6 COMPLIANCE WITH THE RADIOLOGICAL CRITERIA FOR LICENSE TERMINATION

Note: Following the April 15, 2003, meeting on dose modeling, RESRAD dose model computer runs* in support of development of the site derived concentration guideline levels (DCGLs) for soil were submitted for preliminary review. Subsequent discussions with NRC Staff reviewers have resulted in substantive modifications to these calculations. These modifications are in progress and, as previously discussed with the Staff, Section 6 of the LTP will be updated with the final dose modeling computer results and input parameters once our ongoing discussions and NRC review relative to these calculations are complete. We also expect to submit the RESRAD-BUILD dose modeling runs by the end of the year. Modeling for volumetric concrete DCGLs has also been initiated and will be submitted in early 2004.

6.1 Site Release Criteria

6.1.1 Radiological Criteria for Unrestricted Use

The site release criteria for the Yankee Nuclear Power Station (YNPS) site are the NRC's radiological criteria for unrestricted use given in 10 CFR 20.1402 (Reference 6-1):

- <u>Dose Criterion:</u> 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/year, including that from groundwater sources; and

- <u>ALARA Criterion:</u> The residual radioactivity has been reduced to levels that are as low as reasonably achievable (ALARA).

6.1.2 Conditions Satisfying the Site Release Criteria

Levels of residual radioactivity that correspond to the allowable radiation dose and ALARA levels described above are calculated by analysis of various scenarios and pathways (e.g., direct radiation, inhalation, ingestion) through which exposures could be reasonably expected to occur. LTP Section 2.3.2 discusses the radionuclides for which derived concentration guideline levels (DCGLs) must be calculated. These DCGLs form the basis for the following conditions which, when met, satisfy the site release criteria as prescribed in 10 CFR 20.1402:

- The average residual radioactivity above background is less than or equal to the DCGL.

- Individual measurements representing small areas of residual radioactivity that exceed the DCGL, do not exceed the elevated measurement comparison DCGL. The elevated measurement comparison DCGL ($DCGL_{EMC}$) is described in Section 5.4.6.3.

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* YAEC Letter to USNRC, "Calculations for License Termination Plan (LTP) Development," dated June 20, 2003, BYR 2003-052.

- Where one or more individual measurements exceed the DCGL, the average residual radioactivity passes the Wilcoxon Rank Sum (WRS) or Sign statistical test. (See Section 5.7.1 and 5.7.2 for a detailed discussion on application of statistical tests).

- Remediation is performed where ALARA considerations are warranted to reduce the levels of residual radioactivity to below those concentrations necessary to meet the DCGLs. (See Section 4 and Appendix 4.A for detailed discussions of ALARA considerations).

The methods in MARSSIM (Reference 6-2) and the DCGLs may not be appropriate for non-structural components (such as conduit and piping). For those non-structural components and systems to which MARSSIM does not apply, the current “no detectable” criteria (consistent with IEC 81-07) will be applied to free release these items.

6.2 Dose Modeling Approach

6.2.1 Overview

Dose models were developed, which translate levels of residual radioactivity into potential radiation doses to the public. Dose models, appropriate to the YNPS site, are based on the guidance found in NUREG-1549 (Reference 6-3) and NUREG/CR-5512, Volumes 1, 2, and 3 (Reference 6-4). A conceptual model was based on the site conditions expected at the time of unrestricted release. Conditions at the YNPS site, such as potential soil contamination greater than 15 cm below the soil surface, require that site-specific dose modeling be performed. The dose modeling approach taken for the YNPS site is consistent with the information provided in Section 5 and Appendix I of NUREG-1757 (Reference 6-5) for-site specific modeling, including the information regarding source term abstraction and scenarios, pathways, and critical groups.

The dose model is defined by three factors: 1) the scenario, 2) the critical group and 3) the exposure pathways. The scenarios described in NUREG/CR-5512, Volume 1, address the major exposure pathways of direct exposure to penetrating radiation and inhalation and ingestion of radioactive materials. The scenarios also identify the critical group, which is the group of individuals reasonably expected to receive the greatest exposure to residual radioactivity within the assumptions of the particular scenario. The scenarios and their modeling are specifically designed to be reasonably conservative by generally overestimating rather than underestimating potential dose.

