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Table of Contents:

1. Purpose

This analysis is prepared by the Mined Geologic Disposal System (MGDS) Waste Package Development Department (WPDD) in response to a request received via a QAP-3-12 Design Input Data Request(Reference 5.1) from Waste Acceptance, Storage, & Transportation (WAST) Design (formerly MRS/MPC Design). This design analysis is an answer to the Design Input Data Request to provide:

> *8) Specific requirements for long-term criticality control.*

The time period for long-term criticality control requirements encompass the time phases of operations (pre-closure), containment (first 1,000 years post-closure), and isolation (the time period beyond the containment phase, at least to 10,000 years post-closure). The purpose and objective of this analysis is to provide specific long-term disposal criticality control requirements for the Multi-Purpose Canister (MPC) Subsystem Design Procurement Specification (DPS), so as to not preclude MPC compatibility with disposal in the MGDS.(References 5.2, 5.3, and 5.4) The response is stated in Section 8 herein and will be available for transmittal as an attachment to a QAP-3-12 Design Input Data Transmittal.

2. Quality Assurance

The Quality Assurance (QA) program applies to this analysis (activity). The information in this analysis concerning disposal long-term criticality control for the MPC will be used to form requirements which will be used in the MPC DPS. This activity can affect the proper functioning of the Mined Geologic Disposal System (MGDS) MPC waste package; the waste package has been identified as an MGDS Q-List item important to safety and waste isolation (Reference 5.5). The waste package is on the Q-List by direct inclusion by the Department of Energy (DOE), without conducting a QAP-2-3 evaluation. The work performed for this analysis is covered by a Waste Package Development (WPD) QAP-2-0 work control Activity Evaluation entitled "MPC Design Compatibility with the MGDS" (Reference 5.6). The QAP-2-0 evaluation determined that such activities are subject to Quality Assurance Requirements and Description (QARD) (Reference 5.7) requirements. Applicable procedural controls are listed in the evaluation.

3. Method

The procedure followed for this document consisted of the following:

A. Reading the request for design data input and supporting background information.(References 5.1, 5.2, and 5.3)
B. Identifying the items important to long-term disposal criticality control.
C. Writing justifications for MGDS requirements for the MPC DPS.(Reference 5.4)
D. Updating the data for design input data transmittal with any new information.

4. Design Inputs

4.1 Design Parameters

Not applicable.

4.2 Criteria

This design analysis provides the repository disposal criticality control design criteria for MPCs, based upon criteria from requirements documents. The TBD associated with 4.2.5 will not be carried forward based on the rationale that the conclusions derived by this analysis are conservative bounding requirements. The criteria cited in requirement documents that have bearing on this analysis include:

4.2.1 From the MGDS-Requirements Document (RD) (Reference 5.8);

"**3.2.2.6 Criticality Protection**

A. All systems for processing, transporting, handling, storing, retrieving, emplacing, and isolating radioactive waste shall be designed to ensure that a nuclear criticality accident is not possible unless at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. Each system shall be designed for criticality safety under normal and accident conditions. The calculated effective multiplication factor (k_{eff}) must be sufficiently below unity to show at least a 5% margin, after allowance for the bias in the method of calculation and the uncertainty in the experiments used to validate the methods of calculation. [10CFR60.131(b)(7)]"

4.2.2 From the MGDS-RD (Reference 5.8);
"**3.2.3.2.3 MGDS-Transportation Interface Requirements**

...

M. The waste package design shall interface with the MPC design to ensure compliance with the nuclear criticality requirements specified in Section 3.2.2.6 of this MGDS-RD. [10CFR60.131(b)(7)] [CRD 3.2.2.5]

The MPC design is responsible for maintaining the SNF subcritical under normal and accident conditions."

4.2.3 From the MGDS-RD (Reference 5.8);
"**3.7.3.3 Waste Package Requirements** ...

B. **Integrity.** ...

3. The waste package design shall ensure loaded wastes are maintain subcritical in compliance with the nuclear criticality requirements specified in Section 3.2.2.6 of this MGDS-RD. [10CFR60.131(b)(7)] [CRD 3.2.2.5]"

4.2.4 From the Engineered Barrier Design (EBD)-RD (Reference 5.9);
"**3.2.2.6 CRITICALITY PROTECTION**

A. The Engineered Barrier Segment shall be designed to ensure that a nuclear criticality accident is not possible unless at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. Each system shall be designed for criticality safety under normal and accident conditions. The calculated effective multiplication factor must be sufficiently below unity to show at least a five percent margin, after allowance for the bias in the method of calculation and the uncertainty in the experiments used to validate the methods of calculation. [MGDS-RD 3.2.2.6.A][10CFR60.131(b)(7)]"

