June 13, 2002

LICENSEES: Saxton Nuclear Experimental Corporation (SNEC) and GPU Nuclear, Inc. (GPU)

FACILITY: Saxton Nuclear Experimental Facility (SNEF)

SUBJECT: SUMMARY OF MEETING BETWEEN THE SNEC, GPU AND NRC STAFFS

On May 22, 2002, representatives of the NRC staff met at NRC Headquarters in Rockville, Maryland, with representatives of the SNEC and GPU, the licensees for the SNEF. Attachment one is a list of meeting attendees. Attachment two are the slides used by the licensees during the meeting. Attachment three is a report entitled "Preliminary Guidelines for Evaluating Dose Assessments in Support of Decommissioning," attachment four is a report entitled "Use of Two-Stage or Double Sampling in Final Status Decommissioning Surveys," and attachment five is an example table of MARSSIM Classifications which were given to the licensees by the NRC staff during the meeting.

The plant was operated between 1962 and 1972, and it was shut down in May 1972. In February 1975, the plant was placed in SAFSTOR until 1986, when phased dismantlement began with the removal of the support buildings, contaminated soil, and some materials in the containment. The licensees' decommissioning plan became the Post-Shutdown Decommissioning Activities Report. The resubmitted License Termination Plan (LTP) was accepted for detailed technical review in March 2000.

Technical review of the LTP has generated requests for additional information (RAI). This meeting was scheduled to discuss (1) NRC staff review of information that the licensees presented to the NRC in their response to RAI3 (RAI dated January 17, 2001, from the NRC), (2) NRC staff review of additional characterization data provided by the licensees, and (3) issues from continuing NRC staff review of the LTP. Discussion topics for the meeting were forwarded to the licensees in a letter from the NRC dated May 13, 2002 (ADAMS accession no. ML021290289). The discussions with the licensees' technical staff and consultants provided clarification and a better understanding of the site specific technical data and related information.

The licensees indicated that water samples taken from the angle well under the containment vessel (CV) were sent to an outside lab for analysis. The lab results should be available for NRC review around the end of June. The licensees stated that more than 900 subsurface soil and water samples were taken during the CV anchoring project and from wells located around the CV. Based on the current sample data and the licensees' expectation that the outside lab results will also show that no contamination is present, the licensees intend to classify the area under the CV as non-impacted. The NRC staff agreed to provide feedback to the licensees on the format for presenting this data in the LTP.

The licensees indicated that more than 10,000 samples (including about 400 samples analyzed at off-site laboratories) of various media have been analyzed during the decommission process. In general, other than within the CV, there have been no positive hits for transuranics (TRUs), even in areas where Cs-137 was present in high concentrations. Such sample data shows TRUs present at background levels. For example, the licensees explained that some soil samples from near the CV had 500 to 600 pCi/g of Cs-137 and no detectable TRU, indicative that TRU did not transport out from the CV liner to the surrounding soil. The licensees provided a table of TRU/hard to detect nuclide (HTDN) data for 1994 through 2002. The NRC staff asked the licensees to revise the table to include clarifying footnotes (e.g., state analytical techniques used and other radionuclides analyzed but not listed). Also, the licensees will revise the table to cross reference the data to those sample locations denoted previously in the LTP figures. The licensees stated that additional data from 1996 to 1999 was previously sent to NRC. The NRC staff agreed to provide guidance to the licensees on how the TRU/HTDN data should be presented in the LTP.

The licensees stated that concrete debris inside the CV from the current demolition process has yet to be removed. All debris now sits at the bottom of the CV. The licensees informed the NRC staff that characterization data for the inner CV surface will likely not be available prior to LTP approval. The licensees also stated that the radionuclides assessed during the final status survey (FSS) for the inner CV surface will be the suite derived from concrete in the CV spent fuel pool. All areas of CV liner will be cleaned prior to FSS. The licensees estimates that 50 m^2 of the CV liner is potentially activated; this is less than 5 percent of the total CV surface area. The LTP will be revised to describe the licensees' survey process for identifying activated areas.

The licensees have yet to decide on the method by which the steel supports will be attached to the inside of the CV. The supports may be welded in place or simply held in place by tension. In the latter case, the supports could be removed during the FSS to reveal any hidden surfaces for radionuclide evaluation. The licensees agreed to revise the LTP to describe the characterization process and FSS design for all survey units involving the steel supports. The licensees indicated that steel supports had already been welded to the outside of the CV. The LTP will also be revised to denote all survey units that include the outer steel supports and discuss the design of the FSS.

The licensees agreed to review, and clarify as appropriate, the LTP discussion on FSS design for survey units. The licensees also agreed to include a commitment in the LTP that boundaries and characterization data specific to each survey unit would be included in the design package for the corresponding FSS. The NRC staff provided the licensees with example formats for presenting this information. Consequently, the NRC staff agreed that the format of Table 5-2 "Initial Classifications of Site Areas," was acceptable. However, the licensees indicated that the table would be revised to include a numeric value for each survey area, in addition to the current text designation, in order to facilitate reference to a FSS package.

The licensees informed the NRC staff that the most conservative ratio representing the radionulcide mix for an area will be used for those survey units where TRUs and/or HDTNs are present at MDA during the FSS. (Generally, the most conservative ratio is established during the characterization process.) In such cases, the licensees do not intend to follow the

MARSSIM method to assess 10 percent of the FSS samples for all radionuclides in a survey unit. The LTP will be revised to reflect this decision.

The licensees explained that during the decommissioning process, all surfaces had been coin smeared to assess the presence of removable alpha contamination. Based on these results, the licensees determined that beta/gamma contamination is the predominant concern.

The NRC staff agreed that for the characterization data currently in the LTP for which no uncertainty was provided, the LTP did not need to be revised to include such information. Regarding the addition of new characterization data, a similar procedure could be followed, unless the NRC staff requested that specific data include uncertainties.

The licensees agreed to revise the LTP to describe the FSS design for residual material in subsurface soils. In addition, the licensees indicated that background determinations for survey units were still ongoing as part of the survey unit design process. New text regarding this issue will be added to the LTP. The NRC staff indicated that this would be an area of focus during in-process inspections.

The NRC staff indicated that the descriptive text currently in the LTP concerning the content of the FSS report was not adequate. The NRC staff explained that NUREG-1727 included appropriate guidance on the content of the FSS report. The NRC staff agreed to cooperate with the licensees as they revise the LTP to describe the content of the FSS report.

The licensees agreed to delete all text in Chapter 5 referring to the collection of additional samples prior to any statistical analysis. The method as described in the LTP contradicted the MARSSIM guidance. Instead, the NRC staff provided the licensees with a letter report that describes an acceptable method for taking additional samples. This option will be described in the LTP if the licensees choose to use it. The NRC staff asked the licensees to indicate in the LTP potential survey units where this option would be used.

The NRC staff asked the licensees to revise the LTP to explain the methods to be used to prevent recontamination of the lower half of the CV liner during the removal of the CV dome. The licensees agreed to do such. However, the licensees stated that this information may not be available until after LTP approval. The NRC staff responded that in such case, this would then be an in-process inspection item.

The licensees indicated that although Table 5-5, “Survey Design Summary,” indicates less than 100 percent scan coverage for land areas not designated as Class 1, the licensees intend to conduct 100 percent scan of such areas.

In addition, the licensees agreed to the following LTP revisions:

> Include in Section 1 of the LTP, a list of LTP changes that would require NRC approval by a license amendment. (The NRC staff will provide the licensees with the appropriate list.)
>
> Sections 3 and 4 of the LTP will be revised, as appropriate, to reflect the removal of the concrete from the inside of the CV liner.

Figure 5-1 will be revised to show the storm drain system.

Figure(s) specific to the discharge canal will be revised such that the sampling locations specified in the corresponding characterization tables are readily identified.

Tables 2.3a, 2.3b, and 2.6a will be revised to clarify sample type descriptions (e.g., scrap samples) and corresponding footnotes added as appropriate.

The discussion in Section 5.4.4.2 on the adequacy of a background reference will be revised to reflect the guidance in NUREG-1727, Appendix E.

A letter with additional LTP text clarifications and/or deletions that the NRC staff would like to discuss with the licensee would be sent to the licensees prior to the next meeting scheduled for June 21, 2002. The NRC staff indicated that reclassification of a survey unit was one such topic for discussion.