The approach outlined above was used to develop dose models to calculate DCGLs for soil and concrete. It should be noted that the scenarios described in NUREG/CR-5512, Volume 1, were developed to estimate potential radiation doses from radioactive material in buildings (building occupancy scenario) and soil.

6.2.2 Resident Farmer Scenario

6.2.2.1 Scenario Definition

The resident farmer scenario, described as the "Residential Scenario" in NUREG/CR-5512, Volume 1, was selected to conservatively estimate human radiation exposures resulting from residual radioactivity in soil to determine corresponding DCGLs.

6.2.2.2 Critical Group

The average member of the critical group was determined to be the resident farmer who lives on the plant site following decommissioning, grows all or a portion of his/her diet on site, and uses the water from a groundwater source on the site for drinking water and irrigation. The dose from residual radioactivity in soil is evaluated for the average member of the critical group as required by 10 CFR Part 20, Subpart E, and described in NUREG -1757, Appendix I, and NUREG-1549.

It is unlikely that any other set of plausible human activities could occur onsite that would result in a dose exceeding that calculated for the hypothetical resident farmer. It is more likely that the behavior of future occupants would result in a lower dose. For example, it is more likely that the YNPS site will be reused for land conservation. The hypothetical dose from the soil to an individual in these settings would be less than for a resident farmer, since the receptor would not ingest food derived from onsite. Therefore, the use of the resident farmer as the average member of the critical group is both conservative and bounding for the calculation of soil DCGLs.

6.2.2.3 Exposure Pathways

The potential exposure pathways that apply to the resident farmer are listed below and are based upon those in NUREG/CR-5512, Volume 1:

- Direct exposure to external radiation from residual radioactivity;
- Internal dose from inhalation of airborne radionuclides; and
- Internal dose from ingestion of
    - Plant foods grown in media containing residual radioactivity and irrigated with water containing residual radioactivity,
    - Meat and milk from livestock fed with fodder grown in soil containing residual radioactivity and water containing residual radioactivity,
    - Drinking water (containing residual radioactivity) from a well,
    - Fish from a pond containing residual radioactivity, and
    - Soil containing residual radioactivity.

6.2.3 Building Occupancy Scenario

6.2.3.1 Scenario Definition

The building occupancy scenario, based upon NUREG/CR-5512, Volume 1, was selected to estimate human radiation exposure resulting from residual radioactivity in concrete from standing buildings and to determine corresponding DCGLs.

6.2.3.2 Critical Group

Given the fact that the buildings associated with the YNPS site are commercial, the average member of the critical group is an adult engaging in light industrial work within the buildings following decommissioning of the site. The person occupies a commercial facility in a normal manner without deliberately disturbing sources of residual radioactivity. The dose from residual radioactivity in the concrete from the standing building is evaluated for the average member of the critical group as required by 10 CFR Part 20, Subpart E, and described in NUREG -1757, Appendix I.

6.2.3.3 Exposure Pathways

The potential exposure pathways, described in NUREG/CR-5512, Volume 1, are listed below:

- Direct exposure to external radiation from
  - Material deposited on the walls
  - Material deposited on the floor
  - Submersion in airborne dust
- Internal dose from inhalation of airborne radionuclides
- Internal dose from inadvertent ingestion of radionuclides

6.2.4 Code Selection

The RESRAD Family of Codes has been selected for use at YNPS. The RESRAD computer codes are pathway-analysis models developed at Argonne National Laboratory (ANL). This family of computer codes includes RESRAD, used to analyze pathways associated with soil, and RESRAD-BUILD, used to analyze pathways associated with buildings.

The RESRAD computer code (Version 6.21) was used in this analysis to consider three major exposure pathways to a resident farmer from residual radioactivity:

- Direct exposure to external radiation from soil containing residual radioactivity;
- Internal exposure from inhalation of airborne radionuclides; and
- Internal exposure from ingestion of radionuclides.

The RESRAD-BUILD computer code (Version 3.21) is used in this analysis to consider five exposure pathways to occupants of a building from residual radioactivity:

- External exposure directly from the sources;
- External exposure to material deposited on the floor;
- External exposure due to air submersion;
- Inhalation of airborne radioactive particulates; and
- Inadvertent ingestion of radioactive material directly from the sources.

