April 21, 2000

Dist. done

Stephan Brocoum, Acting Assistant Manager
Office of Licensing and Regulatory Compliance
U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Yucca Mountain Site Characterization Office
P.O. Box 30307
North Las Vegas, NV 89036-0307

SUBJECT: U.S. NUCLEAR REGULATORY COMMISSION/U.S. DEPARTMENT OF ENERGY TECHNICAL EXCHANGE MEETING ON DRAFT SAFETY EVALUATION REPORT FOR DISPOSAL CRITICALITY ANALYSIS METHODOLOGY TOPICAL REPORT, REVISION 0

Dear Mr. Brocoum:

Enclosed are the summary highlights of the March 22, 2000, Technical Exchange Meeting between the staff of the U.S. Nuclear Regulatory Commission (NRC) and representatives of the U.S. Department of Energy (DOE). The main purpose of the meeting was to discuss the draft Safety Evaluation Report on the Disposal Criticality Analysis Methodology Topical Report, Revision 0 submitted to NRC for review in January 1999. The meeting was held at the NRC's Headquarters in Rockville, Maryland.

If you have any questions regarding this letter, please contact Meraj Rahimi of my staff. Mr. Rahimi can be reached at (301) 415-6616.

Sincerely,

[Original signed by:]

C. William Reamer, Chief
High-Level Waste and Performance
Assessment Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure: Summary Highlights of NRC/DOE Technical Exchange

cc: See attached distribution list

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Summary Highlights
of NRC/DOE Technical Exchange
on Draft Safety Evaluation Report
for Disposal Criticality Analysis Methodology
March 22, 2000
Las Vegas, Nevada

The summary highlights of the Technical Exchange between the Department of Energy (DOE) and the Nuclear Regulatory Commission (NRC) staff are provided in the following. The purpose of the meeting was to discuss the results of staff evaluation documented in Draft Safety Evaluation Report on Disposal Criticality Analysis Methodology Topical Report, Revision 0 issued by the NRC in March 22, 2000.

The meeting agenda, the attendance list, and copies of the presenters' slides are provided as Attachments 1, 2, and 3, respectively. The following paragraphs discuss only those Open Items for which DOE expressed different views than that provided in the draft SER.

- As part of the staff evaluation criteria, NRC indicated that per Regulatory Guide 3.71, credit for fuel burnup may be taken only when the amount of burnup is confirmed for each assembly by physical measurements. DOE proposed to present additional information which is based on performing burnup verification measurements on a sample of spent fuel population. NRC indicated that staff will consider any additional information which DOE desires to submit before releasing the final SER.

- With respect to the open item on the probability design criterion, DOE indicated that probability criterion is used for design purposes and no critical configurations will be screened out based on the probability criterion presented in the TR. DOE also indicated that screening for the purpose of Total System Performance Assessment (TSPA) is performed by DOE TSPA staff, and the intention is to provide all the probability and consequence analyses to DOE TSPA staff. NRC indicated that TR should at least show the approach for criticality analyses feeding into TSPA analyses. DOE agreed to provide information with respect to interface between the criticality methodology described in TR and subsequent TSPA analyses in the Overall Methodology section.

- On the issue of multi-parameter versus single parameter trending, NRC agreed to examine the information provided to the staff prior to the meeting. However, the staff expects the information to be provided formally along with the information from the first, second bullets and any other comments on the other open items or conditions.

- With respect to including a criticality margin in screening the critical configurations after performing regression analyses, the staff agreed to examine their position in light of including all uncertainties from regression or lookup table calculations.

- On the issue of validation approach for the power model, DOE indicated that a distribution instead of using an average value for the power will be used for the purpose of consequence analysis. NRC indicated that they will re-consider this open item depending on the assumption about the type of distribution.

- With regard to methodology, modeling, and validation approach for postclosure disposal criticality risk, DOE stated that it is the DOE TSPA responsibility to analyze the criticality risk. However, NRC believes that evaluation of any event, such as criticality, has to be performed in its entirety and in terms of its impact on repository performance. The TR is the vehicle by which the DOE's approach with regard to determining postclosure criticality risk can be described in a complete and comprehensive manner.

