered.

3.2 Step 2:

This step involves defining the scenarios and pathways that are important for the site dose assessment. For a licensee using the generic screening parameters, this step has already been completed by the NRC, based on the generic scenarios and pathways for screening that have been defined and described in NUREG/CR-5512, Volume 1. Information on generic scenarios and pathways is presented in Appendix C.1.

3.3 Step 3:

This step involves system conceptualization, which includes conceptual and mathematical model development and assessment of parameter uncertainty. For a licensee using generic screening, this step has already been completed by NRC, using the models described in NUREG/CR-5512, Volume 1, and implemented in the DandD software. Information on generic models for system conceptualization is presented in Appendix D.1.

Thus, a licensee using generic screening could use the DandD software containing pre-defined models and default parameters, or as noted in Step 4, could instead use the radionuclide-specific default concentrations contained in Tables A-1 or A-2 of Appendix A of this NUREG. The minimum justification for the use of the default models, scenarios, and

parameters consists of a statement by the licensee that no conditions exist at the site, outside those incorporated in the default scenarios and modeling assumptions, that would cause the calculated dose to increase. Examples of site-specific features that may require modeling beyond the defaults include (but are not limited to) known groundwater contamination, large quantities of contaminated material (such as slag piles), or buried wastes.

3.4 Step 4:

This step involves the dose assessment for the site. For a licensee using generic screening, the licensee can either: (a) use the generic screening concentrations that correspond to the 25 mrem/yr dose criterion which have already been calculated by the NRC (see Tables A-1 or A-2 of Appendix A of this NUREG) to compare against the site contamination levels obtained in Step 1, or (b) run DandD with the appropriate site specific source term.

Defense and justification provided by the licensee for the selection and use of the DandD code would not be necessary. The licensee would provide to the NRC a copy of the DandD generated report to verify the version of DandD that was used in the analysis. Defense is needed of the source characterization and to show that DandD is applicable for the site conditions (discussed under Step 3).

3.5 Step 5:

This is the first major decision point in the framework and involves answering the question of whether the dose assessment results of Step 4 are less than the dose criterion of 25 mrem/yr in 10 CFR 20, Subpart E. For a licensee using DandD or equivalent code with default values and site source term, or using the generic screening concentrations of Tables A-1 or A-2, the licensee would find either that:

- a) The result in Step 5 is that the calculated dose is less than 25 mrem/yr or site contamination is less than or equal to the values in Tables A-1 or A-2. **If this is the case, proceed to Step 6**
- b) The result in Step 5 is that the calculated dose is greater than 25 mrem/yr or the site contamination is greater than the values in Table A-1 or A-2. **If this is the case, it means that the contamination at the site is such that the licensee cannot use the generic screening approach to terminate the licensee. Rather, in order to terminate the license, the licensee would need to evaluate other options such as incorporating site specific information into the dose assessment. Thus, if this result is found, the licensee should proceed to Chapters 4 or 5 and use the framework steps applicable to use of site specific information.**

3.6 Step 6:

If the result in Step 5 is that the calculated dose is less than 25 mrem/yr or the contamination at the site is less than the values in Tables A-1 or A-2, the licensee can proceed to satisfy ALARA requirements, if not already addressed (see Section 4.0 of Regulatory Guide x.xxx)

3.7 Step 7:

In this step the final paperwork requirements are completed, including documenting any survey results used to calculate the source term and the results of the dose calculations, and the licensee would request that their license be terminated by the NRC.

4.0 Use of the framework for licensees that use Site Specific Information to modify site parameters

This chapter describes the use of the framework for the wide range of licensees that may use site specific information in their dose assessment. As described in Section 2.2, there are a wide range of options for using site specific data ranging from modifying parameters, to modifying models, to remediating the site, to restricting site use.

This chapter describes use of the framework specifically for those licensees that choose the option of modifying parameters without further consideration of other options. This chapter is prepared separately from Chapter 5 (which includes a more in-depth evaluation of options) because it is thought that a number of licensees will have relatively low levels of contamination and will seek to perform a dose assessment by changing default parameters to more adequately represent their site. This could include those licensees who attempt to use the generic screening approach of Chapter 3 but who do not meet the unrestricted release criteria in step 5.

This chapter only describes the option of changing modeling parameters but is not intended to limit the options a licensee may pursue. For example, it is possible that a licensee could combine obtaining additional site data to revise parameters with remediating a site, or could even proceed directly to remediate a site. A licensee who is uncertain of what option is most appropriate should proceed to Chapter 5. This chapter provides information for licensees who, possessing relatively simple contamination patterns, have used a correspondingly simple consideration of their options to conclude that modifying parameters from the screening values will provide a simple, cost effective means to comply with the dose criteria of Subpart E. It should be further noted that licensees who proceed through the framework as outlined in Chapter 4 can still proceed to Chapter 5 if necessary.

An example of the use of the framework for the situation discussed in this chapter is given in Appendix G as Case 2.

4.1 Steps 1- 5

Licensees using this approach are assumed to have little information about their site initially and are assumed to go through the process of generic screening to determine if their site can be released using the generic screening concentrations. Thus, Steps 1 - 5 would be the same as described in Chapter 3. It is further assumed that these licensees on their initial pass would end up in Step 5b in which the contamination at the site is such that the licensee cannot use the generic screening approach to meet the dose criteria of Subpart E. Thus, rather than proceeding to Step 6 and 7, these licensees would proceed to Step 8.

4.2 Step 8 - Define Site Characterization, Remediation, And Restricted Use Options

The purpose of Step 8 is to define options for proceeding with the license termination process. These options are presented here as information for licensees in planning their dose assessments and their submittals to the NRC. As described in Chapter 1 above, it is thought that a well thought out consideration of options for compliance with Subpart E and for

submittals to NRC will enhance the process of decision-making on both on the licensee's and the NRC's part by allowing the licensee to make decisions in a timely manner that are both cost-effective and have a sound technical basis.

There are basically three options that the licensee could apply either alone or in combination:

- a) Option 1 - Activities that reduce uncertainty (information/data collection) in the calculated dose through use of source terms, pathways, models, and/or parameters that better represent the site based on some additional site information gathering or characterization ,
- b) Option 2 - Activities that reduce contamination (remediation), and
- c) Option 3 - Activities that reduce exposure (land-use restrictions).

Chapter 4 assumes that the licensee will proceed to use Option 1. Most sites would perform an analysis of the options that is relatively simple and arrive at Option 1 because the nature of the contamination or the site conditions appear likely to support a lower estimated dose. Licensees might elect to use Option 1 before proceeding to other more complex activities such as excavating, transporting and disposing of soil from the site that would be involved in Option 2 or establishing institutional controls for restricted use that would be involved in Option 3. An example of a process of considering options that a licensee might use before arriving at a decision to use Option 1 is shown in Table 5.2.

For Option 1, licensees should do the following:

- a) Review the parameters in the NUREG/CR-5512 model and what they represent: The parameter distributions and their rationale are presented in Attachment 1. The rationale for parameter selection for the generic screening approach is presented in Section 2.2.1 of this NUREG where it is noted that generic screening analysis is intended by NRC to provide a specified level of confidence in the dose estimate and to control the amount by which the dose could exceed the criterion.
- b) Consider how to modify the parameters to incorporate site specific information and determine the data needs to modify the parameters: Attachment 1 provides information regarding the valid ranges for site specific parameter changes that a license could propose without an additional uncertainty analysis. As a consequence, the licensee needs little supporting information to defend changes to the parameter values that are within the limits specified in the parameter analysis. This is important in evaluating the relative worth of collecting additional data on these parameters under Step 9 of the decision framework. Appendix E provides information on how to modify the parameters used in the dose assessment .

4.3 Step 9 - Analyze Options in terms of Cost and Likelihood of Success

This step involves the analysis of options in terms of cost and the likelihood of success. As noted above in Step 8, the purpose of this step is to provide information for the licensee so that the evaluation of options considers both the probability that a desired result will be achieved, (i.e., meeting the criteria of Subpart E), and that achieving the desired result is done in a cost-effective manner.

For the licensee choosing Option 1, Step 9 should consist of the following:

- a) an evaluation of the level of detail and information sources to use to better estimate values for the model parameters that will be updated with site-specific information. . Such an evaluation is important because there are many options for modifying parameters which range in cost and complexity depending on whether low or no cost information is easily accessible or will require expensive or specialized laboratory analysis . This evaluation can be done by reviewing the parameters in Appendix E.
- b) The cost and time needed to review each parameter should be estimated, along with the likelihood that the approach will be successful in meeting the desired endpoint (i.e., meeting the criteria of Subpart E). The analysis should also address the uncertainty associated with each potential outcome.

If the activity is successful, then the revised calculation of dose will meet the Subpart E criteria,, no follow on activities are necessary, and no other significant costs would be incurred. On the other hand, if the activity is unsuccessful, the eventual total cost ends up being the cost to conduct the activity plus the cost to conduct any necessary follow-on activities to get the dose to an acceptable level.

- c) A decision should be made regarding the method for gathering information to revise parameters based on a and b, above. Note that *actual* success or failure of this effort will not be realized until the second iteration of Steps 4 and 5.

4.4 Step 10 - Select Preferred Option

The activities in Step 9 provide information for the licensee using Option 1. In this case, at this step, the licensee would choose the method for revising the parameters given the cost, timeliness and likelihood of success.

4.5 Step 11 - Implement Preferred Option

Under Step 11, the preferred option is implemented. The licensee obtains the information necessary to support revisions to the parameters that will be modified.

4.6 Step 12 - Revise Model Assumptions, Parameter Values, and Pathways

Under Option 1, the parameter values for the pre-defined models are revised as appropriate. To support a future request for license termination, any site survey results, parameter data, or laboratory tests should be carefully documented. The process that the licensee should go through to justify new parameter values or refine parameter distributions is presented in Appendix E.

4.7 Reiteration of Step 4:

The revised parameter values are used in iteration 2 of the dose assessment. For the licensee only changing parameters, the original default model assumptions and pathways would remain unchanged.

4.8 Reiteration of Step 5:

The revised dose assessment is evaluated to determine if the calculated dose meets the requirements in 10 CFR 20, Subpart E. For a licensee using site specific information to modify the parameter values, the licensee would find either that:

- a) The result in Step 5 is that the calculated dose is less than or equal to the 25 mrem/yr dose criterion of 10 CFR 20.1402. **If this is the case, proceed to Step 6**
- b) The result in Step 5 is that the calculated dose is greater than the 25 mrem/yr dose criterion of 10 CFR 20.1402.. **If this is the case, it means that the contamination at the site is such that the licensee cannot simply revise the parameters of the dose assessment to comply with Subpart E. Rather, in order to terminate the license, the licensee would need to incorporate additional site specific information into the dose assessment, or possibly consider remediation or restricting site use. Since the initial simple approach of revising parameters has not proven acceptable, licensees should proceed to Chapter 5 and use the framework steps applicable to further analysis of options .** The licensee is encouraged to actively work with the NRC during this step to evaluate the appropriateness and adequacy of the analyses before moving on and expending resources on follow on steps.

4.9 Step 6 - ALARA Requirements

If the result in Step 5 is that the 25 mrem/y criterion has been met, the licensee can proceed to satisfy ALARA requirements, if not already addressed. ALARA actions at this step can be based on Section 3 of Reg Guide x.xx. The licensee is encourage to actively work with the NRC to discuss, define, and concur on alternative ALARA actions under this step prior to implementing any actions.

4.10 Step 7 - License Termination and Site Release

In this step the licensee would complete final paperwork requirements, including documenting any survey results used to calculate the source term and the results of the dose calculations, and would request that their license be terminated by the NRC.

5.0 Use of the framework for licensees that use Site Specific Information and Consider a range of Options for using that information

This chapter describes the use of the framework for the wide range of licensees that may use site specific information in their dose assessment. As described Section 2.2, there are a wide range of options for using site specific data. Chapter 4 discussed the framework for those licensees who take the option of merely modifying model parameters. However, there may be sites with complex or substantial contamination for which it may be necessary to:

- a) change the models, scenarios, pathways, and/or parameters used for assessing nuclide behavior to support release of the site for unrestricted use,
- b) remediation of the site by removal of soil or concrete,
- c) restrict future use of the site under the requirements of 10 CFR 20.1403.
- d) perform some combination of a, b, or c.

Licensees with fairly complex situations may already have considerable information about their site. Such licensees may choose not to use generic screening, preferring instead to immediately utilize as much existing site-specific information as possible. Therefore the discussion of the use of the framework for these sites begins with the licensees using site specific information in Steps 1 - 4 rather than using the generic screening approach of Chapter 3 (alternatively, even a licensee with significant site-specific information may find it useful to start with the generic screening in the initial iteration (see Section 4.1)). Licensees using this approach would step through the framework as follows:

5.1 Step 1 - Assimilate Existing Data and Information:

This step involves gathering and evaluating existing data and information. Licensees should check their records to determine the types and amounts of radioactive material they possessed on their site. They should also gather information about any surveys and leak tests that had been performed, as well as any records that would support their ability to terminate the license under 10 CFR Parts 30, 40, 50, 70, or 72, as appropriate.

Data gathered in this step are used to support Step 3 which is development of a conceptual model, and model assumptions and model parameter values. As described above, the licensee has 3 options in this analysis:

- (1) use the pre-defined DandD models and the specified set of site-specific parameter values
- (2) use other existing models and codes and site-specific parameter values
- (3) develop site-specific models and codes and accompanying parameter values

Additional information is needed to support and defend the conceptual model of Step 3 if models other than DandD are used or if site specific parameter values are used. Methods for

obtaining the necessary additional information to support the site specific parameters and models used are described in Appendix E.2.

5.2 Step 2 - Scenario Definition/Pathway Identification:

This step involves defining the scenarios and pathways that are important for the site dose assessment. In this step, the licensee defines potential human activities and identifies migration and exposure pathways that need to be considered. Each of the site release conditions defined in Subpart E (unrestricted use or restricted use) involve potentially different considerations with respect to human activities on or near the site (the critical group) and radionuclide migration pathways. These should be considered as follows:

- a) Scenarios are defined as plausible sets of human activities and future uses of the site. As such, scenarios provide a description of the reasonable future land uses and human activities over the period of interest.

With an understanding of the physical system and potential human activities, one can then develop conceptual models of the site (Step 3). Those conceptual models are translated into mathematical models and implemented in (and solved by) corresponding analytical or numerical models and computer codes. The objective is to calculate a dose (Step 4) which is then compared with dose criteria (Step 5) to assess whether the site complies with requirements of Subpart E.

- b) The definition of scenarios and identification of pathways can be generic or site specific; however, these definitions should be such that they adhere to the constraints of the iterative approach as defined in this document. That is, the simulated dose should decrease with each iteration if the scenarios and pathways are changed based on site-specific information.

The generic scenarios, critical groups, and pathways acceptable to the NRC are described in Appendix C.1. Licensees choosing to modify the generic scenarios, critical groups, and/or pathways should use the information in Appendix C.2 which describes the method the licensee would use to consider appropriate critical groups for their site and to develop site specific scenarios and pathways.

5.3 Step 3 System Conceptualization:

System Conceptualization, as defined here, includes conceptual and mathematical model development and assessment of parameter uncertainty. This assessment of uncertainty includes a process of systematically evaluating the level of uncertainty associated with a specific site and the quantification of that uncertainty. In order to manage the treatment of uncertainty associated with dose assessment at a given site, the four steps of scenario definition, pathway identification, model development, and assessment of parameter uncertainty are treated as a hierarchy, moving from the former of these to the latter.

As with the pathways, conceptual and mathematical models have been defined for the NUREG/CR-5512 methodology and these models (codified in the DandD code) are acceptable

for making dose assessments. Information on the generic models is contained in Appendix D.1. In addition, Appendix D.1 provides information that the licensee should use in evaluating whether or not the generic models are appropriate for their site given the assumptions made in NUREG-5512 and the nature of their site.

If the licensee chooses to develop site-specific models (either through changes to the default parameter values, model assumptions or development of new models), then the licensee would need to defend the model and associated parameters. Information on methods for defend site specific models is contained in Appendix D.2, including information on development of the model (D.2.1), use of a deterministic or probabalistic approach (D.2.2), and selection of codes (D.2.3).

5.4 Step 4 - Dose assessment

This step involves the dose assessment for the site, which means running the DandD or equivalent software with the appropriate site specific source term.

In this step, the licensee will calculate potential doses using mathematical representations of the conceptual models. This step involves the execution of the numerical model(s) that implement the mathematical equations and will provide the basis for (1) assessing compliance with the individual dose criteria and (2) an analysis of the impact of uncertainty in models and input parameters on the model output. In doing so, this step includes the propagation of uncertainty in parameters through exposure models and should provide a quantitative representation of the uncertainty in the dose given those models and parameters.

NRC has implemented the default scenarios, critical groups, pathways, model assumptions and parameter values from Steps 2 and 3 in the DandD code. The licensee has the option of using DandD for the dose assessment, under the conditions discussed in Appendix D.1 for justifying assumptions and parameter values for their site. The rationale and approach for using the generic models and code selection are contained in Appendix D.1.1 and D.1.2.

Information on methods to perform site specific dose assessments is contained in Appendix D.2.1 through D.2.3.

5.5 Step 5 - Can the site be released

The dose assessment using the site specific information generated in Steps 1 - 4 is evaluated to determine if the calculated dose meets the requirements in 10 CFR 20, Subpart E. For a licensee using the site specific information, the licensee would find either that:

- a) The result in Step 5 is that the calculated dose is less than or equal to the 25 mrem/yr dose criteria of 10 CFR 20.1402. **If this is the case, proceed to Step 6**
- b) The result in Step 5 is that the calculated dose is greater than the 25 mrem/yr dose criteria of 10 CFR 20.1402.. **If this is the case, it means that the contamination at the site is such that the licensee would need to consider additional options to terminate the licensee. In order to terminate the license, the licensee would need**

incorporate additional amounts of site specific information into the dose assessment, or possibly consider remediation or restricting site use. Thus, if this result is found, the licensee should proceed to Step 8. The licensee is encouraged to actively work with the NRC during this step to evaluate the appropriateness and adequacy of the analyses before moving on and expending resources on follow on steps.

5.6 Step 8 - Define Site Characterization, Remediation, And Restricted Use Options

The purpose of this step is to for the licensee to better define its options for proceeding with the license termination process. These options are presented here as information for licensees in planning their dose assessments and their submittals to the NRC. As described in Chapter 1 above, it is thought that a well thought out consideration of options for compliance with Subpart E and for submittals to NRC will enhance the process of decision-making both on the licensee's and the NRC's part by allowing the licensee to make decisions in a timely manner that are both cost-effective and have a sound technical basis. It will also allow the licensee to define the most effective and cost-efficient decontamination and decommissioning strategy. Section 5.6.1 presents the principal options and Section 5.6.2 present the actions that a licensee should take in considering these options. Table 5.1 presents a summary of a licensee's possible process for considering the options.

5.6.1 Defining options

There are basically three options that the licensee could use. Generically, the options are:

- 1) Option 1 - Activities that lower dose by reducing uncertainty (information/data collection)
- 2) Option 2 - Activities that lower dose by reducing contamination (remediation)
- 3) Option 3 - Activities that lower dose by reducing exposure (land-use restrictions)

The options can be implemented singly or in combination, and the combinations can be performed either in parallel or in series to provide the optimal solution. In addition, there could be a large number of combinations of site characterization data collection options. Examples of combined alternatives include:

- * site characterization for revision of source term (Option 1) combined with remediation (Option 2) followed by unrestricted release,
- * site characterization for revision of source term (Option 1) combined with literature/database review to support default parameter replacement (Option 1) followed by unrestricted release,
- * site characterization for revision of source term (Option 1) combined with literature/database review to support default parameter replacement (Option 1) combined with remediation (Option 2) followed by unrestricted release,

- * remediation (Option 2) combined with land-use restrictions (Option 3) followed by restricted release. Another example is the application of land-use restrictions to some portions of the site and remediation and unrestricted release to other portions of the site to reduce long-term maintenance, monitoring and assurance costs.

5.6.2 Specific Licensee Actions Under the Options

A licensee in Step 8 should go through a consideration of the options in a manner similar to the following (Table 5.1 presents a summary of a licensee's possible process for considering the options):

1) **Option 1 - Activities that lower dose by reducing uncertainty (information/data collection and revision of source term, parameters, and/or models)**

This option would be pursued if existing information does not result in the dose criterion being met, but further reduction of uncertainties and relaxation of conservatism through use of site-specific data are likely to result in a calculation of dose that meets the criteria of Subpart E. Specifically, these activities are data and information collection activities that would result in a reduction of uncertainty in the calculated doses through use of source terms, pathways, models, and/or parameters that better represent the site.

In Option 1 licensees should do the following:

- a) Review the default parameter values in the NUREG/CR-5512 model and what they represent: The default parameter distributions and their rationale are presented in Appendix C. The rationale for the default parameter selection is presented in Section 2.2.1 where it is noted that the screening parameters are selected by NRC to provide a specified level of confidence in the dose estimate and control the amount by which the dose could exceed the criterion.
- b) Consider how to modify the default parameters to consider site specific information and determine the data needs to modify the parameters: The parameter analysis indicated in Appendix C provides information regarding the valid ranges for site specific parameter changes that a license could propose without an additional uncertainty analysis. As a consequence, the licensee needs little supporting information to defend changes to the parameter values that are within the limits specified in the parameter analysis. This is important in evaluating the relative worth of collecting additional data on these parameters under Step 9 of the decision framework.
- c) Consider whether modification of the critical group is appropriate: Various site uses and scenarios can be postulated within the limits of reasonable future uses for the site and surrounding properties. Licensees need to specifically define the critical group. Initial iterations of the decision process defined by this document may simply involve use of the screening scenarios and screening groups listed in the previous section. Subsequent iterations may involve site

specific scenarios and critical groups (referred to as "site specific critical groups"). Background information on critical groups is contained in Appendix C.3 and information on developing site specific scenarios and critical groups is in Appendix C.2

(2) Option 2 - Activities that lower dose by reducing contamination (remediation)

This option involves remediation activities that remove actual contamination from the site or reconfigure contamination (physically or chemically) such that transport to a receptor is decreased. Option 2 results in actual reduction of the quantity of residual radioactivity remaining on the site.