Information on the use of these codes and their applications are outlined in NUREG/CRs-6676, -6692, -6697, -6755 (References 6-6, 6-7, 6-8 and 6-9) and the "Users Manual for RESRAD, Version 6-0" (Reference 6-10).

6.2.5 Input Parameter Selection Process

The dose and conceptual models are quantified by a set of input parameters. Incorporated within RESRAD Version 6.21 and RESRAD-BUILD Version 3.21 are probabilistic modules that allow the evaluation of dose as a function of parameter distributions. A schematic flow diagram of the parameter selection process is provided in Figure 6-1. Each step of the selection process is discussed below.

6.2.5.1 Classification (Type):

The input parameters were classified as behavioral, metabolic or physical, consistent with NUREG/CR-6697. Behavioral parameters depend on the behavior of the receptor and the scenario definition. Metabolic parameters represent the metabolic characteristics of the receptor and are independent of the scenario definition. Physical parameters are the parameters that would not change if a different group of receptors were considered.

6.2.5.2 Prioritization

The parameters were prioritized in order of importance consistent with NUREG/CR-6697. Prioritization was based on:

- The relevance of the parameter in dose calculations,
- The variability of the dose as a result of changes in the parameter value,
- The parameter type and
- The availability of parameter-specific data.

Priority 1 parameters are considered to be high priority; priority 2 parameters are considered to be medium priority; and priority 3 parameters are considered to be low priority.

6.2.5.3 Treatment

The parameters were treated as either "deterministic" or "stochastic" depending on parameter type, priority, availability of site-specific data and the relevance of the parameter in dose calculations. The "deterministic" modules of the code use a single value for input parameters and generate a single value for dose. The "probabilistic" modules of the code use probability distributions for stochastic input parameters and generate a range of doses.

The behavioral and metabolic parameters are treated as deterministic and were assigned values from NUREG/CR-5512, Volume 3, NUREG/CR-6697, or the applicable code's default library. Physical parameters for which site-specific data are available are also treated as deterministic.

The remaining physical parameters, for which no site-specific data are available to quantify, are classified as either Priority 1, 2, or 3. Priority 1 and 2 parameters are treated as stochastic and are assigned a probability distribution from NUREG/CR-6697. The priority 3 physical parameters are treated as deterministic and are assigned values from NUREG/CR-5512, Volume 3, NUREG/CR-6697, or the applicable code's default library.

6.2.5.4 Sensitivity Analyses

In order to determine the values for the remaining input parameters, a sensitivity analysis was performed to determine which of the stochastic parameters have an influence on the resulting dose and associated DCGLs. The analysis was performed using the probabilistic modules of RESRAD, Version 6.21, and RESRAD-BUILD, Version 3.21.

The stochastic parameters, as identified in the preceding paragraphs, were generally assigned distribution types and corresponding distribution statistical parameters from NUREG/CR-6697, Attachment C. Sensitivity analyses were performed on the stochastic parameters using the assigned distributions. To perform the sensitivity analysis, the following information was required:

Sample Specifications: The analyses were run using 2000 observations for soils, 300 observations for building occupancy and 1 repetition for both scenarios. The Latin Hypercube Sampling (LHS) technique was used to sample the probability distributions for each of the stochastic input parameters. The correlated or uncorrelated grouping option was used to preserve the prescribed correlations

Input Rank Correlations: Correlation coefficients were assigned between correlated parameters.

Output Specifications: All of the output options were specified.

Sensitivity analyses were performed for each of the radionuclides. The Partial Rank Correlation Coefficient (PRCC) for the peak of the mean dose was used as a measure of the sensitivity of each parameter.

For the resident farmer scenario, a parameter was identified as sensitive if the absolute value of its PRCC (|PRCC|) was greater than or equal to 0.25 and non-sensitive if the |PRCC| value was less than 0.25. For the building occupancy scenario, a parameter was identified as sensitive if the |PRCC| value was greater than or equal to 0.10 and non-sensitive if the |PRCC| value was less than 0.10. These thresholds (So) were selected based on the guidance included in NUREG/CR-6676 and -6692.