/RA/

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Docket No. 50-146

Attachments: As stated

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MEETING BETWEEN THE NRC STAFF AND
THE SAXTON EXPERIMENTAL CORPORATION

May 22, 2002

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Attachment 1

Preliminary Guidelines for Evaluating Dose Assessments in Support of Decommissioning

Introduction

The purpose of this guideline is to provide a consistent approach for staff to evaluate dose assessments conducted to demonstrate compliance with the current license termination rule (LTR). Staff is currently developing a standard review plan (SRP) for decommissioning that will include guidance on evaluating dose assessments used to demonstrate compliance with the LTR. This interim guideline along with draft Regulatory Guide DG4006 issued August 1998 can be used by staff who are currently working on decommissioning case work involving dose assessments while the SRP is being developed. This preliminary guideline is designed to not only provide a consistent approach to reviewing dose assessments but also to ensure consistency between staff reviews during the interim period and guidance likely to come out in the SRP. This guideline documents current approaches being considered by staff for conducting dose assessments.

Because staff is still working to resolve several significant issues such as an acceptable approach to moving from screening to site-specific analyses, an acceptable rationale for changing land-use scenarios, and acceptable justification for modifying parameters and selecting computer codes, this interim guideline will change as issues are resolved and additional insights are gained through testing, interaction with industry, and comments from users. Accordingly, this guideline should be viewed as a “living” document.

NUREG-1549, cited in Regulatory Guide DG4006, lays out a process (Figure 1) for identifying decommissioning options that consider potential doses a hypothetical future land user could receive and the inherent uncertainty in estimating this potential long-term dose. The framework provides a process that balances the need for more data to reduce uncertainty with the need to limit data collection costs (i.e., licensees can direct resources and expenditures to areas important to demonstrating compliance). Thus, the framework is consistent with the agency’s overall goal of risk-informed regulation.

Recognizing that there is uncertainty in calculating future doses is an important consideration. Whether the dose assessment is a deterministic analysis (i.e., where a single resulting dose is determined) or a probablistic analysis (i.e., where a range of potential doses is determined), the analyst and reviewer need to recognize that the result from the analysis is not an absolute measure of the real dose that a specific individual is likely to receive. In other words, there is some uncertainty in the estimate in terms of the true likely dose.

Uncertainty refers to lack of knowledge about specific factors, parameters, or models. In a dose assessment, there are three sources of uncertainty; these are: model uncertainty, scenario uncertainty, and parameter uncertainty (Bonano et. al, 1988 and Kozak et. al, 1991). Because of difficulty with quantifying scenario and modeling uncertainty, ideally we would like to use conservative assumptions regarding the scenarios and conceptual model used in the analysis. Parameter uncertainty on the other hand can be quantified through the use of a probablistic analysis (NCRP, 1996 and Maheras and Kozak, 1990). Regardless of whether or not uncertainty is quantified, it is important that both the analyst and reviewer need to be aware that there are inherent uncertainties in a dose assessment and these uncertainties need to be considered in interpreting the results.

NUREG-1549 identifies the following six key components in dose assessments:

- Determining the source inventory (Step 1)
- Defining future land-use scenarios (Step 2)
- Identifying exposure pathways (Step 2)
- Developing conceptual models (Step 3)
- Calculating the dose (Step 4)
- Evaluating uncertainty and sensitive parameters (Steps 8 and 9)

Ideally, a computer code to perform the calculation is selected after the conceptual model has been developed; this helps to ensure that the selected computer code can embody the conceptual model of a given site. In this preliminary guideline, two computer codes will be discussed, the DandD and RESRAD computer codes. Accordingly, the guideline primarily addresses reviewing assessments that involve the use of these two codes (i.e., soil or waste contamination). These codes are discussed because it is anticipated that most analyses will involve the use of one of these codes. The DandD code is based upon the methodology described in NUREG/CR-5512. DandD can be used for doing both screening and site-specific analyses in support of decommissioning (NUREG-1549). RESRAD, documented in Yu et. al, 1993[1], is widely used for dose assessments in support of decommissioning. Both codes are based on different conceptual models. The reviewer should ensure that the conceptual model embodied in the code used in the assessment is consistent with the conceptual features of the site based upon what is known about the site. Also, because both codes[2] are only designed for analyzing doses on site, these preliminary guidelines will only address analyses for on-site land use; that is, these guidelines will not cover off-site land-uses which need to be considered for restricted release. The final SRP is expected to provide more guidance on selecting computer codes.

Decommissioning Dose Requirements

The NRC's new license termination rule is contained in Subpart E of 10 CFR Part 20. Subpart E provides the regulatory basis for determining when a site is suitable for license termination. Sections 20.1402 and 20.1403 of Subpart E include requirements for unrestricted and restricted use of facilities after license termination. In addition to specific dose limits, additional requirements include demonstrating that residual radioactivity is as low as reasonably achievable (ALARA), financial assurance, and public participation for restricted use.

§ 20.1402 states that a site is considered acceptable for release 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, and the residual radioactivity has been reduced to levels that are as low as reasonably achievable (ALARA).

§ 20.1403 states that a site is considered acceptable for release with restriction on land use if the residual radioactivity that is distinguishable from background radiation results in a TEDE to an average member of the critical group that does not exceed 25 mrem/yr with the restrictions in place and the TEDE does not exceed 100 mrem/yr or 500 mrem/yr to the average member of the critical group if the land-use restrictions fail at some point. In addition, to these dose limits, § 20.1403 has additional requirements (such as ALARA, financial assurance, and public participation).

The dose objective for both unrestricted and restricted use requires an assessment considering no land-use restrictions, which means that the average member of the critical group (a hypothetical future land user) is located on the site. An acceptable resident farmer scenario is described in NUREG-1549 for this purpose. The final SRP is expected to provide additional insights on how someone could justify changing or using an alternative scenario. The dose objective for restricted release also requires an assessment assuming that the land-use restrictions are effective; accordingly, this may necessitate analyzing potential doses to the average member of the critical group located off site or outside of the restricted area. Even with effective on-site restrictions, radionuclides can become mobilized and travel to areas where restrictions are not in place. Because the two computer codes addressed in this guideline cannot be used to analyze radionuclide transport away from the contaminated area, this interim guideline only addresses dose assessment for complying with unrestricted use of the site and restricted release assuming the restrictions have failed. Analyses involving transport of contaminants off site will have to be dealt with on a case-by-case basis, and may require the involvement of staff hydrogeologists. Again, the final SRP is expected to address dose assessment for both unrestricted and restricted release of decommissioning sites.

In addition, because it is covered in Regulatory Guide DG-4006, this interim guideline will not address ALARA demonstration.

Besides the dose limit and ALARA requirement, there are several other aspects of § 20.1402 §20.1403 to consider from a dose assessment perspective. First, Subpart E establishes a 1000-year time frame for the assessment of soil

[1]Updates on RESRAD can be found at: http://www.ead.anl.gov/~resrad/reshstry.html.

[2]**Appendix K of the RESRAD User's Manual describes an approach for using RESRAD to evaluate doses off site; however, staff is not prepared at this time to recommend this as an acceptable approach.**

contamination. This is important in not only establishing a time frame for the analysis, but means that parameters affecting the rate of radionuclide migration can become important in demonstrating compliance. For example, radionuclide adsorption (especially in the contaminated and unsaturated zones) can slow up radionuclide migration sufficiently to prolong their contribution to the calculated dose beyond the 1000-year period. Accordingly, staff reviewers need to be especially cognizant of the likely importance of such parameters to demonstrating compliance. The time frame is also important in the types of future events and processes that need to be considered in the analysis.

Second, Subpart E excludes radon, instead demonstrating compliance with the LTR will be achieved by evaluating doses from radium (the principal precursor to radon). In particular, the background to the license termination rule states that radon is excluded because it is difficult to distinguish radon resulting from a site activity from background radon. In addition, it is difficult to predict design features of future building construction which will greatly affect doses that someone will receive. Therefore, the background to the LTR recommends that licensees with residual radioactivity that contains radium should evaluate the applicability of the EPA radon guidelines, including local building codes designed to minimize the impact of indoor radon levels. The DandD code does not address radon. RESRAD does allow for evaluating effects from radon. Accordingly, for the purpose of this evaluation, the radon exposure pathway will have to be turned off in the analysis using RESRAD.