(3) Option 3 - Activities that lower dose by reducing exposure (land-use restrictions)

This option would be pursued if the licensee is considering restricting use of the site as a means of terminating the license. If Option 3 is pursued, the licensee is required by 10 CFR 20.1403 to conduct the following additional analyses and activities: (1) demonstrate that achieving unrestricted release is not ALARA, (2) provide legally enforceable institutional controls that would limit the exposure to individuals to 25 mrem/yr, (3) provide financial assurance for the controls, and (4) seek advice from those in the community who may be affected by the decommissioning. In order to comply with these requirements, a licensee should do the following as part of considering Option 3:

- a) Because use of Option 3 requires a demonstration to the NRC that further reduction in dose levels to unrestricted use is not ALARA (i.e. NRC would prefer unrestricted use), licensees should fully evaluate unrestricted release for the first iteration through the decision process by fully considering Option 1 and/or Option 2. Any site-specific information gathered to support Options 1 or 2 can be used in a later iteration analyzing restricted release.
- b) The dose modeling for Option 3 should include as much site-specific information (gathered as part of Option 1) as necessary to provide a reasonable evaluation of future impacts, both with and without institutional controls in effect, to show compliance with restricted release criteria, i.e., the screening parameters are not sufficient to support a decision to select restricted use
- c) The dose assessment under Option 3 should evaluate site specific critical groups as follows:
 - (1) the site specific critical group present as defined by the institutional controls used to restrict use. For example, if a site is restricted to industrial use, the site specific critical group would be a group of workers occupying the building.
 - (2) the site specific critical group possibly affected by transport to exposed individuals outside the control boundary (and possibly physically off site

and somewhat removed from the actual location of the contamination, e.g., groundwater movement of radionuclides offsite).

- (3) the site specific critical group which would be exposed in the event of failure of institutional controls and which thus effectively has access to the site as if the site were unrestricted. The site specific critical group in this case would likely be the resident farmer scenario used in generic screening, unless the licensee is able to define and defend an alternate site specific critical group and scenario.
- d) Conduct the regulatory activities that will need to be completed prior to NRC granting a license termination under 20.1403 Guidance on these aspects are contained in Regulatory Guide 1.xxx.

For a set of hypothetical options, Table 5.1 provides an example of how a licensee might identify and summarize their options. In making such a table, column 1 would be the expected outcome following the activities in each of the options even though this would be uncertain at this point in the process. Column 2 of the table would be a translation of the expected outcome, at least qualitatively, into a beneficial impact on the calculated dose. Column 3 would define the action that would be needed to demonstrate the new state of knowledge or to realize the new state of the site.

In preparing a table like Table 5.1, if there are limits on the time or funds available, then only the options that are below such constraints (if successful), should be considered. If such constraints do not exist then all viable and realistic options should be considered and presented to the NRC.

Table 5.1 - Example Options Definition Table

Expectation	Effect on Dose	Action
Source is believed to be of lower concentration than currently modeled	Simulated dose expected to decrease as concentrations decrease	Collect field data to better characterize source distribution
Experimentally measured kd for this site expected to be higher than default value	Simulated dose expected to decrease as availability to the receptor is decreased	Collect laboratory data to reduce uncertainty in the kd
Soil type is expected to have higher kds than default value	Simulated dose expected to decrease as availability to the receptor is decreased	Collect literature and soil map data to defend alternative soil type/texture
Soil permanently removed to decrease source concentrations	Available mass of contaminant decreases, hence simulated dose would decrease	Remediation by soil removal
Controls are expected to remain in place for the duration of the compliance period (if controls fail, simulated doses are between 25 mrem and 100 mrem)	restrictions will limit access to disposal areas on site while controls are in place; simulated dose will decrease	Dispose of waste and stabilize on current site and apply for restricted release
Controls are expected to remain in place for the duration of the compliance period (if controls fail, simulated doses are between 25 mrem and 100 mrem)	restrictions will limit uses for site while controls are in place to limit exposure time and pathways to individual; simulated dose will decrease	Set land use restrictions and apply for restricted release

5.7 Step 9 - Analyze Options in terms of Cost and Likelihood of Success

This step involves the analysis of options in terms of cost and the likelihood of success. As noted above in Step 8, the purpose of this step is to provide information for the licensee so that the evaluation of options considers both the probability that a desired result will be achieved, (i.e., meeting the criteria of Subpart E), and that achieving that result is done in a cost-effective manner.

Step 9 should be performed in the following manner:

- a) An analysis of the potential outcome should be performed for each of the options identified in Step 8.
- b) The analysis of outcomes should be no more complex than necessary to support a reasonable and cost-effective evaluation of the options. The analysis of outcomes could be very simple (e.g., the option is remediation and the result is meeting the criteria of Subpart E) to as complicated as further refining and expanding the analysis of Step 4.
- c) The cost and time necessary to complete each option should be estimated, along with the likelihood that the option will be successful in meeting the desired endpoint (meeting the criteria of Subpart E). The analysis should also address the uncertainty associated with each potential outcome, and potential for success and failure at achieving the desired endpoint.

For example, if the licensee chose to spend money to collect some additional information on some specific soil properties at their site and spend some money on remediating a small portion of the site, and after this were able to defensibly demonstrate that the dose was below 25 mrem, then their activities would have been successful and the site could be released as unrestricted.

Analysis of options would include explicit evaluation of the associated regulatory requirements. This may mean that options need to be executed in a specified order, or that certain options are not allowed until specific conditions are met (e.g., as noted in Section 5.6.2, Option 3 is not permitted unless the cost or risk of Options 1 or 2 is too high (10 CFR 20.1403(a))).

With regard to costs, the licensee should consider that if the option(s) selected are successful, the license will be released and further costs will be minimized. However, if the selected option(s) are unsuccessful, it may be necessary to perform additional characterization or remediation, or there may need to be an evaluation of restricted use (with its associated costs).

This step should also include ALARA considerations based on the guidance in Regulatory Guide xxx, in terms of cost/benefit calculations as well as qualitative considerations.

- d) A list should be prepared of the options with their corresponding cost, probability of success (i.e., meeting Subpart E criteria), and other important considerations. An example of such a list is shown in Table 5.2.
- e) Make a decision regarding the preferred option (Step 10). In some cases, the decision regarding the preferred option will be obvious; for example, a low cost, high probability of success option will generally be selected over a high cost, low probability of success option, assuming the regulatory requirements are equal. However, the preferred option will not always be obvious, and additional analysis may be needed for sites attempting to balance complex issues. At this point in the decision process, the idea is not to

permanently eliminate options from further consideration, but rather to select the optimum approach for the current state of knowledge.

Note that *actual* success or failure would not be realized until the second iteration of Steps 4 and 5.

The licensee in making a decision regarding the options should consider the following:

- a) for Option 1 - the likelihood of being successful in collecting the data that is needed to reduce the uncertainty enough to change from an unacceptable dose to an acceptable dose (within specified constraints of time and cost);
- b) for Option 2, the likelihood that contamination will be reduced to a level that will result in acceptable dose (within specified constraints of time and cost); or
- c) for Option 3, the likelihood that a specified restriction will be durable and effective in reducing exposure for the necessary time period (within a specified cost).

An example of how the options could be organized is provided in Table 5.2 (for a set of hypothetical alternative actions).

The decision as to which option to select may be the joint responsibility of a number of parties, including the licensee, the NRC, and perhaps other stakeholders. The decision process could include other factors in addition to probability of success and cost (e.g., time to complete the activity, environmental justice, etc.). These other influencing factors can be articulated and presented as part of the results of each of the options defined in the options analysis table. Consequently, the result of Step 9 is a logically represented list of options, and the corresponding cost, likelihood of site release, and other important considerations given that the option is pursued. This analysis will provide information necessary in Step 10.

Table 5.2 - Example Options Analysis Table (Hypothetical)

Alternative Action	Cost (if successful)	Cost (if unsuccessful)	Probability of Success	Required Outcome
Collect field data to better characterize source distribution	\$\$		high	dose less than 25 mrem
Collect laboratory data to reduce uncertainty in Thorium Kd	\$\$		high	dose less than 25 mrem
Collect literature data to defend alternative soil type/texture	\$		medium	dose less than 25 mrem
Remediation by soil removal	\$\$\$		high	dose less than 25 mrem
Stabilize or dispose of waste on site and apply for restricted release	\$\$		medium	dose w/ controls less than 25 mrem; dose w/o controls less than 100 mrem
Set land use restrictions and apply for restricted release	\$\$		low	dose w/ controls less than 25 mrem; dose w/o controls less than 100 mrem

5.8 Step 10 - Select Preferred Option

In Step 10, the decision makers choose the option that will be pursued given the cost, timeliness and likelihood of success, and regulatory requirements of the options identified in Steps 8 and 9, in addition to factors outside the scope of this process.

5.9 Step 11 - Implement Preferred Option

Under Step 11 the preferred option is implemented. A licensee should conduct the following activities:

- a) If a decision is made to use Option 1, then Step 11 is where the data collection would occur. The concentration limits to which the site is cleaned up are based on the scenarios and consequence analysis simulations conducted in the previous steps.

To support a future request for license termination, any site survey results, parameter data, or laboratory tests should be carefully documented.

- b) If a decision is made to use Option 2, then the remedial action is performed and additional data are collected to verify that the remediation reduced the extent and amount of residual contamination to the targeted levels (through a Confirmatory Survey). If the Confirmatory Survey demonstrates that contamination and potential exposure have been reduced to acceptable levels, then the site proceeds to the stage of either restricted or unrestricted release.
- c) If a decision is made to conduct both Options 1 and 2, remediation would be performed in combination with data collection for the purposes of uncertainty reduction.

5.10 Step 12 - Revise Model Assumptions, Parameter Values, and Pathways

Once the preferred option has been implemented, the model assumptions, parameter values, and pathways (as appropriate) are revised. Depending on the results of data collection, the new data can be used to eliminate potential pathways, refute certain model assumptions, to justify new parameter values or refine parameter distributions, or to reduce the estimated extent and amount of residual contamination.

If remediation is performed to portions of the site or to levels that are less than complete, then new parameter values, refined parameter distributions, and/or new model assumptions should be defined to reduce the estimated extent and amount of residual contamination.

5.12 Reiteration of Step 4:

As appropriate, revised scenarios, pathways, parameters, and source terms are used in a second iteration of the dose assessment. Depending on the application, the licensee can leave the original default model assumptions and pathways unchanged, or in other more complicated situations modify assumptions and pathways or apply different models.

5.13 Reiteration of Step 5:

The revised dose assessment is evaluated to determine if the calculated dose meets the requirements in 10 CFR 20, Subpart E. The licensee would find either that:

- a) The result in Step 5 is that the calculated dose is less than or equal to the 25 mrem/yr dose criterion of 10 CFR 20.1402. **If this is the case, proceed to Step 6**
- b) The result in Step 5 is that the calculated dose is greater than the 25 mrem/yr dose criterion of 10 CFR 20.1402.. **If this is the case, it means that the contamination at the site is such that the licensee would need to consider additional options to terminate the licensee. In order to terminate the license, the licensee would need incorporate additional amounts of site specific information into the dose assessment, or possibly consider further remediation or restricting site use. Thus, if this result is found, the licensee should proceed to Step 8 again.** The licensee is encouraged to actively work with the NRC during this step to evaluate the appropriateness and adequacy of the analyses before moving on and expending resources on follow on steps.

5.14 Step 6 - ALARA Requirements

If the result in Step 5 is that the 25 mrem/y criterion has been met, the licensee can proceed to satisfy ALARA requirements, if not already addressed. ALARA actions at this step can be based on Section 4 of Reg Guide x.xx. The licensee is encourage to actively work with the NRC to discuss, define, and concur on alternative ALARA actions under this step prior to implementing any actions.

5.15 Step 7 - License Termination and Site Release

In this step the licensee would complete final paperwork requirements, including documenting any survey results used to calculate the source term and the results of the dose calculations, and would request that their license be terminated by the NRC.

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APPENDICES

Appendix A Default Concentration Values Equivalent To 25 mrem/y

Default Concentration Values To Achieve 25 mrem/y For the Residential Scenario

Table A-1 Concentration (pCi/g) equivalent to 25 mrem/y for the specified percentile of the dose distribution [Not intended for use as cleanup goals]							
Source	75th	90th	95th	Source	75th	90th	95th
3H	1.77E+02	1.08E+02	8.06E+01	166mHo	5.57E+00	5.56E+00	5.56E+00
10Be	1.69E+03	1.51E+03	1.33E+03	181W	1.52E+03	1.51E+03	1.41E+03
14C	4.10E+01	1.16E+01	6.50E+00	185W	1.34E+04	1.03E+04	4.54E+03
22Na	4.55E+00	4.25E+00	3.65E+00	187Re	6.12E+04	4.20E+04	3.03E+04
35S	3.87E+02	2.70E+02	2.08E+02	185Os	3.86E+01	3.85E+01	3.85E+01
36Cl	5.61E-01	3.62E-01	2.93E-01	192Ir	4.14E+01	4.13E+01	4.13E+01
40K	9.13E+00	3.60E+00	1.69E+00	210Pb	9.50E-01	8.46E-01	7.90E-01
41Ca	1.10E+02	6.63E+01	5.15E+01	210Po	9.46E+00	8.87E+00	8.41E+00
45Ca	9.29E+01	5.67E+01	4.28E+01	226Ra	7.77E-01	6.94E-01	6.48E-01
46Sc	1.47E+01	1.47E+01	1.47E+01	226Ra+C	6.03E+00	5.45E+00	5.16E+00
54Mn	1.57E+01	1.48E+01	1.39E+01	228Ra	3.85E+00	3.65E+00	3.54E+00
55Fe	1.13E+04	1.03E+04	9.35E+03	227Ac	5.92E-01	5.31E-01	4.85E-01
57Co	1.51E+02	1.48E+02	1.44E+02	227Ac+C	4.74E+00	4.25E+00	3.89E+00
58Co	3.49E+01	3.47E+01	3.45E+01	228Th	4.89E+00	4.73E+00	4.61E+00
60Co	3.85E+00	3.79E+00	3.68E+00	228Th+C	3.39E+01	3.28E+01	3.20E+01
59Ni	1.21E+04	5.54E+03	1.85E+03	229Th	2.04E+00	1.85E+00	1.71E+00
63Ni	4.43E+03	2.11E+03	7.17E+02	229Th+C	1.63E+01	1.48E+01	1.36E+01
65Zn	1.36E+01	1.08E+01	8.93E+00	230Th	2.10E+00	1.83E+00	1.65E+00
75Se	5.89E+01	5.83E+01	5.78E+01	230Th+C	6.44E+00	5.78E+00	5.36E+00
79Se	2.39E+02	2.07E+02	1.85E+02	232Th	1.22E+00	1.13E+00	1.08E+00
90Sr	2.84E+00	1.72E+00	1.22E+00	232Th+C	1.18E+01	1.10E+01	1.04E+01
93Zr	1.38E+03	1.08E+03	6.48E+02	231Pa	3.66E-01	3.27E-01	2.77E-01
93Zr+C	2.54E+03	1.88E+03	1.25E+03	231Pa+C	3.03E+00	2.67E+00	2.36E+00
93mNb	2.02E+03	1.81E+03	1.49E+03	232U	2.47E+00	1.96E+00	5.88E-01
94Nb	5.81E+00	5.79E+00	5.76E+00	232U+C	1.74E+01	1.46E+01	4.80E+00
93Mo	4.21E+02	2.13E+02	1.49E+02	233U	1.47E+01	9.11E+00	3.70E+00
99Tc	2.92E+01	1.87E+01	1.49E+01	233U+C	1.63E+01	1.40E+01	9.81E+00
106Ru	5.28E+01	5.06E+01	4.83E+01	234U	2.23E+01	1.32E+01	3.78E+00
107Pd	9.07E+03	6.43E+03	4.09E+03	235U	1.13E+01	8.04E+00	3.35E+00
110mAg	5.07E+00	4.92E+00	4.78E+00	235U+C	3.58E+00	3.16E+00	2.75E+00
109Cd	1.54E+02	1.06E+02	7.23E+01	236U	2.36E+01	1.40E+01	3.99E+00
113mCd	8.80E+00	4.95E+00	2.76E+00	238U	2.26E+01	1.39E+01	3.95E+00
119mSn	3.60E+03	3.09E+03	2.26E+03	238U+C	8.21E+00	7.13E+00	5.44E+00
121mSn	1.37E+03	5.70E+02	1.29E+02	237Np	1.77E-01	9.18E-02	5.81E-02
123Sn	8.74E+02	7.71E+02	6.16E+02	237Np+C	1.84E+00	9.81E-01	5.75E-01
126Sn	4.72E+00	4.70E+00	4.66E+00	236Pu	9.11E+00	8.17E+00	7.45E+00
126Sn+C	1.01E+01	1.00E+01	9.89E+00	238Pu	2.81E+00	2.54E+00	2.39E+00
125Sb	2.57E+01	2.56E+01	2.55E+01	239Pu	2.53E+00	2.28E+00	2.15E+00
123mTe	1.86E+02	1.85E+02	1.84E+02	240Pu	2.53E+00	2.28E+00	2.15E+00
127mTe	1.52E+03	1.43E+03	1.33E+03	241Pu	8.28E+01	7.16E+01	4.30E+01
129I	1.70E+00	5.38E-01	2.47E-01	242Pu	2.66E+00	2.41E+00	2.26E+00
134Cs	5.98E+00	5.68E+00	5.36E+00	244Pu	2.42E+00	2.22E+00	2.07E+00
135Cs	2.80E+02	1.83E+02	1.15E+02	241Am	2.39E+00	2.08E+00	1.52E+00
137Cs	1.22E+01	1.10E+01	9.83E+00	243Am	2.30E+00	2.01E+00	1.49E+00
144Ce	1.93E+02	1.84E+02	1.74E+02	242Cm	1.81E+02	1.64E+02	1.56E+02
147Pm	9.08E+03	8.20E+03	7.71E+03	243Cm	3.50E+00	3.20E+00	3.03E+00
147Sm	4.12E+01	3.62E+01	2.89E+01	244Cm	4.58E+00	4.17E+00	3.94E+00

Table A-1 Concentration (pCi/g) equivalent to 25 mrem/y for the specified percentile of the dose distribution [Not intended for use as cleanup goals]							
Source	75th	90th	95th	Source	75th	90th	95th
151Sm	2.01E+04	1.76E+04	1.50E+04	245Cm	1.63E+00	1.38E+00	1.18E+00
152Eu	8.68E+00	8.67E+00	8.66E+00	246Cm	2.42E+00	2.20E+00	2.09E+00
154Eu	8.02E+00	8.01E+00	8.00E+00	247Cm	2.33E+00	2.12E+00	2.02E+00
155Eu	2.86E+02	2.84E+02	2.82E+02	248Cm	6.57E-01	5.98E-01	5.67E-01
153Gd	3.27E+02	3.15E+02	2.83E+02	252Cf	8.00E+00	6.86E+00	5.66E+00
160Th	3.02E+01	3.02E+01	3.02E+01				

Default Concentration Values To Achieve 25 mrem/y For Building Occupancy Scenario

Table A-2 Concentration (dpm/100 cm²) Equivalent to 25 mrem/y for the Specified Quantile of the Dose Distribution				
Source	0.75	0.9	0.95	0.99
3H	1.72e+08	1.40e+08	1.26e+08	1.14e+08
10Be	4.30e+04	3.22e+04	2.82e+04	2.48e+04
14C	5.13e+06	4.15e+06	3.75e+06	3.39e+06
22Na	9.58e+03	9.54e+03	9.54e+03	9.54e+03
35S	1.68e+07	1.30e+07	1.15e+07	1.02e+07
36Cl	6.44e+05	4.91e+05	4.34e+05	3.84e+05
40K	1.05e+05	1.02e+05	1.01e+05	9.92e+04
41Ca	8.12e+06	6.54e+06	5.90e+06	5.33e+06
45Ca	3.78e+06	2.95e+06	2.63e+06	2.36e+06
46Sc	2.89e+04	2.87e+04	2.86e+04	2.85e+04
54Mn	3.16e+04	3.16e+04	3.15e+04	3.14e+04
55Fe	5.91e+06	4.51e+06	3.99e+06	3.54e+06
57Co	2.17e+05	2.10e+05	2.08e+05	2.05e+05
58Co	6.79e+04	6.78e+04	6.76e+04	6.74e+04
60Co	7.27e+03	7.04e+03	6.91e+03	6.78e+03
59Ni	5.49e+06	4.13e+06	3.63e+06	3.21e+06
63Ni	2.36e+06	1.77e+06	1.56e+06	1.38e+06
65Zn	4.90e+04	4.84e+04	4.80e+04	4.76e+04
75Se	1.09e+05	1.08e+05	1.08e+05	1.07e+05
79Se	1.13e+06	9.09e+05	8.17e+05	7.37e+05
90Sr	1.13e+04	8.53e+03	7.51e+03	6.65e+03
93Zr	4.76e+04	3.56e+04	3.12e+04	2.75e+04
93Zr+C	4.36e+04	3.26e+04	2.86e+04	2.52e+04
93mNb	5.21e+05	3.92e+05	3.44e+05	3.04e+05
94Nb	8.87e+03	8.20e+03	7.86e+03	7.53e+03
93Mo	4.47e+05	3.47e+05	3.09e+05	2.75e+05
99Tc	1.70e+06	1.30e+06	1.15e+06	1.01e+06
106Ru	3.16e+04	2.55e+04	2.29e+04	2.08e+04
107Pd	1.20e+06	8.96e+05	7.84e+05	6.91e+05
110mAg	1.03e+04	1.02e+04	1.01e+04	1.00e+04
109Cd	1.43e+05	1.12e+05	9.96e+04	8.93e+04
113mCd	9.84e+03	7.44e+03	6.54e+03	5.79e+03
119mSn	1.45e+06	1.28e+06	1.20e+06	1.12e+06
121mSn	9.03e+05	7.29e+05	6.60e+05	5.97e+05
123Sn	8.09e+05	6.44e+05	5.80e+05	5.22e+05
126Sn	8.62e+03	8.45e+03	8.36e+03	8.28e+03
126Sn+C	8.53e+03	8.36e+03	8.28e+03	8.20e+03
125Sb	4.49e+04	4.43e+04	4.41e+04	4.38e+04