6.2.5.5 Parameter Value Assignment for DCGL Determination

As previously discussed, behavioral and metabolic parameters were assigned values from NUREG/CR-5512 Volume 3, NUREG/CR-6697, or NUREG/CR-6755. If site data was available for physical parameters, that information was used. For Priority 3 physical parameters for which no site data was available, values from NUREG/CR-5512 Volume 3, or NUREG/CR-6697 were used.

Priority 1 and 2 physical parameters were assigned values as follows:

- Priority 1 and 2 physical parameters shown to be sensitive (|PRCC| ≥ So) were assigned conservative values:
  - A site-specific distribution or value, or
  - Depending on whether the parameter was positively or negatively correlated with dose, the 75% or 25% quantile value of the distribution was used, respectively.
  - For distributions where the mean value is greater than the 75% value, the mean value was used.

- Priority 1 and 2 physical parameters shown to be non-sensitive (|PRCC| < So) were assigned:

  - A distribution or site-specific value, or
  - The median value

6.2.6 Code Output and Calculation of DCGL

RESRAD determines an annual peak of the mean dose in mrem/yr, and RESRAD-BUILD determines an average annual dose at the time of the peak dose in mrem/yr. Specifying a unit radionuclide concentration (i.e., 1 pCi/g in RESRAD or 1 pCi/m^2 in RESRAD-BUILD), to be used in conjunction with the parameters selected by the process described previously, a dose conversion factor (DCF) is calculated by the code (in mrem/yr per pCi/g for RESRAD and mrem/yr per pCi/m^2 for RESRAD-BUILD). As suggested in NUREG-1757, DCFs, based upon the peak of the mean dose, were used to calculate the corresponding derived concentration guideline levels (DCGLs) in pCi/g or dpm/100cm^2, representing an annual dose of 25 mrem/yr, using the following equations:

$$\text{DCGL (pCi/g)} = \frac{25 \text{ mrem/yr}}{\text{DCF (mrem/yr / pCi/g)}} \qquad \text{(Equation 6-1)}$$

or

$$\text{DCGL (pCi/m}^2) = \frac{25\ \text{mrem/yr}}{\text{DCF (mrem/yr / pCi/m}^2)}$$ (Equation 6-2)

$$\text{DCGL (dpm/cm}^2) = \text{DCGL (pCi/m}^2) \times (0.037\ \text{dps/pCi}) \times (60\ \text{sec/min}) \times (\text{m/100cm})^2$$ (Equation 6-3)

$$\text{DCGL (dpm/100cm}^2) = \text{DCGL (pCi/m}^2) \times (0.037\ \text{dps/pCi}) \times (60\ \text{sec/min}) \times (\text{m/100cm})^2 \text{ x } 100$$ (Equation 6-4)

6.3 Calculation of DCGLs for Soil

6.3.1 Dose Model

The DCGLs for soil were calculated using the resident farmer scenario. The residual radioactive materials were assumed to be contained in a soil layer on the property that can be used for residential and light farming activities. The average member of the critical group is the resident farmer that lives on the plant site, grows all of his/her diet onsite and drinks water from a groundwater source onsite. The pathways used in this analysis are identified in Section 6.2.2.3.

6.3.2 Conceptual Model

The conceptual model used in the code was based on the site characteristics expected at the time of release of the site. The model is comprised of a contaminated zone underlain by an unsaturated zone underlain by a saturated zone. The contaminated zone is assumed to be at the ground surface with no cover material and the ground water is initially uncontaminated. The model as described is consistent with that described by Yu et al (Reference 6-10). The parameters used to quantify the conceptual model are listed in Appendix 6-A.

6.3.3 Parameter Value Assignment

The process described in Section 6.2.5 was used to determine the parameter input values or distributions. The evaluation of site/regional data and the justification of values assigned to the site-specific parameters that comprise the conceptual model are provided in Appendix 6-A. The values/distributions assigned to all parameters for the sensitivity analyses and the basis for assigning such values/distributions are summarized in Appendix 6.B.