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Safety and Safeguards
U.S. Nuclear Regulatory Commission

Paige Russell
Site Recommendation & License
Team
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ATTACHMENT 2

NRC/DOE Meeting on Disposal Criticality Analysis Methodology
OWFN Room 3B04
March 22, 2000

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Bakr Ibrahim	NRC/HLWB	301-415-6651
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ATTACHMENT 3

Staff Evaluation Criteria

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Staff Evaluation Criteria

- Proposed 10 CFR Part 63
- Yucca Mountain Review Plan (Available on Web for public comment ~ Sept. '00)
- Issue Resolution Status Reports
- Applicable Regulatory Guides and Standards

Proposed 10 CFR Part 63

- 10 CFR Part 63 is the NRC regulation for the proposed repository at Yucca Mountain
- Proposed regulation was published in February, 1999 for public comment
- NRC staff are currently responding to public comments and preparing the final rule
- 10 CFR Part 63 will be made consistent with the final version of the EPA standard for Yucca Mountain (40 CFR Part 197)

Proposed 10 CFR Part 63

- Proposed 10 CFR 63 is a risk-informed, performance-based regulation
- Numerical requirements in the regulation relate to the expected annual dose to the critical group
- No specific design criteria for postclosure criticality are specified

Proposed 10 CFR Part 63

- 10 CFR 63.113(b)
  - *The engineered barrier system shall be designed so that, working in combination with natural barriers, the expected annual dose to the average member of the critical group shall not exceed 0.25 mSv (25 mrem) TEDE at any time during the first 10,000 years after permanent closure, as a result of radioactive materials released from the geologic repository*

Proposed 10 CFR Part 63

- 10 CFR 63.114
  - *Any performance assessment used to demonstrate compliance with 10 CFR 63.113 shall:*

    (d) Consider only events that have at least one chance in 10,000 of occurring over 10,000 years

    (e) Provide the technical basis for either inclusion or exclusion of specific features, events, and processes of the geologic setting in the performance assessment. Specific features, events, and processes of the geologic setting must be evaluated in detail if the magnitude and time of the resulting expected annual dose would be significantly changed by their omission

    (f) Provide the technical basis of either inclusion or exclusion of degradation, deterioration, or alteration processes of engineered barriers in the performance assessment, including those processes that would adversely affect the performance of natural barriers. Degradation, deterioration, or alteration processes of engineered barriers must be evaluated in detail if the magnitude and time of the resulting expected annual dose would be significantly changed by their omission

Draft Yucca Mountain Review Plan

- Currently under development at NRC
- Will be used by NRC staff to ensure that the License Application meets all requirements of 10 CFR Part 63
- Rev. 1 of the Yucca Mountain Review Plan is expected to be released in September, 2000

Draft Yucca Mountain Review Plan

- Review of the postclosure performance assessment will be based on Integrated Subissues

- Aspects of criticality will be evaluated under the following integrated subissues:
  - Degradation of engineered barriers
  - Quantity and chemistry of water contacting waste packages and waste forms
  - Radionuclide release rates and solubility limits
  - Radionuclide transport in the unsaturated zone
  - Radionuclide transport in the saturated zone
  - Mechanical disruption of engineered barriers

Issue Resolution Status Reports

- Provide feedback to DOE on the status of resolution of KTI subissues

- Focus on acceptance criteria for issue resolution and the status of resolution, including areas of agreement and areas where staff has questions or comments

- The NRC goal is to reach closure on all KTI subissues at the staff level before the License Application is submitted by the DOE

Issue Resolution Status Reports

- IRSRs that include acceptance criteria related to postclosure criticality include:
  - Total System Performance Assessment and Integration (TSPAI)
  - Container Life and Source Term (CLST)
  - Evolution of the Near-Field Environment (ENFE)
  - Radionuclide Transport (RT)

TSPAI IRSR Acceptance Criteria

- Scenario Analysis
  - Identification of FEPs
  - Screening of FEPs
  - Categorization of FEPs
  - Definition of Scenario Classes
  - Screening of Scenario Classes
- Model Abstraction
  - Data Sufficiency
  - Data Uncertainty
  - Alternative Conceptual Models
  - Model Uncertainty
  - Model Consistency
- Quality Assurance
- Use of Expert Elicitation

CLST IRSR Acceptance Criteria

- Several acceptance criteria similar to those in TSPAI IRSR
- Selection of design criteria
- Identification of configuration classes and modeling validation and verification
- Assignment of probability
- Calculation of k_{eff}
- Calculation of criticality consequences
- Criticality risk

ENFE IRSR Acceptance Criteria

- Six categories of acceptance criteria
  - Data and model justification
  - Data uncertainty and verification
  - Model uncertainty
  - Model verification
  - Integration
  - Programmatic

RT IRSR Acceptance Criteria

- Evaluation of probability of far-field criticality
- Evaluation of consequences of far-field criticality

Applicable Regulatory Guides and Standards

- DOE referred to:
  - NUREG/CR–2300: modified approach to PRA
  - NUREG/CR–6361: criticality model benchmarking
  - NUREG/CR–5661: critical limits
  - ANSI/ANS–8.1, 8.15, 8.17, and 8.10: criticality control outside reactors
  - Regulatory Guides 3.4 and 3.58: criticality analyses supporting safety in handling, storage, and transportation
- All are applied as analogies, because directly applicable standards/guides do not exist

Applicable Regulatory Guides and Standards (cont.)