Table A-2 Concentration (dpm/100 cm²) Equivalent to 25 mrem/y for the Specified Quantile of the Dose Distribution				
Source	0.75	0.9	0.95	0.99
123mTe	2.72e+05	2.65e+05	2.61e+05	2.57e+05
127mTe	9.96e+05	8.39e+05	7.72e+05	7.10e+05
129I	4.90e+04	4.13e+04	3.79e+04	3.48e+04
134Cs	1.31e+04	1.29e+04	1.28e+04	1.28e+04
135Cs	2.02e+06	1.68e+06	1.53e+06	1.40e+06
137Cs	2.92e+04	2.87e+04	2.83e+04	2.80e+04
144Ce	5.35e+04	4.15e+04	3.68e+04	3.28e+04
147Pm	4.40e+05	3.29e+05	2.89e+05	2.55e+05
147Sm	2.05e+02	1.53e+02	1.34e+02	1.18e+02
151Sm	5.11e+05	3.82e+05	3.35e+05	2.95e+05
152Eu	1.34e+04	1.26e+04	1.22e+04	1.18e+04
154Eu	1.22e+04	1.14e+04	1.10e+04	1.05e+04
155Eu	1.77e+05	1.53e+05	1.43e+05	1.33e+05
153Gd	2.16e+05	2.00e+05	1.94e+05	1.87e+05
160Tb	5.79e+04	5.73e+04	5.71e+04	5.68e+04
166mHo	6.85e+03	6.13e+03	5.79e+03	5.46e+03
181W	1.07e+06	1.07e+06	1.07e+06	1.07e+06
185W	3.05e+07	2.66e+07	2.48e+07	2.31e+07
187Re	2.63e+08	2.00e+08	1.76e+08	1.56e+08
185Os	7.18e+04	7.14e+04	7.12e+04	7.10e+04
192Ir	7.53e+04	7.42e+04	7.37e+04	7.31e+04
210Pb	7.27e+02	5.61e+02	4.97e+02	4.42e+02
210Po	3.29e+03	2.50e+03	2.21e+03	1.95e+03
226Ra	1.41e+03	1.11e+03	9.88e+02	8.83e+02
226Ra+C	4.13e+02	3.19e+02	2.83e+02	2.52e+02
228Ra	2.57e+02	1.94e+02	1.70e+02	1.50e+02
227Ac	2.31e+00	1.74e+00	1.52e+00	1.34e+00
227Ac+C	2.31e+00	1.74e+00	1.52e+00	1.34e+00
228Th	5.29e+01	3.95e+01	3.46e+01	3.05e+01
228Th+C	5.29e+01	3.95e+01	3.46e+01	3.05e+01
229Th	7.10e+00	5.30e+00	4.64e+00	4.08e+00
229Th+C	7.08e+00	5.30e+00	4.64e+00	4.08e+00
230Th	4.71e+01	3.52e+01	3.08e+01	2.71e+01
230Th+C	4.22e+01	3.16e+01	2.78e+01	2.45e+01
232Th	9.36e+00	6.98e+00	6.11e+00	5.39e+00
232Th+C	7.69e+00	5.75e+00	5.04e+00	4.44e+00
231Pa	1.10e+01	8.22e+00	7.20e+00	6.35e+00
231Pa+C	1.91e+00	1.43e+00	1.26e+00	1.10e+00
232U	2.16e+01	1.61e+01	1.41e+01	1.24e+01
232U+C	1.52e+01	1.14e+01	9.96e+00	8.77e+00

Table A-2 Concentration (dpm/100 cm²) Equivalent to 25 mrem/y for the Specified Quantile of the Dose Distribution				
Source	0.75	0.9	0.95	0.99
233U	1.13e+02	8.45e+01	7.42e+01	6.53e+01
233U+C	6.38e+00	4.76e+00	4.17e+00	3.68e+00
234U	1.16e+02	8.65e+01	7.58e+01	6.67e+01
235U	1.25e+02	9.33e+01	8.17e+01	7.18e+01
235U+C	1.88e+00	1.41e+00	1.24e+00	1.09e+00
236U	1.23e+02	9.12e+01	8.01e+01	7.04e+01
238U	1.30e+02	9.65e+01	8.47e+01	7.46e+01
238U+C	2.50e+01	1.87e+01	1.64e+01	1.45e+01
237Np	2.83e+01	2.12e+01	1.85e+01	1.63e+01
237Np+C	5.06e+00	3.78e+00	3.31e+00	2.91e+00
236Pu	1.16e+02	8.68e+01	7.62e+01	6.72e+01
238Pu	3.92e+01	2.93e+01	2.57e+01	2.25e+01
239Pu	3.57e+01	2.66e+01	2.34e+01	2.05e+01
240Pu	3.57e+01	2.66e+01	2.34e+01	2.05e+01
241Pu	1.82e+03	1.36e+03	1.19e+03	1.05e+03
242Pu	3.73e+01	2.78e+01	2.45e+01	2.16e+01
244Pu	3.79e+01	2.83e+01	2.48e+01	2.19e+01
241Am	3.45e+01	2.58e+01	2.25e+01	1.98e+01
242mAm	3.54e+01	2.65e+01	2.31e+01	2.05e+01
243Am	3.47e+01	2.60e+01	2.27e+01	2.00e+01
242Cm	1.57e+03	1.17e+03	1.03e+03	9.06e+02
243Cm	5.04e+01	3.77e+01	3.30e+01	2.91e+01
244Cm	6.30e+01	4.70e+01	4.12e+01	3.63e+01
245Cm	3.36e+01	2.51e+01	2.19e+01	1.94e+01
246Cm	3.39e+01	2.53e+01	2.21e+01	1.95e+01
247Cm	3.69e+01	2.76e+01	2.43e+01	2.14e+01
248Cm	9.26e+00	6.91e+00	6.07e+00	5.34e+00
252Cf	1.11e+02	8.28e+01	7.27e+01	6.39e+01

Appendix B Annual Total Effective Dose Equivalent Factors

Table B1 - Selected percentiles for the TEDE distributions for the residential scenario (mrem/y per pCi/g)

Source	75th	90th	95th	Dose @ 99th/ Dose @ 50th
3H	1.41E-01	2.32E-01	3.10E-01	4.15
10Be	1.48E-02	1.65E-02	1.88E-02	13.17
14C	6.10E-01	2.15E+00	3.85E+00	33.61
22Na	5.49E+00	5.88E+00	6.85E+00	2.98
35S	6.46E-02	9.26E-02	1.20E-01	4.56
36Cl	4.46E+01	6.91E+01	8.54E+01	4.87
40K	2.74E+00	6.94E+00	1.48E+01	19.24
41Ca	2.28E-01	3.77E-01	4.86E-01	6.51
45Ca	2.69E-01	4.41E-01	5.84E-01	6.88
46Sc	1.70E+00	1.70E+00	1.70E+00	1.01
54Mn	1.60E+00	1.69E+00	1.79E+00	1.37
55Fe	2.21E-03	2.43E-03	2.67E-03	10.10
57Co	1.66E-01	1.69E-01	1.73E-01	1.25
58Co	7.17E-01	7.20E-01	7.24E-01	1.05
60Co	6.49E+00	6.60E+00	6.79E+00	1.24
59Ni	2.07E-03	4.51E-03	1.35E-02	39.83
63Ni	5.65E-03	1.19E-02	3.49E-02	39.30
65Zn	1.84E+00	2.32E+00	2.80E+00	3.38
75Se	4.24E-01	4.29E-01	4.32E-01	1.05
79Se	1.05E-01	1.21E-01	1.35E-01	1.92
90Sr	8.80E+00	1.46E+01	2.05E+01	8.42
93Zr	1.82E-02	2.32E-02	3.86E-02	13.38
93Zr+C	9.84E-03	1.33E-02	2.01E-02	12.60
93mNb	1.24E-02	1.38E-02	1.67E-02	7.68
94Nb	4.30E+00	4.32E+00	4.34E+00	1.03
93Mo	5.94E-02	1.17E-01	1.67E-01	11.03
99Tc	8.57E-01	1.34E+00	1.68E+00	5.63
106Ru	4.73E-01	4.94E-01	5.18E-01	1.29
107Pd	2.76E-03	3.89E-03	6.11E-03	12.35
110mAg	4.93E+00	5.08E+00	5.23E+00	1.20
109Cd	1.63E-01	2.35E-01	3.46E-01	10.77
113mCd	2.84E+00	5.05E+00	9.07E+00	19.52
119mSn	6.95E-03	8.10E-03	1.10E-02	14.69
121mSn	1.83E-02	4.39E-02	1.94E-01	61.15
123Sn	2.86E-02	3.24E-02	4.06E-02	5.76
126Sn	5.30E+00	5.32E+00	5.36E+00	2.13
126Sn+C	2.48E+00	2.49E+00	2.53E+00	2.13

Table B1 - Selected percentiles for the TEDE distributions for the residential scenario (mrem/y per pCi/g)

Source	75th	90th	95th	Dose @ 99th/ Dose @ 50th
125Sb	9.71E-01	9.76E-01	9.82E-01	1.16
123mTe	1.34E-01	1.35E-01	1.36E-01	1.22
127mTe	1.64E-02	1.75E-02	1.88E-02	3.54
129I	1.47E+01	4.65E+01	1.01E+02	49.83
134Cs	4.18E+00	4.40E+00	4.66E+00	1.92
135Cs	8.94E-02	1.36E-01	2.18E-01	29.74
137Cs	2.06E+00	2.27E+00	2.54E+00	5.67
144Ce	1.29E-01	1.36E-01	1.44E-01	1.36
147Pm	2.75E-03	3.05E-03	3.24E-03	1.92
147Sm	6.07E-01	6.91E-01	8.66E-01	6.61
151Sm	1.24E-03	1.42E-03	1.67E-03	6.26
152Eu	2.88E+00	2.88E+00	2.89E+00	1.01
154Eu	3.12E+00	3.12E+00	3.12E+00	1.01
155Eu	8.75E-02	8.80E-02	8.86E-02	1.07
153Gd	7.66E-02	7.93E-02	8.83E-02	1.66
160Tb	8.29E-01	8.29E-01	8.29E-01	1.02
166mHo	4.49E+00	4.49E+00	4.50E+00	1.01
181W	1.64E-02	1.66E-02	1.77E-02	1.95
185W	1.87E-03	2.43E-03	5.51E-03	27.86
187Re	4.09E-04	5.95E-04	8.25E-04	7.15
185Os	6.48E-01	6.49E-01	6.50E-01	1.03
192Ir	6.04E-01	6.05E-01	6.05E-01	1.01
210Pb	2.63E+01	2.95E+01	3.17E+01	5.37
210Po	2.64E+00	2.82E+00	2.97E+00	1.69
226Ra	3.22E+01	3.60E+01	3.86E+01	5.60
226Ra+C	4.15E+00	4.58E+00	4.85E+00	5.24
228Ra	6.49E+00	6.84E+00	7.05E+00	1.24
227Ac	4.22E+01	4.70E+01	5.16E+01	8.85
227Ac+C	5.28E+00	5.88E+00	6.43E+00	8.83
228Th	5.12E+00	5.29E+00	5.43E+00	1.15
228Th+C	7.37E-01	7.62E-01	7.81E-01	1.15
229Th	1.22E+01	1.35E+01	1.46E+01	5.99
229Th+C	1.53E+00	1.69E+00	1.83E+00	5.98
230Th	1.19E+01	1.36E+01	1.51E+01	9.18
230Th+C	3.88E+00	4.33E+00	4.67E+00	6.32
232Th	2.05E+01	2.21E+01	2.32E+01	3.01
232Th+C	2.12E+00	2.27E+00	2.40E+00	3.15

Table B1 - Selected percentiles for the TEDE distributions for the residential scenario (mrem/y per pCi/g)

Source	75th	90th	95th	Dose @ 99th/ Dose @ 50th
231Pa	6.82E+01	7.66E+01	9.01E+01	7.49
231Pa+C	8.24E+00	9.38E+00	1.06E+01	7.36
232U	1.01E+01	1.28E+01	4.25E+01	17.79
232U+C	1.43E+00	1.72E+00	5.21E+00	15.34
233U	1.71E+00	2.74E+00	6.76E+00	21.20
233U+C	1.53E+00	1.79E+00	2.55E+00	6.90
234U	1.12E+00	1.89E+00	6.62E+00	22.71
235U	2.22E+00	3.11E+00	7.47E+00	20.57
235U+C	6.99E+00	7.91E+00	9.09E+00	7.19
236U	1.06E+00	1.79E+00	6.27E+00	22.81
238U	1.11E+00	1.80E+00	6.33E+00	21.80
238U+C	3.04E+00	3.51E+00	4.59E+00	7.03
237Np	1.41E+02	2.72E+02	4.30E+02	11.45
237Np+C	1.36E+01	2.55E+01	4.35E+01	10.12
236Pu	2.74E+00	3.06E+00	3.35E+00	2.87
238Pu	8.88E+00	9.83E+00	1.05E+01	1.93
239Pu	9.88E+00	1.09E+01	1.17E+01	2.47
240Pu	9.88E+00	1.09E+01	1.17E+01	2.46
241Pu	3.02E-01	3.49E-01	5.81E-01	11.58
242Pu	9.38E+00	1.04E+01	1.11E+01	2.47
244Pu	1.03E+01	1.13E+01	1.21E+01	2.23
241Am	1.05E+01	1.20E+01	1.65E+01	10.28
243Am	1.09E+01	1.24E+01	1.68E+01	9.96
242Cm	1.38E-01	1.53E-01	1.61E-01	1.43
243Cm	7.15E+00	7.82E+00	8.26E+00	1.41
244Cm	5.46E+00	6.00E+00	6.34E+00	1.42
245Cm	1.53E+01	1.81E+01	2.12E+01	3.93
246Cm	1.03E+01	1.14E+01	1.20E+01	1.42
247Cm	1.07E+01	1.18E+01	1.24E+01	1.35
248Cm	3.80E+01	4.18E+01	4.41E+01	1.42
252Cf	3.12E+00	3.64E+00	4.42E+00	12.34

Table B2 - Selected percentiles for the TEDE distributions for the Building Occupancy scenario (dpm/100 cm²)				
Source	0.75	0.9	0.95	0.99
3H	1.45e-07	1.79e-07	1.98e-07	2.19e-07
10Be	5.81e-04	7.77e-04	8.86e-04	1.01e-03
14C	4.87e-06	6.02e-06	6.66e-06	7.37e-06
22Na	2.61e-03	2.62e-03	2.62e-03	2.62e-03
35S	1.49e-06	1.93e-06	2.18e-06	2.46e-06
36Cl	3.88e-05	5.09e-05	5.76e-05	6.51e-05
40K	2.38e-04	2.45e-04	2.48e-04	2.52e-04
41Ca	3.08e-06	3.82e-06	4.24e-06	4.69e-06
45Ca	6.62e-06	8.48e-06	9.51e-06	1.06e-05
46Sc	8.66e-04	8.71e-04	8.74e-04	8.77e-04
54Mn	7.90e-04	7.92e-04	7.93e-04	7.95e-04
55Fe	4.23e-06	5.54e-06	6.27e-06	7.07e-06
57Co	1.15e-04	1.19e-04	1.20e-04	1.22e-04
58Co	3.68e-04	3.69e-04	3.70e-04	3.71e-04
60Co	3.44e-03	3.55e-03	3.62e-03	3.69e-03
59Ni	4.55e-06	6.05e-06	6.88e-06	7.79e-06
63Ni	1.06e-05	1.41e-05	1.60e-05	1.81e-05
65Zn	5.10e-04	5.17e-04	5.21e-04	5.25e-04
75Se	2.29e-04	2.31e-04	2.32e-04	2.33e-04
79Se	2.21e-05	2.75e-05	3.06e-05	3.39e-05
90Sr	2.22e-03	2.93e-03	3.33e-03	3.76e-03
93Zr	5.25e-04	7.02e-04	8.01e-04	9.10e-04
93Zr+C	5.73e-04	7.66e-04	8.74e-04	9.92e-04
93mNb	4.80e-05	6.38e-05	7.26e-05	8.22e-05
94Nb	2.82e-03	3.05e-03	3.18e-03	3.32e-03
93Mo	5.59e-05	7.20e-05	8.10e-05	9.08e-05
99Tc	1.47e-05	1.93e-05	2.18e-05	2.47e-05
106Ru	7.91e-04	9.81e-04	1.09e-03	1.20e-03
107Pd	2.09e-05	2.79e-05	3.19e-05	3.62e-05
110mAg	2.43e-03	2.45e-03	2.47e-03	2.49e-03
109Cd	1.75e-04	2.24e-04	2.51e-04	2.80e-04
113mCd	2.54e-03	3.36e-03	3.82e-03	4.32e-03
119mSn	1.73e-05	1.96e-05	2.09e-05	2.23e-05
121mSn	2.77e-05	3.43e-05	3.79e-05	4.19e-05
123Sn	3.09e-05	3.88e-05	4.31e-05	4.79e-05
126Sn	2.90e-03	2.96e-03	2.99e-03	3.02e-03
126Sn+C	2.93e-03	2.99e-03	3.02e-03	3.05e-03
125Sb	5.57e-04	5.64e-04	5.67e-04	5.71e-04

Table B2 - Selected percentiles for the TEDE distributions for the Building Occupancy scenario (dpm/100 cm²)				
Source	0.75	0.9	0.95	0.99
123mTe	9.20e-05	9.45e-05	9.58e-05	9.73e-05
127mTe	2.51e-05	2.98e-05	3.24e-05	3.52e-05
129I	5.10e-04	6.06e-04	6.60e-04	7.18e-04
134Cs	1.91e-03	1.94e-03	1.95e-03	1.96e-03
135Cs	1.24e-05	1.49e-05	1.63e-05	1.78e-05
137Cs	8.55e-04	8.72e-04	8.82e-04	8.93e-04
144Ce	4.67e-04	6.03e-04	6.79e-04	7.63e-04
147Pm	5.68e-05	7.59e-05	8.64e-05	9.81e-05
147Sm	1.22e-01	1.63e-01	1.86e-01	2.11e-01
151Sm	4.89e-05	6.54e-05	7.46e-05	8.47e-05
152Eu	1.86e-03	1.98e-03	2.05e-03	2.12e-03
154Eu	2.05e-03	2.20e-03	2.28e-03	2.38e-03
155Eu	1.41e-04	1.63e-04	1.75e-04	1.88e-04
153Gd	1.16e-04	1.25e-04	1.29e-04	1.34e-04
160Tb	4.32e-04	4.36e-04	4.38e-04	4.40e-04
166mHo	3.65e-03	4.08e-03	4.32e-03	4.58e-03
181W	2.33e-05	2.33e-05	2.33e-05	2.33e-05
185W	8.20e-07	9.39e-07	1.01e-06	1.08e-06
187Re	9.52e-08	1.25e-07	1.42e-07	1.60e-07
185Os	3.48e-04	3.50e-04	3.51e-04	3.52e-04
192Ir	3.32e-04	3.37e-04	3.39e-04	3.42e-04
210Pb	3.44e-02	4.46e-02	5.03e-02	5.65e-02
210Po	7.61e-03	9.99e-03	1.13e-02	1.28e-02
226Ra	1.77e-02	2.26e-02	2.53e-02	2.83e-02
226Ra+C	6.06e-02	7.84e-02	8.82e-02	9.91e-02
228Ra	9.71e-02	1.29e-01	1.47e-01	1.67e-01
227Ac	1.08e+01	1.44e+01	1.65e+01	1.87e+01
227Ac+C	1.08e+01	1.44e+01	1.65e+01	1.87e+01
228Th	4.73e-01	6.33e-01	7.22e-01	8.20e-01
228Th+C	4.73e-01	6.33e-01	7.22e-01	8.20e-01
229Th	3.52e+00	4.72e+00	5.39e+00	6.12e+00
229Th+C	3.53e+00	4.72e+00	5.39e+00	6.12e+00
230Th	5.31e-01	7.11e-01	8.11e-01	9.21e-01
230Th+C	5.92e-01	7.90e-01	9.00e-01	1.02e+00
232Th	2.67e+00	3.58e+00	4.09e+00	4.64e+00
232Th+C	3.25e+00	4.35e+00	4.96e+00	5.63e+00
231Pa	2.27e+00	3.04e+00	3.47e+00	3.94e+00
231Pa+C	1.31e+01	1.75e+01	1.99e+01	2.27e+01

Table B2 - Selected percentiles for the TEDE distributions for the Building Occupancy scenario (dpm/100 cm²)				
Source	0.75	0.9	0.95	0.99
232U	1.16e+00	1.55e+00	1.77e+00	2.01e+00
232U+C	1.64e+00	2.20e+00	2.51e+00	2.85e+00
233U	2.21e-01	2.96e-01	3.37e-01	3.83e-01
233U+C	3.92e+00	5.25e+00	5.99e+00	6.80e+00
234U	2.16e-01	2.89e-01	3.30e-01	3.75e-01
235U	2.00e-01	2.68e-01	3.06e-01	3.48e-01
235U+C	1.33e+01	1.77e+01	2.02e+01	2.30e+01
236U	2.04e-01	2.74e-01	3.12e-01	3.55e-01
238U	1.93e-01	2.59e-01	2.95e-01	3.35e-01
238U+C	1.00e+00	1.34e+00	1.52e+00	1.73e+00
237Np	8.83e-01	1.18e+00	1.35e+00	1.53e+00
237Np+C	4.94e+00	6.62e+00	7.55e+00	8.58e+00
236Pu	2.15e-01	2.88e-01	3.28e-01	3.72e-01
238Pu	6.38e-01	8.54e-01	9.74e-01	1.11e+00
239Pu	7.01e-01	9.39e-01	1.07e+00	1.22e+00
240Pu	7.01e-01	9.39e-01	1.07e+00	1.22e+00
241Pu	1.37e-02	1.84e-02	2.10e-02	2.38e-02
242Pu	6.71e-01	8.98e-01	1.02e+00	1.16e+00
244Pu	6.59e-01	8.82e-01	1.01e+00	1.14e+00
241Am	7.25e-01	9.70e-01	1.11e+00	1.26e+00
242mAm	7.06e-01	9.45e-01	1.08e+00	1.22e+00
243Am	7.20e-01	9.63e-01	1.10e+00	1.25e+00
242Cm	1.59e-02	2.13e-02	2.43e-02	2.76e-02
243Cm	4.96e-01	6.64e-01	7.57e-01	8.59e-01
244Cm	3.97e-01	5.32e-01	6.07e-01	6.89e-01
245Cm	7.44e-01	9.96e-01	1.14e+00	1.29e+00
246Cm	7.37e-01	9.87e-01	1.13e+00	1.28e+00
247Cm	6.78e-01	9.07e-01	1.03e+00	1.17e+00
248Cm	2.70e+00	3.62e+00	4.12e+00	4.68e+00
252Cf	2.25e-01	3.02e-01	3.44e-01	3.91e-01

Appendix C - Scenarios, Pathways, and Critical Groups

This appendix provides information for defining the scenarios, pathways, and critical groups that are important for the site dose assessment. This allows for identification of

- a) potential human activities on or near the site which can result in exposure (scenarios)
- b) migration and exposure pathways of the radionuclides (pathways)
- c) critical receptors (the critical group).