6.3.4 DCGL Determination

The input values assigned to sensitive and non-sensitive parameters for the DCGL runs were based on the process described in Section 6.2.5.5 in conjunction with the sensitivity analysis

results presented in Appendix 6-C. The DCGL determination was performed using RESRAD version 6.21 analyses with the input values summarized in Appendix 6-D.

The resulting DCFs, based upon the peak of the mean dose, are provided in Appendix 6-E. The DCGLs determined using Equation 6-1 are also provided in Appendix 6-E.

6.4 Calculation of DCGL for Structures

6.4.1 Surface Contamination

6.4.1.1 Dose Model

The dose model used to calculate the surface DCGLs is based upon the building occupancy scenario as defined in NUREG/CR-5512, Volumes 1, 2, and 3 and NUREG-1757. The scenario assumes that the critical group consists of light industrial workers working in the building following license termination. The pathways used in this analysis are those identified in Section 6.2.3.3.

6.4.1.2 Conceptual Model

The conceptual model was developed based on site characteristics expected at the time of license termination. The model is comprised of a room, with dimensions representing the average wall size expected to remain at the site. The four walls and floor of this room are assumed to be contaminated uniformly and to equal levels. This is considered to be a conservative assumption as normally the amount of contamination on room walls is less than that on the floor and decreases as the distance from the floor increases. No contaminated ceiling is included in the model, as partial rooms/rooms remaining at the time of license termination will either have no ceiling or will be covered with a ceiling constructed of new (uncontaminated) materials. Appendix 6-D provides the details for the determination of the room dimensions.

6.4.1.3 Parameter Value Assignment

The process described in Section 6.2.5 was used to determine the parameter input values or distributions. The evaluation of site/regional data and the justification of values assigned to the site-specific parameters that comprise the conceptual model are provided in Appendix 6-F. The values/distributions assigned to all parameters for the sensitivity analyses and the basis for assigning such values/distributions is summarized in Appendix 6-G. Preliminary runs were performed prior to the sensitivity analyses to determine the time in which the maximum dose occurred.

6.4.1.4 DCGL Determination

The input values assigned to sensitive and non-sensitive parameters for the DCGL runs were based on the process described in Section 6.2.5.5 in conjunction with the sensitivity analysis results presented in Appendix 6-H. The DCGL determination was performed using RESRAD-BUILD version 3.21 analyses with the input values summarized in Appendix 6-I.

The resulting DCFs, based upon the average dose during the year that the maximum dose occurs, are provided in Appendix 6-J. The DCGLs determined using Equation 6-2 through 6-4 are also provided in Appendix 6-J.

6.4.2 Volumetric Concrete Contamination

Two options under consideration for calculating volumetric DCGLs for contamination in concrete are:

- a modified resident farmer scenario using RESRAD, which assumes an instantaneous release of radioactivity from the concrete and

- a modified resident farmer scenario using RESRAD, which uses a diffusion based release rate of radionuclides from the concrete.

Once a decision has been made on the option to be pursued, YAEC will update Section 6.4.2 to provide the details of the methodology and the calculation.

6.5 Calculation of Area Factors

Area factors are required for both soil DCGLs and building surface DCGLs. First, the total doses from all pathways are calculated for each radionuclide and for each area of contamination. Doses relative to the base case contaminated area are then calculated. Finally, area factors are calculated for each radionuclide, which are the reciprocals of the relative doses.

6.5.1 Calculation of Area Factors for the Soils

Area factors for the resident farmer are calculated using the RESRAD 6.21 computer code with input parameters used in the original soils analysis and a unit activity of 1 pCi/g. As the area decreases, the set of ingestion pathway input parameters referred to as Contamination Fractions also decreases, using the equation in Reference 6-10. A Contamination Fraction indicates the fraction of a person's total diet that is obtained from the contaminated area. As the contaminated area decreases below a certain size, it is reasonable to assume that the fraction of the person's total diet from the contaminated area will also decrease proportionately. The RESRAD Contamination Fractions are listed below:

- Fraction of Drinking Water from the Site (FDW)
- Fraction of Household Water from the Site (FHHW)

- Fraction of Livestock Water from the Site (FLW)
- Fraction of Irrigation Water from the Site (FIRW)
- Fraction of Aquatic Food from the Site (FR9)
- Fraction of Plant Food from the Site (FPLANT)
- Fraction of Meat from the Site (FMEAT)
- Fraction of Milk from the Site (FMILK)