- NRC staff review was guided by Regulatory Guide 3.71; DOE has stated (RAI response) that it will refer to 3.71 in place of 3.4 and 3.58.
- NRC accepts with one exception.
  - Reg Guide 3.71 states that "credit for fuel burnup may be taken only when the amount of burnup is confirmed by physical measurements that are appropriate for each type of fuel assembly in the environment in which it is to be stored."
  - NRC believes that consistency with 3.71 requires that burnup measurements must be performed on each of the spent fuel assemblies prior to their loading into the waste package. OPEN ITEM.

Draft Safety Evaluation Report On Disposal Criticality Analysis Methodology Topical Report, Revision 0

Meraj Rahimi
U.S. Nuclear Regulatory Commission

Introduction (cont.)

- Probability of Critical Configurations
- Criticality Evaluation
- Criticality Consequence
- Criticality Risk
- Conclusion

Scope of Draft SER

- Scope established by DOE's "near term"specific requests per Enclosure 2 in RAI
- Staff evaluation limited to methodology and modeling plus its validation approach
- No application of methodology, data, computer codes, specific benchmark experiments, specific isotopes, or examples were evaluated
- Acceptance/approval of items in draft SER is contingent upon stisfactory resolution of pertinent subissues listed in Issue Resolution Status Report (IRSR)

Background

- DOE submitted TR in January 1999
- NRC accepted TR for detailed technical review in February 1999
- NRC issued Request For Additional Information (RAI) in August 1999
- DOE issued responses to RAI in November 1999
- NRC issued draft SER on TR in March 2000

Method of Staff Evaluation

- Divided by each main area
- Each main area evaluated with respect to methodology, modeling approach, and validation approach
- Staff evaluation with respect to each of the three aspects of a major area were performed based on:
  - DOE's specific request
  - Technical basis for the request
  - Technical basis of staff evaluation
  - Results of staff Evaluation

Overall Methodology

DOE's Request

DOE requests acceptance of the risk-informed processes that is the core of the methodology. The risk-informed process is illustrated in Figure 1-1 (discussed in Section 1.5) and revised in Attachment B of Enclosure 1. We do not seek acceptance for a specific application of the methodology, and we understand that we will need to demonstrate acceptability of specific applications to support licensing.

Overall Methodology (cont.)

Basis of Evaluation

- Proposed 10 CFR 63.113 and 63.114 pending final resolution of public comments and finalization of EPA proposed 40 CFR 197

- Multiple barrier requirement per 10 CFR 63.113(a)

Design Criteria

DOE's Request

- *DOE requests acceptance of the four design criteria presented in Section 1.2, Part A of Topical Report as acceptable for ensuring that design options are propoerly implemented for minimizing the potential for, and consequences of, criticality. The design criteria are discussedin Section 3.4, 3.5, 3.6, and 3.7.*
  - Critical Limit
  - Criticality Probability
  - Criticality Consequence
  - Performance Objectives

Critical Limit Design Criterion (cont.)

DOE's Approach

- CL accounts for criticality analysis method bias and uncertainty
- Method bias and uncertainty are obtained from analyzing experimental systems
- Each configuration class will have a corresponding CL values which covers the range of expected configuration parameter values

Critical Limit Design Criterion (cont.)

Evaluation Results

- Section 3.4 is related to criticality analysis methodology
- Staff evaluation of methodology for establishing CL is covered under Criticality Evaluation
- The staff agrees with the concept of establishing CL provided appropriate biases and uncertainties are included in determing CL values

Criticality Probability Design Criterion (cont.)

DOE's Approach

- Two objectives for Criticality Probability Design Criterion
  - To support (for screening purposes) an estimate of the risk of criticality in terms of overall increase in radionuclide
  - To estimate the effectiveness of the variety of criticality control systems based on criticality probability per waste package
- Criticality probability per waste package
  - Expected number of criticalities in 10,000 (one or less than one) divided by approximately 10,000 waste packages = 10^{-4} criticalities per waste package in 10,000 years

Criticality Probability Design Criterion (cont.)

Basis of Evaluation (cont.)

- DOE has stated:
  - "This derived probability criterion is not proposed for regulatory purposes, and will only be used to guide decision processes internal to waste package design."
- Section 3.6 of TR, indicates otherwise:
  - "when the k_{eff} of the configuration analyzed exceeds the CL and the probability of occurance of that configuration exceeds the waste package criterion, currently derived in Section 3.5 as approximately 10^{-4} per waste package in 10,000 years, a consequence analysis is performed."