Analyses with DandD

DandD is designed for two-levels of analyses, generic screening and limited site-specific analyses. Screening analyses with DandD relies on the use of default parameter values, predefined models, and predefined scenarios. The result is expected to provide a prudently conservative estimate of the dose; that is, an overestimation of the actual dose that individuals might receive. Site-specific analyses with DandD involve the use of some site-specific parameter values with predefined models and scenarios. In following the approach outlined in Figure 1, an analyst is encouraged to start the assessment using the generic screening approach. If the generic screening approach shows that the dose limit can be met, the analysis is done. The analyst would then move onto looking at demonstrating ALARA (Step 6). If the generic screening gives doses above the dose limit, the analyst will need to do some type of sensitivity analysis (Step 8 and 9) to identify parameters where more site-specific data would be helpful in refining the parameter and analysis. In going through the framework a second or subsequent time, the analyst will then use DandD with the site-specific parameter value(s). More details on going through the framework are provided in NUREG-1549.

DandD is designed to perform screening analyses using only the source inventory or concentration. The reviewer should ensure: 1) that the source inventory used is appropriate, 2) that the default parameter values have not been changed, and 3) that there is no known existing ground-water contamination at the site or other features not appropriately represented by the DandD conceptual model. Because the source inventory is the only input parameter in a screening analysis, it is important that there be appropriate justification through the use of: 1) measured data, 2) operational and burial records, or 3) possession limits in the license[3].

Assuming that the staff reviewer has determined the acceptability of using DandD (in general, DandD can be used for screening, with adjustments to the source term, unless the site is known to have existing ground-water contamination or other important pathways not included in the generic scenario), the primary consideration will be whether the licensee has appropriately converted the source inventory (i.e., source activity) into concentrations and also whether the licensee has changed any of the default parameters. The scenario (i.e., a resident farmer) and conceptual model are already assumed as part of the code. Accordingly, an analyst following the NUREG-1549 framework would establish their source concentration (Step 1) and then move directly to calculating the dose (Step 5).

The DandD code requires that the source inventory (i.e., activities) be input as a source concentration (i.e., in pCi/g or Bq/g). Accordingly, the inventory must be averaged over some volume. There are three acceptable approaches to calculating the source concentration. These three approaches move from conservative to more realistic ways of dealing with the source concentration.

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[3]For sites with old burials under 10 CFR 20.304, the maximum quantity that was allowed to be buried in trenches, should not be used to estimate the source inventory because NRC has identified instances where disposal limits have been exceeded.

1. **Mass Balance**

Assume that the source activity is distributed uniformly over a default volume of 360 $m^{3)}$ through the following relationship:

$$Conc(i) = \frac{Activity(i)}{(\rho * Ar * T * CF)} \qquad (1)$$

where:

$Conc(i) =$ concentration of radionuclide i (pCi / g)

$Activity(i) =$ total activity of radionuclide i (pCi)

$Ar =$ cultivation area in DandD $(m^2) = 2400\ m^2$

$\rho =$ waste density $(kg/m^3) = 1431\ kg/m^3$ in DandD

$CF =$ conversion factor $(g/kg) = 1000\ g/kg$

$T =$ thickness of the contamination $(m) = 0.15\ m$

$\therefore$

$$Conc(i) = \frac{Activity(i)}{(5.15x10^8)}$$

This approach should be used if the thickness of the contaminated area is unknown and it can be safely assumed the volume of contamination is greater than and equal to 360 m^3. Because of the small volume, it will always provide a conservative source concentration. The 360 m^3 volume is based on a 2400 m^2 cultivation area multiplied by a contamination thickness of 0.15 m. The activity should be adjusted to account for radioactive decay since waste emplacement through the following relationship:

$$A_t = A_0 e^{-(\lambda t)} \quad \Rightarrow \quad A_t \approx A_0\left(\frac{1}{2^n}\right) \qquad (2)$$

where:

$A_t =$ activity (Ci)

$A_0 =$ initial activity (Ci)

$\lambda =$ decay constant (year^{-1})

$= 0.693 / T_{1/2}$

$T_{1/2} =$ half - life (years)

$t =$ time (years)

$n =$ number of half - lives

DandD accounts for the ingrowth of some progeny by assuming that the parent and daughter radionuclides are at secular equilibrium when the progeny has a half-life less than nine hours and a half-life less than ten percent of the parent half-life. An analyst can also assume secular equilibrium for an entire chain by selecting radionuclides that have a "+C" designation.

2. Single Simulation

A single simulation can be used by assuming that the contaminants are distributed uniformly over the volume of contaminated soil and interspersing clean soil, and assuming that the soil is distributed over a surface to a depth of 0.15 m. Figure 2 shows a conceptualization of this alternative. The following relationship can be used to calculate the source concentration:

$$Conc_1(i) = \frac{Activity(i)}{SA * T_w * 1.431x10^6} \qquad (3)$$

where:

$Conc_1(i) =$ Concentration of radionuclide i

The equivalent cultivation area (A_r) that should be used in DandD would be:

$$Ar_1 = \frac{SA * T_w}{0.15} - 200 \qquad (4)$$

This assumes that the area of the hypothetical house is 200 m^2. It should be noted that the average waste concentration can be used if concentration measurements have been made.

For this alternative, the hypothetical individual is assumed to be exposed through all pathways. This second approach requires that the depth of contamination be known. This approach should in general provide comparable results to the dual simulation approach (described below) especially if the ground water is expected to be an important environmental pathway. It should be noted that no credit is taken for an existing cover in order to evaluate the impacts from gamma exposure and because DandD assumes no cover over the contaminated area. This approach may not be appropriate for large contaminated areas, because the activity is diluted more as the area is increased. As a cut off, it is recommended that this approach not be used for contaminated areas larger than 2400 m^2. For burials larger than the 2400 m^2, the analyst should consider using some other method for calculating the source term. The surface area represents the area of contamination plus any interspersing clean soil.

3. Dual Simulation

Assume that the activity is uniformly distributed over the volume of contaminated soil and interspersing clean soil. Further assume that a volume equivalent to the size of the basement is excavated and spread out over the land surface to a depth of 0.15 m. Figure 3 shows a schematic conceptualization of the problem. Note that there will be two different concentrations, $Conc_1$ and $Conc_2$. $Conc_1$ represents radionuclides mixed with the cover material and spread out over the land. $Conc_2$ represents the concentration of the remaining radionuclides left in place (i.e., in the waste but not excavated). The two contaminated zones will not represent the same exposure to the hypothetical farmer. The farmer can be exposed through all pathways from the top zone (at concentration $Conc_1$); however, the farmer's exposure to the second zone will be limited primarily through what is leached out and reaches the ground water. Because of the two concentrations and different exposure pathways associated with each, this conceptual problem will require two simulations with the DandD code. The first simulation is used to evaluate exposure from contaminants spread out over the land surface. For this first simulation all exposure pathways are considered with the exception of drinking water and irrigation (these will be covered in the second simulation). To exclude the drinking water and irrigation pathways set the following parameters to zero: water ingestion, domestic use, infiltration rate, and irrigation rate. If the total activity within the waste area is known, the following approach can be used to calculate source concentrations for this first simulation:

$$
\begin{aligned}
&\text{If } T_c + T_w > 3, \\
&Conc_1(i) = \frac{Activity(i)\left(3 - T_c\right)}{SA * T_w * 4.293x10^6} \\
&\text{If } T_c + T_w < 3, \\
&Conc_1(i) = \frac{Activity(i)}{SA * 4.293x10^6}
\end{aligned}
\tag{5}
$$

where:

$Conc_1(i)$ = concentration of material on the surface (pCi / g)

SA = surface area of contamination (m^2)

T_c = thickness of cap (m)

T_w = thickness of contamination (m)

Derivation of the above equations is provided in Appendix A. In the above formulas, the cap and waste are both assumed to be represented by soil at a density of 1.431 g/cc (the DandD default). In addition, the basement height is assumed to be three meters. The surface area represent the area of contamination and any interspersing clean soil. The cultivation area (Ar) parameter in DandD should be set to 4000 m^2 (i.e., 600 m^3 divided by 0.15 m). The area of the hypothetical house is assumed to be 200 m^2.