Equation D.5 of the RESRAD User's Manual varies the Contamination Fraction for plant food as follows:

$FA=A/2000$, where $0 \leq A \leq 1000\ m^2$
$FA=0.5$, where $A > 1000\ m^2$

Since the $DCGL_w$s were calculated using a conservative value for FA of 1.0, Equation D.5 is multiplied by a factor of 2.0 to yield the contamination fraction of 1.0 at an area of 1000 m^2 (or larger) for plants. Values of the multiplier are listed in Appendix 6-K as a function of the size of the contaminated zone. The same values are conservatively assigned to the contaminated fractions for drinking water, livestock water, irrigation water, and aquatic food.

The values for meat and milk are smaller and are derived below:

$FA=A/20{,}000\ m^2$, where $0 \leq A \leq 20{,}000\ m^2$
$FA=1$, where $A > 20{,}000\ m^2$

Since the $DCGL_w$s were calculated using a conservative value for FA of 1.0, Equation D.5 is adjusted upward by applying the ratio of 20,000 m^2/13022 m^2 (the area assumed for the contaminated area in the soils analyses) or 1.54. Values are listed in Appendix 6-K as a function of the area of the contaminated zone.

The fraction of household water remains set at 1.0 for all sizes of contaminated zones, which is consistent with the RESRAD code input screen that does not allow deviation from the default value of 1.0.

The total doses corresponding to the various areas of the contaminated zone are calculated using the input parameter values listed in Appendix 6-K. Appendix 6.L summarizes the total dose by radionuclide and area. The doses are normalized to the dose for 13022 m^2. Appendix 6.L also provides area factors by contaminated zone area.

6.5.2 Calculation of Area Factors for the Building Surfaces

For the building occupancy scenario, a somewhat different approach is used to compute the area factors used to establish the $DCGL_{EMC}$. While the $DCGL_w$ is the average concentration over the entire survey unit, the $DCGL_{EMC}$ should reflect the exposure an occupant would receive from an area of elevated activity having dimensions that are much smaller than the total interior area of the room. The total surface area of contaminated sources for the base case is 82.03 m^2, which includes the floor and four walls. For areas that are comparable to that for the room as a whole, evaluation against the $DCGL_w$ is appropriate.

The total doses for various areas of the contaminated source are calculated using RESRAD-BUILD. The model used in RESRAD-BUILD is similar to that used in the model for calculating building occupancy $DCGL_w$s. However, only one source is modeled herein, instead of the five sources considered in calculating the building occupancy $DCGL_w$s. The receptor is located at the source midpoint at a distance of 1 m away. All other input parameters are the same as in the building occupancy $DCGL_w$ calculation and are presented in Appendix 6-M.

Appendix 6-N presents the total and relative doses and radionuclide-specific area factors, which are the reciprocals of the relative doses.

6.6 References

6-1 Code of Federal Regulations, Title 10, Section 20.1402, "Radiological Criteria for Unrestricted Uses."

6-2 NUREG-1575, "Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)," dated December 1997.

6-3 NUREG-1549, "Decision Methods for Dose Assessment to Comply with Radiological Criteria for License Termination," dated July 1998.

6-4 NUREG/CR-5512, "Residual Radioactivity from Contamination"
Volume 1: "Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent," dated October 1992.
Volume 2: "User's Manual DandD Version 2.1," dated April 2001
Volume 3: "Parameter Analysis, Draft Report for Comment," dated October 1999.

6-5 NUREG-1757, "Consolidated NMSS Decommissioning Guidance," dated September 2003.

6-6 NUREG/CR-6676, "Probabilistic Dose Analysis Using Parameter Distributions Developed for RESRAD and RESRAD-BUILD Codes," dated May 2000.

