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Non-Q Design Analysis Cover Sheet

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1. PURPOSE

The objective of this analysis is to explore the Westinghouse mixed-oxide (MOX) and Combustion Engineering MOX assembly waste package (WP) resistance to rock fall, slap-down, and two meter drop events. This analysis will be used to evaluate the structural performance of the waste packages. The purpose of this analysis is to document the models and methods used in the calculations. The results of this analysis are not intended to show direct compliance with any design requirements.

2. QUALITY ASSURANCE

There are no Quality Assurance (QA) controls applicable to this analysis. The work reported in this document is part of the Plutonium Disposition support effort being conducted under the purview of Special Studies within the MGDS M&O Systems Engineering office. The work performed for this analysis is covered by a QAP-2-0 analysis, titled *Studies Not Supported by the Office of Civilian Radioactive Waste Management*, generated by the Waste Package Development Group (Ref. 5.11). The QAP-2-0 evaluation determined such activities not to be subject to *Quality Assurance Requirements and Description* (QARD) (Ref. 5.12) requirements. Nevada Site Administrative Line Procedure NAP-MG-013 entitled *Design Analysis for MGDS Products Not Subject to QARD Requirements* was used to prepare this document.

3. METHOD

Basic principles of strain energy and calculations of stress were used to develop correlations between the results obtained from the finite-element analyses of UO₂ spent fuel waste packages and the MOX assembly waste packages.

4. DESIGN INPUTS

4.1 Design Parameters

Westinghouse MOX Pressurized Water Reactor (PWR) fuel assembly mass = 522 kg (Ref. 5.1)

Combustion Engineering MOX PWR fuel assembly mass = 664 kg (Ref. 5.2, p. 69)

UO₂ PWR commercial spent nuclear fuel (SNF) assembly mass = 780 kg (Ref. 5.3)

MOX BWR fuel assembly mass = 303 kg (Ref. 5.2, p. 9)

UO₂ BWR fuel assembly mass = 331.1 kg (Ref. 5.3)

The total MPC WP masses:

21 PWR MPC WP mass = 65,900 kg (Ref. 5.4)

12 PWR MPC WP mass = 47,752 kg (Ref. 5.4)

40 BWR MPC WP mass = 65,463 kg (Ref. 5.4)

24 BWR MPC WP mass = 47,089 kg (Ref. 5.4)

For the two meter drop calculations:

$\sigma_{UO2\ 21\ PWR} = 777\text{ MPa}$ (maximum principal stress in the skirt, Ref. 5.5, p. 30)

$\sigma_{UO2\ 21\ PWR} = 509\text{ MPa}$ (maximum principal stress in the WP body, Ref. 5.5, p. 30)

$\sigma_{UO2\ 24\ BWR} = 1153\text{ MPa}$ (maximum principal stress in the skirt, Ref. 5.5, p. 33)

$\sigma_{UO2\ 24\ BWR} = 417\text{ MPa}$ (maximum principal stress in the WP body, Ref. 5.5, p. 33)

For the slap down calculations:

$\sigma_{UO2\ 21\ PWR} = 397\text{ MPa}$ (maximum principal stress, Ref. 5.10, p. 28)

$\sigma_{UO2\ 24\ BWR} = 305\text{ MPa}$ (maximum principal stress, Ref. 5.10, p. 29)

For the rock fall evaluation:

Critical rock mass for 21 PWR MPC = 32,100 kg (Ref. 5.6, p. 19)

Critical rock mass for 12 PWR MPC = 24,800 kg (Ref. 5.6, p. 19)

Critical rock mass for 40 BWR MPC = 33,200 kg (Ref. 5.6, p. 19)

Critical rock mass for 24 BWR MPC = 25,200 kg (Ref. 5.6, p. 19)

4.2 Criteria

The following criteria are applicable to the design subject; however, it is not the intent of these analyses to show complete compliance or the resolution of the following requirements from the Engineered Barrier Design Requirements Document (EBDRD) (Ref. 5.7):

- 4.2.1 "The Engineered Barrier Segment shall maintain performance under rock-induced loading (TBD)."

[EBDRD 3.7.F]

This requirement is addressed throughout the document by performing analyses of rock falls onto the WP.