The second simulation is used to evaluate exposure from the remaining inventory, which could leach into the ground water. Because we are primarily interested in exposure from contaminated ground water, several parameters will have to be set to zero in order to eliminate or reduce the exposure from the other pathways (i.e., external, inhalation, plant ingestion, and resuspension). Accordingly, the following parameters will have to be set to zero for the second simulation: floor dust, resuspension factor, indoor dust, outdoor dust, gardening dust, indoor breathing, outdoor breathing, gardening breathing, time spent gardening, time spent outdoors, and soil ingestion rate. In addition, the indoor shielding factor should be set to 1.0 and the plant mass loading factor should be set to 0.0011 (the smallest value allowed in DandD)[4]. As with the first simulation, the surface area represents the area of contamination plus interspersing clean soil. The second simulation can be eliminated entirely if the licensee can demonstrate conclusively that the ground water will not be used at the site. Further, the second simulation can be eliminated if the contaminated volume is $\leq$600 m^3 which represents excavation of the entire source term. If the second simulation is eliminated, then all pathways including drinking water and irrigation should be evaluated in assessing the material brought to the surface. Source concentrations for the second simulation can be obtained using the following functional relationship:

$$Conc_2(i) = \frac{Activity(i)}{SA * T_w * 1.431x10^6} \qquad (6)$$

where:

$$Conc_2(i) = concentration\ in\ waste\ area\ for\ second\ simulation\ (pCi/g)$$

For this second simulation, we do not account for the activity removed for the first simulation because irrigation and drinking water are excluded in the first simulation. Accordingly, the whole activity is used in evaluating impacts from exposure from these pathways in the second simulation. The cultivation area (Ar) parameter in DandD should be calculated as follows:

$$Ar_2 = SA - 200 \qquad (7)$$

Again, the area of the hypothetical house is assumed to be 200 m^2.

The total dose can be obtained by summing the dose from the two simulations. If the peak doses for both simulations occur at roughly the same time, the reported doses from each simulation can be simply added together. However, if the two peaks occur at vastly different times, some type of integration of the two dose curves will be needed. In any event, it will be always conservative to simply sum the two peak doses.

The activities for both equations (5) and (6) should be adjusted to account for radioactive decay since waste burial. This third approach (i.e., the dual simulation approach) also requires that the depth of contamination be known. In addition, it accounts for the presence of an existing cover over the burial. If there is no cover over the burial area, the formulations are still valid, the analyst only has to set T_c to zero. Although less conservative than the mass balance and single simulation approaches, the dual simulation approach should be appropriate in most cases because it is consistent with the assumed resident farmer scenario. That is, the resident farmer scenario assumes that an individual's activities take place over the whole area and is not limited to exposures from isolated spots; thus, the concentration contacted over time is best represented by a spatially averaged concentration. However, for large areas this approach is not appropriate because the activity becomes more diluted as the surface area gets larger. As a cut off, it is recommended that this approach not be used for contaminated areas larger than the 2400 m^2 area assumed in DandD. For burials larger than this, the analyst will need to consider using some other method to devise the source term. Staff is currently working on a method that can be used for these cases.

The above formulas can be used if the analyst knows the total activity in the waste area. If concentration measurements have been made, the average concentration can be used. For the first simulation, the average concentration can be used in the following relationship:

---

[4]It should be noted that even with this small mass loading factor, the agricultural pathway maybe a dominant pathway. Accordingly, it is recommended that the dose from the agricultural pathway be subtracted from the total dose for the second simulation.

$$\text{If } T_c + T_w > 3,$$
$$Conc_1(i) = \frac{\left[\overline{Conc(i)}(3 - T_c)\right]}{3}$$
$$\text{If } T_c + T_w < 3, \tag{8}$$
$$Conc_1(i) = \frac{\overline{Conc(i)} * T_w}{3}$$
where:
$$\overline{Conc(i)} = \text{average concentration of rationuclide i from measurements } (pCi/g)$$

For the second simulation, the arithmetic average concentration from the measurements can be used directly in the analysis.

For all three of these approaches, it is assumed that the activity is uniformly distributed over some defined volume. In using either of the last two approaches it is important to assess the appropriateness of assuming that the activity is uniformly distributed over the waste volume. This assumption may not be appropriate for situations where the waste is very heterogeneous or if there are isolated large areas of elevated concentrations. Demonstrating the appropriateness of assuming an uniform distribution should be based on an evaluation of the dose from assuming a non-uniform distribution.

No credit is assumed to be taken for any waste containers (e.g., metal drums or boxes); that is, containers are assumed to have failed or decayed. In general, this assumption should be appropriate because of the expected lifespan of most waste containers are expected to be short relative to the time frame of the dose assessment. The equations described in these three approaches can be easily evaluated, especially for a large number of radionuclides, in a spreadsheet.

After evaluating the source concentration, the staff reviewer should evaluate the licensee's DandD output report. Any changes to default parameters are echoed in the output. Accordingly, it is important that staff reviewer request a copy of the licensee's output report. Staff can also determine that the default parameter set has not been altered by running DandD using the licensee's source concentration as input. A copy of the DandD code can be downloaded at: **http://techconf.llnl.gov/radcri/java.html**, under "**dose assessment**" and "***decontamination and decommissioning software***." The installation instruction file "***readme.txt***" can also be downloaded. A user's manual for DandD is still under development.

Staff is still developing an acceptable approach for reviewing dose assessments involving DandD where one or more of the default parameters have been changed. The approach used to select the default parameter set for DandD is designed to ensure a specific confidence level for generic screening. Although this approach is appealing by providing additional insights on the confidence level of the screening analysis, it has a significant drawback in that the confidence level is maintained if one or more of the default parameters are changed only by re-sampling all of the other parameters and changing them as well. In other words, changing one or more of the default parameters and leaving the others unchanged may not give the same confidence level. One clear way to maintain this confidence level is to re-sample all the parameters each time any one parameter is changed. Accordingly, staff is currently pursuing the development of a Monte Carlo version of DandD that will be capable of such analyses. It is envisioned that the Monte Carlo version of DandD will be developed so that the Monte Carlo features are fairly transparent to users not familiar with probablistic analyses. In general, staff believes that changing a suite of parameters associated with a single exposure pathway will not greatly effect the confidence level. Accordingly, in the interim, staff can use the following approach to evaluating site-specific assessments using the DandD code:

- Initially perform a screening analysis with all default parameters.

- Identify the key radionuclide(s) and exposure pathways (i.e., those contributing the greatest fraction to the total dose). This can be read directly from the printout.

- Rerun DandD with the site-specific parameter values. Site-specific parameters should be changed as a group as described in Appendix C of NUREG-1549. If the dominant exposure pathway does not change, it is probably appropriate to change a group of default parameters without re-sampling for all parameters. If the dominant exposure pathway changes, it is probably not appropriate to change a subset of the default parameter set without considering the influence of the other parameters.

- The licensee will need to provide justification, as it relates directly to their particular site, for all parameter values where defaults are not used. In general, the behavioral and metabolic parameters listed in Table 1 should not be altered. Values for these parameters were selected specifically for the screening (critical) group assumed in the assessment. However, the following four behavioral parameters may be changed, if justified, to modify the screening group assumptions: ingestion rate of vegetables, fruits, and grain (Uv), ingestion rate of beef, poultry, milk, and eggs (Ua), ingestion rate of fish (Uf), and ingestion rate of drinking water (Uw).

Staff reviewers are encouraged to read Appendices A and C of NUREG-1549 for additional guidance on changing the critical group and modifying parameters.

Analyses with RESRAD

RESRAD is a computer code developed by Argonne National Laboratory (ANL) for the Department of Energy (DOE) to calculate site-specific residual radiation guidelines and radiation dose to future hypothetical on-site individuals at sites contaminated with residual radioactive material. The RESRAD code was adopted by DOE in Order 5400.5 for derivation of soil cleanup criteria and dose calculations, and it is widely used by DOE, other federal agencies, and industry. Because it is so widely used and will likely be used by NRC licensees, it is being specifically addressed in this interim guideline. Staff plans to develop more guidance in the SRP on suitable criteria for accepting computer codes.

The RESRAD code is continuously updated. The latest version is 5.82. Staff reviewers will need to ensure that the latest version has been used in assessments that they are reviewing. If an earlier version has been used, the analyst should be required to document that the earlier version is not expected to give significantly different results from the latest version. The RESRAD web site (http://www.ead.anl.gov/~resrad/reshstry.html) provides information on all the updates from one version to another.

RESRAD, like DandD, has an assumed conceptual model (see Figure 1.1 of Yu et. al, 1993); therefore, the analyst only has to determine if the assumed conceptual model is appropriate for the problem. However, unlike DandD, RESRAD does not have prescribed land-use scenarios. The analyst must develop the land-use scenario by switching on or off various exposure scenarios. For the standard resident farmer scenario used by the NRC, all of the exposure pathways should be switched on with the exception of the radon pathway. The staff reviewer should request that the analyst provide justification for excluding any of the other pathways. For example, if it can be shown that the ground water at the site cannot be used because of either widespread ambient contamination (e.g., salinity) or low yields, it should be justifiable to exclude the ground-water pathway. A finding that the ground water is unsuitable is typically made in coordination with State agencies. Staff plans to develop additional guidance on appropriate rationale for excluding pathways. In the interim such rationale will have to be looked at on a case-specific basis.