4.2.5 From the EBD-RD (Reference 5.9);
"**3.7.1.3 INTERNAL STRUCTURE REQUIREMENTS**

A. The internal structure shall provide separation of the waste forms such that nuclear criticality shall not be possible unless at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. The calculated effective multiplication factor (k_{eff}) must be sufficiently below unity to show at least a five percent margin after allowance for the bias in the method of calculation and the uncertainty in the experiments used to validate the methods of calculation (TBD). [MGDS-RD 3.2.2.6.A] [10CFR60.131(b)(7)]"

4.2.6 An additional criterion needed to implement the criteria stated in the requirement documents is: Basket materials which are to provide a disposal criticality control function must be long-term performance materials of sufficient thickness to meet the long-term criticality control requirements (i.e., for credit to be taken for the material). In general long-term performance materials are materials which will perform their function (carrying a neutron absorber or separating fuel assemblies) for the required time under the credible range of repository conditions during disposal. The current candidate materials which qualify as long-term performance materials are listed in the design analysis, "Analysis of Key Component Materials Requirements" (Reference 5.12).

4.2.7 In addition to the formal criteria above, an informal criterion is: While meeting the performance criteria and requirements, the costs for waste packages shall be kept as low as reasonably achievable.

4.3 Assumptions

The assumptions, as utilized in section 7 of this analysis, conservatively bound the basis for the design requirements specified in the section 8 conclusions. Consequently, these assumptions will require no additional confirmation. Based on this same rationale, TBV-221-DD associated with Reference 5.10 will not be carried to the output of this analysis.

4.3.1 The regulatory period of disposal criticality control is assumed as 10,000 years. This assumption is based in accordance with 10 CFR 60.131(b)(7) and 40 CFR 191.13(a), and is consistent with DOE's recommendation to the National Academy of Sciences for the repromulgation of the EPA Standard for Yucca Mountain. This assumption is used throughout.

4.3.2 It is assumed that the MPC basket structural and support materials, if they are to provide a disposal criticality control function, need to define the spent fuel assemblies arrangement and the arrangement of any criticality control materials for the disposal regulatory period (10,000 years) or as long as the fuel assemblies remain intact (spacer grids). The basis for this assumption is MGDS requirements (Reference 5.8, 3.2.1.7C) and the knowledge that fuel assemblies are designed to be under-moderated (collapsed fuel assemblies are less reactive than intact assemblies). This assumption is used in sections 4.2 and 7.1.

4.3.3 It is assumed that the neutron absorber, if disposal long-term criticality control credit is to be taken for it, will need to be finely dispersed in a long-term performance carrier material. The level of dispersion will need to be quantified when the material test results become available. The basis for this assumption is engineering and scientific estimates of long-term material performance and the historic neutronics behavior of materials. This assumption is used in section 7.2.

4.3.4 It is assumed that approximately that 25% additional neutron absorber will be required to account for loss over the time period of disposal criticality control under the possible repository conditions, for neutron absorber finely dispersed in a carrier material with long-term performance equivalent or greater than stainless steel. This assumption is only applicable if disposal long-term criticality control credit is to be taken for the material. The basis for this assumption is engineering and scientific estimates of long-term material performance for boron finely dispersed in a stainless steel matrix. This assumption is used in section 4.2 and 7.2.

4.3.5 It is assumed that a 5 year cooling time is appropriate for long-term disposal criticality evaluations using burnup credit. The basis for this assumption is preliminary evaluations of the time effects on criticality potential for intact SNF. This assumption is used in section 7.3.

4.3.6 From the Key assumptions in the MGDS's Controlled Design Assumptions (CDA) Document (Reference 5.10), Key assumption 009 is that the MGDS "Will receive credit for burnup." This assumption is based upon encouraging interactions with the Nuclear Regulator Commission (NRC) staff through the Burnup Credit Committee, chaired by Department of Energy (DOE) Headquarters. This assumption is used in section 7.3.

4.3.7 It is assumed that warm moist/humid conditions will be experienced by some of the emplaced waste packages for significant amounts of time (thousands of years). These conditions are expected to induce significant degradation to the internal components/materials once the outer barriers have been breached. The bases for this assumption is preliminary probabilistic evaluations of waste package/repository conditions and configurations factoring in thermal/geo-hydraulic models of water movement. This assumption is used in section 4.2 and 4.3.