- 4.2.2 "The design of waste packages shall include, but not be limited to, consideration of the following factors: solubility, oxidation/reduction reactions, corrosion, hydriding, gas generation, thermal effects, mechanical strength, mechanical stress, radiolysis, radiation damage, radionuclide retardation, leaching, fire and explosion hazards, thermal loads, and synergistic interactions."

[EBDRD 3.7.1.B]

Requirement 3.7.1.B items addressed throughout the document are considerations of mechanical strength and mechanical stress.

- 4.2.3 “The waste package shall contribute to limiting the dispersal of radioactive waste materials in the event of accidents or other dynamic effects.”

[EBDRD 3.7.1.H]

The dynamic effects of the rock fall, two meter drop, and slap down events on the WP are analyzed and addressed throughout this document.

- 4.2.4 “The waste form shall be capable of withstanding a drop of (TBD) onto a flat, essentially unyielding surface without breaching.”

[EBDRD 3.7.1.1.F]

The structural evaluations of the two meter drop event are performed for the WP and presented throughout this document.

- 4.2.5 “The container shall contain the radioactive waste materials during all normal handling and emplacement operations and, in the event of accidents or other dynamic effects, contribute to limiting dispersal of the waste. The container shall also have the mechanical integrity to sustain routine handling and transportation loads (TBD).”

[EBDRD 3.7.1.2.A]

The dynamic effects of the rock fall, two meter drop, and slap down events on the WP are analyzed and addressed throughout this document.

- 4.2.6 “The internal structure of the waste package shall be configured to accommodate the spent fuel waste form, provide mechanical stability of the waste form, and facilitate loading of the waste form into the waste package.”

[EBDRD 3.7.1.3.B]

With regard to Requirement 3.7.1.3.B, the internal structure of the WP is analyzed in this document in order to determine whether or not the internal structure is capable of providing the mechanical stability of the waste form. This requirement is addressed throughout the document.

4.3 Assumptions

In the course of developing this document, several assumptions were made regarding the rock fall, two meter drop, and slap down analyses. These assumptions along with the assumptions contained in the Controlled Design Assumptions (CDA) Document (Ref. 5.8) (TBV-221-DD) are identified below.

The relevant assumptions from the CDA (Ref. 5.8) are as follows:

Assumption Identifier: Key 011

Subject: Horizontal In-Drift Emplacement

Waste packages will be emplaced in-drift in a horizontal mode.

Assumption Identifier: EBDRD 3.7.F

Subject: Rock-Induced Waste Package Loading

The waste package must be able to withstand a uniform external pressure of 0.50 MPa and a dynamic load of 50 kN and still maintain structural integrity.

Assumption Identifier: EBDRD 3.7.1.1.F **Subject:** Waste Package Drop Tolerance

The waste package, after being sealed, shall be capable of withstanding a 2-m drop onto a flat, essentially unyielding surface without breaching.

Assumption Identifier: EBDRD 3.7.1.3.D **Subject:** Waste Package Internal Structure Loads

For ACD, the loads imposed on the internal structure are similar to the waste package loads.

- Static load of 25,000 N, handling.
- Withstand a drop of 2 m.

All assumptions identified in this section will require verification (or superseding assumptions) as the waste package design proceeds and should be treated as TBV items for preliminary design.

4.3.1 For conservatism, it is assumed that all of the kinetic energy of the WP is stored in the WP in terms of the strain energy. Furthermore, the floor surface is essentially unyielding, so the deflection of the surface is very small compared to the deflection on the WP. This assumption is used in Section 7.

4.3.2 Because of similar mass, size, and stiffness, the resulting stress on the 12 PWR MPC is assumed to be the same as 24 BWR MPC. A similar assumption is also made for the results of 21 PWR MPC which can be used for the 40 BWR MPC. This assumption is used in Section 7.

4.4 Codes and Standards

N/A. There are no codes and standards used in this document.