RESRAD, like DandD, requires that the radioactive inventory be input as a source concentration. Because RESRAD is designed for conducting site-specific analyses, it is expected that for most analyses, the analyst will have data on radionuclide concentrations at the site[5]. Given that we are assuming a resident farmer scenario, it

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[5]RESRAD is primarily designed to look at radioactively contaminated soils; therefore, for analyses involving other types of wastes, the analyst will have to make some assumptions about the waste form and how the radionuclides will be released from this waste form. These

should be appropriate to use the arithmetic average of the radionuclide concentration in the analysis (note this also includes any interspersing clean soil). RESRAD allows the user to input information on the area and thickness of the contaminated zone (i.e., these are not fixed, although defaults are provided). For surface contamination ($\leq$0.9 m, the default rooting depth in RESRAD), the site-specific mean concentration, area of contamination, and thickness of the contamination can be used directly in the code. For deeper contamination or if the contaminated area is capped (such as with burials) some assumptions must be made about how much waste will be brought to the surface and how it will be mixed with uncontaminated soil. In general, the schematic in Figure 3 should apply. Analyzing this conceptual model, as with DandD, requires two simulations. During the first simulation it is assumed that a small volume of waste (600 m^3) is brought to the surface and spread out over an area to a depth of 0.9 m. For the first simulation, we are interested in the dose from exposure to the material brought to the surface, such as, direct gamma radiation, inhalation, soil ingestion, and plant ingestion (excluding irrigation with contaminated water). Exposure from ground water, irrigation, and aquatic use will be considered in the second simulation. Accordingly, the drinking water and aquatic pathways should be switched off for the first simulation. In addition, the irrigation rate should be set to zero. The source concentration for this first simulation would be derived using equation (8) as previously defined.

The concentrations should be adjusted to account for radioactive decay. The area that should be used in the first simulation should be 700 m^2 (i.e., 600 m^3 divided by 0.9 m). The assumed contaminated thickness would be 0.9 m (note: T_w that should be used in the above formulation represents the true contaminated zone thickness in its current configuration). The second simulation looks at effects from exposure from the remaining waste. The primary environmental transport pathway for this remaining waste will be ground water. For the second simulation the external gamma, inhalation, and soil ingestion pathways should be switched off. In addition, the mass loading for foliar deposition parameter should be set to zero. Further, if the contaminated zone is presently capped, the contaminated zone can be assumed to be covered for the second simulation, unless there are reasons to believe that the cover will be removed (e.g., through a high soil erosion rate). The source concentration for the second simulation should be the mean concentration for the waste area. This includes interspersing clean soil. The contaminated area and thickness used in the second simulation would be based upon the true existing waste zone configuration. Accordingly, to use this approach the analyst will have to know something about the waste zone configuration.

An alternative to using the dual simulation approach is to simply assume that the waste is uniformly distributed over the source volume, taking no credit for the cover (i.e., by assuming that the cap is not present). This should provide comparable, but conservative results to the dual simulation approach especially if the ground water is an important pathway. Using this simpler approach, the analyst would use the mean concentration as the source concentration.

In using either of these approaches it is important for the staff reviewer to assess the appropriateness of assuming that the activity is uniformly distributed over the waste volume. This assumption may not be appropriate for situations where the waste is very heterogeneous or if there are isolated large areas of elevated concentrations.

If all that is known is the source inventory (activities), such as at some old burial sites, the source concentration can be calculated with equations (5) and (6). It should be noted that the density for the contaminated zone should be set to 1.431 or the concentration should be calculated with the same density assumed in the analysis.

Because RESRAD is designed for site-specific analyses, a single default parameter set has not been established for performing generic screening analyses. Although RESRAD has default parameters, these parameters may or may not be suitable or provide a conservative estimate of the dose for any given site. The same can also be said about the parameter values recommended in PG-8-08 (U.S. NRC, 1994). As an example, Kamboj et. al (1996) found three site-specific parameters (distribution coefficient, contamination zone thickness, and contamination area) caused residual soil cleanup guidelines calculated by RESRAD to vary by as much as a factor of 40 at 17 Formerly Utilized Sites Remedial Program (FUSRAP) sites. To ensure consistency between the critical group used in DandD analyses, analysts are encouraged to use the parameters listed in Table 2. In addition, analysts are encouraged to use site or regional data to the extent possible to establish site-specific parameter values for other parameters. For example, regional climatic data (such as precipitation) can be obtained at: http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwnolos~Product~PB-016#TABLES.

Given the large number of parameters in RESRAD it is not practical and may not be necessary for an analyst to justify all of their selected parameter values. The important thing is for there to be appropriate justification for those

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assumptions should be clearly laid out.

parameters that have the greatest influence on the calculated dose. This is consistent with the philosophy inherent in the NUREG-1549 framework. To identify key parameters that possibly should be justified, the following approach is recommended:

1. Run RESRAD using as much site or regional data as possible to define physical parameters, along with the behavioral parameters listed in Table 2 and the source concentration as previously described. It is also recommended that the mass balance approach be used for the ground water pathway for contaminated areas that are $\leq 1000\ m^2$. The mass balance ground-water model is more consistent with the assumed exposure scenario.

2. Identify the key exposure pathways (i.e., those contributing the greatest percentages to the dose). As an example, Kamboj et. al (1996) found in general for the 17 FUSRAP sites, that:

   A. for radionuclides with large distribution coefficients (>100 cm^3/g) associated with a thick source zone, the plant ingestion pathway was important.

   B. for radionuclides with small distribution coefficients, the water dependent pathways were important.

   C. for radionuclides with intermediate distribution coefficients (between 40-100 cm^3/g) associated with a shallow source zone, the dust inhalation and external gamma pathways were important.

   D. for radionuclides with intermediate distribution coefficients associated with a thick source zone, the plant ingestion pathway was important.

3. Identify the parameters associated with that pathway from Table 3 (Yu et. al, 1993b).

4. Perform sensitivity analyses on those parameters to determine which ones have the greatest influence on the calculated dose. There are several ways to evaluate parameter sensitivity. The simplistic approach is to calculate partial derivatives where the change in the dose is evaluated with respect to the change in each parameter while holding the other parameters constant. For example,

$$S(j) = \frac{\partial D}{\partial P(j)} \approx \frac{\Delta D}{\Delta P(j)} = \frac{D_2 - D_1}{P(j)_2 - P(j)_1} \qquad (9)$$

where:

$S(j) =$ sensitivity of parameter $P(j)$

$D =$ dose

$P =$ input parameter j

Differences in magnitude of parameters can make direct comparison of their sensitivity difficult. Therefore, for comparison purposes it is best to normalize the sensitivity through some type of relationship as follows:

$$S(j) = \left[\frac{\overline{P(j)}}{F\left(\overline{P(j)}\right)}\right]\left(\frac{\Delta D}{\Delta P(j)}\right) \qquad (10)$$

Where:

$\overline{P(j)} =$ mean or baseline value for parameter $P(j)$

$F\left(\overline{P(j)}\right) =$ dose when all baseline or mean parameters are used

The partial derivative approach can be easily implemented in RESRAD. RESRAD allows the user to perform sensitivity analyses on specified parameters. These sensitivity analyses look at each parameter individually. The effects of the sensitivity are provided in plots. Information for equation (10) can be read directly off these plots. Because the relative sensitivity of a given parameter may change as a function of the simulation time, it is recommended that the maximum change in the dose be used to evaluate the sensitivity. One potentially significant drawback to using the partial derivative approach is that it does not allow consideration of potential correlation between parameters (i.e., parameters are assumed to be independent of each other).
An alternative to the partial derivative approach is to use some type of probablistic approach (such as a Monte Carlo analysis) that allows the simultaneous variation of multiple parameters at once. To easily assess the relative effects of any one parameter on the dose, the probablistic approach is used in conjunction with some type of statistical analysis (such as regression or correlation analysis). There is a probablistic version of RESRAD 5.82 which could be used for such analyses; however, the current version is somewhat limited only allowing a maximum of 17 parameters to be treated as uncertain, and 100 samples of each of the uncertain parameter. In addition, the user is limited to choosing from among only five different statistical distributions; namely, normal, lognormal, uniform, loguniform, and triangular. Because of the limitation in the number of parameters and realizations that can handled at one time, it may be necessary to perform multiple analyses to cover all of the parameters that may have to be treated as uncertain. This limits the viability of considering multiple parameters at the same time. Accordingly, no attempt should be made at interpreting the uncertainty results as a true measure of the uncertainty in the dose estimate.