4.3.8 The long-term disposal conditions to be assumed (before the complete disposal criticality analysis methodology is developed) for generating loading curves and performing disposal criticality analysis for MPCs include:

1. Barriers and MPC shell -
   a. The outer and inner containment barriers are assumed to be breached
   b. The MPC shell is assumed to be breached
2. Presence of moderator -
   a. The entire package is assumed to be filled with water (1.0 g/cc)
   b. Water is assumed to be present in the fuel rod pellet-clad gap
3. Credit for the presence of neutron absorber - (if used)
   a. No credit is taken for boron in aluminum carrier materials (Al-B, BORAL™, etc.)
   b. Credit is taken for only 80% of the boron initially loaded into stainless steel (SS-B) carrier materials
   c. Credit is taken for 100% of the hafnium initially loaded into zirconium-hafnium alloys
4. Credit for the structural/spacing provided by the basket materials -
   a. No credit is taken for the presence of materials which can not be demonstrated to have long-term performance in the possible repository conditions (e.g., all aluminum is assumed to have corroded away)

b. All structural welds and/or sensitized region around welds in the MPC baskets are assumed to have failed unless the welds are between long-term performance materials and the welds are made such as to not adversely effect the degradation of the long-term performance material (i.e., material welding temperature limits followed, welding stresses are relieved)
c. Credit will not be taken for basket components providing support or spacing around and between fuel assemblies unless the basket components are made of sufficiently thick long-term performance materials, to last for the regulatory period under repository conditions (e.g., thin fuel cell sleeve material would be assumed to collapsed to the point that they are touching the fuel assembly, flux traps not made from long-term performance material would be assumed to be collapsed)
d. Credit will not be taken for basket components which provide spacing (to establish separative water gaps) around and between fuel assemblies unless the basket components are made of long-term performance materials which span the full length or width of active fuel
e. When basket support or spacing components made of sufficiently thick long-term performance materials depend upon a component not sufficiently thick or made of a long-term performance material (e.g., a spacer bolt not made of long-term performance which provides the support plate spacings in a support plate flux trap design) the component must be assumed to fail and the effect determined (e.g., the failure of the spacer bolt would allow tilting of the support plates which reduces the flux trap spacing and lowers the criticality control potential)

5. Credit for isotopes present in spent fuel (burnup credit) -
   a. The isotopes assumed in spent fuel for disposal burnup credit criticality analyses include: Mo-95, Tc-99, Ru-101, Rh-103, Ag-109, Nd-143, Nd-145, Sm-147, Sm-149, Sm-150, Sm-151, Sm-152, Eu-151, Eu-153, Gd-155, U-233, U-234, U-235, U-236, U-238, Np-237, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Am-241, Am-242m, and Am-243
   b. The isotope concentrations are calculated at 5 years to reflect the earliest time fuel can be accepted and the highest reactivity based upon fuel characteristics
   c. Best estimates are used for the normalization factors (f_{BUC}) (Reference 5.11) to adjust the calculated isotope concentrations to the concentrations measured by radiochemical assays of spent nuclear fuel assemblies (assuming at least 30 samples/assays per isotope)

This group of assumed conditions is based upon system conditions postulated in the preliminary disposal criticality analysis methodology. This assumption is used in Section 4.2, 7.5, and 8.

4.3.9 It is assumed, that to be effective as a criticality control mechanism, moderator displacing filler material (e.g., iron shot) must have access to essentially all free spaces in a loaded waste package and fill up at least 85% of the total free volume of a loaded waste package, with loose as-poured filler bulk density. The free spaces in a loaded MPC consist of the internal unoccupied spaces. The combination of the free spaces make up the free volume. The free volume is defined as the total internal volume of the MPC less displacement volume of all objects therein (e.g., fuel assemblies, basket components) where water can collect. With long-term degradation of materials, any sealed volumes in the basket must also be included as free volume. The basis for this assumption is preliminary evaluations of the criticality control potential of different mixtures of graded (nominally 1 mm in diameter) iron shot. (NOTE: 85% of the volume filled, not 85% of the water displaced) This assumption is used in section 7.6.

4.4 Codes and Standards

Not applicable.