Scenarios are defined as plausible sets of human activities and of future uses of the site. As such, scenarios provide a description of the plausible future land uses, human activities and behavior of the natural system.

With an understanding of the potential human activities and the physical system, one can then develop conceptual models of the site (See main text, Figure 1, Step 3, and Appendix D). Those conceptual models are translated into mathematical models and implemented in (and solved by) corresponding analytical or numerical models and computer codes. The objective is to calculate a dose (main text, Figure 1, Step 4) which is then compared with dose criteria (main text, Figure 1, Step 5) to assess whether the site complies with requirements.

The definition of scenarios and identification of pathways and the dose assessment based on that definition, can be generic or site specific. A licensee should use a critical group that is appropriate for its site. Licensees might:

- (a) if they have very simple situations, use screening scenarios, critical groups, and pathway parameters developed in NUREG-5512 and described in this NUREG,
- (b) if they have relatively simple situations, use the default screening scenarios but develop more site-specific parameters and/or pathway analyses, or
- (c) if they have more complex situations, define and use site specific scenarios and site specific critical groups for use with site specific pathway analysis and parameters.

If the generic approach of "a" is used, a licensee would not need to provide justification for use of the approach. For either situations "b" or "c" above, the licensee would need to provide site specific data to defend the use of alternative scenarios, critical group definitions, and more complex pathway analysis, models, and parameter revision.

Section C.1 describes the rationale for and licensee actions in using the generic approach. Section C.2 describes the method the licensee would use in developing site specific scenarios, critical groups, and pathways. Section C.3 provides background information regarding the critical group, including its regulatory basis and the concept of use of the term critical group by standards setting bodies like ICRP. Description of methods for changing parameters is contained in Appendix E.

C.1 Generic Scenarios, Critical Groups, and Pathways

Scenario descriptions acceptable to NRC for use in generic screening are developed and contained in NUREG/CR-5512 [Kennedy and Strenge, 1992]. NUREG/CR-5512 provides 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), the conceptual modeling approaches, the default parameter values and bases for revising parameters and pathways based on site specific information. There are two critical groups used for screening (referred to here as "screening groups" based on the default scenarios of NUREG/CR-5512:

- 1) Building occupant for reuse of structures. This scenario accounts for exposure to fixed and removable thin layer or surface contamination sources. The building occupant is defined as a person who works in a commercial building following license termination. The pathways that apply to the building occupant include:
 - a) external exposure to penetrating radiation from surface sources,
 - b) inhalation of resuspended surface contamination,
 - c) inadvertent ingestion of surface contamination.

The models that can be used to mathematically represent these pathways are described in Appendix D. The parameters that are used to describe these pathways are presented in Appendix E. It is possible to modify the parameters for the building occupant based on Appendices E.

- 2) Resident farmer for contaminated soil sites. This scenario accounts for potential exposure to residual radioactive contamination in soil. For this scenario, the soil contamination is assumed to be contained in a surface-layer. The resident farmer is defined as a person who lives on the site following license termination, grows some portion of their diet on the site, and drinks water from an on-site well. The pathways that apply to the resident farmer include:
 - a) external exposure to penetrating radiation from volume soil sources while outdoors
 - b) external exposure to penetrating radiation from volume soil sources while indoors
 - c) inhalation exposure to resuspended soil while outdoors
 - d) inhalation exposure to resuspended soil while indoors
 - e) inhalation exposure to resuspended surface sources of soil tracked indoors
 - f) direct ingestion of soil

- g) inadvertent ingestion of soil tracked indoors
- h) ingestion of drinking water from a groundwater source
- l) ingestion of plant products grown in contaminated soil
- j) ingestion of plant products irrigated with contaminated groundwater
- k) ingestion of animal products grown onsite (i.e., after animals ingest contaminated drinking water, plant products, and soil)
- l) ingestion of fish from a contaminated surface-water source

The models that can be used to mathematically represent these pathways are described in Appendix D. The parameters that are used to describe these pathways are presented in Appendix E. It is possible to modify the parameters for the resident based on Appendix E.

Thus, the licensee can use the screening groups listed above which NRC has developed in NUREG/CR-5512. When using the NUREG/CR-5512 scenarios, screening groups, or pathways, licensees generally do not need to provide justification or documentation for selecting and using the scenarios and pathways included. A licensee has the option of using the screening group with default parameters or modifying the parameters used for the screening group based on site specific information and providing justification for the parameter revision (as described in Appendix E),

C.2 Site Specific Scenarios, Critical Groups, and Pathways

A licensee may develop site specific scenarios, critical groups, and pathways based on site-specific information. This information could describe a critical group, referred to here as a "site-specific critical group," which is different from the screening group. Use of a site specific critical group would occur in cases where, for example:

- a) the licensee could justify that the site was such that major pathways (e.g., the agricultural pathway) of the screening group could be eliminated, either because of physical reasons or site use reasons,
- b) there was a specific sensitive group on the site,
- c) restricted use was proposed for a site

Modifying scenarios and developing site-specific critical groups 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 site specific issues such as historical and planned future land use, and physical characteristics that constrain site use. It will often be necessary to evaluate several potential critical groups, based on different combinations of site-specific scenarios developed from expected pathways and demographics,

to determine the group receiving the highest exposure. It is especially important to evaluate the homogeneity of specific groups to determine if what appears to be one group is actually multiple groups. The following guidelines for defining the site-specific critical group and the homogeneity of the critical group should be followed.

- a) If the distribution of dose equivalents for the workers ranges over more than a factor of ten, then they should be treated as two or more different groups.
- b) If the dose evaluation is being done to determine the site-specific cleanup level, then the distribution of dose equivalents should not range over more than a factor of three, since the fraction of the source upper bound in that case has been defined to be one.

For restricted release, similar considerations apply. However, now the nature of the critical group changes due to site restrictions and institutional controls which can restrict certain kinds of activities or land or water uses. 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.

In developing site specific scenarios, critical groups, and pathways, a licensee's analysis should encompass the following:

- a) An evaluation of whether the generic scenarios of NUREG/CR-5512 applicable to its site and, if not, for each scenario, whether major exposure pathways can be modified or eliminated from further consideration based on site-specific conditions (NUREG/CR-5512 notes that pathways can be added or eliminated, as appropriate, using site-specific data and that possibly different, scenarios and associated pathways may be necessary for complex site specific analyses beyond those in NUREG/CR-5512).

This evaluation should include adequate justification, based on site specific data, for eliminating scenarios and/or pathways from the analysis.

As examples, for a site in a predominantly urban or industrial location or for a site in a particularly rocky environment, a licensee may want to defend not using the screening group in favor of a scenarios more representative of prevailing (and future) uses of the land. The licensee in this cases might indicate that the historical and planned future land use or the physical characteristics of the site were such as to preclude the generic resident farmer scenario of Appendix C.1. Such a demonstration would be enhanced in cases where the radionuclides at the site were relatively short-lived and the time period over which such a situation might need to last were therefore also relatively short. This approach could be appropriate for the situations noted here based on their characteristics (and therefore be an unrestricted use of the site), and would not require the licensee establish institutional controls to restrict site use under 10 CFR 20.1403.

Similarly, a licensee should consider other aspects of the site and critical groups that might be exposed including factors related to plumbing systems, floor drains, and embedded piping, ventilation ducts, building external surfaces, and embedded contamination in surfaces.

Table C.1 provides a possible set of scenarios that licensees may consider for use in site specific dose assessments.

Table C.1 Potential Scenarios for use in Dose Assessments	
<p>These scenarios are applicable for unrestricted release of the site and for analyzing restricted release sites assuming institutional controls fail. The NUREG/CR-5512 scenarios may be based on the screening group, but the scenario definition and pathways may be changed due to site specific considerations (e.g. no drinking water, no pond, etc.). Some of these scenarios are also appropriate for restricted release of the site. In addition, they may be considered for unrestricted sites for which geography or realistic future uses of the site would preclude certain uses (such as agriculture).</p>	
C	Building occupancy (Generic screening - NUREG/CR-5512 based).
C	Residential farmer (Generic screening - NUREG/CR-5512 based).
C	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.
C	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).
C	Recreational (where the site is preserved for recreational uses only).
C	Hybrid Building occupancy (adds contaminated soil, building may or may not be contaminated).
C	Drinking water (no on-site use of groundwater; off-site impacts of contaminated plume).

- b) An analysis of exposure pathways. For this analysis, the licensee should begin with at least the pathways prescribed by NUREG/CR-5512 (and as listed for the building occupant and resident farmer scenarios in Appendix C.1 of this NUREG). After considering those pathways, the licensee may then wish to conduct a more thorough pathway analysis. The objective of this approach (i.e., proceeding from generic to more site specific pathways) is to focus resources on the pathways, and models associated with those pathways, that have the highest likelihood of significant exposures to the critical group. Applying this pathway analysis process results in a set of the dominant pathways for the site-specific scenarios (see Table C.1) that could be further pared down using site-specific conditions and screening criteria. Licensees will need to document their pathway analyses and provide justification for the elimination of pathways from dose assessments.

A brief summary of the NRC-recommended pathway analysis process is as follows:

- 1) Compile a list of exposure pathways applicable to any type of contaminated site (this list is developed in NUREG/CR-5512 and summarized in Appendix C.1 of this NUREG)

- 2) Categorize the general types of contamination at the site (e.g. sediment or soil, deposits in buildings and equipment, surface contamination, surface waters, groundwater, industrial products such as slag).
- 3) Screen out insignificant pathways for each contaminant type.
- 4) Identify the physical processes pertinent to the pathways for the site.
- 5) Separate the list of exposure pathways into unique pairs of exposure media (e.g. source to groundwater, groundwater to surface water, etc.). Determine the physical processes that are relevant for each exposure media pair and combine the processes with the pathway links.
- 6) 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.

C.3 Background Information Related to “Critical Group”

This section provides background information on the critical group which a licensee can use in understanding the terms “critical group,” “screening group”, and “site specific critical group.”

C.3.1 The requirements in Subpart E for Critical Groups

The dose calculated from residual radioactivity at a decommissioned site is dependent upon how the receptor and the physical characteristics of the site are defined. With regard to the receptor, Subpart E contains the following specific requirements:

- 1) 20.1402 states that the criterion for unrestricted release is 25 mrem/y to the average member of the critical group:
- 2) 20.1403, in setting criteria for restricted release, addresses two separate critical groups and hence a licensee would have to evaluate two separate critical groups for restricted use as follows:
 - a) 20.1403(b) states that the criterion for restricted release is 25 mrem/y to the average member of the critical group with institutional controls in place (per 20.1403(b), because site restrictions limiting or eliminating certain kinds of activities are highly site specific, the nature of the critical group is also highly site-specific (see Section C.2)
 - b) 20.1403(e) states that , if the institutional controls are no longer in effect, the criterion is that the dose to the average member of the critical group is less than either 100 mrem (1 mSv) per year or 500 mrem (5 mSv) per year : A second critical group would have to be evaluated based on consideration of the restrictions failing and essentially unrestricted use occurring. The considerations as to the

critical group for this situation would be similar as those noted above for 20.1402.

The terms "critical group" and "average member" are defined and discussed in the regulations in the following way:

- a) The critical group for decommissioning is defined in 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." NUREG/CR-5512, Volume 1, similarly describes the Critical Group as an individual or relatively homogeneous group of individuals expected to receive the highest exposure within the assumptions of the particular scenario.
- b) The average member of the Critical Group is an individual who in turn is assumed to represent the most likely exposure situation based on prudently conservative exposure assumptions and parameter values within the model calculations.

C.3.2 Background information on Critical Groups

The definition and evaluation of a critical group is a site-specific and often complex process that has been discussed in NRC documents as well as documents produced by national and international organizations. The practice of defining and using a Critical Group when assessing individual public dose from low levels of radioactivity similar to those expected from a decommissioned site is proposed in Section 5.5.1 of the 1990 recommendations of the International Commission on Radiological Protection (ICRP 1991) and has been adopted in the current draft of the Environmental Protection Agency "Draft Federal Radiation Protection Guidance for Exposure of the General Public"(EPA97).

ICRP 46 (ICRP 1985) contains a detailed and useful definition of the critical group that could be applied to decommissioning sites:

"46. The critical group should be representative of those individuals in the population expected to receive the highest dose equivalent, and should be relatively homogeneous with respect to the location, habits and metabolic characteristics that affect the doses received. It may comprise existing persons, or a future group of persons who will be exposed at a higher level than the general population. When an actual group cannot be defined, a hypothetical group or representative individual should be considered who, due to location and time, would receive the greatest dose. The habits and characteristics of the group should be based upon present knowledge using cautious, but reasonable, assumptions."

Similar definitions can be found in IAEA Safety Series No. 57 (IAEA 1995) and several NRC documents related to low and high level waste.

ICRP 43 (ICRP 1984) contains an approach for defining homogeneity for the critical group:

“69. ...It is suggested that, in general, to satisfy the homogeneity requirement the ratio of maximum to minimum values should not exceed an order of magnitude. For many distributions, therefore, the mean will be a factor of two to three lower than the maximum postulated. The necessary degree of homogeneity in the critical group depends on the magnitude of the mean dose equivalent in the group as a fraction of the relevant source upper bound. If that fraction is less than about one tenth, a critical group should be regarded as homogeneous if the distribution of individual dose equivalents lies substantially within a total range of a factor of 10, i.e., a factor of about 3 on either side of the mean. At higher fractions, the total range should be less, preferably no more than a factor of 3.”

Appendix D - Dose Models

System Conceptualization (see main text, Figure 1, Step 3) includes conceptual and mathematical model development and assessment of parameter uncertainty. The system conceptualization represents the process of systematically evaluating the level of uncertainty associated with a specific site and the quantification of that uncertainty. In order to manage the treatment of uncertainty associated with dose assessment at a given site, the four steps of scenario definition, pathway identification, model development, and assessment of parameter uncertainty are treated as a hierarchy, moving from the former of these to the latter. This appendix discusses development of models for calculating dose.

The licensee uses the dose models to perform dose assessments (see main text, Figure 1, Step 4) using the mathematical representations of the conceptual models (codified in DandD or equivalent software). The dose assessment involves the execution of the numerical model(s) that implement the mathematical equations and will provide the basis for (1) assessing compliance with the individual dose criteria and (2) an analysis of the impact of uncertainty in models and input parameters on the model output.

As is the case for the scenarios and pathways (see Appendix C), a licensee can use models in dose assessment that are either generic or site-specific. The following sections describe the process which a licensee should use in selecting models for dose assessment at its site.

D.1 Generic models

D.1.1 Mathematical models

As with scenarios and pathways (see Appendix C), conceptual and mathematical models have been defined for the NUREG/CR-5512 methodology and these models (codified in the DandD code) are acceptable for making generic dose assessments. A licensee can use these models (and DandD) for its dose assessment based on an evaluation of whether or not the NUREG/CR- 5512 models are appropriate for their site given the following assumptions made in developing the 5512 models and any change in the model assumptions or scenarios for site-specific analyses (NUREG/CR-5512, Section 4.1.2):

- a) If the NUREG/CR-5512 models and default parameters are used, the licensee would only need to provide information that demonstrates the models are appropriate and to describe and defend the source term.
- b) Initial radioactivity is contained in the top layer (building surface or soil)
- c) The remainder of the unsaturated zone and groundwater are initially free of contamination
- d) The activity in the aquifer is diluted by the volume of water in the aquifer

D.1.2 Selection of Codes

As noted above the mathematical models in NUREG/CR-5512 are codified in the DandD code. As noted in NUREG-0856 [Silling, 1983], it is important that codes and databases used in the analysis be properly verified and documented according to a rigorous quality assurance (QA)/quality control (QC) program. If the NUREG-5512 screening scenarios and groups are used and the DandD code is used to conduct the analysis, the licensee does not need to perform QA/QC, as the NRC has already completed this for this code.

If the DandD is used, the licensee does not need to provide defense and justification for the selection and use of this code or for the use of default pathways, assumptions, and parameter values. NRC has already defined these default assumptions and parameter values such that their implementation provides NRC the necessary confidence that if the site meets the unrestricted dose criteria, the likelihood of an incorrect regulatory decision is very low. The licensee would only need provide to the NRC a copy of the DandD generated report to verify the version of DandD that was used in the analysis. Defense would be needed for the source characterization and for the alternative parameter values used (see Appendix E).

D.2 Site Specific Models

Site specific models might be developed by a licensee because they either find that the generic models do not describe their site, or because they choose to use a model different from the generic model developed in NUREG-5512 (and codified in DandD).

If site-specific models are developed (either through changes to the default parameter values, model assumptions or development of new models), then the licensee needs to defend the model and associated parameters.

D.2.1 Site specific Model development

D.2.1.1 Conceptual models

If site-specific models and parameters are used, the licensee needs to develop and defend conceptual models of the physical system that describe the specific physical processes and exposure mechanisms for each pathway. The conceptual model includes the set of assumptions of how the described system can be simplified for representation with a mathematical model. The simplification of the physical system into a mathematical model requires the analyst to make consistent, defensible assumptions. The licensee needs to present and provide adequate defense for each assumption. In general, a defensible simplifying assumption is one for which the simulated outcome (dose) would not be increased by a more complex (realistic) representation of the system.

It is likely that there is uncertainty in the conceptual model, that more than one possible interpretation of the system can be justified based on the existing information. This uncertainty should be addressed by developing multiple alternative models of the system and proceeding forward through the framework with all the conceptual models that are consistent with available data and result in doses that exceed the dose criteria. The conceptual models that result in

doses that exceed the dose criteria will be determined under Step 4. If the conceptual model uncertainty is incorporated in the dose assessment, then the value of data that would reduce or eliminate the uncertainty in the conceptual model can be estimated.

D.2.1.2 Mathematical models

The conceptual model describes how the contaminants move from the source to the receptor. The mathematical models, and the numerical links between those models, are the equations that implement the conceptual model. Each transport and exposure pathway may require a separate conceptual and mathematical model.

The source model generally describes a boundary condition for a contaminant transport model or the concentration for a model of direct exposure to the source. The pathway models provide an estimate of the amount and distribution (concentration) of the contaminant. The exposure model translates the concentration into an amount of energy (or mass) absorbed or ingested as a function of human behaviors. Finally, the exposure is translated into a dose based on the ICRP 26, 30 and 48 models (a regulatory based requirement for TEDE).

D.2.1.3 Source models

Source models are developed based on the following:

- a) Possible mathematical representations of the source include constant concentration, specified mass flux and time variant concentration or flux boundary conditions. If the NUREG/CR-5512 models are used, then the source is represented with an initial activity density or concentration (the total amount of activity for each isotope per unit area on a building surface or per unit volume in the upper soil layer) which changes over time due to radioactive decay (depletion due to decay, production from decay of the parent) and transport away from the source area (by leaching from soil or resuspension from the building surface). The leaching and resuspension processes are modeled as fractional releases of the total source mass.
- b) In the analysis of the dose due to contamination of building surfaces, the DandD models estimate the dose due to inhalation as a function of the concentration in air. A resuspension factor is used to estimate the concentration in air as a function of the concentration on the surface. The licensee may choose to propose a site or contamination specific resuspension factor. [Insert text on the type of support that they would need to provide]
- c) In the DandD models, soil contamination is divided into two components: sorbed mass and leached mass. All the mass that is not retarded by sorption is leached from the source and transported to the groundwater system during the first simulated year. In reality, the amount of mass that is transported to the groundwater system in the first year will be a function of the infiltration rate and the contaminant solubility which is a function of the geochemical conditions and the physical and chemical nature of the source of contamination. The licensee may choose to perform laboratory experiments or conduct geochemical modeling to support a more realistic representation of the

source. It is recommended that the identification and selection of options for site specific analyses be weighed in terms of the potential benefit, time frame and costs (Steps 8-10).