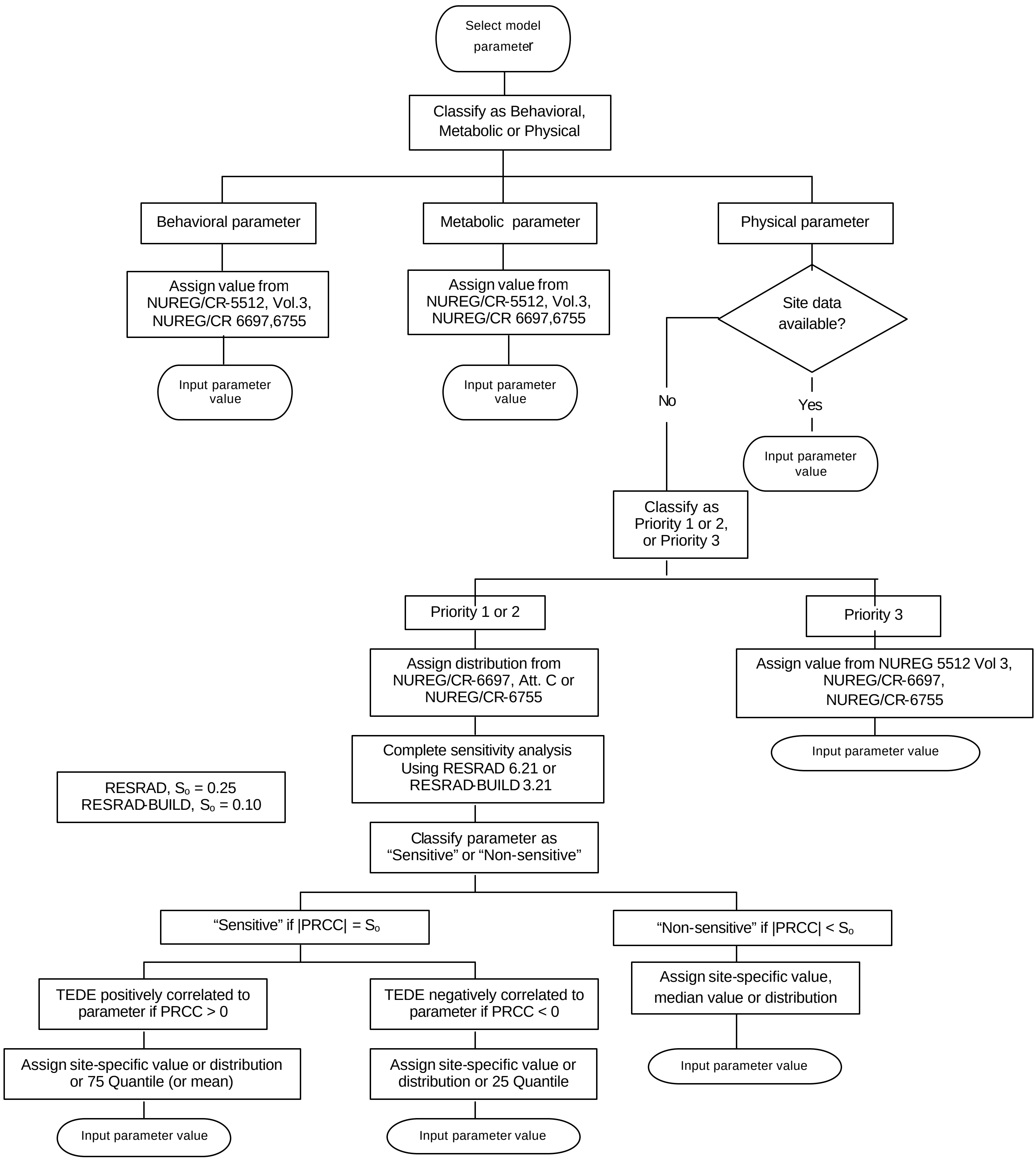
6-7 NUREG/CR-6692, "Probabilistic Modules for the RESRAD and RESRAD-BUILD Computer Codes," dated November 2000.

6-8 NUREG/CR-6697, "Development of Probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes, dated November 2000.

6-9 NUREG/CR-6755, "Technical Basis for Calculating Radiation Doses for the Building Occupancy Scenario Using the Probabilistic RESRAD-BUILD 3.0 Code," February 2002.

6-10 ANL/EAD-4, "Users Manual for RESRAD Version 6.0," Yu, C. et al., dated July 2001.

Figure 6-1
Parameter Selection Process



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