5. References

5.1 CRWMS M&O IOC, from J. B. Stringer to W. D. Schutt, "MPC Design Procurement Specification", CH.MRS.NLS.11/93.081, November 16, 1993, with attachment; QAP-3-12 Design Input Data Request, N. L. Seagle to W. D. Schutt November 13, 1993

5.2 "Multi-Purpose Canister (MPC) Subsystem Design Procurement Specification Requirements Backup Analysis", DI: DBG000000-01717-0200-00001 REV 10, October 5, 1994

5.3 CRWMS M&O IOC, from J. B. Stringer, "MPC System Design Procurement Specification TBVs", VA.DES.JBS.11/94.004, November 2, 1994

5.4 Multi-Purpose Canister (MPC) Subsystem Design Procurement Specification, DI: DBG000000-01717-6300-00001 REV 04, September 1, 1994

5.5 Yucca Mountain Site Characterization Project Q-List, YMP/90-55Q, REV 3, December 1994

5.6 Activity Evaluation, *MPC Design Compatibility with the MGDS*, DI: BB0000000-01717-2200-00003 REV 03, September 5, 1995

5.7 Quality Assurance Requirements and Description (QARD), DOE/RW-0333P Rev 5, October 31, 1995

5.8 Office of Civilian Radioactive Waste Management Mined Geological Disposal System Requirements Document, DOE/RW-0404P, DI: B00000000-00811-1708-00002 REV 01, DCN01, May 1995

5.9 Yucca Mountain Site Characterization Project Engineered Barrier Design Requirements Document, YMP/CM-0024, Rev 0, ICN 1, September 21, 1994

5.10 Controlled Design Assumption Document (TBV-221-DD), DI: B00000000-01717-4600-00032 REV 02, December 19, 1995

5.11 DeHart, M. D. "Sensitivity and Parametric Evaluations of Significant Aspects of Burnup Credit for PWR Spent Fuel Packages", ORNL/TM-12973, June 1995.

5.12 "Analysis of Key Component Materials Requirements", DI: BB0000000-01717-0200-00007 REV 00, CRWMS M&O, March 1996

5.13 Burrus, W. R., "How Channeling Between Chunks Raises Neutron Transmission Through Boral," Nucleonics, **16**, 1, 91 (Jan. 1985).

5.14 "Safety Analysis Report for the NLI-1/2 Spent Fuel Shipping Cask", Rev. 17, Certificate of Compliance No. 9010 (Aug. 1986).

5.15 Wells, A. H.; Marnon, D. R.; and Karam, R. A.; "Criticality effect of Neutron Channeling Between Boron Carbide Granules in Boral for a Spent-Fuel Shipping Cask", Transactions of the American Nuclear Society, Volume 54, TANSAO 54 1-386 ISSN: 0003-018X, June 1987.

5.16 CRWMS M&O IOC, from J. K. McCoy to D. A. Thomas, "Basket materials", M&O Correspondence Number: LV.WP.JKM.01/95.038, January 25, 1995

5.17 Van Konynenburg, R. A.; McCright, R. D.; Roy, A. K.; and Jones, D. A. "Engineered Materials Characterization Report For The Yucca Mountain Site Characterization Project, Volume 2 Design Data", REV 0, December 30, 1994

5.18 "UCF Waste Package Criticality Analysis", DI: BBAA00000-01717-0200-00005 REV 00A, CRWMS M&O, December 1995

5.19 "Analysis of MPC Access Requirements for Addition of Filler Materials", DI: BB0000000-01717-0200-00010 REV 00, CRWMS M&O, March 1996

6. Use of Computer Software

Not applicable.

7. Design Analysis

The analysis lists the items identified as important to long-term disposal criticality control for the MPC, justifications for the requirements in the MPC DPS (Reference 5.4), and an updated set of MGDS design input data to the MPC DPS (Reference 5.4) for clarification. The long-term referred to in this design analysis covers the first 10,000 years after permanent closure of the repository.

The items identified in this design analysis include:

1. Basket Structural and Support Materials
2. Criticality Control Material
3. Burnup Credit
4. Reactor Record Verification Measurements
5. Analyses of MPCs
6. Reactivity Control Additives

7.1 Basket Structural and Support Materials

The first item identified as important to long-term disposal criticality control for MPCs is the basket structural and support materials. The basket structural and support materials will define the geometric arrangement of the spent nuclear fuel (SNF) assemblies and any criticality control material. Ensuring that the SNF assemblies and criticality control materials retain their relative arrangement (fuel assemblies in an array with control material between assemblies) is important for criticality control inside a basket. The basket structural materials are therefore important to criticality control and must be long-term performance materials.