5. REFERENCES

- 5.1 *Plutonium Disposition in Existing Pressurized Water Reactors*, DOE/SF/19683-6, DOE-AC03-93SF19683, Westinghouse Electric Corporation, Pittsburgh, PA, June 1, 1994, Appendix A, p. A-1.
- 5.2 Reference Spent Fuel Characteristics for Plutonium Disposition Reactors Rev.0, O. W. Hermann, et al., ORNL/MD/LTR-6, Oak Ridge National Laboratory Letter Report, Jan 24, 1995.
- 5.3 *Multi-Purpose Canister Issue Evaluation*, Concurrence by MPC Implementation Team, Issue No. MPC-011, July 20, 1993, CRWMS/M&O.
- 5.4 *Waste Package Sizing Spreadsheet ACD Sizing, Masses, and Costing*, W. Wallin, Interoffice Correspondence LV.WP.WEW.7/95-229, July 14, 1995, CRWMS M&O.
- 5.5 *Scoping Evaluation to Explore - Two Meter Drop Finite-Element Analysis of Multi-Purpose Canister Waste Packages*, Document Identifier (DI) Number: BBA000000-01717-0200-00005 REV 00, CRWMS M&O.
- 5.6 *Scoping Evaluation to Explore - Rock Fall Accident Condition Analysis on Multi-Purpose Canister Waste Packages Correlated from Interlocking Basket Waste Package Design Analysis*, DI Number: BBAB00000-01717-0200-00004 REV 00, CRWMS M&O.
- 5.7 *Engineered Barrier Design Requirements Document*, YMP/CM-0024 Rev. 0, ICN 1, Yucca Mountain Site Characterization Project.
- 5.8 *Controlled Design Assumptions Document*, DI Number: B00000000-01717-4600-00032 REV 03, CRWMS M&O. (TBV-221-DD)
- 5.9 *Mechanics of Materials*, SI Metric Edition, Ferdinand P. Beer and E. Russell Johnston, Jr., McGraw-Hill Ryerson Limited, Toronto, Canada, 1987.
- 5.10 *Scoping Evaluation to Explore - Slap Down Finite-Element Analysis of Multi-Purpose Canister Waste Packages*, DI Number: BBAB00000-01717-0200-00003 REV 00, CRWMS M&O.
- 5.11 *Studies Not Supported by the Office of Civilian Radioactive Waste Management*, DI Number: BB0000000-01717-2200-00035 REV 01, CRWMS M&O .
- 5.12 *Quality Assurance Requirements and Description (QARD)*, DOE/RW-0333P Rev 5.

6. USE OF COMPUTER SOFTWARE

N/A. There is no software used to support this document.

7. DESIGN ANALYSIS

7.1 Effect of the WP Mass on Stress Magnitudes

The result of impact between the WP and the essentially unyielding surface due to a two meter drop or slap down event is a non-uniform distribution of stress on the WP. In order to determine a relation between the stress on the WP containment barriers and the WP mass impacted onto the surface, the concept of kinetic and strain energy can be used. The beam theory suggests that the elastic strain energy stored in a beam is directly proportional to the square of the stress (Ref. 5.9, pp. 474-477). It is also known that the kinetic energy is directly proportional with the mass. Thus, in order to establish a relation between the stress and the mass, the change in the kinetic energy of the WP is to be determined with respect to the strain energy stored in the WP due to impact.

The potential energy of the WP is converted into kinetic energy by the time it falls to the essentially unyielding surface. Assuming that all of the kinetic energy of the WP is spent deflecting the containment barriers, which is a conservative approach, strain energy stored in the barriers will be equal to the kinetic energy of the WP (see Assumption 4.3.1). Hence, as a result of the previously described relations of strain and kinetic energy with the magnitudes of stress and mass, respectively, the stress on the WP is determined to be directly proportional to the square root of the WP mass. This relation can be expressed as follows:

$$\sigma \propto (\text{waste package mass})^{1/2}$$

7.2 WP Description and Mass Calculations

The MPC basket assembly is the same for both the MOX and UO₂ spent fuels. The basket structure consists of square tubes to accommodate most varieties of commercial SNF assemblies. The central tubes are enclosed on all four sides by aluminum boron (Al-B) for heat transfer and criticality control. The outermost tubes have Al-B on only three sides, with the side oriented towards the basket periphery uncovered. The basket assembly is supported by structural angles and enclosed in the MPC shell. The MPC is placed in a disposal container which consists of inner and outer barriers.