Criticality Consequence Design Criterion (cont.)

DOE's Request

The Criticality Consequence criterion discussed in Section 3.6: the expected radionuclide increase from any criticality event will be less than 10 percent of the radiologically significant radionuclide inventory (curies present at time of criticality) that is available for release and transport to the accessible environment. This criterion is intended to ensure that the average radionuclide rement from any single criticality is much less than the uncertainty of the performance assessment dose estimation, and is also used to define a waste package criticality control design requirement in support of defense-in-depth with respect to the Repository Performance Objective in item 4.

Criticality Consequence Design Criteria (cont.)

Basis of Evaluation

- Criticality Consequence Criterion pertains only to increase in isotopic inventory
- RAI 3-23 acknowledges consideration of time dependencies of temperature and power in consequence analysis
- No Consequence Criteria for transient or external criticalities are include in TR

Performance Objective Design Criteria

DOE's Request

The repository Performance Objectives criterion discussed in Section 3.7:the ability to satisfy dose rate performance objectives will not be compromised by the radionuclide increment due to criticality events (if any).

Performance Objective Design Criteria (cont.)

Evaluation Results

- Staff agrees with using dose at accessible environment as performance objective criterion for criticality event provided:
  - All aspects of criticality event consequences such as increase in radionuclide inventory, heat output, and degradation of EBS are considered
  - Dfine what is considered to be significant
  - Probability-consequence from all critical events included into full TSPA per Figure 1-1 of TR

Criticality Evaluation (cont.)

DOE's Request (cont.)

- *DOE requests acceptance of the following aspects of the probability method:*
  (1) Development and use of a table of k_{eff} for the range of possible configuration parameters to construct a regression for k_{eff} as a function of these parameters or for direct table lookup and interpolation (Section 3.5, page 3-21 and modification of this paragraph given in the response to RAI 3-16)...

Criticality Evaluation (cont.)
Material Composition (cont.)

Results of Methodology Evaluation

- Acceptance of corrosion, geochemistry, and configuration generation models contingent on appropriate verification and validation
- Staff agrees with the concept of burnup credit for disposal criticality provided:
  - Bounding reactor operating parameter values are established
  - Appropriate isotopic model validation is performed
  - Independent burnup verification is performed
- Staff does not agree change in intial isotopic inventory could be due to decay only

Criticality Evaluation (cont.) K_{eff} Evaluation (cont.)

Results of Methodology Evaluation

- The staff agrees with criticality evaluation methodology portion of Figure 3-3 provided:
  - Initial criticality analysis for range of configuration parameter values in each class is not too coarse

Criticality Evaluation (cont.) Regression Analysis (cont.)

Evaluation Results for Regression Methodology

- Staff agrees with regression or lookup table approach provided:
  - All configuration and waste form parameters affecting k_{eff} values are identified
  - Interpolation for lookup tables must be within a small range
  - Verfication of k_{eff} values from regression or lookup tables are performed

Criticality Evaluation (cont.)
Isotopic Analysis (cont.)

Evaluation of Modeling Approach

- No specific computer code is approved at this point
- Modeling of spent fuel irradiation must include all important variables:
  - Dissolved boron concentration, moderator density, fuel pellet temperature, burnable absorber, power shaping, and control rods, axial and radial leakage, and void coefficient
- Open Item
  - Inadequacy of a 1-D approach for simulating irradiation history of three dimensional heterogenous fuel assemblies

Criticality Evaluation (cont.)
K_{eff} Analysis (cont.)

Evaluation of Modeling Approach

- No specific criticality computer code is approved at this point
- Staff does not have objections to using well establish Monte Carlo based computer codes for determining k_{eff} values for waste packages
- Open Item
  - DOE needs to assess the impact of temperature on nuclides with crosss section evaluated at room temperature

Criticality Evaluation (cont.) Regression Analysis (cont.)

Modeling Approach (cont.)

- Effect of boron remaining in solution included by correctin factor
  - $k_{eff} = k_{eff} + \Delta k_{eff} = k_{eff} (1+ \Delta k_{eff}/k_{eff})$
  - Where: $\Delta k_{eff}/k_{eff} = C_0+C_1\ln(B)+C_2\ln(B)^2 +C_3\ln(B)^3+C_4T+C_5O$
- With over 2000 k_{eff} values, lookup tables may be used

Criticality Evaluation (cont.)
Regression Analysis (cont.)

Staff Evaluation of Modeling Approach (cont.)