The determination of what basket materials are acceptable is an extensive ongoing process. With the extensive constraints on the basket materials, the MGDS will need to specify what materials are acceptable.(Reference 5.12) The first MGDS disposal criticality control requirement is that the MGDS will specify materials that are acceptable for the MPC basket structural and support material.(Reference 5.12)

7.2 Criticality Control Material

The next item identified as important to long-term disposal criticality control for MPCs is the criticality control material. The criticality control material consists of a neutron absorber and carrier material. The neutron absorber material is important to controlling the neutron flux, and hence criticality. The carrier material is important in maintaining the presence of the neutron absorber material. Two important characteristics of an acceptable disposal criticality control material are: a fine dispersion of the neutron absorber, and the long-term performance of the carrier material.

There are two factors influencing the decision to require a fine dispersion of neutron absorber constituent isotope(s): neutronics performance, and removal concern as a consequence of long-term degradation of the carrier material. The neutronics performance factor is to minimize neutron streaming pathways that would reduce the effectiveness of the neutron absorbing material.(References 5.13, 5.14, and 5.15) Limiting the credit allowed for coarse dispersions has a strong licensing precedence with the NRC.(Reference 5.14) The long-term performance factor is to assure that localized corrosion will not remove the neutron absorber from a large section of the material, as would be the case in a material with a coarse dispersion, such as BORAL™. The fine dispersion will ensure that the loss of the carrier material is proportional to the loss of neutron absorber. This is important in the long-term degradation modeling of the MPC basket for criticality analyses.(Reference 5.16 and 5.17) For credit to be taken for a criticality control material, the neutron absorber must be finely dispersed in an acceptable long-term performance carrier material.(Reference 5.12)

Even with the neutron absorber finely dispersed through the carrier material, a significant amount of neutron absorber material can be removed from the criticality control material. The removal mechanisms will include both depletion by the neutron flux and physical loss/leaching resulting from the degradation and corrosion of the carrier material. Credit will be given for only 80% of the neutron absorber in the as manufactured criticality control material. The amount of credit given is an assumption based upon engineering and scientific estimates of long-term material performance, with some cursory calculations, for boron finely dispersed in a long-term performance stainless steel matrix.

Based upon the criticality control material item, the next MGDS disposal criticality control requirement is that the MGDS will specify that the neutron absorber constituent isotope(s) be finely dispersed in an long-term performance carrier material. The verification of the requirement will require results from the material performance testing program. Such a testing program is currently being pursued, but will not produce any conclusive results for years.

Based upon the removal of neutron absorber material, the MGDS will specify that the MPC have 25% additional neutron absorber material above the analytically determined amount initially required in carrier materials with long-term performance equivalent to stainless steels; the additional neutron absorber is to allow for the removal of neutron absorber material during the time interval of criticality control prescribed (indirectly) in the MGDS-RD. The verification of the requirement will require results from the material performance testing program. Such a testing program is currently being pursued, but will not produce any conclusive results for years.

7.3 Burnup Credit

The next item identified as important to long-term disposal criticality control for MPCs is burnup credit. Burnup credit is advantageous for demonstrating criticality control for storage and transportation, and essential for disposal in the reference repository. The burnup credit methodology in nuclear criticality calculations accounts for the reduced stored energy (lower criticality potential) in SNF, compared to the stored energy (criticality potential) in fresh nuclear fuel. The burnup credit criticality control method allows use of large capacity packages, with a significant cost savings from alternative criticality control methods. Burnup credit, Principal Isotope burnup credit to be precise, is the primary criticality control method planned for the MGDS to meet the long-term criticality control requirements for disposal. (The Principal Isotopes are the primary contributors to criticality potential for disposal.) Without Principal Isotope burnup credit, other more costly and potentially less reliable criticality control methods will need to be employed to meet the long-term criticality control requirements. Burnup credit is considered an essential aspect of the long-term criticality control strategy in the MGDS, especially for large capacity packages.

A Burnup Credit Topical Report has been written by WAST to address the issue of burnup credit for pressurized water reactor (PWR) SNF. The Burnup Credit Topical Report was issued in May 1995 using a lesser degree of burnup credit (actinide only burnup credit) for the MPC. Another topical report will be issued in FY97 which will include a higher degree of burnup credit (actinide and fission product burnup credit). A third topical report will cover burnup credit for boiling water reactor (BWR) SNF. An MGDS Disposal Criticality Analysis Topical Report is planned which will cover the entire disposal criticality analysis process (short and long-term), including the burnup credit methodology. The current schedules have the final release of the Disposal Criticality Analysis Topical Report in FY98.

