OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
SPECIAL INSTRUCTION SHEET

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The material composition and geometry (i.e., configurations of fissionable and other materials) may vary significantly during the time period of regulatory concern. Thus, different sets of experimental data are used in the validation process to represent different ranges of degraded waste form configurations that may occur during the disposal time period. The range of applicability criterion will be developed from the experimental database and documented as part of the License Application. As indicated in Figure 3-3, parametric criticality evaluations are compared with the range of applicability criterion. These comparisons establish the configurations covered by the experimental database. The process of satisfying the range of applicability criterion also identifies the applicable CL criterion for the configuration. If the criterion is not satisfied, the range of applicability may be extended by extrapolating the trended CL data and identifying a conservative k_{eff} margin to be applied. Although not shown in Figure 3.3, another option is to enlarge the range of the experimental database by adding additional experiments. If this option is chosen, new trending analyses are made, and the range of applicability criterion and the CL criterion would be revised to reflect the new experimental data. The approach for extending the range of applicability is described in Subsection 4.1.3.3.3.

Values of k_{eff} from the parametric criticality evaluations are compared with the CL criterion. This comparison separates the configuration classes based on their potential for criticality. For configurations where the peak k_{eff} may exceed the CL criterion over some portion of the parameter range of a configuration class, multivariate regressions for k_{eff} are developed as a function of parameters that significantly affect criticality. These parameters include the amounts of fissionable material (e.g., based on burnup, enrichment, and cooling time for commercial SNF), absorber material, moderator material, and degradation products. The multivariate regressions are developed from MCNP calculations for representative configurations and values of these parameters. The standard error of regression is established during the development of the regression expressions and is added to the predicted k_{eff} values for comparison with the CL criterion. The regression expressions provide a convenient method for identifying the range of parameter values where k_{eff} may exceed the CL. Potential design options can then be implemented for reducing k_{eff} of configurations that exceed the CL. The regression expressions also facilitate developing loading curves (e.g., for commercial SNF, identifying acceptable enrichment versus burnup ranges for assemblies loaded in waste packages). The process for developing the multivariate regressions for k_{eff} will be documented as part of the License Application.

The range of parameters and parameter values covered by the regressions must be checked against the range of applicability criterion and a conservative k_{eff} margin applied if the trended CL data must be extrapolated. For those configurations showing potential for criticality, an estimate of the likelihood (probability) of the configuration is made. The regression expressions also facilitate probability calculations. The portion of the methodology for estimating the probability of occurrence of potential critical configurations is described in the following section.

3.5 ESTIMATING PROBABILITY OF CRITICAL CONFIGURATIONS

This section describes the general portion of the methodology for estimating the probability of occurrence of criticality in the fissionable material contained in a waste package emplaced in the repository. Acceptance is sought for this portion of the methodology for estimating the probability of occurrence for potentially critical configurations. Further details of the models used in this portion of the methodology are given in Section 4.3, and the application of this methodology to two specific types of waste forms and waste packages is illustrated through with borated stainless steel plates for criticality control and containing the 15×15 assembly with Zircaloy clad fuel rods. Other characteristics of the problem are given in CRWMS M&O 1998r and summarized in Appendix C.

The verification of PWRPROB involved two calculations using MathCAD, Version 7 to check that the PWRPROB Monte Carlo simulation was producing correct output. These MathCAD calculations are described in Attachment IV of CRWMS M&O 1998r. First, the fully degraded basket k_{eff} regression expression was used, along with the waste stream data, to calculate the fraction of the waste stream that would exceed a k_{eff} of 0.98 in a fully degraded basket with oxide uniformly distributed at 33 volume percent. The results of this MathCAD calculation are shown in Attachment IV (page 2) of CRWMS M&O 1998r as a plot of the fraction of fuel assemblies exceeding the k_{eff} limit versus time (from 3,000 to 100,000 years). A similar case was executed for a single Monte Carlo trial of PWRPROB using specific input values that were used in the MathCad calculation (i.e., fixing the distributional inputs such that only a single value could be "sampled"). The results of the single trail of PWRPROB are provided in Figure 6-4 of CRWMS M&O 1998r. This figure shows nearly identical results to those in Attachment IV (of CRWMS M&O 1998r) following complete basket degradation, which occurs by approximately 20,000 years in this case. The peak occurs at 20,000 year for both plots. The similarity of shape and values of the two traces in Figure 6-4 of CRWMS M&O 1998r indicates that Monte Carlo framework of PWRPROB is properly processing the input and submodel outputs, and that the waste stream data and the regression expression are being properly used.

A more limited, but easier to understand, verification is provided by comparing the cumulative probability of k_{eff} exceeding 0.98 before 100,000 years for waste packages being loaded with the entire distribution of burnup-enirchment pairs for the inventory of PWR assemblies expected at the repository. This is called the noloadcurve strategy, since all of the fuel is loaded in the same type of waste package without using a loading curve to segregate the SNF with the highest criticality potential so that it can be handled in a waste package with more robust criticality control. The degradation process of the waste package is characterized as (1) the ion oxide becomes uniformly distributed, and (2) the boron is removed as the basket is corroded. The MathCAD calculation is given in CRWMS M&O 1998r, Attachment IV, and summarized in Table 4-4. The rows of the table represent parameters that are either factors in the final probability calculation (last row) or factors in the calculation of the time to corrode all the borated stainless steel.