Two potential drawbacks to the use of the probablistic approach are that it requires information on the probability density function (pdf) of each parameter that is assumed to vary and it requires information on the degree of correlation between parameters. Analysts will have to use their best professional judgement in selecting appropriate probability density functions. It is best to avoid making strong assumptions about distribution types; instead, the widest distribution consistent with the state of knowledge should be selected. The analyst can also use the maximum entropy theory (Buckley, 1985) as a basis for selecting distribution functions. Table 4 shows distributions that would be used based upon the maximum entropy theory. In general, analysts should use broad ranges of parameter values to represent the large uncertainty.

Staff is still developing guidance on how to perform sensitivity and uncertainty analyses. It is anticipated that additional guidance will be developed on how to develop pdf's.

5. Request licensees to provide additional site-specific information on the most sensitive parameters.

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Table 1. Behavioral and Metabolic Parameters in DandD.

Parameter	Type	Description	Value	Units
DIET	B	Fraction of annual diet derived from home-grown foods	1	
TTR	B	Total time in exposure period	365.26	d
TCA(1)	B	Food consumption period for beef	365.25	d
TCA(2)	B	Food consumption period for poultry	365.25	d
TCA(3)	B	Food consumption period for milk	365.25	d
TCA(4)	B	Food consumption period for eggs	365.25	d
TCV(1)	B	Food consumption period for leafy vegetables	365.25	d
TCV(2)	B	Food consumption period for other vegetables	365.25	d
TCV(3)	B	Food consumption period for fruits	365.25	d
TCV(4)	B	Food consumption period for grain	365.25	d
TD	B	Drinking water consumption period	365.25	d
TF	B	Fish consumption period	365.25	d
THA(1)	B	Holdup period for beef	20	d
THA(2)	B	Holdup period for poultry	1	d
THA(3)	B	Holdup period for milk	1	d
THV(1)	B	Holdup period for leafy vegetables	1	d
THV(2)	B	Holdup period for other vegetables	14	d
THV(3)	B	Holdup period for fruits	14	d
THV(4)	B	Holdup period for grains	14	d
TTG	B	Total time in gardening period	90	d
XF(1)	B	Fraction of contaminated beef cattle forage	1	
XF(2)	B	Fraction of contaminated poultry forage	1	
XF(3)	B	Fraction of contaminated milk cow forage	1	
XF(4)	B	Fraction of contaminated hen forage	1	
XG(1)	B	Fraction of contaminated beef cattle grain	1	
XG(2)	B	Fraction of contaminated poultry grain	1	
XG(3)	B	Fraction of contaminated milk cow grain	1	
XG(4)	B	Fraction of contaminated hen grain	1	
XH(1)	B	Fraction of contaminated beef cattle hay	1	
XH(2)	B	Fraction of contaminated poultry hay	1	
XH(3)	B	Fraction of contaminated milk cow hay	1	
XH(4)	B	Fraction of contaminated hen hay	1	
XW(1)	B	Fraction of contaminated beef cattle water	1	
XW(2)	B	Fraction of contaminated poultry water	1	
XW(3)	B	Fraction of contaminated milk cow water	1	
XW(4)	B	Fraction of contaminated hen water	1	
Ar	B	Area of land cultivated	2400	m^2
ti	B	Exposure period indoors	240	d/y
tx	B	Exposure period outdoors	40.2	d/y
tg	B	Exposure period gardening	2.92	d/y
SFi	B	Indoor shielding factor	0.5512	
GR	B	Soil ingestion transfer rate	0.05	g/d
IR	B	Irrigation rate	1.29	L/m^2*d
Vdr	B	Volume of water removed from aquifer for domestic use	118000	L
Uv	B	Ingestion rate of vegetables, fruits, and grain	80.4	kg/y

Ua	B	Ingestion rate of beef, poultry, milk, and eggs	317.2	kg/y
Uf	B	Ingestion rate of fish	20.6	kg/y
Uw	B	Ingestion rate of drinking water	1.31	L/d
Vr	M	Volumetric breathing rate indoors	0.9	m^3/h
Vx	M	Volumetric breathing rate outdoors	1.4	m^3/h
Vg	M	Volumetric breathing rate gardening	1.7	m^3/h

Table 2. Initial Parameters for RESRAD

Parameter	**Value**	**Units**
Inhalation rate	1.169e+04	m^3/y
Mass loading for inhalation	3.14e-06	g/m^3
Shielding factor for external gamma radiation	0.5512	
Fraction of time spent indoors	0.6571	
Fraction of time spent outdoors	0.1101	
Fruits, vegetables, and grain consumption	112	kg/y
Leafy vegetable consumption	21.4	kg/y
Milk consumption	233	L/y
Meat and poultry consumption	65.1	kg/y
Fish consumption	20.6	kg/y
Soil ingestion	18.26	g/y
Drinking water intake	478.5	L/y
Contamination fraction of drinking water	1	
Contamination fraction of livestock water	1	
Contamination fraction of irrigation water	1	
Contamination fraction of aquatic food	1	
Contamination fraction of plant food	1	
Contamination fraction of meat	1	
Contamination fraction of milk	1	
Livestock fodder intake for meat	27.1	kg/d
Livestock fodder intake for milk	63.25	kg/d
Livestock water intake for meat	50	L/d
Livestock water intake for milk	60	L/d
Growing season for non-leafy vegetables	0.25	y
Growing season for leafy vegetables	0.123	y
Growing season for fodder	0.15	y
Storage time for fruits, non-leafy veg., and grain	14	d
Storage time for leafy vegetables	1	d
Storage time for milk	1	d
Storage time for meat and poultry	20	d

Storage time for livestock fodder	0	d
Fraction of grain in beef cattle feed	0.0743	
Fraction of grain in milk cow feed	0.0308	
Well pumping rate	118	m^3/y
Irrigation rate	0.5	m/y

Table 3. Parameters associated with various exposure pathways in RESRAD.

Parameter	External	Inhalation	Plant Ingestion	Meat Ingestion	Milk Ingestion	Aquatic	DW	Soil Ingestion
CZ Density	✓		✓	✓	✓	✓	✓	✓
UZ Density			✓	✓	✓	✓	✓	
SZ Density			✓	✓	✓	✓	✓	
CZ Porosity	✓	✓	✓	✓	✓	✓	✓	✓
UZ Porosity			✓	✓	✓	✓	✓	
SZ Porosity			✓	✓	✓	✓	✓	
CZ Eff. Porosity	✓	✓	✓	✓	✓	✓	✓	✓
UZ Eff. Porosity			✓	✓	✓	✓	✓	
SZ Eff. Porosity			✓	✓	✓	✓	✓	
CZ Hyd. Cond.	✓	✓	✓	✓	✓	✓	✓	✓
UZ Hyd. Cond.			✓	✓	✓	✓	✓	
SZ Hyd. Cond.			✓	✓	✓	✓	✓	
Precipitation	✓	✓	✓	✓	✓	✓	✓	✓
Runoff coeff.	✓	✓	✓	✓	✓	✓	✓	✓
ET coeff.	✓	✓	✓	✓	✓	✓	✓	✓
CZ b-parameter	✓	✓	✓	✓	✓	✓	✓	✓
UZ b-parameter			✓	✓	✓	✓	✓	
SZ b-parameter			✓	✓	✓	✓	✓	
CZ erosion rate	✓	✓	✓	✓	✓	✓	✓	✓
Hyd. gradient			✓	✓	✓	✓	✓	
Length ∥ aquifer			✓	✓	✓	✓	✓	
Watershed area			✓	✓	✓	✓	✓	
Watertable drop			✓	✓	✓	✓	✓	
Well depth			✓	✓	✓	✓	✓	
UZ thickness			✓	✓	✓	✓	✓	
Area of CZ	✓	✓	✓	✓	✓	✓	✓	✓
Kd’s	✓	✓	✓	✓	✓	✓	✓	✓

Fractions of Annular areas	✓							
Leach rate	✓	✓	✓	✓	✓	✓	✓	✓
Shielding factor for inhalation		✓						
Depth of roots			✓	✓	✓			
Thickness of CZ	✓	✓	✓	✓	✓	✓	✓	✓
Dilution length for airborne dust		✓	✓	✓	✓			
Seafood consumption						✓		
Shape factor	✓							
Mass loading for foliar deposition			✓	✓	✓			
Depth of soil mixing layer			✓	✓	✓			

CZ = contaminated zone
UZ = unsaturated zone
SZ = saturated zone

Table 4. Probably density functions based upon the maximum entropy theory.