D.2.1.4 Transport models

The potential transport mechanisms for moving the contaminant from the source to the receptor include mechanical disturbances by the receptor (direct exposure to the source) and diffusive and advective transport via air (wind), surface water and groundwater (unsaturated and saturated). The models for these processes can be very complex (e.g. three-dimensional, transient, advection-dispersion equations for flow through heterogeneous media with source and sink terms) or simplified empirical models (e.g., transfer functions like resuspension factor). The level of complexity of the model that can be justified depends on the nature of the simplifying assumptions (conservative, reasonably conservative) and the information available to support the model (a complex model may be more realistic, but the data necessary to support the development of parameter values may not be available or obtainable). Multiple, simple alternative models may be necessary to evaluate the system when the relative conservatism cannot be determined *a priori*.

D.2.1.5 Exposure models

The conceptual model describes the human behaviors (scenario and pathways) that lead to, and control the amount of, exposure. It includes the consumption rates (e.g. rates of respiration times the volume of intake per inhalation) for each media and the time and duration of exposure.

D.2.1.6 Dose models

The dose criterion in 10 CFR 20.1402 is based on the TEDE concept. The TEDE is to be calculated based on the definition of TEDE in Subpart E and the models referred to in NUREG/CR-5512.

Once the numerical models are developed, the licensee presents all the mathematical models and how each model is linked. The model parameters are defined in this process.

D.2.2 Use of deterministic or probabilistic approach for site specific models

In preparing site specific models, the licensee can either conduct the analyses deterministically or probabilistically. A deterministic estimate of dose clearly and demonstrably bounds the potential doses, whereas a probabilistic approach quantitatively depicts system performance as a distribution of potential outcomes based on uncertainty and variation in models and parameters. Regardless of the type of analyses the licensee chooses to use, the same level of defense would be needed to demonstrate that the analyses provide sufficient information for the license termination decision. In addition, the licensee would need to demonstrate that their analyses are consistent with the framework such that if additional data were collected, the simulated dose would decrease. These two approaches are:

a) Option 1 - Deterministic analysis

Deterministic analysis involves the calculation of a single value of the dose using single values for input parameter values. Single estimates of dose often can be conducted easily, but the selection of appropriate models and parameter values may be difficult. When performance is measured against a single estimate, uncertainty is addressed by providing reasonable assurance that this estimate conservatively bounds actual performance. Given the uncertainties inherent in these dose assessments, it is expected that bounding analyses will use simple modeling approaches, assumptions, and parameter values that readily can be demonstrated as being conservative (i.e., produce simulated doses that are consistently greater than actual doses).

b) Option 2 - Probabilistic analysis

Probabilistic approaches encompass a wide range of analysis techniques and methods. For this report, the probabilistic approach refers to the use of a formal, systematic uncertainty analysis to quantify the uncertainty in performance estimates because of uncertainty and variability in models and parameters. Probabilistic analyses under this framework would involve the analysis of individual scenarios, each with multiple possible pathways, and possibly with alternative models for certain pathways. Parameter uncertainty would likely be quantified and propagated through the dose assessment models. Parameter uncertainty is often evaluated using a Monte Carlo analysis where the input variables representing parameter uncertainty and the output of model(s) are in the form of distribution functions [see Davis, *et al.*, 1990]. An output distribution is produced by evaluating the performance many times, using sets of input values based on random and Latin Hypercube Sampling (LHS) [Iman and Shortencarier, 1984]. The specification of the parameter distribution should reflect the level of knowledge about the parameter or "degree of belief" rather than concentrate on rigorous statistical efforts to determine distributions. As a result, this approach does not require extreme amounts of site specific data to specify the parameter distributions, and in fact can be conducted with small amounts of data/information. Assigning probabilities to scenarios, which is characteristic of some probabilistic approaches, is not recommended for dose assessments under this framework. That is, compliance will be assessed and demonstrated for each scenario independent of other scenarios. Similarly, assigning probabilities to alternative models is not recommended under this framework.

Probabilistic analyses may be used to support compliance determination based on a deterministic value taken from the resulting distribution of output or compliance determination based on a comparison of the entire output distribution to the performance objective.

D.2. Selection of site specific codes

The licensee will need to defend and justify their selection and use of a given computer code in order for their analyses to be acceptable to the NRC. In principle, the selection of a given

computer code should be based on the scenarios, critical groups, and pathways defined in Appendix C and the mathematical model defined in Section D.1 of this appendix. To do this, the licensee will need to demonstrate that the mathematical representation of a given fate or transport process as implemented within the selected code is not inconsistent with the set of assumptions defined in Appendix C and will have to verify that the mathematical representation as implemented in the code is correct.

If enough uncertainty exists such that alternative conceptual models exist (i.e., alternative sets of assumptions are proposed), then it will probably be necessary to select alternative codes or alternative configurations of the same code and conduct the analyses with each of these. The licensee will need to provide results from the conceptual models with doses that exceed the performance objective or from all the conceptual models. Often times, it will not be possible to deduce, until after the quantitative dose assessment, which model yields the highest doses.

The options for code selection for a site specific analysis and the defense needed under each option are:

a) Use DandD with alternative parameter values and modified/eliminated pathways

If the licensee elects to use DandD but modify or eliminate the generic pathways listed developed in NUREG/CR-5512 (and listed in Appendix C.1), the licensee will need to describe the modifications to the DandD pathways for their site and justify that the modified site representation in DandD is appropriate to use for their proposed conceptual model. The licensee will need to provide to the NRC a copy of the DandD generated report to verify the version of DandD that was used in the analysis and to describe the DandD code's representation of the licensee's conceptual model.

b) Licensee-selected code

If appropriate, the licensee can elect to use a code other than DandD. As described above this may occur if the site is such that the DandD (i.e., NUREG-5512) models are not appropriate for the site or if the licensee chooses or prefers another code. Other codes that might be used include other standard codes (e.g., RESRAD) or codes which are developed by the licensee. In either case, the licensee will have to:

- (1) demonstrate that the set of implicit assumptions associated with the code that they have chosen are consistent with the site specific scenario and pathways (see Appendix C) and the site conceptual model(s) (see Section D.1 above).
- (2) if the licensee uses a code that has default parameter values built in, defend the appropriateness of those parameter values for their site within the context of the framework. That is, the licensee would have to demonstrate that if additional data were collected, the simulated doses would be very unlikely to increase.
- (3) defend the model assumptions implied by the use of the code (i.e., the model assumptions should be consistent with the framework).

- (4) provide to the NRC, as necessary, a copy of the code executable, user's manual for the code, an electronic copy of the input file, and an electronic copy of the output file.

As noted in NUREG-0856 [Silling, 1983], it is important that codes and databases used in the analysis be properly verified and documented according to a rigorous quality assurance (QA)/quality control (QC) program. Thus for either case a or b above, the license would need to perform QA/QC for the code used.

Appendix E: Parameter Descriptions and Information for Changing Parameters

E.1 Parameter Descriptions and Information for Changing Parameters

Tables E-1 through E-6 list parameters to be evaluated if model parameters are changed from the defaults. Each of the tables indicates a definition of the parameter and also considerations involved in modifying the parameter. More details about the parameter distributions are contained in Attachment 1 to this NUREG.

The evaluation and potential modification of the parameter will be different depending upon whether the parameter is physical, behavioral, or metabolic, and upon whether a deterministic or probabilistic analysis is performed. Note that, for deterministic calculations, parameters that are not modified using regional or site-specific information will be set to the value of the 95th or 5th percentile of their original distribution, as noted in the parameter descriptions below.

Physical parameters are presented in Tables E-1 through E-3 as follows:

- Table E-1 Physical Parameters That Need to be Evaluated if Water Pathway Parameters are changed
- Table E-2: Physical parameters Which Should Be Evaluated If Diet or Ingestion Parameters Are Changed
- Table E-3: Physical Parameters Which do not need to Be Changed If Other Parameters Are Changed

These parameters were originally defined to encompass the variability expected across all licensees in all regions of the country. These parameters usually depend on physical features of the site that may vary based on local geological and meteorological characteristics. Modifications to these parameters can be based on the development of a narrower distribution that better represents site-specific features or location, or selection of a more realistic but still bounding deterministic value from within the distribution developed for the default analysis. Some physical parameters are surrogates for multiple processes within the model and are not correlated to specific physical processes that will be significantly different from site to site, or development of site-specific information may require complex or expensive specialized analyses that would not normally be justified for a decommissioning action. These parameters are in a separate table to clarify which parameters need to be changed and which parameters may be changed whenever parameter modification is chosen as the preferred option.

Behavioral parameters represent the average member of the screening group and are contained in Tables E-4 and E-5 as follows. :

- Table E-4 Behavioral parameters that need to be evaluated for site specific critical groups
- Table E-5 Behavioral parameters that may be changed to account for modifications to screening group assumptions

These parameters are based on the variability between individuals in the screening group. The metabolic parameters are contained in Table E-6, which also includes discussion of

dependent parameters, represent the physiological variability between individuals in the screening group. These parameters were defined by development of distributions representing the screening group, then selecting the mean of the distribution to represent the average member of the group for the deterministic value to be used in the default modeling. These mean values and underlying distributions are not expected to change based on site-specific information unless the licensee proposes a site-specific critical group which is different from the screening group. Therefore, a licensee who chooses the option of modifying parameters will generally not need to modify the behavioral and metabolic parameters.

However, a critical group may be defined for restricted use scenarios, or to account for physical features or legal requirements which cause the screening group to not be representative of the current and future use of the site. If the screening group definition is modified or replaced with a site-specific critical group, licensees should evaluate, and modify as appropriate, all behavioral and metabolic parameters related to the critical group.

Table E-1: Parameters That Need to be Evaluated if Water Pathway Parameters are changed - Physical		
Parameter	Description	Discussion
H ₂	Thickness of the unsaturated zone	<p><u>Definition:</u> The thickness of the unsaturated zone is used in determining radionuclide leach rates from the unsaturated zone to the saturated zone. The default distribution was developed from area-weighted data from observation wells across the U.S. Information on H₂ (also called water table depth) is readily available from state or city governments and the USGS.</p> <p><u>Site Specific parameters:</u> Because data are easily available and because it is not possible, <i>a priori</i>, to determine whether a thick or thin unsaturated zone is more conservative, licensees using deterministic modeling should use the best estimate of the minimum value for their site.</p>

Table E-1: Parameters That Need to be Evaluated if Water Pathway Parameters are changed - Physical

Parameter	Description	Discussion
λ, f_1, f_2	Infiltration rate & saturation ratios	<p><u>Definition:</u> Infiltration rate is measured as the volume of water per unit area per unit time that percolates deeply beneath the root zone and becomes infiltration. The saturation ratio is the volume of water relative to the volume of the pore space, and also the ratio of the moisture content to the porosity. Both these parameters will vary based on regional climate characteristics and site soil texture. A full discussion of these parameters and their derivation, as well as possible information sources for site-specific values, is contained in Attachment 1.</p> <p><u>Site specific parameters:</u> Because data are easily available, and because it is not possible, <i>a priori</i>, to determine whether high or low values are more conservative, licensees using deterministic modeling should use the best estimate of the median value for their site.</p>
IR	Irrigation water application rate	<p><u>Definition:</u> This parameter represents the annual average quantity of groundwater used to irrigate on site agricultural products. It is used, along with the area of land cultivated (A_c) to calculate the volume of water removed from the aquifer per year for irrigation.</p> <p><u>Site specific parameters:</u> Licensees may propose changes to this parameter based on regional precipitation and regional soil moisture levels and other soil properties, and data that support alternative irrigation rates for certain forage crops or edible foods that may be supported due to prevailing dietary patterns or land use patterns. Because it is not possible, <i>a priori</i>, to determine whether high or low values are more conservative, licensees using deterministic modeling should use the best estimate of the median value for their site, based on a multi-year state-specific annual average irrigation rate (attached parameter description report contains such data for twenty-seven states).</p>

Table E-1: Parameters That Need to be Evaluated if Water Pathway Parameters are changed - Physical

Parameter	Description	Discussion
$n_1, n_2, \rho_1, \rho_2, P_s$	Porosities, soil bulk densities, and soil areal density of the surface plow layer	<p><u>Definition:</u> Porosity is a measure of the relative pore volume in the soil and is the ratio of the volume of the voids to the total volume. Soil bulk density relates the mass of dried soil to its total volume (solids and pores together). Soil areal density of the surface plow layer is a measure of the mass of soil per square meter in the surface layer, with an assumed depth of 15 cm for the DandD model. Porosity varies with soil texture, and distributions based on the 12 Soil Conservation Service textural classifications are listed in the attached parameter descriptions. Bulk density can be defined as functionally related to porosity: Bulk density = (1 - porosity)*2.65. Soil areal density is calculated as a conversion of units from bulk density plus the 15 cm depth assumption: Areal density = 150*bulk density or Areal density = 397.5*(1 - porosity).</p> <p><u>Site specific parameters:</u> Because it is not possible, <i>a priori</i>, to determine whether high or low values are more conservative, licensees using deterministic modeling should use the best estimate of the median value for their site, based on the site-specific soil texture.</p>

Table E-2: Parameters Which Should Be Evaluated
If Diet or Ingestion Parameters Are Changed - Physical

Parameter	Description	Discussion
Q_f Q_g Q_h Q_w	Animal feed intake rates for forage grain hay water	<p><u>Definition:</u> These parameters represent the average daily quantities of on-site produced foods and on-site well water consumed by livestock. Default values were developed based on the assumption that the total annual diet for the animals is derived from on-site contaminated feed and water from the on-site well.</p> <p><u>Site Specific parameters</u> Licensees may propose parameter modifications based on limitations on the types or quantities of feed that can be raised on the site and the existence and quality of the on-site well. Intake rates can be used to directly account for the contaminated fraction of feed and water in the animal diet. [Deterministic calculations should be based on the 95th percentile value of the default or revised distribution]</p>
Y_g	Crop yields (grain)	<p><u>Definition:</u> This parameter represents the average yield of all grain crops consumed by each of the four food-producing animals evaluated in the model, per unit area of cultivated land at the site. The distribution was based on the production of three main grain crops (corn, sorghum, and oats) in direct proportion to the production across the United States.</p> <p><u>Site specific parameters</u> Licensees may modify this parameter by limiting the distribution to crop types likely to be grown in the area of their site, as well as incorporating climatic conditions and soil features that may affect production. [Deterministic calculations should be based on the 95th percentile value of the default or revised distribution]</p>
Y_h	Crop yields (stored hay)	<p><u>Definition</u> This parameter represents the average yield of all hay crops consumed by each of the four food-producing animals evaluated in the model, per unit area of cultivated land at the site.</p> <p><u>Site specific parameters</u> Licensees may modify this parameter by limiting the distribution to crop types likely to be grown in the area of their site, as well as incorporating climatic conditions and soil features that may affect production. [Deterministic calculations should be based on the 95th percentile value of the default or revised distribution]</p>

Table E-2: Parameters Which Should Be Evaluated
If Diet or Ingestion Parameters Are Changed - Physical

Parameter	Description	Discussion
Y _v	Crop yields (stored vegetables, fruits, & grains)	<p><u>Definition</u> This parameter represents the amounts of garden produce grown per unit area of cultivated land at the site and is based on the production of all crops in direct proportion to the production across the United States.</p> <p><u>Site specific parameters</u> Licensees may modify this parameter by limiting the distribution to crop types likely to be grown in the area of their site. [Deterministic calculations should be based on the 95th percentile value of the default or revised distribution]</p>

Table E-3: Parameters Which do not need to Be Changed
If Other Parameters Are Changed* - Physical

Parameter	Description	Discussion
B _{iv}	Vegetation concentration factors for uptake	<p><u>Definition</u> This parameter is affected by multiple factors that vary non-linearly in time and across locations.</p> <p><u>Site specific parameters</u> Licensees are not expected to modify the default without specialized site-specific analysis. Licensees may propose different values based on published, peer reviewed data not evaluated in the parameter analysis. However, no further analysis is required by the licensee, and this parameter does not have to be modified if other parameters are changed. [Deterministic calculations should be based on the 95th percentile value of the default or revised distribution]</p>
f _{Ca}	Fraction of carbon in animal products	<p><u>Site specific parameters</u> Licensees are not expected to modify the default without specialized site-specific analysis. Licensees may propose different values based on published, peer reviewed data not evaluated in the parameter analysis. However, no further analysis is required by the licensee, and this parameter does not have to be modified if other parameters are changed. [Deterministic calculations should be based on the 95th percentile value of the default or revised distribution]</p>
CDO, CDG	Air dust-loading outdoors & gardening	<p><u>Definition</u> These parameters represent the long-term averages for respirable particulate material in outdoor air.</p> <p><u>Site specific parameters</u> Licensees may propose alternate values based on site-specific, local climatic conditions which impact dust loading such as wind speed, soil moisture, soil type, topography, and vegetation cover. Table 3.2.2 in the attached parameter description provides additional information. [Deterministic calculations should be based on the 95th percentile value of the default or revised distribution]</p>

Table E-3: Parameters Which do not need to Be Changed
If Other Parameters Are Changed* - Physical

Parameter	Description	Discussion
f_{Ch} , f_{Cg} , f_{Cf}	Fraction of carbon in forage, stored grain, and stored hay	<p><u>Site specific parameters</u> Licensees are not expected to modify the default without specialized site-specific analysis. Licensees may propose different values based on published, peer reviewed data not evaluated in the parameter analysis. However, no further analysis is required by the licensee, and this parameter does not have to be modified if other parameters are changed. The one exception is f_{Cf} because of the different forage crops that grow in different regions throughout the U.S. Regional data may support a different value based on specific forage crop growth. [Deterministic calculations should be based on the 95th percentile value of the default or revised distribution]</p>

Table E-3: Parameters Which do not need to Be Changed
If Other Parameters Are Changed* - Physical

Parameter	Description	Discussion
KD_{ki}	Partition coefficients	<p><u>Definition</u> Partition coefficients define the ratio between radionuclide solid concentrations (radionuclide quantity adsorbed on the soil/rock particles) and radionuclide liquid concentrations (radionuclide quantity dissolved in the soil/rock pore water) under equilibrium conditions. These coefficients are used to calculate radionuclide retardation and define the transport velocities in the soil layer and unsaturated zone. Transport velocities determine the radionuclide leaching rates. Partition coefficients noticeably affect doses because they significantly influence the mass transfer rates between soil, unsaturated zone, and aquifer and the subsequent concentrations in soil, drinking water, and water used for agricultural purposes. Radionuclides most sensitive to this parameter tend to be those whose leaching rates are comparable to or greater than the radionuclide radioactive decay constant. Partition coefficients are not correlated to soil type or texture, or other easily measurable site characteristics.</p> <p><u>Site specific parameters</u> Licensees using deterministic analyses may only replace the default values with values determined from site-specific testing or propose different values based on published, peer reviewed data not evaluated in the parameter analysis. However, no further analysis is required by the licensee, and this parameter does not have to be modified if other parameters are changed. [Deterministic calculations should be based on the 95th or 5th percentile value of the default or revised distribution, depending on the specific radionuclide]</p>

Table E-3: Parameters Which do not need to Be Changed
If Other Parameters Are Changed* - Physical

Parameter	Description	Discussion
RF _r	Resuspension factor	<p><u>Definition:</u> This parameter represents the ratio of the long-term average <u>respirable</u> contaminant concentration in air to the long-term average floor surface contaminant concentration due to contaminated soil tracked indoors.</p> <p><u>Site specific parameters</u> Licensees are not expected to modify the default without specialized site-specific analysis. Licensees may propose different values based on published, peer reviewed data not evaluated in the parameter analysis. However, no further analysis is required by the licensee, and this parameter does not have to be modified if other parameters are changed. [Deterministic calculations should be based on the 95th percentile value of the default or revised distribution]</p>
r _v	Interception fraction for vegetation	<p><u>Definition</u> This parameter represents the average fraction of all deposited contaminates retained on all plants grown for food and animal feed after above-ground irrigation with contaminated groundwater.</p> <p><u>Site specific parameters</u> Licensees may modify this parameter based on the chemical form of their source term, since different distributions can be supported based on contaminants which are negatively-charged versus positively-charged or insoluble (see attached parameter discussion for details). [Deterministic calculations should be based on the 95th percentile value of the default or revised distribution]</p>

Table E-3: Parameters Which do not need to Be Changed
If Other Parameters Are Changed* - Physical

Parameter	Description	Discussion
V_{dr}	Volume of water removed from the aquifer per year for domestic uses	<p><u>Definition</u> This parameter represents the annual volume of groundwater removed from the aquifer for domestic uses, including such things as showers, washing, and water used for drinking and cooking. V_{dr} includes the volume of water used for drinking, defined by U_w, and along with the volume of water used for irrigation, establishes the total volume of water in the aquifer.</p> <p><u>Site specific parameters</u> Since this parameter is influenced by site-specific considerations such as climate, rainfall, and societal restrictions on water use, licensees may propose alternative values for this parameter based on the State-specific values in the attached parameter description document, USGS county data, or other equivalent information. [Deterministic calculations should be based on the 95th percentile value of the default or revised distribution]</p>
W_f W_g W_h W_v	wet-to-dry conversion factors (forage) (grain) (hay) (vegetables, fruits, & grains)	<p><u>Definition</u> Wet-to-dry conversion factors correspond to the fraction of dry matter in the particular crop, and varies with the type of crop and the growing conditions. The value for grain, both as used for animal feed and as consumed by humans, is proposed as a constant because there is so little variability between different grain crops.</p> <p><u>Site specific parameters</u> Conversion factors for fruits, vegetables, and hay/forage crops do vary based on the crop type, and licensees may propose different distributions from the defaults based on site-specific information about the specific crops that could be grown in that area. [Deterministic calculations should be based on the 95th percentile value of the default or revised distribution]</p>

Table E-3: Parameters Which do not need to Be Changed
If Other Parameters Are Changed* - Physical

Parameter	Description	Discussion
Y _f	Crop yields (forage)	<p><u>Definition</u> This parameter represents the average yield of all forage crops consumed by each of the four food-producing animals evaluated in the model, per unit area of cultivated land at the site. The default distribution is based on the production of hay, as that was determined to be most representative.</p> <p><u>Site specific parameters</u> Licensees may modify this parameter by limiting the distribution to crop types likely to be grown in the area of their site, as well as incorporating climatic conditions and soil features that may affect production. [Deterministic calculations should be based on the 95th percentile value of the default or revised distribution]</p>
P _d	Floor dust-loading	<p><u>Definition</u> This parameter represents the long term average mass of contaminated soil per unit area of floor inside the residence. It is used with the resuspension factor to calculate the airborne particulate concentration due to resuspension of soil tracked indoors.</p> <p><u>Site specific parameters</u> Licensees are not expected to modify the default without specialized site-specific analysis. Licensees may propose different values based on published, peer reviewed data not evaluated in the parameter analysis. However, no further analysis is required by the licensee, and this parameter does not have to be modified if other parameters are changed. [Deterministic calculations should be based on the 95th percentile value of the default or revised distribution]</p>

*Licensees performing probabilistic analyses may use the original distributions developed for the default analyses in their calculations. Licensees using deterministic calculations should use the value of the 95th or 5th percentile of the original distribution or the value recommended in the parameter discussion, as stated in this table.