- Open Items
  - Inclusion of cross dependency of configuration parameters for k_{eff} regression equations
  - Validity of approach for correction factors developed for boron remaining in solution

Criticality Evaluation (cont.)
Isotopic Validation Approach

DOE' Request (cont.)

- *Reactor operating histories and conditions must be selected together with axial burnup profiles such that the isotopic concentrations used to represent commercial SNF assemblies in waste package design shall produce values for k_{eff} that are conservative in comparison to any other expected combination of reactor history, conditions, or profiles.*

Criticality Evaluation (cont.) Isotopic Validation Approach

DOE's Request (cont.)

- *The values for the isotopic concentrations representing commercial SNF must produce conservative values for k_{eff} for all postclosure time periods for which criticality analyses are performed.*

Criticality Evaluation (cont.) Isotopic Validation Approach

Staff Evaluation (cont.)

- Staff concludes second requirement does not address methodology for establishing isotopic code bias and uncertainty
- Staff does not have any objection to using second requirement for confirming bounding values for reactor operating parameters
- Open Item
  - DOE is required to develop an acceptable mehtodology for establishing bias and uncertainties associated with isotopic model

Criticality Evaluation (cont.)
K_{eff} Validation Approach

DOE's Request

DOE requests acceptance of the criticality model validation process described in Section 4.1.3. Acceptance of this item is requested in Section 1.2, Part G of the Topical Report and discussed further in the response to RAI 1-3. Specifically, DOE requests acceptance that the process presented in Subsection 4.1.3.2 for calculating the criticality limit values and the general approach presented in Subsection 4.1.3.3 for establishing the range of applicability of the critical limit values define the validation process for the criticality model.

Criticality Evaluation (cont.)
K_{eff} Validation Approach (cont.)

DOE's Approach

- Use of Commercial Reactor Criticals (CRC) and Laboratory Critical Experiment (LCE)
- Use of CL for establishing demarkation between critical and subcritical conditions
  - $k_s + \Delta k_s \leq CL$
- Establishing CL
  - $CL = k_c(x) - \Delta k_c(x) - \Delta k_m$

Criticality Evaluation (cont.)
K_{eff} Validation Approach (cont.)

Staff Evaluation

- Staff believes in performing multi-parameter trending for CL
  - $CL = k_c(x,y,z,...) - \Delta k_c(x,y,z,...) - \Delta k_m$
  - $\Delta k_c(x,y,z,...)$ Includes isotopic bias and uncertainties
- Staff accepts Δk_m to be included in screening configurations provided is included in all screening
- Staff agrees with DOE approach on NDTL and DFTL

Steady-State Criticality Consequence Analysis (cont.)

DOE's Request (cont.)

- *(3) Determination of radionuclide increment from depletion code (ORIGEN-S) as a function of power, integrated over the duration of the criticality (Section 4.4.1.1 as augmented in the response to RAI 4-51).*

Criticality Evaluation (cont.) RegressionValidation Approach

Staff evaluation

- Response to RAI 3-16(d) indicates regression coefficient for high plutonium content fuel exhibit inaccuracies
- Open Items
  - Regression equations or lookup tables must be verified for configuration parameter ranges
  - Variabilities and uncertainties introduced by regression equations annd lookup tables to be included

Steady-State Criticality Consequence Analysis (cont.)

Staff Evaluation of Methodology

- Staff agrees with the proposed methodology except:
- Open Items
  - Other types of moderators, especially with respect to external criticality must be considered
  - Other types of consequences must be included from steady-state criticality

Steady-State Criticality Consequence Analysis (cont.)

DOE's Request for Validation Approach

DOE seeks acceptance of the validation process for the steady-state criticality consequence model, specifically that computer code can be written to perform the numerical integration of power over time and distribution of drip rates, as well as calculating the heat loss according to well-known physics formulae.

Steady-State Criticality Consequence Analysis (cont.)

Staff Evaluation of Methodology

- Staff agrees that for sustained steady-state criticality drip rate must be equal to removal rate
- Staff acceptance of drip rate is dependent on satisfactory resolution of subissues in pertinent IRSRs
  - Climate Change
  - Hydrologic Effects of Climate Change
  - Present Day Shallow Infiltration
  - Deep Percolation
  - Matrix Diffusion
  - Other related subissues

Steady-State Criticality Consequence Analysis (cont.)

Staff Evaluation of Validation Approach

- Using well-known physics formulae does not provide validity of model
- Hand calculations can be used for verification
- Open Item
  - Validation approach for power model for steady state criticality consequence

Steady-State Criticality Consequence Analysis (cont.)