State of Knowledge	Probability Density Function
no constraint	uniform distribution
mean	exponential distribution
mean, variance	4-parameter lognormal, beta

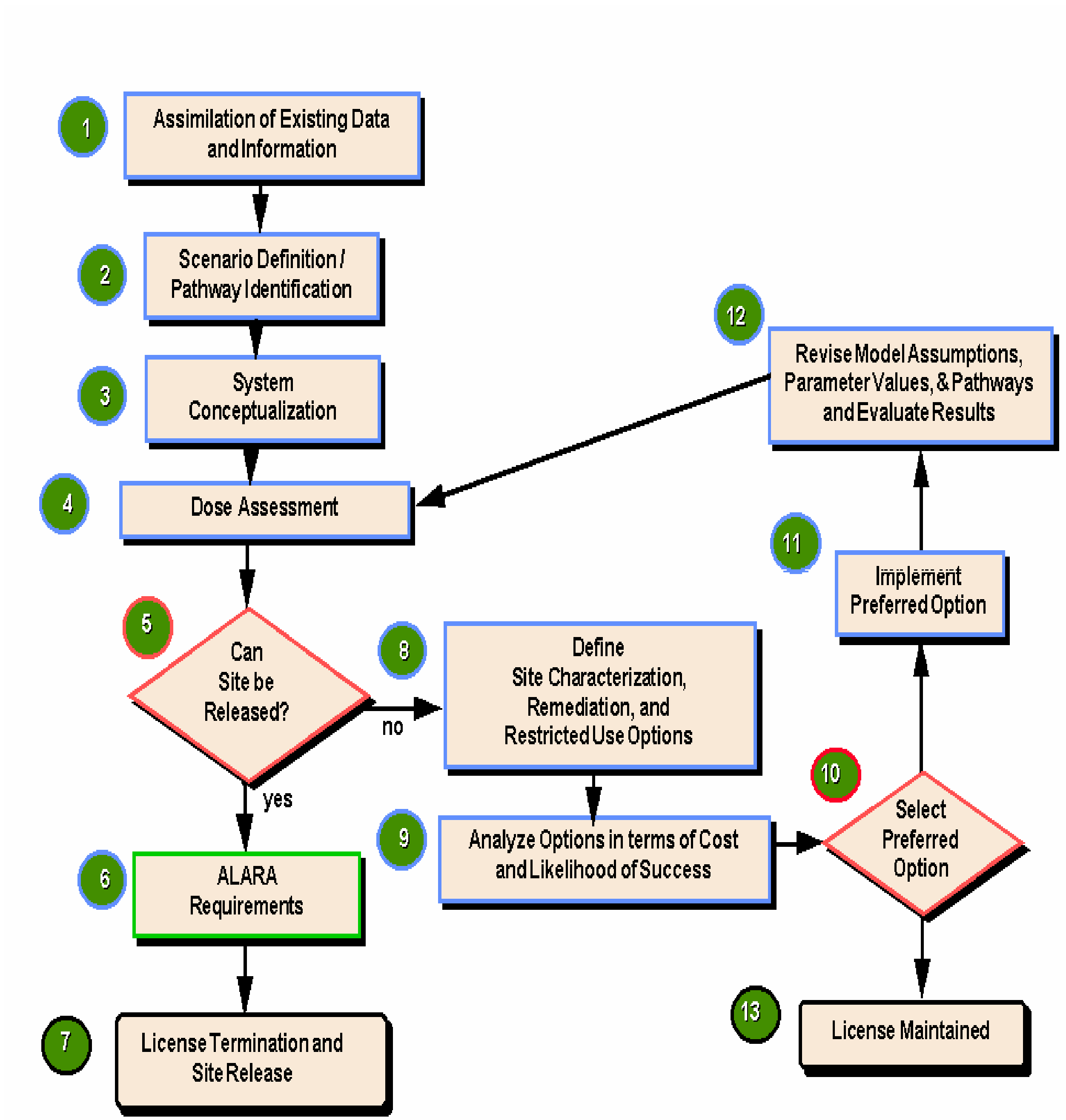

Figure 1 NUREG-1549 Decision Framework.

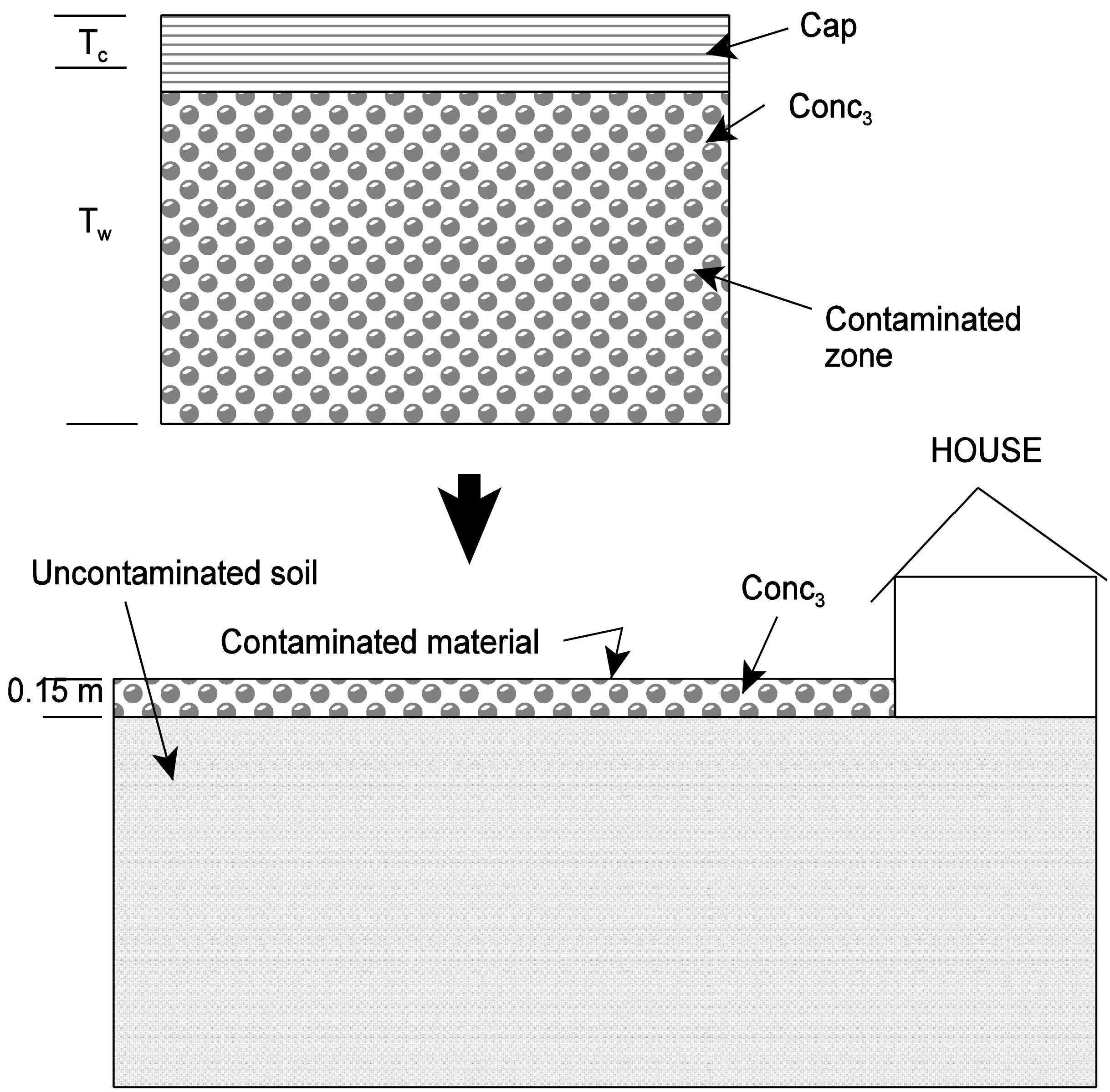

Figure 2. Alternative conceptual disposal.