Table E-4: Parameters That Need to be Evaluated for Site-Specific Critical Groups - Behavioral

Parameter	Description	Discussion
t _i , t _x , t _g	Exposure periods	<p><u>Definition</u> During the one year scenario period, the average member of the screening group is assumed to divide their on-site time between indoor, outdoor, and gardening activities.</p> <p><u>Site specific parameters</u> If the screening group definition is modified or replaced with a site-specific critical group, licensees should re-evaluate this parameter and modify it as appropriate. For example, if the critical group does not engage in agricultural activities, gardening time, along with ingestion rates of domestic produce, cultivated area, and irrigation rate would be 0. [Deterministic calculations should be based on the mean value of the default distribution]</p>
U _v , U _a , U _f	Ingestion rates of home produced food	<p><u>Definition</u> These parameters represent ingestion rates of home produced leafy vegetables, other vegetables, fruits, grains (U_v); beef, poultry, milk, eggs (U_a); and fish (U_f). The default ingestion rates represent the diet of the average member of the screening group. These parameters are also important for defining the area of land cultivated parameter A_r.</p> <p><u>Site specific parameters</u> While the defaults represent values developed from information in national surveys, site-specific values may be different based on regional and meteorological conditions that impact agricultural practices and local dietary habits. U_f can be set to zero if the site does not contain a pond or surface water that could support fish, or if any existing pond or surface water will not be contaminated with residual radioactivity during the 1000 year period following license termination. [Deterministic calculations should be based on the mean value of the default distribution]</p>

Table E-4: Parameters That Need to be Evaluated for Site-Specific Critical Groups - Behavioral		
Parameter	Description	Discussion
U _w	Drinking water ingestion rate	<p><u>Definition</u> This parameter represents the long-term average daily ingestion of drinking water from an on-site well.</p> <p><u>Site specific parameters</u> Licensees may modify (reduce or set to zero) this parameter based on site-specific physical factors that affect the existence or quality of the well, or based on information supporting a finding that an on-site well would not become contaminated by residual radioactivity during the 1000 year analysis period. [Deterministic calculations should be based on the mean value of the default distribution unless this pathway is completely eliminated]</p>
SFI	Indoor shielding factor	<p><u>Definition</u> This parameter represents the attenuation of gamma radiation by structural materials such as walls, floors, and foundations in residential buildings. The model uses a single, constant value for all radionuclides and all structural materials.</p> <p><u>Site specific parameters</u> Licensees may substitute alternative values for this parameter from Table X.XX based on a shielding factor for the specific energy range for the radionuclides in their source term. It will usually not be acceptable to limit the structural requirements for future structures that may be built on the site unless the licensee proposes restricted release, and such restrictions would not hold for the analysis of dose when controls fail.</p>
GR	Soil ingestion transfer rate	<p><u>Definition</u> This parameter represents the quantity of soil ingested per day, averaged over the one year duration of the scenario, by inadvertent transfer from hands or other objects that have been in contact with a contaminated surface, such as food, cigarettes, etc. into the mouth.</p> <p><u>Site specific parameters</u> If the screening group definition is modified or replaced with a site-specific critical group, licensees should re-evaluate this parameter and modify it as appropriate. [Deterministic calculations should be based on the mean value of the default distribution]</p>

Table E-5: Parameters That May be Changed to Account for Modifications to Screening Group Assumptions - Behavioral

Parameter	Description	Discussion
U_v, U_a, U_f	Ingestion rates of home produced food	<p><u>Definition</u> These parameters represent ingestion rates of home produced leafy vegetables, other vegetables, fruits, grains (U_v); beef, poultry, milk, eggs (U_a); and fish (U_f). The default ingestion rates represent the diet of the average member of the screening group. These parameters are also important for defining the area of land cultivated parameter A_r.</p> <p><u>Site specific parameters</u> While the defaults represent values developed from information in national surveys, site-specific values may be different based on regional and meteorological conditions that impact agricultural practices and local dietary habits. U_f can be set to zero if the site does not contain a pond or surface water that could support fish, or if any existing pond or surface water will not be contaminated with residual radioactivity during the 1000 year period following license termination. [Deterministic calculations should be based on the mean value of the default distribution]</p>
U_w	Drinking water ingestion rate	<p><u>Definition</u> This parameter represents the long-term average daily ingestion of drinking water from an on-site well.</p> <p><u>Site specific parameters</u> Licensees may modify (reduce or set to zero) this parameter based on site-specific physical factors that affect the existence or quality of the well, or based on information supporting a finding that an on-site well would not become contaminated by residual radioactivity during the 1000 year analysis period. [Deterministic calculations should be based on the mean value of the default distribution unless this pathway is completely eliminated]</p>

Table E-6: Parameters That May Need to be Evaluated - Other

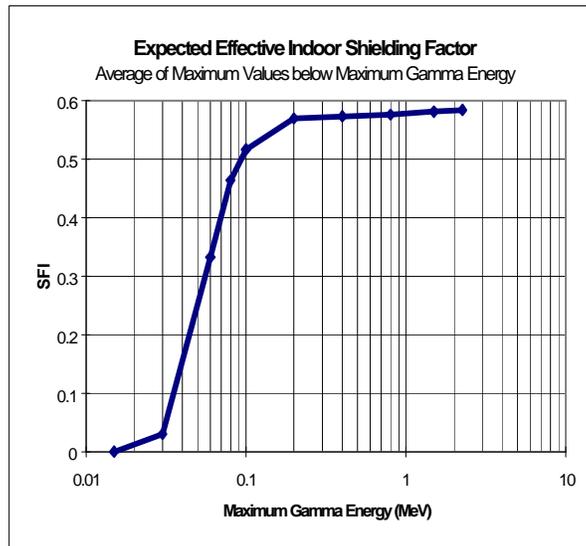
Parameter	Type	Description	Discussion
V_{irr}	physical (dependant)	Volume of water removed from the aquifer per year for irrigation use	<p><u>Definition</u> This parameter represents the volume of water removed from the aquifer for irrigation of all crops grown on site.</p> <p><u>Site specific parameters</u> It is calculated as a function of the irrigation rate (IR) and the land area under cultivation (A_r) and must be changed if either IR or A_r, or both, are changed.</p>
A_r	physical (dependant)	Area of land cultivated	<p><u>Definition</u> This parameter represents the area of land that is used for the production of agricultural products for both human and animal consumption. A_r is calculated as a function of the number of food and animal products considered in the diet, the ingestion rates for those products by the individual, and the yields for the food and animal products.</p> <p><u>Site specific parameters</u> Licensees may propose changes to the food and animal products that compose the on-site resident's diet based on the types of products that can be raised on the site, or physical limits on the site area that can be cultivated. A_r should be recalculated if the types of foods, ingestion rates, or yields are changed. In addition, if the screening group definition is modified or replaced with a site-specific critical group, licensees should re-evaluate this parameter and modify it as appropriate.</p>
CDI	physical (dependant)	Air dust-loading indoors	<p><u>Definition</u> This parameter represents the process of infiltration of contaminated airborne particles into the house (mass-loading) as the mass of infiltrating particles per unit volume of air.</p> <p><u>Site specific parameters</u> It is calculated as a function of CDO (air dust-loading outdoors) and PF (penetration factor) and must be changed if either CDO or PF, or both, are changed.</p>

Table E-6: Parameters That May Need to be Evaluated - Other

Parameter	Type	Description	Discussion
DIET	behavioral (constant)	Fraction of annual diet derived from home-grown foods	<p><u>Definition</u> This parameter was originally intended to represent the fraction of the average member of the screening group's diet that was derived from food grown on site in the contaminated area. However, it was determined during the parameter analysis that a single diet fraction value for all food types was not representative of the screening group. Therefore, this parameter was set to 1, and the behavior of the screening group, which is expected to produce different fractions of each food product, is represented by the consumption rates U_v, U_a, and U_f. The consumption rates have been redefined to represent the consumption of food derived from on-site production rather than the rate of consumption in general.</p> <p><u>Site specific parameters</u> Therefore, this parameter should normally not be changed.</p>
SFO	physical (constant)	Outdoor shielding factor	<p><u>Definition</u> This parameter represents attenuation of the external dose rate during periods outdoors based on shielding by clean cover or other materials. Under normal circumstances associated with unrestricted release, and for evaluation of restricted release following failure of controls, this parameter should not be changed from 1.</p> <p><u>Site specific parameters</u> This parameter can be changed to account for physical controls under restricted release conditions.</p>
V_r, V_x, V_g	metabolic	Volumetric breathing rates while indoors, outdoors, and gardening	<p><u>Definition</u> These parameters represent the annual average breathing rate of the average member of the screening group while indoors, outdoors, and gardening.</p> <p><u>Site specific parameters</u> If the screening group definition is modified or replaced with a site-specific critical group, licensees should re-evaluate this parameter and modify it as appropriate.</p>

The following table lists shielding factors based on the maximum energy of the source term. Licensees may modify the SFI parameter in the model (E[SFI]) based on the maximum energy for their site-specific source term. For example, if the source term maximum energy is less than 0.4 MeV, the default value for SFI can be replaced with 0.574.

Table E.7 Shielding Factors For Various Materials vs. Energy; SFI Replacement Values Based on Maximum Energy						
Energy (MeV)	Concrete			Wood	Energy (MeV)	E[SFI]
	3.5"	5.25"	7.0"	1.0"		
0.015	1.36e-12	2.55e-24	2.55e-24	2.05e-06	0.015	5.13e-07
0.03	8.10e-03	8.10e-03	8.10e-03	9.67e-02	0.03	3.03e-02
0.06	2.41e-01	2.41e-01	2.41e-01	6.08e-01	0.06	3.33e-01
0.08	3.80e-01	3.77e-01	3.77e-01	7.22e-01	0.08	4.64e-01
0.1	4.38e-01	4.32e-01	4.31e-01	7.67e-01	0.1	5.17e-01
0.2	5.07e-01	4.86e-01	4.79e-01	8.07e-01	0.2	5.70e-01
0.4	5.17e-01	4.78e-01	4.62e-01	8.14e-01	0.4	5.74e-01
0.8	4.89e-01	4.25e-01	3.94e-01	8.24e-01	0.8	5.77e-01
1.5	4.91e-01	4.05e-01	3.59e-01	8.45e-01	1.5	5.82e-01
2.25	5.14e-01	4.22e-01	3.69e-01	8.57e-01	2.25	5.85e-01



E.2 Assimilating Existing Data and Information

This step involves gathering and evaluating existing data and information. Licensees should check their records to determine the types and amounts of radioactive material they possessed on their site. They should also gather information about any surveys and leak tests that had been performed, as well as any records that would support their ability to "Certify the disposition of all licensed material, including accumulated wastes, by submitting a completed NRC Form 314 or equivalent information" [10 CFR 30.36(j)(1)].

Data are used to support Step 3 which is development of a conceptual model, and model assumptions and model parameter values. As described above, the licensee has 2 options in this analysis:

- (1) use the pre-defined DandD models and one or more site-specific parameter values
- (2) develop site-specific models and accompanying parameter values

Additional information is needed to support and defend the conceptual model of Step 3 if models other than DandD are used or if site specific parameter values are used. Types of potentially useful information include: processes that utilized the potential contaminants, releases and mitigative actions, hydrologic conditions (soil moisture content, conductivities, depth to groundwater, hydraulic gradients, hydraulic conductivities), soil type and texture, clay content, geochemical conditions (Kd, pH), atmospheric conditions (annual averages or time and date specific conditions), geology (unconsolidated sediments, fractured rock). Methods for obtaining the necessary additional information to support the site specific parameters and models used are described in Sections 4.1.1 through 4.1.4.

The 12/6/96 Draft of MARSSIM chapter 3 discusses the Historical Site Assessment (HSA) process. Only one of the five objectives of the HSA apply to Step 1 of the D&D decision framework. The common objective of Step 1 and the HSA is to identify the potential, likely or known sources of radioactive material and radioactive contamination based on existing information. Section 3.4 and Appendix G of the MARSSIM draft provide useful guidance on sources of information and Section 3.6 discusses how to identify potentially contaminated media. (Note: it may be more appropriate to reference Section 3.6 in the discussion on the applicability of the 5512 pathway assumptions (Step 2) and models (Step 3) to the site.) (The other objectives of the HSA (identifying sites that pose a threat to human health and those that do not, assessing the likelihood of contaminant migration, providing useful information for developing and analyzing surveys, and providing an initial classification of the site or specific areas of the site as impacted or non-impacted) are similar to objectives of later steps in the framework. These inconsistencies arise because the MARSSIM methodology assumes that the DCGLs are established prior to beginning the MARSSIM process. A dose assessment is needed in order to establish the DCGLs. In order to perform that dose assessment, knowledge about the potential contamination and exposure mechanisms is needed. In the D&D framework, DCGLs would be proposed in Step 6 as part of the ALARA analysis, or in Step 8 when remediation options are defined.)

E.2.1 Source data

The licensee gathers and interprets all pertinent and legitimate *existing* site data and other relevant information that can be used to define characteristics of the residual radioactive (and

non-radioactive) contamination at the site. In defining the residual contamination, all existing information on the amount, location and distribution of all possible contaminants should be evaluated. Where data are unavailable, the licensee may estimate the amount and distribution of the potential contaminant based on initial inventories (mass balance approach) and the processes involved in generating the original materials (e.g., ore processing, contained source, laboratory analyses). The uncertainty in the extent and amount of residual contamination for each substance will depend on the amount and variability of the data. The uncertainty in the magnitude and distribution of the source should be represented or bounded in the later dose assessment in order to evaluate the worth of collecting additional data about the residual contamination. The uncertainty in the extent and amount of residual contamination can be accounted for in the dose assessment by employing conservative assumptions about the source magnitude and distribution.

As noted in Chapter 3 of the 12/6/96 draft of MARSSIM useful sources of information about the potential amount, form and distribution of radioactive contaminants include licenses, site permits, authorization documents, operating records, financial records, site plots, blueprints, photographs, aerial photos and maps. Licenses, permits and authorizations may indicate the quantities of radioactive material, chemical and physical form and types of operations. Operation records may include accounts of intentional and accidental releases of radioactivity (leaks, spills, disposal, storage, routine emissions). These accounts may include estimates of the amount, distribution, and the chemical and physical form of the potential contaminants. Financial records may provide evidence of the amount of material entering and leaving the site. Maps, figures and photos provide information for evaluating the location of potential contamination based on operations.

E.2.2 Hydrogeologic data

Existing data on the geology, surface water and groundwater systems at the site are used to support the conceptual model, defend the use of the DandD models and support the dose assessment model parameter values.

The data used to develop the default parameter values for the 5512 models provides a data base for estimating the uncertainty in the model parameter values (Step 3) and for evaluating how that uncertainty might be reduced given site specific information (Step 8). The hydrologic data in the 5512 parameter analysis include the range in observed unsaturated zone thickness (depth to groundwater), unsaturated zone and soil porosity, saturation ratios (volumetric moisture contents), infiltration rates and volume of surface water pond.

As noted in the 12/6/96 draft of MARSSIM, potentially useful site-specific information includes rainfall; the location of nearby wetlands, intermittent streams, drainages and surface water bodies (rivers, lakes, oceans, coastal tidal waters) relative to the potential sources of contamination; flooding potential; runoff rates; runoff barriers; infiltration rates; soil/subsurface permeabilities; depth to groundwater; and type of groundwater system (karst, fractured rock, porous media; confined; unconfined). Table G.1 in the 12/6/96 draft of MARSSIM, indicates useful sources of hydrogeologic data (in this document it includes geologic, hydrologic and groundwater characteristics). In addition to data collected during operations, other agencies that may have useful hydrogeologic information and experts include: the USGS, state

geological surveys, state environmental agencies, state departments of transportation, local colleges and universities, local well drillers, local water authorities, local health departments, EPA regional offices, U.S. Army Corps of Engineers, FEMA, US Fish and Wildlife, and national databases (WATSTORE, STORET, GRIDS, National Wetland Inventory Maps).

E.2.3 Chemical data

Existing data on the chemical properties of the potentially contaminated material are used to support the conceptual model and dose assessment model parameter values. The data used to develop the default parameter values for the 5512 models provides a data base for estimating the uncertainty in the distribution coefficients (Step 3) and for evaluating how that uncertainty might be reduced given site specific information (Step 8). This data set can be evaluated in terms of the soil type and site specific information on the soil type can be used to justify reducing the uncertainty in this parameter value.

The Soil Conservation Service is the agency that may have useful information and experts to contact regarding soil type and potentially useful data bases include the National Soil Geographic Database, State Soil Geographic Database, and the Soil Survey Geographic Database. All of the databases are available through EPA's website. Other sources of site specific information include local experts at universities or colleges, state geological surveys and environmental agencies.

E.2.4 Land-Use data

If a site-specific critical group is proposed, land-use data will be used to defend the characteristics of the critical group and model parameter values.

As noted in Appendix G of the 12/6/96 draft of MARSSIM, local planning and zoning officials, tax assessor, and local university or college geography departments are potential sources of land-use information. The USGS is a source of land use and land cover information and the U.S. Bureau of the Census TIGER Map Service is a source of demographics information.

A key point of this framework is that new site data collection does not take place until Step 12. New data collection is deferred until the data that would make a difference in decision making and are cost effective to collect can be defined through cost/benefit and data-worth activities (Steps 8, 9 and 10). Otherwise, money may be spent on collection of superfluous data.

To start this decision process using the modeling approach described in Volume 1 of NUREG/CR-5512, only information on the nature and extent of the residual contamination is needed. For new sites of any type the same approach is recommended. However, other sites may have evolved further in the process prior to using this approach. In this case, all relevant site data should be included and evaluated. This information would provide the bulk of the primary background information for any NEPA analysis and documentation for these sites. This information may be augmented under later steps where additional data collection activities occur.

Appendix F - Area Factors

F.5.0 Area Factors / Elevated Measurement Criteria: Integration of Modeled Risk with Areal Extent of Contamination

Area Factors are used to calculate the maximum concentration, distributed over a specific area, that can remain following decommissioning without requiring additional clean up. They are used to determine the elevated measurement comparison value, as described in NUREG-1505, Chapter 5. Area factors are calculated as a ratio of the dose conversion factor (DCF) based on the default contaminated area to the DCF based on the contaminated area of interest. Since area factors can be applied to any site and are calculated generically, they are based on default parameters developed at a P_{crit} level of 0.05 (Beyeler, et. al, 1996). This level of conservatism is reasonable in the context of developing allowable multiples of the guideline levels for use at sites that will be released from license.

All calculations for area factors in this report were done using the Residential and Building Occupancy Scenarios in DandD version 1.0. The source term in all cases is based on a unit concentration, equivalent to 1 pCi/g in the Residential Scenario and 1 dpm/100 cm² in the Building Occupancy Scenario. DandD parameters with links to area are shown on the spreadsheets included in Appendix A, along with proposed modifications based on area of contamination. If the parameter is not listed, no change was made to the Level 1 (L1) default. For the purposes of these calculations, the L1 parameters are set at the $P_{crit} = 0.05$ level.

F.5.1 General Assumptions

F.5.1.1 Areal Distribution

A) Residential Scenario

For contamination under a house (the house scenario), it is assumed that the house has an area of about 2,000 square feet (~186 m²). The contamination is assumed to be completely covered by the house until it exceeds a size of 186 m², at which time the contaminated area exceeding 186 m² is assumed to be in the cultivated area (garden).

For contamination in a garden (the garden scenario), the contaminated area is assumed to be completely in the garden until the size exceeds the default garden size or a garden size associated with the area needed to support 50% of the individual's diet. Once the contaminated area exceeds the garden size, the excess is assumed to be under the house.

B) Building Occupancy Scenario

For contaminated areas inside buildings, the baseline room is assumed to have a floor area of 4 meters x 4 meters and a ceiling height of 3 meters. External dose is based on the assumption of an infinite flat plane with uniform contamination.

7.1.2 Diet (Residential Scenario Only)

The assumption is made that no more than 50% of a person's diet would be from the contaminated area. Beyond 50%, site-specific adjustments should be made to the parameters because the scenario has been extended beyond the original assumptions made in the construction of the resident farmer scenario. The fraction of the diet is related to area using the L1 baseline area and diet fraction. For contaminated areas other than the default area, the fraction is calculated as the ratio of the default diet fraction to the default area, multiplied by the contaminated area. As explained above, the maximum fraction is limited to 0.5.

Fraction of Diet from Contaminated Area (DIET) #

$$\frac{L1 \text{ Fraction of Diet}}{L1 \text{ Contaminated Area}} \times \text{Contaminated Area (A)}, \quad (1)$$

$$DIET \# 0.5$$

7.1.3 Time

A) Residential Scenario

This model is structured in such a way that it is not simple to modify the time of exposure to an external source without also affecting the inhalation and ingestion pathways. The time variables used to control time spent indoors and outdoors affect both the time of exposure to external sources, as well as time inhaling resuspended dust and secondary ingestion. Time of exposure is important because it is used as a surrogate for modification of the source geometry. This model currently only supports an infinite flat plane geometry.