The long-term evaluations, using burnup credit methodologies, have shown that the criticality potential of SNF changes with cooling time out of a reactor (Reference 5.18). The criticality potential of SNF is initially decreasing with time out to approximately 200 years, before increasing out to approximately 20,000 years, and then generally decreasing from that time on. Initial evaluations have indicated that the criticality potential at the out year peak (~20,000 years) is lower than the criticality potential at 5 years. To conservatively bound the criticality potential evaluations, the SNF cooling time used in burnup credit evaluations should be 5 years.

Evaluations have shown that the burnup credit methodology is important for disposal packages. The MGDS will require that MPCs be analyzed for criticality control using an approved burnup credit methodology for 5 year cooled SNF.

7.4 Reactor Record Verification Measurements

The next item identified as important to long-term disposal criticality control for MPCs is the requirement for reactor record verification measurements. To use burnup credit in a waste package (uncanistered fuel (UCF) or MPC), the fuel assemblies' burnups must be known. Records of calculated burnups from incore instrument measurements are kept for every assembly in every commercial power reactor. The NRC has indicated a reluctance to accept these reactor records of burnups without verification. Therefore, the reactor records of all types of fuel assemblies (PWR and BWR) in all types of basket designs (burnup credit and flux trap) must be verified with a measurement. These reactor record verification measurements are anticipated to be required at least until the NRC becomes confident in the accuracy of the data in the reactor records. This issue comes from the fact that by using alternative control measures, burnup credit is not necessary for criticality control of some

SNF (BWR in particular) during storage and transportation, but verification measurements will be required for all assemblies to use burnup credit for disposal.

Verification of reactor records is required for burnup credit and also enhances MGDS licensing flexibility. The MGDS will require that the burnup of all SNF assemblies (PWR and BWR) to be loaded into MPCs be verified with a NRC approved measurement. The requirement for verification measurements does not affect the design of MPCs, only the loading requirements.

7.5 Analyses of MPCs

The next item identified as important to long-term disposal criticality control for MPCs is the analysis of MPCs for determining their acceptability for disposal and for determining what fuel can be loaded into them for disposal. In order to perform long-term disposal criticality analysis or generate loading curves, conditions for the waste package and repository environment need to be known. Since the conditions are not presently known and the methodology to establish conditions is still being developed, long-term conditions need to be assumed in the interim for the analyses of MPCs for disposal. The waste package conditions to be assumed (before the disposal criticality analysis methodology is developed) for generating loading curves and performing long-term criticality analysis for disposal consider the waste package barriers and MPC shell, the presence of moderator, the presence of neutron absorber, credit for the structural/spacing provided by the basket materials, and credit for the isotopes in the spent fuel.

7.5.1 Barriers and Shell

Due to long-term corrosion, the disposal container's outer and inner containment barriers are assumed to be breached. The MPC shell is also assumed to be breached.

7.5.2 Presence of Moderator

With the barriers breached the entire package is assumed to be filled and surrounded (by at least 30 cm) by water (1.0 g/cc). Water is also assumed to have filled the pellet-clad gap in the fuel rods (fuel rod cladding breached).

7.5.3 Credit for the Presence of Neutron Absorber

For the long-term, no credit is taken for the presence of boron in aluminum carrier materials (Al-B, BORAL™, etc.). Credit is taken for only 80% of the boron initially loaded into stainless steel (SS-B) carrier materials. Credit is taken for 100% of the hafnium initially loaded into zirconium-hafnium alloys.

7.5.4 Credit for the Structural/Spacing Provided by the Basket Materials

Credit can not be taken for the presence of materials which are not long-term performance materials (Reference 5.12) (e.g., no credit is taken for the presence of aluminum). All structural welds and/or sensitized region around welds in the MPC baskets are assumed to have failed unless the welds are between long-term performance materials and the welds are made such as to not adversely effect the degradation of the long-term performance material (i.e., material welding temperature limits followed, welding stresses are relieved). Individual basket designs must be evaluated to determine their ability to contribute to the criticality control function for the required period of time. The particular type of basket design will determine how important a contribution they make to criticality control (only some what for a "burnup credit" basket, but very important for a flux trap design).