Staff Evaluation of Validation Approach

- Using well-known physics formulae does not provide validity of model
- Hand calculations can be used for verification
- Open Item
  - Validation approach for power model for steady state criticality consequence

Other Open Items

- Methodology, modeling, and validation approach for transient criticality consequence
- Methodology, modeling, and validation approach for postclosure disposal criticality risk

Internal Criticality Scenarios

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Internal Criticality Scenarios

- DOE requested acceptance of the external scenario list of TR Figure 3-1. These scenarios are:
  - IP–1: Liquid accumulates in WP and WP internal structures degrade slower than WF
  - IP–2: Liquid accumulates in WP and WP internal structures and WF degrade at similar rates
  - IP–3: Liquid accumulates in WP and WP internal structures degrade faster than the WF
  - IP–4: WP bottom is penetrated, allowing water to flow through and WP internal structures degrade slower than WF
  - IP–5: WP bottom is penetrated, allowing water to flow through and WP internal structures and WF degrade at similar rates
  - IP–6:WP bottom is penetrated, allowing water to flow through and WP internal structures degrade faster than waste form

Internal Criticality Scenarios

- List developed from TSPA-VA scenario development and was subjected to expert review
- RAI responses dealt with clarification and with description of a methodology that will be used to determine whether seismic events can lead to a configuration that yields a transient criticality
  - Seismic predecessor configurations will be identified
  - Probability determined from probability of predecessor configuration being generated and probability of seismic event subsequently occurring
  - Consequences based on transient criticality calculation

Internal Criticality Scenarios

- NRC staff evaluation based on:
  - CLST IRSR
  - TSPAI IRSR
  - Comparison with preliminary DOE FEPs database

- NRC staff accepts list in TR Figure 3-1, provided DOE incorporates the additional seismic evaluation described in response to RAI 3-1

External Criticality Scenarios

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External Criticality Scenarios

- DOE requests acceptance of the external scenario list of TR Figure 3-2. These scenarios are:
  - NF–1: solute transport of fissile material from the WP and accumulation in the invert
  - NF–2: slurry transport of fissile material from the WP and accumulation on the invert
  - NF–3: colloidal transport of fissile material from the WP and accumulation in the invert
  - NF–4: water ponds in drift, WP and WF degrade, and fissile material accumulates in clays at the bottom of the drift
  - NF–5: water ponds in drift, WP degrades, and intact WF sits in pond

External Criticality Scenarios (cont.)

- FF–1: solute transport of fissile material from the drift and chemical accumulation in the unsaturated zone
- FF–2: colloidal transport of fissile material from the drift and accumulation in the unsaturated zone
- FF–3: solute transport of fissile material from the drift and chemical accumulation in the saturated zone

- List developed from TSPA-VA scenario development; subjected to expert review
- RAI responses dealt with clarification and with description of an additional external igneous intrusion configuration

External Criticality Scenarios (cont.)

- NRC evaluation based on
  - ENFE IRSR
  - RT IRSR
  - TSPAI IRSR
  - comparison with preliminary DOE FEPs database
- NRC staff accepts list in TR Figure 3-1, with two exceptions, which are considered OPEN ITEMs:
  - The DOE needs to provide a modeling approach for igneous-activity induced criticality (RAI 3-1 and response)
  - The DOE is required to include a configuration involving FM precipitation due to dry-out in a perched water basin in the scenario list (DOE FEPs database entry 2.2.14.07.00)

Internal Criticality Configurations

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Internal Criticality Configurations: Methodology and Modeling Approach

- DOE requested acceptance of a method for generating a comprehensive set of potential postclosure configurations, including
  - Degradation methodology
    - Ability to calculate the loss of fissionable elements and neutron absorbers
    - Ability to calculate the composition of degradation products precipitating in the waste package
    - Use of a steady-state geochemistry code
  - Configuration generator
    - Use of time-dependent, first-order differential equations, solved by numerical integration, to track the concentration, or amount of fissionable or neutron absorber material
    - Development of coefficients of these equations by abstraction from steady-state geochemistry code calculations
    - Random variation of terms in these equations to reflect uncertainty in the rates and location of natural processes

Internal Criticality Configurations: Methodology and Modeling Approach

- DOE methodology: Quantify parameter ranges for internal configurations by determining:
  - Corrosion rates for all internal components
  - Location of all potentially reacting materials
  - Concentration of FM, neutron absorbers, and corrosion products
  - Whether clays are formed inside the WP
  - Range of hydration of degradation products
  - Amounts of undegraded materials and solid degradation products remaining
  - Quantity of FM or neutron absorbers adsorbing to corrosion products
  - Physical processes will be periodically evaluated, including:
    - Locations for solids
    - Density and physical structure of corrosion products
    - Thermal and structural behaviors of internal structures and the waste form
    - Effects of external events