The time of exposure to an external source is important for evaluating the effect of contaminated areas smaller or larger than the default area. For example, if it is assumed that a person has an equal probability of being at any location on the site at any time during the analysis period, then the time of exposure to the source can be related to the size of the contaminated area versus the entire site area. If the entire site is contaminated, the person is exposed to the source the entire time they are on the site. If one quarter of the site is contaminated, the person can be assumed to be exposed to the source for one quarter of their time on site. It is important to note that these simplifying assumptions are only valid within the context of this model, which was designed to evaluate distributed, relatively homogeneous low activity sources. It would not be valid, for example, to apply these assumptions or this model to an exposure assessment for a high energy gamma sealed source.

While it is easiest to adjust the external exposure pathway by changing the duration of exposure, other pathways are best adjusted by applying a correction based on the ratio of the contaminated area to the site area while using the default exposure time. In addition, the external exposure pathway is complicated by the fact that it is divided into three components and uses two shielding factors. The components are gardening,

outside activities other than gardening, and indoors. Separate shielding factors are applied to indoor and outdoor activities. Since both contamination in the garden and contamination under the house are being evaluated, it is important to be able to change both shielding factors and time spent in each of the three locations. In addition, this allows the time indoors, for example, to be used as a surrogate for time of exposure without impacting the time exposed to resuspended dust from soil tracked indoors.

Given these complications, adjustments to the time of exposure for the external dose pathway are made after the model has first been run with adjustments to all other parameters¹.

The external dose in the residential scenario is calculated by summing the time spent indoors, outdoors on site, and gardening. Additional details regarding the external dose pathway and how it is integrated into the residential scenario can be found in NUREG/CR-5512, Volume 1, page 5.52 to 5.54. The equation used to calculate external dose² is as follows:

$$\begin{aligned}
 DEXR_i = & \left[24 \left(t_g/t_{tg} \right) SFO C_{si,j,1}^{J_i} S\{A_{stj}, t_{tg}\} DFER_j \right] \\
 & \% \left[24 \left(t_x/t_{tr} \right) SFO C_{si,j,1}^{J_i} S\{A_{stj}, t_{tr}\} DFER_j \right] \\
 & \% \left[24 \left(t_i/t_{tr} \right) SFI C_{si,j,1}^{J_i} S\{A_{stj}, t_{tr}\} DFER_j \right]
 \end{aligned} \tag{2}$$

where

$DEXR_i$ = external dose from 1 year of residential scenario exposure to radionuclide i in soils (mrem for a year of residential scenario)

$DFER_j$ = external dose rate factor for radionuclide j for exposure to contamination uniformly distributed in the top 15 cm of residential soil (mrem/h per pCi/g)

A_{stj} = concentration factor for radionuclide j in soil at the beginning of the current annual exposure period per initial

¹A Quattro workbook containing adjusted parameter sets and all calculations is attached. Names of workbook pages containing calculations associated with adjustments to the external exposure pathway have a standard format consisting of the radionuclide name followed by "ext fix". For example, the page associated with Cobalt-60 is named "Co ext fix".

²Equation 5.69, NUREG/CR-5512, Volume 1

		unit concentration of parent radionuclide I in soil at time of site release (pCi/g per pCi/g)
C_{si}	=	concentration of parent radionuclide I in soil at time of site release (pCi/g dry-weight soil)
SFI	=	shielding factor by which external dose rate is reduced during periods of indoor residence (dimension less)
SFO	=	shielding factor by which external dose rate is reduced during periods of outdoor residence and gardening (dimension less)
J_i	=	number of explicit members of the decay chain for parent radionuclide I
$S\{A_{sij}, t_{tr}\}$	=	time-integral operator used to develop the concentration time integral of radionuclide j for exposure over a 1-year period per unit initial concentration of parent radionuclide I in soil (pCi•d/g per pCi/g dry-weight soil)
$S\{A_{sij}, t_{tg}\}$	=	time-integral operator used to develop the concentration time integral of radionuclide j for exposure outdoors over one gardening season during 1-year period per unit initial concentration of parent radionuclide I in soil (pCi•d/g per pCi/g dry-weight soil)
t_g	=	time during the gardening period that the individual spends outdoors gardening (d for a year of residential scenario)
t_i	=	time in the 1-year exposure period that the individual spends indoors (d for a year of residential scenario)
t_x	=	time in the 1-year exposure period that the individual spends outdoors, other than gardening (d for a year of residential scenario)
t_{tg}	=	total time in the gardening period (d)
t_{tr}	=	total time in the residential exposure period (d)
24	=	unit conversion factor (h/d).

The concentration time-integral factors, $S\{\}$, are evaluated for all radionuclides in a decay chain. The factors represent the time integral of concentration during the exposure period of interest.

The concentration factor, A_{stj} , defines the concentration of each radionuclide in soil in a decay chain at the beginning of the current year of the dose evaluation. The concentration includes material initially present in the soil, plus material that has migrated to ground water and been redeposited onto the farmland soil by irrigation with the contaminated water during the previous year.

Equation 2 can be reorganized and simplified to isolate the times and shielding factors of interest:

$$DEXR_i = K \times [(t_i \times SFI) \% (t_x \times SFO) \% (t_g \times SFO)] \quad (3)$$

Where

K = combined L1 parameters

and other variables are as defined above.

Assuming that the receptor has an equal probability of being at any point on the site, the time of exposure to the contaminated area can be calculated by multiplying the default exposure time by the ratio of the size of the contaminated area to the Level 1 (L1) default area size. The external dose due to exposure to a contaminated area of any size is calculated by applying the times and shielding factors associated with the area of interest.

The shielding factors are not adjusted in the same way as time of exposure for area of contamination. They are only used to turn the indoor or outdoor external exposure pathway completely on or off. When the pathway needs to be turned off, the shielding factor is set to zero. If the pathway is on, the shielding factor is set to the L1 level. Therefore, the time of exposure is the primary way that the external exposure is varied to account for the size of the contaminated area. The revised external dose is calculated by multiplying K , which is composed of known L1 values, by the modified exposure times and shielding factors:

$$DEXR_i(A) = K \times [(t_i(A) \times SFI) \% (t_x(A) \times SFO) \% (t_g(A) \times SFO)] \quad (4)$$

Where

A = contaminated area (m^2),

$DEXR_i(A)$ = external dose based on area A from 1 year of residential scenario exposure to radionuclide i in soils (mrem for a year of residential scenario)

and other variables are as described above.

Once the revised external dose has been calculated, the area-corrected DCF, $DCF_{(A)}$, can be calculated. $DCF_{(A)}$ is calculated by first running DandD with parameters (except time) adjusted for the contaminated area of interest. The resulting $DCF_{(X)}$ (DCF without time of exposure modification) is then adjusted by first subtracting the external dose contribution calculated without accounting for the time factor, then adding the corrected external dose:

$$DCF_{(A)} = [DCF_{(X)} \& DEXR] \% DEXRi(A) \quad (5)$$

The area factor can then be calculated by dividing the baseline $DCF_{(L1)}$ by the area corrected $DCF_{(A)}$ for the specific contaminated area of interest.

B) Building Occupancy Scenario

Calculation of external exposure for the building occupancy scenario is simpler than the residential scenario because all exposure occurs inside the building and no shielding factors are used. However, the same need exists to separate the time of exposure to external sources from inhalation and ingestion. Therefore, the external dose is modified after the model is run, in the same general way as described above, and the area-corrected DCF is calculated as shown in equation 5.

7.2 Parameter Specific Assumptions

Most parameters in both the residential and building occupancy scenarios are modified by being multiplied by the ratio of the contaminated area of interest to the L1 default contaminated area. This provides a reasonable and repeatable method for adjusting the impact of various pathways, based on the assumption that such a ratio can act as a reasonable surrogate for variations in the contaminated fraction based on area.

An example of the application of the ratio of contaminated area to L1 default area is demonstrated with the air dust loading factors. These factors are described in NUREG/CR-5512, Volume 1, pages 6.10 through 6.12. The use of dust loading rather than resuspension was originally selected because it was assumed to be the most straight-forward approach for prospective screening, and would require the least number of assumptions regarding input parameters. The base assumption is that the dust loading parameter represents contaminated, respirable dust. Unfortunately, dust loading does not allow direct incorporation of the impact of contaminated area size on the contaminated fraction of resuspended dust. However, a crude approximation of the impact of area can be incorporated by assuming that as the contaminated area decreases in size, the amount of contaminated material versus clean material available for resuspension also decreases. Therefore, while the total amount of dust in the breathing zone would remain the same, the fraction contributed by contaminated soil could be assumed to decrease in direct proportion to the contaminated area. This is

approximated by modifying the dust loading parameters by the ratio of contaminated area to the L1 default area.

The resuspension factor, used in the building occupancy scenario, is difficult to adjust because it is insensitive to the distribution of contamination and the size of the contaminated area. As a first approximation, and within the constraints of this study, it is assumed that the resuspension factor can vary between the minimum value assumed in the parameter analysis ($1E-6 \text{ m}^{-1}$), and a maximum of the L1 default for areas equal to or greater than the assumed default room size. Analogous to the discussion of dust loading, this approach is based on the assumption that while the resuspension factor may remain constant, the contaminated fraction of material that is resuspended decreases with a reduction in the size of the contaminated area.

For the house scenario, the ratio is modified by the area (186 m^2) that is assumed to be under the house, and which therefore does not contribute to any pathway except external exposure. The fish ingestion parameter is only used to turn aquatic food ingestion on or off, as is the contaminated water ingestion pathway.

Shielding factors are set to either the L1 default value or zero, since they are only used to turn the external exposure pathway on or off. For example, when no contamination is located under the house, the indoor shielding factor is set to zero, and when all contamination is located under the house, the outdoor shielding factor is set to zero.

In most cases, the L1 default parameter value is assumed to be the maximum reasonable value, and areas larger than the default do not cause the parameter value to increase. Since the default is set at a known conservative value, it is not necessary and would likely be unduly unrealistic to assume higher values. Exceptions are the fraction of the diet from the on-site garden, which can increase to a maximum of 0.5, and the time spent gardening, which is tied to garden size.

Appendix G - Examples

1. Example applications

A logical, consistent decision process is viewed as a useful tool that will support licensee planning of decommissioning activities and NRC review of license termination requests. To support this process, Chapter 2 of this NUREG describes a decision framework to support implementation of the dose criteria of Subpart E of 10 CFR 20. Three example applications are described in this Appendix which illustrate the cases described in Chapters 3, 4, and 5 of this NUREG.

2.1 Case 1 - Use of the Framework for licensees who use Generic screening

Step 1 Assimilating existing data and information

In checking records to determine the types and amounts of radioactive material they possessed on their site, and gathering information about any surveys and leak tests that had been performed, the licensee in this example determines that:

- a) all waste has been properly disposed,
- b) sources have been properly transferred to another licensee,
- c) minor amounts of contamination have been detected inside a laboratory building during routine surveys.

Step 2 - Scenario Definition/pathway identification

The licensee would note that:

- a) The building occupancy scenario applies, with the associated inhalation, secondary ingestion, and external exposure pathways (building occupancy applies to situations where contamination exists on interior building surfaces (but not in the soil) and where the building will be re-used for commercial (not residential) purposes following license termination.
- b) for the simple case considered here, Step 2 has already been completed by the NRC, based on the generic scenarios and pathways for screening that have been defined and described in NUREG/CR-5512, Volume 1.

Step 3 - System Conceptualization

For the simple case considered here, Step 3 (conceptual and mathematical model development and assessment of parameter uncertainty) has already been completed by NRC, using the models described in NUREG/CR-5512, Volume 1, by its preparation of the DandD software and the generic screening tables of Appendix A and B.

Step 4 - Dose Assessment

In this example, the licensee could either:

- a) run DandD and plug in the maximum surface contamination concentrations from the existing building surveys
- b) compare the maximum surface contamination concentrations from the existing building surveys to the generic screening concentrations in Tables A-1 or A-2 of Appendix A.

The maximum survey results should be used because, if the dose assessment using these values indicates that the dose is below the 25 mrem/yr criterion, there will be a high assurance that the site meets the dose requirements and additional refinement of the source term will be unnecessary.

Step 5 - Determining if Site can be released

Based on Step 4, the licensee can then simply answer the question of whether the dose assessment results from the model are less than the dose criterion of 25 mrem/yr in 10 CFR 20, Subpart E.

In this example, the model results are much less than the 25 mrem criterion.

Step 6 - ALARA requirements

In Step 6 the licensee would satisfy any remaining ALARA requirements (see Reg Guide xxx, Section 3).

Step 7 - License Termination and Site Release

The licensee would:

- a) complete paperwork requirements, including documenting the survey results used to calculate the source term and the model output,
- b) submit necessary forms and request to have their license terminated by the NRC.

2.2 Case 2 - Licensees who use site specific information but only modify site parameters

This example illustrates use of the framework for a licensee that uses site specific information in their dose assessment. As described Section 2.2, there are a wide range of options for using site specific data ranging from modifying parameters, to modifying models, to remediating the site, to restricting site use.

This example describes use of the framework specifically for those licensees that conclude that the option of modifying parameters will provide a simple, cost effective means to comply with the dose criteria of Subpart E with only limited consideration of other options. This example is prepared separately from Case 3 (which includes a more in-depth evaluation of options) because it is thought that a number of licensees will have relatively low levels and patterns of contamination and will seek to perform a dose assessment by changing certain parameters to more adequately represent their site. This example is not intended to limit the options a licensee may pursue.

In this example, the licensee is interested in terminating the license for an outdoor location that is believed to have areas of soil contamination from leaks in a waste tank.

Although this licensee has a more complex situation than that described in Case 1, they would still follow the same processes in Steps 1 - 5 described for Case 1, at least for the first iteration.

Step 1 - Assimilate Existing Data and Existing Data and Information

The licensee would gather as much information as possible about their site. This might include:

- a) radionuclides and processes used,
- b) quantities and forms of material that might still remain on site,
- c) other information (e.g.,) useful for performing a site dose assessment.

Step 2 - Scenario definition and pathway identification

In this example:

- a) because some small amount of soil contamination exists, the residential farmer scenario applies, with the associated inhalation, ingestion, and external exposure pathways (the residential farming scenario applies to situations where contamination exists on soil surfaces to a depth of less than 15 cm with potential for use of the land for residential purposes following license termination).
- b) The licensee decides to begin the decision process by using the pre-defined scenarios and pathways in the residential scenario (soil contamination) described in NUREG/CR-5512, Volume 1. As for Case 1, for the simple case considered here, Step 2 has

already been completed by the NRC, based on the generic scenarios and pathways for screening that have been defined and described in NUREG/CR-5512, Volume 1.

Step 3 - System Conceptualization

The licensee continues the process of using the pre-defined methods by using the default parameters and the DandD software. For the simple case considered here, Step 3 has already been completed by NRC, using the models described in NUREG/CR-5512, Volume 1, by its preparation of the DandD software and the generic screening tables of Appendix A and B.

Step 4 dose assessment,

The licensee runs DandD using a source term developed from the information gathered in step one, and which is the maximum reasonable value they believe they can defend.

Step 5 - Can site be released

Based on the results of the dose assessment in Step 4, it is clear that the site does not meet the Subpart E dose criterion of 25 mrem/yr.

The licensee would therefore proceed to Step 8.

Step 8 - Define Options for Site

There are three options that the licensee could apply either alone or in combination:

- a) Option 1 - Activities that reduce uncertainty (information/data collection),
- b) Option 2 - Activities that reduce contamination (remediation), and
- c) Option 3 - Activities that reduce exposure (land-use restrictions).

Table 2.2.1 lists some of the options that a license could consider, the first two related to Option 1, and the next two related to Options 2 and 3, respectively. In this example, the nature of the soil contamination is relatively simple, and the options are relatively straightforward. In this case the licensee conducts the following fairly simple thought process regarding the options in Table 2.2.1:

- a) The 1st item in the table would reduce uncertainty in the source term (Option 1) and would require additional site characterization;
- b) The 2nd item would replace the default kd with a more site specific value based on the site soil type (Option 1) and would require collection of some additional data;

- c) The 3rd option in the table would result in an actual reduction of the quantity of residual radioactivity remaining on the site by use of soil removal activities such as excavating, transporting, and disposing of the soil at a licensed burial site (Option 2).
- d) The 4th item in the table, reduction of exposure by restricting use, would require the licensee (per 10 CFR 20.1403) to demonstrate that unrestricted release was not ALARA and to convene an SSAB. This would require additional site specific modeling to ensure that the decision has a sufficient basis (Option 3).

Based on the review, the licensee the licensee chooses Option 1 (and specifically b above), and considers the following in determining what type of information to collect:

- a) Reviews the parameter distributions and their rationale as presented in Appendix A.1.2;
- b) Considers how to modify the parameters to consider site specific information and determine the data needs to modify the parameters. This would involve review of Appendix A.1.2 which provides information regarding the valid ranges for site specific parameter changes that a license could propose without an additional uncertainty analysis and for which the licensee would need little supporting information to defend changes. This is important in evaluating the relative worth of collecting additional data on these parameters under Step 9 of the decision framework.

Table 2.2.1 - Example Options Definition Table

Expectation	Effect on Dose	Action
Source is believed to be lower concentration than currently modeled	Simulated dose expected to decrease as concentrations decrease	Collect field data to better characterize source distribution
Soil type is expected to be predominantly clay and consequently have higher Kds	Simulated dose expected to decrease as availability of radionuclides to the receptor is decreased	Collect literature and soil map data to defend alternative soil type/texture
Enough soil is expected to be permanently removed to decrease source concentrations so dose level is acceptable	Actual available mass of contaminant decreases, hence simulated dose would decrease	Remediation by soil removal
Controls are expected to remain in place for the duration of the compliance period (if controls fail, simulated doses are between 25 mrem and 100 mrem)	Restrictions will limit uses for site while controls are in place to limit exposure time and pathways to individual; simulated dose will decrease	Set land use restrictions and apply for restricted release

Step 9 - Analysis of Options

To evaluate the likelihood of success, an analysis of the potential outcome (consequence analysis) will need to be performed for each of the options. Depending on the option, this consequence analysis could be very simple (e.g., the option is complete remediation and the consequence is effectively restoring the system to an acceptable condition) to as complicated as refining and expanding the dose assessment. The cost and time necessary to complete each option would also need to be estimated. The consequence analysis should also address the uncertainty associated with each potential outcome. The desired endpoint is a determination of the likelihood or probability that employing a given option will result in meeting the criteria of 10 CFR 20, Subpart E.

The result of the activities performed under Step 9 is a logically organized list of options, and the corresponding cost, likelihood of site release (probability of success), and other important considerations given that the option is pursued. Table 2.2.2 contains examples of how the options could be organized. In some cases, the decision regarding the preferred option will be obvious; for example, a low cost of success and failure, high probability of success option will always be selected over a high cost, low probability of success option. However, the preferred

option will not always be obvious, and additional analysis may be needed for sites attempting to balance complex issues.

Table 2.2.2 - Example Options Analysis Table				
Alternative Action	Cost (if successful)	Cost (if unsuccessful)	Probability of Success	Required Outcome*
Collect field data to better characterize source distribution	\$\$	\$\$	medium	dose less than 25 mrem
Collect literature data to defend alternative soil type/texture	\$	\$	medium	dose less than 25 mrem
Remediation by soil removal	\$\$\$	\$\$\$	high	dose less than 25 mrem
Set land use restrictions and apply for restricted release				dose w/ controls less than 25 mrem; dose w/o controls less than 100 mrem

*These assume each option is performed in isolation. If performed in combination with other options, each option on its own would not need to achieve a dose less than 25 mrem

To analyze the potential outcome of the selected options, the licensee can use the DandD software to perform some low cost "what-if" calculations. For example, they can review the existing information about their source term and try to estimate how it would change based on additional characterization. Based on the quality of the existing information, they may be able to modify the source term and obtain a less bounding value. This modified source term would then be input into the model and a revised dose estimate calculated.

In the same way, the licensee could review site specific or regional data to determine the predominant soil type at their site. If the soil type is not well characterized by a clean sand, as was used to define the default soil parameters, the licensee could investigate the impact of changing parameters associated with soil type, such as kd. This process can be continued for other model parameters that the licensee believes could be changed based on site-specific information. This is similar to performing an informal sensitivity analysis, and will help focus attention to those parameters likely to have the most impact on the calculation of dose. The licensee can then direct resources to reducing the uncertainty in those parameters, or can determine that a different approach is necessary before any higher cost activities, such as soil removal or site surveys, are begun.

For this example case, it is assumed that a preliminary evaluation of the remediation option indicates that it is not cost effective to remove the contaminated soil and transport it off site. However, the preliminary analysis is based on the default dose screening and initial bounding estimate of the source term, both of which impact the estimated soil volume requiring

remediation, and the cost of remediation. These estimates will change as more site-specific data is obtained, which may make remediation a more reasonable option at another point in the decision process. At this point in the decision process, the idea is not to permanently eliminate options from further consideration, but rather to select the optimum approach for the current state of knowledge.

This step in the decision framework should support an evaluation of the cost and time impacts of both success and failure. Generally, low cost / high likelihood of success options, or combinations of options, are preferred. This step should also include ALARA considerations, in terms of cost/benefit calculations as well as qualitative considerations. With regard to costs, the licensee should consider that if the option(s) selected are successful, the license will be released and further costs will be minimized. However, if the selected option(s) are unsuccessful, it may be necessary to perform additional characterization or remediation, or there may need to be an evaluation of restricted use (with its associated costs).

Step 10 - Select Preferred Option

Based on the DandD analysis and cost estimates for this example, the licensee decides choose Option 1 and specifically to:

- a) perform additional characterization of the source term, with the expectation that this will result in the source term estimate being reduced.
- b) use the additional characterization that will also involve obtaining data on the site soil type to support revision of the default kd.