Three different fuel assembly masses are considered in the structural evaluations of the waste packages including the PWR fuel assemblies: Westinghouse MOX PWR, Combustion Engineering MOX PWR, and a design basis UO₂ PWR. The total masses of the Westinghouse

and Combustion Engineering MOX PWR fuel assemblies are 522 kg and 664 kg, respectively. The corresponding mass used in the MPC commercial SNF finite-element models was 780 kg (see Section 4.1). Table 7-1 shows assembly and total package (for the large, 21 assembly package) masses for these fuel assemblies. The total fuel masses are calculated by multiplying each assembly mass by 21.

The total package mass of UO₂ 21 PWR MPC WP was given as 65,900 kg (see Section 4.1). The corresponding masses of the other two waste packages are calculated as follows:

$$\begin{aligned} \text{Difference between the design basis and Westinghouse fuel assembly masses} &= 780 - 522 \\ &= 258 \text{ kg} \end{aligned}$$

$$\text{Westinghouse MOX PWR total package mass} = 65,900 - (258) \cdot (21) = 60,482 \text{ kg}$$

$$\begin{aligned} \text{Difference between the design basis and} &= 780 - 664 = 116 \text{ kg} \\ \text{Combustion Engineering fuel assembly masses} & \end{aligned}$$

$$\text{Combustion Engineering MOX PWR total package mass} = 65,900 - (116) \cdot (21) = 63,464 \text{ kg}$$

Table 7-1. 21 PWR MPC Mass Comparisons

	Westinghouse MOX PWR	Combustion Engineering MOX PWR	UO ₂ PWR
Assembly Mass (kg)	522	664	780
Total Fuel Mass (kg)	10,962	13,944	16,380
Total Package Mass (kg)	60,482	63,464	65,900

Table 7-2 shows assembly and total package (for the small, 12 assembly package) masses for the fuel assemblies. The total fuel masses are calculated by multiplying each assembly mass by 12.

The total package mass of UO₂ 12 PWR MPC WP was given as 47,752 kg (see Section 4.1). The corresponding masses of the other two waste packages are calculated as follows:

$$\text{Westinghouse MOX PWR total package mass} = 47,752 - (258) \cdot (12) = 44,656 \text{ kg}$$

$$\text{Combustion Engineering MOX PWR total package mass} = 47,752 - (116) \cdot (12) = 46,360 \text{ kg}$$

Table 7-2. 12 PWR MPC Mass Comparisons

	Westinghouse MOX PWR	Combustion Engineering MOX PWR	UO ₂ PWR
Assembly Mass (kg)	522	664	780
Total Fuel Mass (kg)	6,264	7,968	9,360
Total Package Mass (kg)	44,656	46,360	47,752

Two different fuel assembly masses are considered in the structural evaluations of the waste packages including the BWR fuel assemblies: MOX BWR and a design basis UO₂ PWR. The total masses of these fuel assemblies are 303 kg and 331.1 kg, respectively (see Section 4.1).

The total package mass of UO₂ 40 BWR MPC WP was given as 65,463 kg (see Section 4.1).

$$\begin{aligned}\text{Difference between the UO}_2 \text{ and MOX BWR fuel assembly masses} &= 331.1 - 303 \\ &= 28.1 \text{ kg}\end{aligned}$$

The corresponding mass of the MOX BWR waste package is calculated as follows:

$$\begin{aligned}\text{MOX BWR (placed into 40 BWR MPC) total package mass} &= 65,463 - (28.1) \times (40) \\ &= 64,339 \text{ kg}\end{aligned}$$

The total package mass of UO₂ 24 BWR MPC WP was given as 47,089 kg (see Section 4.1).