Internal Criticality Configurations: Methodology and Modeling Approach

- DOE modeling approach:
  - Corrosion models and degradation models will be consistent with models used in the TSPA, where available
  - Degradation models for other components will be developed from laboratory data
  - Geochemical analyses will be performed with a qualified commercial software code, such as EQ3/6
  - Configuration generator code will be used to track the concentrations of neutronically significant isotopes
    - Uses time-dependent, first-order differential equations to represent the chemical transformation of elements based on coefficients developed from detailed calculations of a qualified commercial geochemistry code
    - Based on water transport, solubility of materials, and chemical conditions, tracks transport of elements within and outside of waste package
    - Used with Monte Carlo analysis to quantify the uncertainty in the processes and data

Internal Criticality Configurations: Methodology and Modeling Approach

- RAI responses included:
  - DOE indicated that they would evaluate all configurations identified as potentially autocatalytic in published articles
  - Additional clarification
- NRC staff evaluation based on:
  - CLST IRSR

Internal Criticality Configurations: Methodology and Modeling Approach

- No specific codes have been accepted for the analysis
- NRC staff accepts the use of degradation models that have been reviewed and accepted during the review of the TSPA, provided:
  - DOE can demonstrate that no assumptions were made in the modeling which were conservative for TSPA calculations, but not conservative for criticality calculations
- NRC staff accepts the use of a commercial steady-state geochemistry code that tracks the quantity of water in the WP, provided:
  - The code is properly qualified for use in repository conditions

Internal Criticality Configurations: Methodology and Modeling Approach

- NRC staff accepts the use of differential equations to track the concentration of materials as long as the coefficients are based on sufficient and appropriate data

Internal Criticality Configurations: Validation Approach

- DOE requested acceptance of the validation process for the degradation analysis methodology
- DOE approach:
  - No revalidation of models already validated for the TSPA
  - The geochemical code will be compared against:
    - Analytical solutions
    - Results obtained by chaining several thousand individual EQ6 runs, adjusting the water mass between runs
    - Other geochemistry-transport codes
- RAI responses dealt with:
  - Validation of geochemical calculations - DOE clarified the approach that will be taken to validate the geochemistry code

Internal Criticality Configurations: Validation Approach

- NRC staff evaluation based on:
  - CLST IRSR
  - TSPAI IRSR
- NRC staff finds that the proposal to not revalidate models validated for the TSPA is acceptable provided:
  - The validation of these models is found to be acceptable during review of TSPA
  - The models do not contain assumptions that are conservative for TSPA analyses but non-conservative for criticality analyses
- NRC staff finds that the proposed validation process for the geochemistry code is acceptable
- The corrosion models and supporting data for other materials will be evaluated in the license application

Internal Criticality Configurations: Validation Approach

- DOE requested acceptance of the validation process for the configuration code

- DOE approach:
  - Appropriate hand calculations will be utilized to ensure that the code is appropriately tracking the locations of important materials

Internal Criticality Configurations: Validation Approach

- NRC staff evaluation based on:
  - CLST IRSR
  - TSPAI IRSR

- NRC staff accepts the proposed methodology for validation of the configuration generator code

External Criticality Configurations

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External Configuration Methodology

- DOE requested acceptance of a method for generating external configurations
- DOE approach: Quantify parameter ranges for configurations by determining:
  - An FM source term based on internal configurations
  - Water flow rates and patterns
  - Sorption along flow paths
  - Mineral precipitation along flow paths
  - Alternate flow paths as a result of fracture filling
  - Reaction products at interface with reducing zone

External Configuration Methodology (cont.)

- NRC evaluation based on:
  - ENFE IRSR
  - RT IRSR
- Staff finding is that the DOE approach to generating external configurations is acceptable.
  - Tied to site and design features
  - Encompasses the range of realistic mechanisms (exception: open item concerning dry-out mechanism)

External Configuration Modeling Approach

- DOE requested acceptance for
  - Application of an accumulation model for FM, and
  - Application of a CGC.
- DOE approach: Calculation of external FM accumulation by the use of
  - A geochemistry-transport code (e.g., PHREEQC),
  - A geochemistry code used in a mode that simulates transport (e.g., modified EQ3/6), or
  - Both, supplemented by a CGC
- RAI responses
  - Clarified the types of geochemical parameters to be included in modeling and
  - Provided illustrative discussions of modeling approach

External Configuration Modeling Approach (cont.)