The cumulative probability was estimated to be approximately 8.2 x 10^{-4} per PWR WP (last item in above table), which agrees very closely with that inferred from the Monte Carlo results presented in Figure 6-1 of CRWMS M&O 1998r (also reproduced as Figure C-31 of Appendix C of this document). In that figure, the no-loading curve gives a cumulative probability of 6 x 10^{-4} at 100,000 years.

The probabilistic criticality calculation models, as described in Subsections 4.3.2 and 4.3.3, can not be fully validated without the specific waste form, waste package design, and repository features that are to be licensed. Therefore the final validation process for the probabilistic models will be completed for License Application.

1.2.1 Engineered Barrier System Design

The EBS design (the underground structures) used in the example is the EBS Viability Assessment design (CRWMS M&O 1997a). Figure C-4 shows a view of the EBS design used in the example evaluation. The EBS design for the example has the following properties:

- 5.5 meter diameter emplacement drifts (CRWMS M&O 1997a, Fig. 7-20)
- ~1200 meter long drifts (CRWMS M&O 1997a, Fig. 7-1)
- Pier emplaced waste packages (CRWMS M&O 1997a, Fig. 7-20)
- Piers consist of a carbon steel box filled with concrete resting on a pre-cast concrete invert segment (CRWMS M&O 1997a, Fig. 7-20)
- Waste package pedestal supports are made of carbon steel and are attached to the piers (CRWMS M&O 1997a, Fig. 7-20)
- Invert material is pre-cast concrete (CRWMS M&O 1997a, Fig. 7-20)
- 15.4 meter nominal center-to-center spacing between emplaced 21 PWR waste packages (CRWMS M&O 1997k, Table 7.5-2)
- 28 meters nominal spacing between emplacement drifts (CRWMS M&O 1997a, Fig. 7-20)
- No backfill in the emplacement drifts (CRWMS M&O 1998m, Key 0046).

Figure C-4 shows three types of waste packages in the drift; however the PWR waste package was the only type specifically addressed in the example evaluation.

NOTE: The current EBS Design is still evolving and may not resemble the design presented here.

1.3 REPOSITORY SITE CHARACTERISTICS

The repository site used in the example is the proposed Yucca Mountain Site in Nevada. The Yucca Mountain site is an unsaturated site in volcanic tuff.

1.3.1 General Physical Description

The repository emplacement horizon is situated in Topopah Spring welded Unit 2 tuff (TSw2). The emplacement horizon is more than 200 meters below the ground surface and 200 meters above the water table (CRWMS M&O 1996f p. 5-4). Figure C-5 provides a sketch of the Waste Package (WP) Emplacement Concept used for the sample evaluation, including a cutaway pillar showing the different types of rock layers found between the surface and water table at the Yucca Mountain site. A detailed description of the rock layers can be found in Determination of Available Volume for Repository Siting analysis (CRWMS M&O 1997b, p. 30). The pillar in Figure C-5 shows only a portion of a single emplacement drift.

6.0 RISK EVALUATION

This section discusses the results of a sample risk evaluation performed for the potential critical events identified in Section 3.0. The probability of the potential critical configuration occurring (from Section 4.0) and the consequence of the resulting criticality (from Section 5.0) are combined into a risk of violating the performance objectives of the facility.

6.1 TOTAL SYSTEM PERFORMANCE ASSESSMENT DOSE ESTIMATION

As previously discussed in Section 3.1 of the main report, a performance assessment evaluation will be conducted prior to a detailed TSPA analysis that uses an incremented source term. If the consequence is determined to be insignificant upon evaluation of the incremented source term, no criticality perturbations to TSPA analyses will be conducted. However, if detailed TSPA calculations are warranted, the approach described in Section 3.1 of the main report and using the models described in Section 4.4 of the main report will be implemented.

An example calculation was conducted for this report (CRWMS M&O 1998l) using an incremented source term from the long-term, static internal waste package criticality event discussed in the previous section. The results of the example evaluation indicate that, for the example potential criticality event, there was no significant adverse effect to the repository total system performance. The dose to the public was not significantly increased by the inclusion of the potential criticality events identified as part of the example evaluations.

The key isotopes contributing to release and dose to man were determined in TSPA-VA to be ^{99}Tc, ^{129}I, ^{234}U, ^{237}Np, and ^{242}Pu. ^{129}I and ^{99}Tc provided peak release to and doses at the accessible environment at early times and ^{237}Np provided peak, and generally highest release at later times in the base case simulations conducted for TSPA-VA. Gaseous fission products such as ^{85}Kr are ignored because only a small amount are produced even for the longest criticality event (0.186 Ci ^{85}Kr/assembly from CRWMS M&O 1996b (App. X, p. 81), and the estimated travel times for gases to the surface are at least one order of magnitude greater than the half-life for ^{85}Kr (200 to 600 year travel time from CRWMS M&O 1996b, (p. 3-40) versus 10.7 year half-life from General Electric Company 1989 (p. 29). The percent change from the decay only inventory of each of the key radionuclides for each of the three steady-state criticality event durations was reviewed and is presented in Table C-16. These data indicate that the greatest increase in source term inventory occurs for the longest criticality event (10,000 year event).

A TSPA analysis has been performed (CRWMS M&O 1998l) using only the additional source term generated by a 10,000 year duration steady-state criticality event occurring 15,000 years after closure. Based on the cumulative probability of PWR waste package criticality discussed in Section 4.0 of this appendix, criticality was assumed to occur only within a single 21 PWR waste package. Dissolution rate of the source term was assumed to be the same as the initial waste form itself, since the criticality event was assumed to occur within the cladding.