The corresponding mass of the MOX BWR waste package is calculated as follows:

$$\begin{aligned}\text{MOX BWR (placed into 24 BWR MPC) total package mass} &= 47,089 - (28.1) \times (24) \\ &= 46,415 \text{ kg}\end{aligned}$$

7.3 Rock Fall Analysis

The MOX and the UO₂ fuel assembly waste packages are identical in all respects, except the weight of their contents. Since the static load on the waste packages due to gravitational acceleration is negligibly smaller than the dynamic impact load due to a rock fall, the waste packages with either fuel assembly type will have the same performance in response to the rock fall event. The following critical rock masses for a rock fall height of 8.4 m are, therefore, obtained from Ref. 5.6:

Critical rock mass for 21 PWR MPC = 32,100 kg (see Section 4.1)

Critical rock mass for 12 PWR MPC = 24,800 kg (see Section 4.1)

Critical rock mass for 40 BWR MPC = 33,200 kg (see Section 4.1)

Critical rock mass for 24 BWR MPC = 25,200 kg (see Section 4.1)

7.4 Two meter Drop Analysis

The two meter drop event has been analyzed for both large and small SNF waste packages. To avoid unnecessary duplication only one ANSYS model was built for each of the large and the small waste packages. In particular, the cases chosen for analysis were the large PWR (21 assemblies) waste package and the small BWR (24 BWR assemblies), which is approximately the same size and mass as the 12 PWR assembly waste package. For both cases, ANSYS was run for each of the UO₂ and the maximum principal stresses were thereby determined (Ref. 5.5) (Assumption 4.3.2). The corresponding maximum principal stresses for the Westinghouse and Combustion Engineering MOX PWR were determined by scaling the UO₂ maximum principal stresses according to package weight as follows:

$\sigma \propto (\text{waste package mass})^{1/2}$ (see Section 7.1)

$\sigma_{\text{UO}_2 \text{ 21 PWR}} = 777 \text{ MPa}$ (maximum principal stress in the skirt, see Section 4.1)

$\sigma_{\text{UO}_2 \text{ 21 PWR}} = 509 \text{ MPa}$ (maximum principal stress in the WP body, see Section 4.1)

$\sigma_{\text{UO}_2 \text{ 24 BWR}} = 1158 \text{ MPa}$ (maximum principal stress in the skirt, see Section 4.1)

$\sigma_{\text{UO}_2 \text{ 24 BWR}} = 417 \text{ MPa}$ (maximum principal stress in the WP body, see Section 4.1)

Thus, for the Westinghouse MOX PWR fuel assemblies:

For the 21 PWR MPC:

$\sigma_{\text{Westinghouse MOX PWR}} / \sigma_{\text{UO}_2 \text{ 21 PWR}} = (m_{\text{Westinghouse MOX PWR}} / m_{\text{UO}_2 \text{ 21 PWR}})^{1/2}$

$\sigma_{\text{Westinghouse MOX PWR}} = 777 * (60,482 / 65,900)^{1/2} = 744 \text{ MPa}$ (stress in the skirt)

$\sigma_{\text{Westinghouse MOX PWR}} = 509 * (60,482 / 65,900)^{1/2} = 488 \text{ MPa}$ (stress in the WP body)

For the 12 PWR MPC:

$\sigma_{\text{Westinghouse MOX PWR}} / \sigma_{\text{UO}_2 \text{ 24 BWR}} = (m_{\text{Westinghouse MOX PWR}} / m_{\text{UO}_2 \text{ 24 BWR}})^{1/2}$

$\sigma_{\text{Westinghouse MOX PWR}} = 1158 * (44,656 / 47,089)^{1/2} = 1128 \text{ MPa}$ (stress in the skirt)

$\sigma_{\text{Westinghouse MOX PWR}} = 417 * (44,656 / 47,089)^{1/2} = 406 \text{ MPa}$ (stress in the WP body)

For the Combustion Engineering (C. E.) MOX fuel assemblies:

For the 21 PWR MPC:

$\sigma_{\text{C. E. MOX PWR}} / \sigma_{\text{UO}_2 \text{ 21 PWR}} = (m_{\text{C. E. MOX PWR}} / m_{\text{UO}_2 \text{ 21 PWR}})^{1/2}$

$\sigma_{\text{C. E. MOX PWR}} = 777 * (63,464 / 65,900)^{1/2} = 763 \text{ MPa}$ (stress in the skirt)

$\sigma_{\text{C. E. MOX PWR}} = 509 * (63,464 / 65,900)^{1/2} = 500 \text{ MPa}$ (stress in the WP body)

For the 12 PWR MPC:

$\sigma_{\text{C. E. MOX PWR}} / \sigma_{\text{UO}_2 \text{ 24 BWR}} = (m_{\text{C. E. MOX PWR}} / m_{\text{UO}_2 \text{ 24 BWR}})^{1/2}$

$\sigma_{\text{C. E. MOX PWR}} = 1158 * (46,360 / 47,089)^{1/2} = 1149 \text{ MPa}$ (stress in the skirt)

$\sigma_{\text{C. E. MOX PWR}} = 417 * (46,360 / 47,089)^{1/2} = 414 \text{ MPa}$ (stress in the WP body)

The results are summarized in Table 7-3.