Particular designs will need to be examined to determine the potential degraded states for that design. Burnup credit and neutron absorber credit basket designs, with baskets made up of thin fuel cell sleeve around each fuel, would be evaluated for the collapse of the fuel cell opening. In most cases the fuel cell openings in burnup credit/neutron absorber credit baskets would be assumed to be collapsed to the point that the walls of the fuel cell sleeve are touching the fuel assembly.

Flux trap design have components which provide separative gaps between fuel assemblies. The degradation of all the components that work to provide the separative gaps would be evaluated. The likely degraded state of a flux trap basket would be the collapse of the separative gap.

When evaluating the structural and support portions of designs for long-term disposal criticality control, certain rules of what credit can be assumed are applied. Credit can not be taken for basket components providing support or spacing around and between fuel assemblies unless the basket components are made of sufficiently thick long-term performance materials, to last for the regulatory period under repository conditions (e.g., thin fuel cell sleeve material would be assumed to collapsed to the point that they are touching the fuel assembly, flux traps not made from long-term performance material would be assumed to be collapsed). Credit can not be taken for basket components which provide spacing (to establish separative water gaps) around and between fuel assemblies unless the basket components are made of long-term performance materials which span the full length or width of active fuel. When basket support or spacing components made of sufficiently thick long-term performance materials depend upon a component not sufficiently thick or made of a long-term performance material (e.g., a spacer bolt not made of long-term performance which provides the support plate spacings in a support plate flux trap design) the component must be assumed to fail and the effect determined (e.g., the failure of the spacer bolt would allow tilting of the support plates which reduces the flux trap spacing and lowers the criticality control potential).

7.5.5 Credit for Isotopes Present in Spent Fuel (burnup credit)

The isotopes present in spent fuel change with time. The isotopes assumed in spent fuel for disposal burnup credit criticality analyses include: Mo-95, Tc-99, Ru-101, Rh-103, Ag-109, Nd-143, Nd-145, Sm-147, Sm-149, Sm-150, Sm-151, Sm-152, Eu-151, Eu-153, Gd-155, U-233, U-234, U-235, U-236, U-238, Np-237, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Am-241, Am-242m, and Am-243. The isotopes assumed are referred to collectively as the Burnup Credit Principal Isotopes. The isotope concentrations are calculated at 5 years to reflect the earliest time fuel can be accepted and the highest reactivity based upon fuel characteristics. Best estimates are used for the normalization factors (f_{BUC}) (Reference 5.11) to adjust the calculated isotope concentrations to the concentrations measured by radiochemical assays of spent nuclear fuel assemblies (assuming at least 30 samples/assays per isotope).

The MGDS will require that MPCs be analyzed for criticality control under the conditions described above, when determining the acceptability of designs for disposal or for generating loading curves. Formal verification of this requirement would require the results of material performance testing currently being pursued. However, conclusive results would not be available for years.

7.6 Reactivity Control Additives

The final item identified as important to long-term disposal criticality control for MPCs is reactivity control additives. Reactivity control additives in the form of moderator-displacing filler materials or disposal control rod assemblies (DCRAs) are considered as a contingency plan, in case an MPC preferred criticality control measure is deemed unsuitable or insufficient (e.g., unacceptable materials, insufficient degree of burnup credit) for disposal.

The MGDS will require that the MPC design not preclude the addition of a moderator displacing filler material or DCRAs.(Reference 5.19) The addition of DCRAs or sufficient moderator displacing filler material for criticality control must not be precluded by the MPC internal basket design (this includes all structural and support components inside the MPC shell).(Reference 5.19) The MPC DPS (Reference 5.4) already includes a requirement for a plan to open and reseal the MPC. A companion analysis (Reference 5.19) goes into more detail concerning the MPC internal design restrictions for access requirements for the addition of filler materials.

The operational considerations for adding a filler material are of concern for verifying the feasibility of this concept. A testing program scheduled for FY96 will help resolve the filler material issue. The criteria for achieving the addition of sufficient filler material is assumed to be access to essentially all free spaces in the MPC and filling at least 85% of the free volume inside a loaded package oriented vertically with loose as-poured filler bulk density. This criteria is based upon the selection of graded iron shot (nominally 1 mm diameter) as the filler material. The material used as a filler affects the actual water displacement required.

The iron in the iron shot absorbs some neutrons, so the amount of water that needs to be displaced for criticality control is reduced.