The combination of these two actions should have a medium cost and a high likelihood of success.

Step 11 - Implement preferred option

The licensee:

- a) develops a characterization plan that will support both radiological and soil data requirements,
- b) obtains regional soil maps
- c) performs a radiological site survey. If the licensee has a very high expectation that the additional information will be sufficient to support a revised dose assessment that is less than or equal to 25 mrem, it may be worthwhile to design the site survey so that it can be used as a final site survey. However, it is important to note that the final site survey has more extensive requirements than may be needed if the site requires remediation. The extra cost of a final site survey should be weighed against the need to repeat the survey at a later time.

Step 12 - Revise Model Assumptions:

In this example, the licensee revises the parameter values associated with soil type (kd) and source term are modified based on the site data. To support the future request for license termination, the site survey results, soil maps, and methods used to revise Kd are carefully documented.

Reiteration of Step 4 - Iteration 2 Dose Assessment

The revised source term and parameter values are used in iteration 2 of the dose assessment in step 4. In this example, the licensee decides to leave the original default model assumptions and pathways unchanged, and continues to use the DandD software.

In this example, when the revised parameter values are input into the model, the result is a dose less equal to 25 mrem/y.

Reiteration of Step 5

Since the dose assessment result is equal to 25 mrem/y, and the site survey met the minimum requirements for a final release survey, the site can be released.

Step 6 - ALARA

the licensee can move on to consider any remaining ALARA requirements. The licensee can document that best practice procedures were applied as part of its operational program. In addition, ALARA was incorporated and documented in the options definition (step 8), analysis of options (step 9), and selection of the preferred option (step 10).

Step 7 - Release of Site

Based on the above, the license can be terminated and the site released. The licensee submits all required forms, including NRC Form 314, and documentation of the decision process, and the site is released for unrestricted use.

Case 3: Uranium Contaminated Soil

This example will demonstrate the use of the decision methodology to evaluate compliance with the 25 mrem/y dose criterion for a site with residual soil contamination consisting of depleted uranium. The fictitious site, for the purposes of this example, has been placed in south-central Pennsylvania, in an area that is used for both industrial and agricultural purposes, to support a demonstration of how regional and site-specific data can be used to support parameter changes within the dose model.

Step 1

The licensee in this example had processed uranium metals for many years, and several outdoor locations are contaminated from that processing. Although this licensee faces a more complex situation than that described in Cases 1 and 2, they would still follow the same steps described above, at least for the first iteration. As before in step one, they would gather as much existing information as possible about their site, including radionuclides and processes used, quantities and forms of material that might still remain on site, and anything else that would be useful for performing a site dose assessment.

Based on the information gathered in step one, the licensee determines that although uranium of various isotopic ratios had been used over several years, operational and special purpose surveys have generally indicated that the contaminant in soil is depleted uranium, and is well characterized by the following activity percentages: 90% U^{238} , 9% U^{234} , and 1% U^{235} . For this example, the licensee is evaluating two separate soil contamination areas. One area, (area A), is directly adjacent to an existing storage area, and the other, (area B), is a large open area that had contained a large structure. The structure was demolished and removed several years ago. Area A is approximately 10 m², and contains a localized area of highly elevated residual radioactivity; area B is 10,000 m² with contamination expected to be relatively uniform and primarily in the top few inches.

Step 2

For the scenario definition and pathway identification in step two, the licensee in this example decides to begin the decision process by using the pre-defined scenarios and pathways in the residential scenario (soil contamination) described in NUREG/CR-5512, Volume 1.

Step 3

In step three, the licensee decides to use the existing default parameters for the NUREG/CR-5512 models and to perform the analysis using the DandD software.

Step 4

For step four, the dose assessment, the licensee runs DandD using the source term developed from the information gathered in step one. This source term is the maximum reasonable value that is defensible given the existing data sources. The result of the initial dose assessment is as follows: Area A, 20 pCi/g DU, 127 mrem/y; Area B, 9.5 pCi/g DU, 60.5 mrem/y.

Step 5 / Step 8

Based on the results of step four, in step five it is clear that the site does not meet the Subpart E dose criterion of 25 mrem/yr for either area A or B. The licensee therefore proceeds to step eight and begins defining options for meeting the 10 CFR Part 20 requirements for license termination. Note that there are basically three options that the licensee can apply either alone or in combination: Option 1 - Activities that reduce uncertainty (information/data collection), Option 2 - Activities that reduce contamination (remediation), and Option 3 - Activities that reduce exposure (land-use restrictions). Table 3.1 lists some of the options that a licensee could consider, including three related to reduction of uncertainty, one related to reducing contamination, and one related to reducing exposure.

As mentioned in the Case 2 discussion, when evaluating activities that reduce uncertainty under Option 1, it is useful to begin by looking at the default parameter values and dose conversion factor datasets used in the NUREG/CR-5512 model and what they represent. The default parameter values for the NUREG/CR-5512 modeling (that have been implemented in DandD) were developed based on probability distributions representing the expected variability across the country. A probabilistic parameter analysis was performed to develop default radionuclide-specific concentrations and which also provided information regarding the valid ranges for site specific parameter changes that a licensee could propose without an additional uncertainty analysis. Therefore, the licensee needs minimal supporting information to defend changes to the parameter values that are within the limits specified in the parameter analysis. This is important in evaluating the relative worth of collecting additional data on these parameters under Step 9 of the decision framework.

For example, in evaluating the default parameter values the licensee could look at parameters which impact the water pathway, and which can easily be modified based on site-specific information. For this example, the water pathway parameters listed below were changed since easily-obtainable site-specific information was available. [Note that, as discussed in Appendix E, these parameters should be modified as a group to avoid introducing inconsistencies into the model.] The associated cost for this activity could, for example, be the cost of accessing USGS and state-sponsored sites on the Internet, or the cost of obtaining copies directly from those agencies or the library. This approach of moving away from the reasonably conservative values used in the NUREG/CR-5512 modeling based on site-specific information could be used by all sites until the point that further reduction in simulated dose would require model changes. At that point, probability distributions for the new model parameters would have to be developed and defended by the licensee.

For example, in evaluating the default dose conversion factor datasets the licensee could investigate the values for uranium and associated chain radionuclides that are used in the model. The dose conversion data set in the model is taken directly from Federal Guidance Report 11, and is based on International Commission on Radiological Protection (ICRP) Report 30. In 1994, the ICRP published report 68, which incorporates updated dosimetric information and modeling that resulted in significant changes to the dose factors for uranium and its associated chain radionuclides. While most licensees should use the ICRP 30 values during operations to avoid conflicts with current reporting requirements under 10 CFR Part 20,

licensees engaged in decommissioning activities may wish to propose the use of more recent dosimetric information and models to support the best technically defensible approach for estimating the dose from residual radioactivity. Such proposals would not conflict with current reporting requirements for operational facilities. The model output can be adjusted using the updated ingestion and inhalation (1 μm AMAD) CEDE factors in ICRP 68, based on the Table B.1 values to match as closely as possible the assumptions used in 10 CFR Part 20 (i.e. adult male workers).

Model Parameters That Will be Modified Using Site-Specific Information

H₂: Thickness of the unsaturated zone

The thickness of the unsaturated zone is used in determining radionuclide leach rates from the unsaturated zone to the saturated zone. The default distribution was developed from area-weighted data from observation wells across the U.S. Information on H₂ (also called water table depth) is readily available from state or city governments and the USGS. Data for this parameter are easily available, and licensees using deterministic modeling should use the minimum value (thinnest unsaturated zone) applicable to their site.

U_f: Ingestion rate for fish from an on-site pond

If the site does not currently support a pond or surface water source (that is or could be impacted by residual contamination from the site during the 1000 year analysis period) that contains edible fish, this parameter should be set to zero. This is equivalent to setting the pond volume to zero. (Note that, in this case, setting this parameter to zero directly eliminates the aquatic pathway.) If a pond does exist at the site, this parameter should be left at the default value.

I, f₁, f₂: Infiltration rate & saturation ratios

Infiltration rate is defined as the volume of water per unit area per unit time that percolates deeply beneath the root zone and becomes infiltration. The saturation ratio is the volume of water relative to the volume of the pore space, and also the ratio of the moisture content to the porosity. Both these parameters will vary based on regional climate characteristics and site soil texture. A full discussion of these parameters and their derivation, as well as possible information sources for site-specific values, is contained in the attached parameter definitions. Because data are easily available, and because it is not possible, *a priori*, to determine whether high or low values are more conservative, licensees using deterministic modeling should use the best estimate of the median value for their site.

IR: Irrigation water application rate

This parameter represents the annual average quantity of groundwater used to irrigate on site agricultural products. It is used, along with the area of land cultivated (A_r) to calculate the volume of water removed from the aquifer per year for irrigation. Licensees may propose changes to this parameter based on regional precipitation and regional soil moisture levels and other soil properties, and data that support alternative irrigation rates for certain forage crops or edible foods that may be supported due to prevailing dietary patterns or land use patterns. Because it is not possible, *a priori*, to determine whether high or low values are more conservative, licensees using deterministic modeling should use the best estimate of the median value for their site, based on a multi-year state-specific annual average irrigation rate

$n_1, n_2, \rho_1, \rho_2, P_s$: Porosities, soil bulk densities, and soil areal density of the surface plow layer
 Porosity is a measure of the relative pore volume in the soil and is the ratio of the volume of the voids to the total volume. Soil bulk density relates the mass of dried soil to its total volume (solids and pores together). Soil areal density of the surface plow layer is a measure of the mass of soil per square meter in the surface layer, with an assumed depth of 15 cm for the DandD model. Porosity varies with soil texture, and distributions based on the 12 Soil Conservation Service textural classifications are listed in the attached parameter descriptions. Bulk density can be defined as functionally related to porosity: Bulk density = (1 - porosity)*2.65. Soil areal density is calculated as a conversion of units from bulk density plus the 15 cm depth assumption: Areal density = 150*bulk density or Areal density = 397.5*(1 - porosity). Because it is not possible, *a priori*, to determine whether high or low values are more conservative, licensees using deterministic modeling should use the best estimate of the median value for their site, based on the site-specific soil texture.

As stated above, the options that have been identified in this iteration include three related to reduction of uncertainty. One option is related to reduction of the estimated source term, one is related to reduction of the modeled exposure through use of site-specific parameter values, and one would update the dose conversion factors. The fourth option listed in Table 3.3 would result in an actual reduction of the quantity of residual radioactivity remaining on the site. If the final option, reduction of exposure through restricted release, were pursued, the licensee would be required by 10 CFR 20, Subpart E, to demonstrate that unrestricted release was not ALARA. This would require additional site specific modeling to ensure that the decision had a sufficient basis.

Table 3.3 - Options Definition Table		
Expectation	Effect on Dose	Action
Source is believed to be a lower concentration than currently modeled	Simulated dose expected to decrease as concentrations decrease	Collect field data to better characterize source distribution
Better estimates of parameter values based on site-specific information will be less restrictive	Simulated dose expected to decrease as availability of radionuclides to the receptor is decreased	Collect literature and soil map data to defend alternative soil parameter values
Updated dosimetry is expected to reduce the estimated dose per unit intake	Simulated dose is expected to decrease based on better characterization of uranium dosimetry	Collect literature values and adjust model output
Enough soil is expected to be permanently removed to decrease source concentrations so dose level is acceptable	Actual available mass of contaminant decreases, hence simulated dose would decrease	Remediation by soil removal

Table 3.3 - Options Definition Table		
Expectation	Effect on Dose	Action
Controls are expected to remain in place for the duration of the compliance period (if controls fail, simulated doses are between 25 mrem and 100 mrem)	Restrictions will limit uses for site while controls are in place to limit exposure time and pathways to individual; simulated dose will decrease	Set land use restrictions and apply for restricted release

Step 9

The licensee now moves to step 9, analysis of options in terms of cost and the likelihood of success. To evaluate the likelihood of success, an analysis of the potential outcome (consequence analysis) will need to be performed for each of the options. Depending on the option, this consequence analysis could be very simple (e.g., the option is complete remediation and the consequence is a demonstration of compliance with the 10 CFR 20, Subpart E requirements) to as complicated as refining and expanding the dose assessment. The cost and time required to complete each option should be estimated. The consequence analysis should also address the uncertainty associated with each potential outcome. The desired endpoint is a determination of the likelihood or probability that employing a given option will result in meeting the criteria of 10 CFR 20, Subpart E.

The result of the activities performed under Step 9 is a logically organized list of options, and the corresponding cost, likelihood of site release (probability of success), and other important considerations given that the option is pursued. Table 3.4 contains examples of how the options could be organized. In some cases, the decision regarding the preferred option will be obvious, however, this may not be true for certain situations and additional analysis may be required for sites attempting to balance complex issues.

Table 3.4 - Options Analysis Table				
Alternative Action	Cost (if successful)	Cost (if unsuccessful)	Probability of Success	Required Outcome ¹
Collect field data to better characterize source distribution	\$\$	\$\$	low (A ²) medium (B ³)	dose less than 25 mrem
Collect literature data to defend alternative soil type/texture	\$	\$	low (A) medium (B)	dose less than 25 mrem
Collect literature values and adjust model output	\$	\$	medium (A) medium (B)	dose less than 25 mrem

Table 3.4 - Options Analysis Table				
Alternative Action	Cost (if successful)	Cost (if unsuccessful)	Probability of Success	Required Outcome ¹
Remediation by soil removal	\$\$\$ \$\$\$\$	\$\$\$ \$\$\$\$	high (A) high (B)	dose less than 25 mrem
Set land use restrictions and apply for restricted release ⁴				dose w/ controls less than 25 mrem; dose w/o controls less than 100 mrem

¹These assume each option is performed in isolation. If performed in combination with other options, each option on its own would not need to achieve a dose less than 25 mrem

² Area A

³ Area B

⁴ See discussion under Case 2 for an explanation of this option

To analyze the potential outcome of the selected options, the licensee can use the DandD software to perform some low cost "what-if" calculations. For example, they can review the existing information about their source term and try to estimate how it would change based on additional characterization. Based on the quality of the existing information, they may be able to modify the source term and obtain a less bounding value. This modified source term would then be input into the model and a revised dose estimate calculated.

In the same way, the licensee could review site specific or regional data to determine the predominant soil type at their site, the depth to groundwater, and average precipitation rates. Using this information, the licensee could investigate the impact of changing parameters affecting water pathways. This process can be continued for other model parameters that the licensee believes could be changed based on site-specific information. This is similar to performing an informal sensitivity analysis, and will help focus attention to those parameters likely to have the most impact on the calculation of dose. The licensee can then direct resources to reducing the uncertainty in those parameters, or can determine that a different approach is necessary before any higher cost activities, such as soil removal or site surveys, are begun.

For this example case, a preliminary evaluation of the remediation option indicates that it is not cost effective to remove the contaminated soil and transport it off site for area B, but is cost effective for area A. This preliminary analysis is based on the initial dose screening and initial bounding estimate of the source term, both of which impact the estimated soil volume requiring remediation, and the cost of remediation. These estimates will change as more site-specific data is obtained, which may make remediation a more reasonable option for area B at another point in the decommissioning process. At this point in the decision process, the idea is not to permanently eliminate options from further consideration, but rather to select the optimum approach for the current state of knowledge.

Step 9 in the decision framework should support an evaluation of the cost and time impacts of both success and failure. Assuming all options meet the regulatory requirements, in general,

low cost / high likelihood of success options, or combinations of options, are preferred. This step should also include ALARA considerations, in terms of cost/benefit calculations as well as qualitative considerations. With regard to costs, the licensee should consider that if the option(s) selected are successful, the license will be released and further costs will be minimized. However, if the selected option(s) are unsuccessful, it may be necessary to perform additional characterization or remediation, or there may need to be an evaluation of restricted use (with its associated costs).

Step 10

Once the various options have been evaluated, the preferred option can be selected in step 10. Based on the DandD analysis, quality of the survey data available for area A, and cost estimates, the licensee decides to remediate area A. This involves removal of a relatively small volume of soil that has been well characterized, and is expected to result in the area easily meeting the unrestricted release criterion. The decision to remediate in this case is based primarily on information specific to the licensee's business practices and plans related to the future use of area A. For area B, the licensee decides to perform additional characterization to obtain data on the site soil type to support revision of the parameters associated with soils and groundwater. The dose model results will also be modified by the dose factors obtained from ICRP 68. The combination of these options should have a medium cost and a high likelihood of success. At this stage in the analysis, unrestricted release is preferred, and therefore restricted release not considered further at this time.

Step 11

Under step 11, the preferred option is implemented. The contaminated soil in area A is removed and disposed of off-site. Following the remediation, a final survey is performed and documented, and a revised source term for area A is developed from the survey data. The licensee also develops a characterization plan for area B that supports the soil data requirements, then obtains regional soil maps and other data associated with the site geology and hydrology.

Step 12

Once the preferred option has been implemented, the model assumptions, parameter values, and pathways (as appropriate) are revised in step 12 of the decision process. For this example, the area A source term is revised and the area B parameter values associated with soil and groundwater are modified based on the site data and the revised dose factors are obtained. To support the future request for license termination, the site survey results, soil maps, and methods used to revise K_d and dose factors are carefully documented. Table 3.5 lists the parameters, information sources, and revised model parameter values.

Table 3.5 Revised Parameters and Supporting Information

Symbol	Parameters	Discussion
H_2	Thickness of the unsaturated zone	This example site is located in the lower Susquehanna river basin in Cumberland County near Carlisle, Pennsylvania. General information about the lower Susquehanna river basin was obtained through two web sites supported by the USGS. Information associated with the National Water-Quality Assessment Program was obtained from http://www.rvares.er.usgs.gov/nawqa/ne/lsus/lsus_factsheet.html . Depth to water information was obtained from http://www.pah2o.er.usgs.gov/gw_report/ . This site contains monthly information for observation wells in counties within the Susquehanna river basin. Each months data includes the minimum and maximum mean depth to water that has ever been recorded for the entire period that the well has been monitored. For the Cumberland county well, data have been recorded since 1951. As a first approximation, the licensee uses the minimum value that has ever been recorded for this well of 12.39 feet, or 3.78 meters.
U_f	Ingestion rate for fish from an on-site pond	This site does not support a pond, and therefore U_f is set to 0.
I, f_1, f_2	Infiltration rate & saturation ratios	A silt loam soil texture was determined to be representative of the top 20 cm of soil in the study area, based on information was obtained from the STATSGO data set. Based on Table 1 in the attached parameter discussion for infiltration rate, the mean saturated hydraulic conductivity (K_{sat}) is 9.33E-05 cm/s. This is equivalent to an infiltration fraction of about 6%. Infiltration is estimated as follows: $I = AR \cdot IF$, where AR is the application rate (precipitation plus irrigation) and IF is infiltration fraction. However, the infiltration rate used in the calculations is the lesser of the calculated rate and the saturated hydraulic conductivity. In this case, the calculated value for I is 3.0 in/y, compared to a K_{sat} of 1.16E3 in/y. Therefore, I is <u>3.0 in/y</u> .

Table 3.5 Revised Parameters and Supporting Information		
Symbol	Parameters	Discussion
IR	Irrigation water application rate	Mean annual precipitation ranges from 38 to 44 inches in the lower Susquehanna river basin (with 41 inches used as the best estimate for calculating infiltration). Based on the 1992 Census of Agriculture, the average acre-feet/y of water applied from wells for the Mid-Atlantic water resource area was 0.73. This is equivalent to an irrigation rate of 1.37 acre-feet per acre, or <u>1.14 L/m²/d</u> . Irrigation information obtained from the 1992 Census of Agriculture was downloaded from http://www.census.gov/ftp/pub/prod/1/agr/92fris/
$n_1, n_2, \rho_1, \rho_2, P_s$	Porosities, soil bulk densities, and soil areal density of the surface plow layer	Porosity was obtained for the study area from the STATSGO data set, and has been set to <u>0.51</u> . Bulk density = $(1 - \text{porosity}) * 2.65 = \underline{1.30 \text{ g/cm}^3}$. Soil areal density = $397.5 * (1 - \text{porosity}) = \underline{195 \text{ kg/m}^2}$.
DCFs for U238, U235, U234	ICRP 68 dose conversion factors	Since 99% of the dose is from ingestion, the TEDE results from the model are modified by the ratio of the ICRP 68 ingestion factor to the ICRP 30 ingestion factor. ICRP 30 and ICRP 68 ingestion factors are as follows (Sv/Bq): U238: 6.88E-8, 4.4E-8 U235: 7.19E-8, 4.6E-8 U234: 7.66E-8, 4.9E-8

Second Iteration, Step 4

The revised source term and parameter values are used in iteration 2 of the dose assessment in step 4. In this example, the licensee decides to leave the original default model assumptions and pathways unchanged, and continues to use the DandD software. [Note that in other more complicated situations a licensee might seek to modify these assumptions and pathways. For example, if the groundwater pathway was more complex than could be handled by DandD, especially if the licensee needed to account for real transport or needed to better characterize the actual aquifer, a more complex groundwater model could be substituted within DandD. A detailed submittal discussing such changes would need to be developed]. When the revised parameter values are input into the model, the result following remediation for area A (for 2 pCi/g) is less than 5 mrem/y, and for area B (for 9.5 pCi/g) the dose is less than 25 mrem/y.

Second Iteration, Step 5 & Step 6

This brings the licensee back to step 5 and the question regarding whether the site can be released. Since the dose assessment result is less than or equal to 25 mrem/y, and the licensee can move on to consider any remaining survey and ALARA requirements. The

licensee can document that best practice procedures were applied as part of its operational program. ALARA was incorporated and documented in the options definition (step 8), analysis of options (step 9), and selection of the preferred option (step 10).

Step 7

Based on the above, the license can be terminated and the site released. The licensee submits all required forms, including NRC Form 314, and documentation of the decision process, and the site is released for unrestricted use.