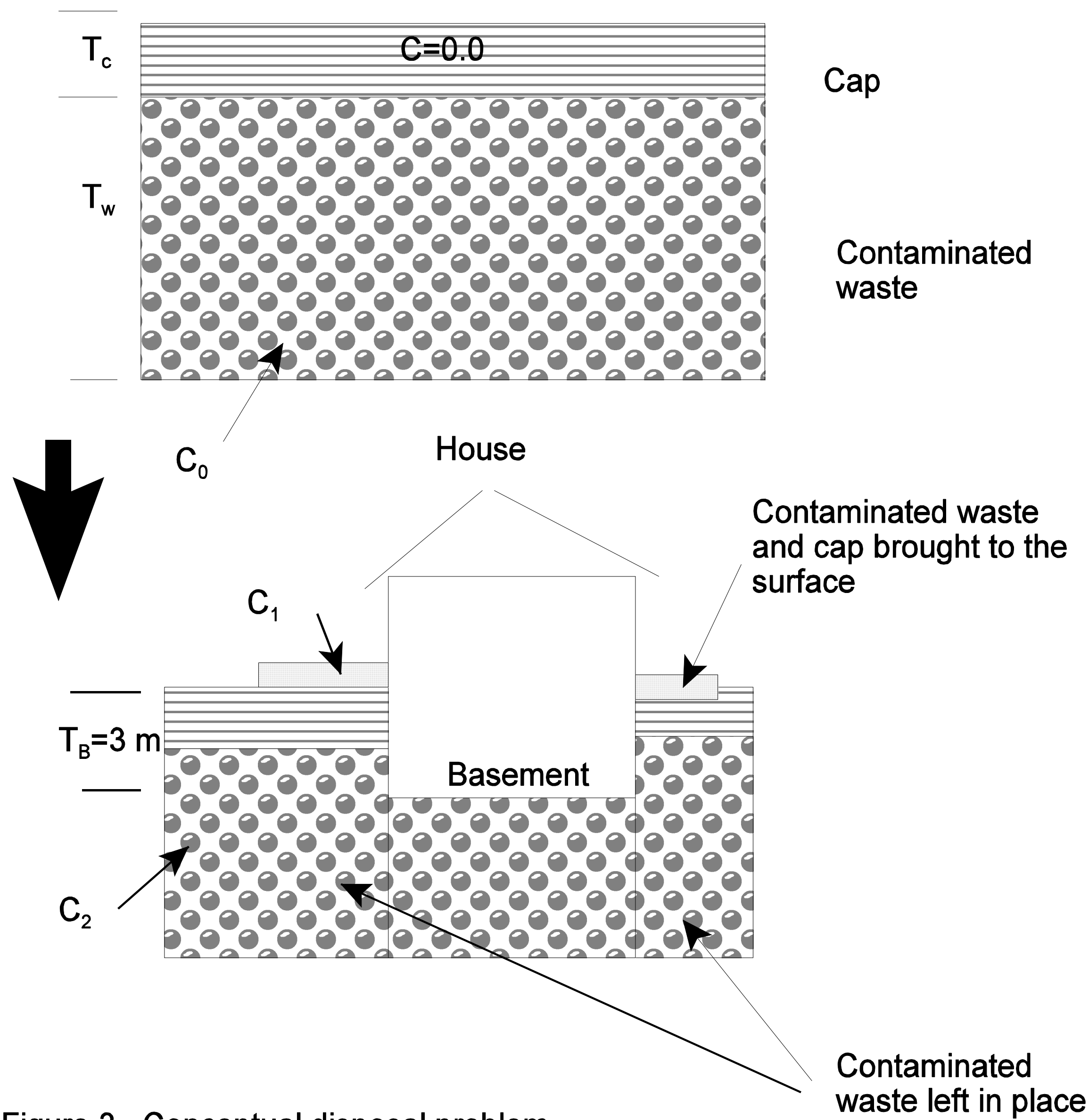

Figure 3. Conceptual disposal problem.

Appendix A

Derivation of Equations 4-8

Equation 4:

For DandD the cultivation area needs to be equivalent to the area of contaminaiton. Therefore for the single simulation approach, the size of the area of contamination is an equivalent volume of the waste limited to a depth of 15 cm.

$$Ar_2 = \frac{Vol_{waste}}{0.15}$$

where:

$Ar_2 =$ cultivation area for DandD (m^2)

$Vol_{waste} =$ volume of contamination (m^3)

$= SA * T_w$

$SA =$ surface area of contamination (m^2)

$T_w =$ thickness of contaminated zone (m)

We subtract out the area taken up by the house; therefore, the equivalent cultivation area is:

$$Ar_2 = \frac{SA * T_w}{0.15} - 200$$

Equation 5:

The initial concentration in the waste or contamination zone can be derived as follows:

$$Conc_O(i) = \frac{Activity(i)}{Vol_{waste} * \rho_{waste} * CF}$$

where:

$Conc_O(i) =$ initial concentration of radionuclide i in the waste or or contamination zone (pCi / g)

Vol_{waste} = volume of waste $(m^3) = SA * T_w$

SA = surface area of waste or contamination (m^2)

T_w = thickness of waste or contamination (m)

ρ_{waste} = density of waste = 1431 kg / m^3 (DandD default)

CF = conversion factor = 1000 g / kg

$\therefore$

$$Conc_O(i) = \frac{Activity(i)}{SA * T_w * 1.431x10^6}$$

The concentration in the material brought to the surface, for the first simulation will depend upon how much of the basement extends into the waste or contamination zone. This concentration can be represented as a fraction of the volume of material excavated to the total volume of material in the basement.

$$Conc_1(i) = Conc_O(i) * Fraction_1$$

where:

$$Conc_1(i) = \text{concentration of radionuclide i in the material brought to the surface (pCi / g)}$$

$$Fraction_1 = \frac{Vol_e}{Vol_b}$$

$$Vol_e = \text{volume excavated } (m^3)$$

$$= A_b(T_b - T_c) \qquad T_b < T_c + T_w$$

$$= A_b * T_w \qquad T_b > T_c + T_w$$

where:

A_b = area of house (m^2)

T_b = thickness of the basement (m)

T_c = thickness of the cap (m)

T_w = thickness of contamination (m)

Vol_b = volume of the basement (m^3)

$$= A_b * T_b$$

If we assume a basement thickness of 3 meters,

$$Vol_e = A_b(3 - T_c) \qquad 3 < T_c + T_w$$

$$= A_b * T_w \qquad 3 > T_c + T_w$$

$\therefore$

$$Conc_1(i) = Conc_O(i)\frac{A_b(3 - T_c)}{A_b * 3} \qquad 3 < T_c + T_w$$

$$= Conc_O(i)\frac{A_b * T_w}{A_b * 3} \qquad 3 > T_c + T_w$$

Cancelling terms and substituting in $Conc_O(i)$:

$$Conc_1(i) = \frac{Activity(i)(3 - T_c)}{SA * T_w * 4.293x10^6} \qquad 3 < T_c + T_w$$

$$= \frac{Activity(i)}{SA * 4.293x10^6} \qquad 3 > T_c + T_w$$

Equation 6:

For the second simulation, we are not concerned about the impacts from gamma radiation or plant uptake; therefore, the 0.15 m contaminated zone thickness is not important. Therefore, concentrations can be determined based upon the existing geometry of the contamination zone. The concentration in the waste or contamination zone is simply:

$$Conc_2(i) = \frac{Activity(i)}{Vol_{waste} * \rho_{waste} * CF}$$

where:

$Conc_2(i)$ = concentration of radionuclide i in waste or contamination zone (pCi / g)

$Activity(i)$ = total activity of radionuclide i in waste or contamination zone (pCi)

Vol_{waste} = volume of waste (m^3) = $T_w * SA$

T_w = thickness of contamination zone (m)

SA = surface area of contamination zone (m^2)

ρ_{waste} = waste density = 1431 kg / m^3

CF = conversion factor = 1000 g / kg

$\therefore$

$$Conc_2(i) = \frac{Activity(i)}{SA * T_w * 1.431 \times 10^6}$$

Equation 7:

The cultivation area should be equivalent to the area of contamination. The default cultivation area cannot be used if the contamination is assumed to spread out over an area different than the default of 2400 m^2. In this case, the size of the area of contamination is SA. In addition, we need to subtract the assumed area of the house; accordingly,

$$Ar_2 = SA - 200$$

Equation 8:

Derivation of equation 8 is the same as equation 5; however, the initial concentration ($Conc_0(i)$) is assumed to be the average from the measurements.