Table 7-3. Maximum Principal Stresses (MPa) in the outer barrier
(ultimate tensile strength 515 MPa, Ref. 5.5) resulting from two meter drop

Package type and stress location	Westinghouse MOX PWR	Combustion Engineering MOX PWR	UO ₂ PWR
21 PWR, skirt	744	763	777
21 PWR, body	488	500	509
12 PWR*, skirt	1128	1149	1158
12 PWR*, body	406	414	417

* Simulated by the 24 BWR package which is approximately the same size and mass (Assumption 4.3.2)

These results clearly show that, for all three waste packages, the maximum principal stress will exceed the ultimate tensile strength (515 MPa) of the outer barrier in the package skirt, but not in the package body. Although the lower weight of the MOX PWR waste packages result in lower maximum principal stresses than for the UO₂ PWR waste package, the waste package damage from the two meter drop is the same for all cases. In all of the three waste packages the skirt failure is acceptable because a failure in this region will not cause loss of radionuclide containment.

The MOX BWR waste package (placed into 40 BWR MPC) has also been designed to comply with the two meter drop test. The results of the MOX BWR are correlated from the simulation of 21 PWR MPC which is approximately the same size and mass with 40 BWR MPC:

$$\sigma_{\text{MOX BWR}} / \sigma_{\text{UO}_2 \text{ 21 PWR}} = (m_{\text{MOX BWR}} / m_{\text{UO}_2 \text{ 21 PWR}})^{1/2}$$

$$\sigma_{\text{MOX BWR}} = 777 * (64,339 / 65,900)^{1/2} = 768 \text{ MPa (stress in the skirt)}$$

$$\sigma_{\text{MOX BWR}} = 509 * (64,339 / 65,900)^{1/2} = 503 \text{ MPa (stress in the WP body)}$$

The results of the two meter drop test for BWR fuel assembly waste packages are presented in Table 7-4. The maximum stress and strain magnitudes were obtained near the outer barrier skirt since the most of the impact energy is absorbed by the skirt in terms of the strain energy.

Table 7-4. Maximum Principal Stress Comparison

	MOX BWR	UO ₂ BWR
Maximum Principal Stress on Package Extension Skirt (MPa)	768	777
Maximum Principal Stress on Package Body (MPa)	503	509

It is determined that there is no material breach or ductile rupture on the package body, which is above the region where the skirt is extended from the outer barrier, because the maximum first principal stress (503 MPa) is less than the ultimate tensile strength of the outer barrier (515 MPa) for this region.

7.5 Slap Down Analysis

For the slap down test the initial waste package orientation is with its axis at an angle of 30° with respect to vertical which results in rotation of the waste package onto its side. The slap-down principal stresses are evaluated using the same methodology as the waste package two meter drop scenario. The maximum principal stresses for the UO₂ fuel assembly MPC configurations are obtained from Ref. 5.10 (see Section 4.1) and used in the following calculations:

Westinghouse MOX PWR fuel assemblies:

For 21 PWR MPC:

$$\sigma_{\text{Westinghouse MOX PWR}} / \sigma_{\text{UO}_2 \text{ 21 PWR}} = (m_{\text{Westinghouse MOX PWR}} / m_{\text{UO}_2 \text{ 21 PWR}})^{1/2}$$

$$\sigma_{\text{Westinghouse MOX PWR}} = 397 * (60,482 / 65,900)^{1/2} = 380 \text{ MPa}$$