8. Conclusions

The information provided in this design analysis gives the specific design requirements for repository long-term disposal criticality control for the MPC, so as to not preclude MPC compatibility with the MGDS. Based on the rationale that this analysis specifies conservative bounding requirements, further confirmation will not be required. The analysis is prepared in concert with Reference 5.12.

The specific requirements for disposal criticality control for an MPC are shown below. The specific requirements for long-term criticality control are:

a) The MGDS will specify materials which are acceptable for the MPC basket materials (i.e., structural, support, criticality control),

b) The MGDS will specify that the neutron absorber constituent isotope(s) be finely dispersed in a long-term performance carrier material,

c) The MGDS will specify that the MPC have 25% additional neutron absorber material above the analytically determined amount initially required, for carrier materials with long-term performance at least equivalent to stainless steels, if used for disposal criticality control; the additional neutron absorber is to allow for the removal of neutron absorber material during the time interval of disposal criticality control,

d) The MGDS will require that MPCs be analyzed for criticality control using an approved burnup credit methodology for 5 year cooled SNF,

e) The MGDS will require that MPCs be analyzed for disposal criticality control performance and for generating loading curves under the following long-term disposal conditions (until the disposal criticality analysis methodology is developed and approved):
   1. Barriers and MPC shell -
      a. The outer and inner containment barriers are assumed to be breached
      b. The MPC shell is assumed to be breached
   2. Presence of moderator -
      a. The entire package is assumed to be filled with water (1.0 g/cc)
      b. Water is assumed to be present in the fuel rod pellet-clad gap
   3. Credit for the presence of neutron absorber - (if used)
      a. No credit is taken for boron in aluminum carrier materials (Al-B, BORAL™, etc.)
      b. Credit is taken for only 80% of the boron initially loaded into stainless steel (SS-B) carrier materials

   c. Credit is taken for 100% of the hafnium initially loaded into zirconium-hafnium alloys
4. Credit for the structural/spacing provided by the basket materials -
   a. No credit is taken for the presence of materials which can not be demonstrated to have long-term performance in the possible conditions (e.g., all aluminum is assumed to have corroded away)
   b. All structural welds and/or sensitized region around welds in the MPC baskets are assumed to have failed unless the welds are between long-term performance materials and the welds are made such as to not adversely effect the degradation of the long-term performance material (i.e., material welding temperature limits followed, welding stresses are relieved)
   c. Credit will not be taken for basket components providing support or spacing around and between fuel assemblies unless the basket components are made of sufficiently thick long-term performance materials, to last for the regulatory period under repository conditions (e.g., thin fuel cell sleeve material would be assumed to collapsed to the point that they are touching the fuel assembly, flux traps not made from long-term performance material would be assumed to be collapsed)
   d. Credit will not be taken for basket components which provide spacing (to establish separative water gaps) around and between fuel assemblies unless the basket components are made of long-term performance materials which span the full length or width of active fuel
   e. When basket support or spacing components made of sufficiently thick long-term performance materials depend upon a component not sufficiently thick or made of a long-term performance material (e.g., a spacer bolt not made of long-term performance which provides the support plate spacings in a support plate flux trap design) the component must be assumed to fail and the effect determined (e.g., the failure of the spacer bolt would allow tilting of the support plates which reduces the flux trap spacing and lowers the criticality control potential)
5. Credit for isotopes present in spent fuel (burnup credit) -
   a. The isotopes assumed in spent fuel for disposal burnup credit criticality analyses include: Mo-95, Tc-99, Ru-101, Rh-103, Ag-109, Nd-143, Nd-145, Sm-147, Sm-149, Sm-150, Sm-151, Sm-152, Eu-151, Eu-153, Gd-155, U-233, U-234, U-235, U-236, U-238, Np-237, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Am-241, Am-242m, and Am-243
   b. The isotope concentrations are calculated at 5 years to reflect the earliest time fuel can be accepted and the highest reactivity based upon fuel characteristics
   c. Best estimates are used for the normalization factors (f_{BUC}) to adjust the calculated isotope concentrations to the concentrations measured by radiochemical assays of spent nuclear fuel assemblies (assuming at least 30 samples/assays per isotope), and

f) The MGDS will require that the addition of a moderator displacing filler material or disposable control rod assemblies for criticality control not be precluded by the MPC internal basket design (this includes all structural and support components inside the

MPC shell)(for filler material this means access to essentially all free spaces and at least 85% fill of the free volume).

9. Attachments

Not used.