- NRC evaluation based on:
  - ENFE IRSR
  - RT IRSR
- Staff finding is that the DOE approach to modeling external critical configurations is acceptable

External Configuration Validation Approach

- DOE requested acceptance for
  - Validation process for CGC (hand calculations)
  - Validation process for accumulation methodology
- DOE approach:
  - Comparison between codes (e.g., EQ3/6 and PHREEQC)
  - Comparison with experimental data
  - Comparison with natural analogs
  - Hand calculations for CGC
- RAI responses provided useful examples of validation, as well as example sensitivity analyses that would boost confidence; revised TR will discuss PHREEQC and modified EQ3/6

External Configuration Validation Approach (cont.)

- NRC evaluation based on:
  - ENFE IRSR
  - RT IRSR.
- Staff finds that the validation approach is acceptable, provided:
  - DOE revises code descriptions in the TR as promised in response to RAI 4-33
  - DOE revises TR discussions of validation to include more detailed descriptions and specifically mentioning comparison against more detailed analytical solutions
  - DOE applies the principles of the uses of appropriate and bounding laboratory and natural analog data as discussed in response to RAI 4-33
  - DOE judiciously applies uncertainty and sensitivity analyses to boost confidence

Probability of Critical Configurations

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Probability of Critical Configurations: Methodology and Modeling Approach

- DOE requested acceptance of the method used to estimate the probability of criticality, including:
  - The use of the Monte Carlo methodology using random sampling of parameters characterizing configurations and determination of k_{eff} by calculation from the regression expression or table lookup and interpolation as a function of these parameters to obtain a sample of up to 1 million values of k_{eff} to simulate a probability distribution
  - Incorporation of the WAPDEG-generated probability distribution for time of breach and duration of the "bathtub" as two of the parameters

Probability of Critical Configurations: Methodology and Modeling Approach

- DOE methodology:
  - Assign probability distributions to parameters
  - Sample a single value for each parameter, using conditional probability distributions to account for correlations
  - Calculate concentrations and locations of important isotopes for each time step and use a regression equation to determine k_{eff}
  - Repeat many times to determine the probability of criticality
- DOE modeling - internal:
  - Sample infiltration into the drift
  - Sample WP failure time and drip rate determined by the TSPA programs WAPDEG and RIP based on this drip rate
  - Sample the height of WP penetration
  - Sample the waste form characteristics and determine whether this fuel can yield a criticality event

Probability of Critical Configurations: Methodology and Modeling Approach

- DOE modeling - internal (cont.)
  - Sample the degradation rates of the waste form and the internal components of the WP, accounting for correlations
  - Calculate the amounts of material remaining in the WP using the configuration generator code or detailed calculations of a commercial geochemistry code
  - Test whether the k_{eff} of the configuration exceeds the critical limit
  - Increment time repeat prior two steps until a time limit is reached or a hole develops in the bottom of the WP

Probability of Critical Configurations: Methodology and Modeling Approach

- DOE modeling - external
  - Sample flow rate, concentration of fissile materials, and pH of the water flowing out of the WP, accounting for correlations as necessary
  - Sample the external path leading to an external criticality location, transport parameters, and accumulation parameters
  - Calculate the amounts of fissionable material removed from the flow
  - Evaluate the k_{eff} of configurations having a significant accumulation of fissionable material using a regression equation

Probability of Critical Configurations : Methodology and Modeling Approach

- RAI responses included:
  - Description of the procedure that will be taken if intermediate steps cannot materialize (sufficiently accurate regression fit cannot be found)
  - DOE indicated that corrosion rates used in the LA will be based primarily on laboratory data to avoid excessive reliance on expert elicitation
  - Additional clarifications

Probability of Critical Configurations : Methodology and Modeling Approach

- NRC staff evaluation based on:
  - TSPAI IRSR
  - CLST IRSR
  - ENFE IRSR
  - RT IRSR
- NRC staff accepts the use of the Monte Carlo technique to determine the probability of critical conditions
- NRC staff accepts the use of data reviewed and accepted during the review of TSPA-LA, provided:
  - Correlations among parameters are accounted for
  - DOE demonstrates that ranges from the TSPA are not conservative estimates for the calculation of dose, but non-conservative for criticality calculations

Probability of Critical Configurations: Validation Approach

- DOE requested acceptance of the validation process for the probability calculation that will be implemented by the Monte Carlo probability calculation methodology

- DOE approach: Verify that the code used to calculate the probability is performing the calculations and sampling from the input parameter distributions properly using:
  - Hand calculations
  - A commercial mathematical equation solver

Probability of Critical Configurations: Validation Approach

- NRC evaluation based on:
  - CLST IRSR
  - TSPAI IRSR

- NRC staff finds that the proposed methodology for validation of the Monte Carlo code is acceptable provided that a sufficient number of these calculations are conducted to demonstrate that the code is performing the calculations properly across the range of the sampled parameters