For 12 PWR MPC:

$$\sigma_{\text{Westinghouse MOX PWR}} / \sigma_{\text{UO}_2 \text{ 24 BWR}} = (m_{\text{Westinghouse MOX PWR}} / m_{\text{UO}_2 \text{ 24 BWR}})^{1/2}$$

$$\sigma_{\text{Westinghouse MOX PWR}} = 305 * (44,656 / 47,089)^{1/2} = 297 \text{ MPa}$$

For the Combustion Engineering MOX fuel assemblies:

For 21 PWR MPC:

$$\sigma_{\text{C.E. MOX PWR}} / \sigma_{\text{UO}_2 \text{ 21 PWR}} = (m_{\text{C.E. MOX PWR}} / m_{\text{UO}_2 \text{ 21 PWR}})^{1/2}$$

$$\sigma_{\text{C.E. MOX PWR}} = 397 * (63,464 / 65,900)^{1/2} = 390 \text{ MPa}$$

For 12 PWR MPC:

$$\sigma_{\text{C.E. MOX PWR}} / \sigma_{\text{UO}_2 \text{ 24 BWR}} = (m_{\text{C.E. MOX PWR}} / m_{\text{UO}_2 \text{ 24 BWR}})^{1/2}$$

$$\sigma_{\text{C.E. MOX PWR}} = 305 * (46,360 / 47,089)^{1/2} = 303 \text{ MPa}$$

For the MOX BWR fuel assemblies:

For 40 BWR MPC:

$$\sigma_{\text{MOX BWR}} / \sigma_{\text{UO}_2 \text{ 21 PWR}} = (m_{\text{C. E. MOX BWR}} / m_{\text{UO}_2 \text{ 21 PWR}})^{1/2}$$
$$\sigma_{\text{MOX BWR}} = 397 * (64,339 / 65,900)^{1/2} = 392 \text{ MPa}$$

Thus, the maximum stress magnitude is 392 MPa for the MOX BWR as compared with 397 MPa for the UO₂ BWR waste package. This maximum principal stress is located in the skirt of the waste package toward the end that is away from the initial contact point. The maximum tensile stress is less than the ultimate tensile strength (515 MPa) of the outer barrier material. It can, therefore, be concluded that the slap-down accident will not result in a breach of the outer barrier, nor of the skirt, in either case.

8. CONCLUSIONS

The MOX and the UO₂ fuel assembly waste packages are identical in all respects, except the weight of their contents so they will have the same performance in response to the rock fall test. For that reason, the results of the rock fall are identical with the results obtained from the UO₂ fuel assembly MPC configuration finite-element analyses:

Critical rock mass for 21 PWR MPC = 32,100 kg (see Section 4.1)

Critical rock mass for 12 PWR MPC = 24,800 kg (see Section 4.1)

Critical rock mass for 40 BWR MPC = 33,200 kg (see Section 4.1)

Critical rock mass for 24 BWR MPC = 25,200 kg (see Section 4.1)

The remaining standard structural analyses were the two meter drop and the slap-down accidents. The results of the slap down analysis showed that the MOX PWR/BWR waste packages and the UO₂ PWR will pass the test without experiencing any damage. This left the two meter drop as the only one of importance in comparing MOX PWR waste packages and the UO₂ PWR.

The two meter drop test has been analyzed for both the large and small SNF waste packages. To avoid unnecessary duplication only one ANSYS model was built for each of the large and the small waste packages (Ref. 5.5). In particular, the cases chosen for analysis were the large PWR (21 assemblies) waste package and the small BWR (24 BWR assemblies), which is approximately the same size as the 12 PWR assembly waste package. For both cases, ANSYS was run for each of the UO₂ and the maximum principal stresses were thereby determined (Ref. 5.5). The corresponding maximum principal stresses for the Westinghouse and Combustion Engineering MOX fuel assembly waste packages were determined by scaling the UO₂ maximum principal stresses according to package weight.

The results given in Section 7.4 clearly show that, for all waste packages, the maximum principal stress will exceed the ultimate tensile strength (515 MPa) of the outer barrier in the package skirt, but not in the package body. Although the lower weight of the MOX fuel assembly waste packages result in lower maximum principal stresses than for the UO₂ fuel assembly waste

package, the damage from the two meter drop is the same for all cases. It is concluded that the waste package body does not experience failure due to the two meter drop event and in all of the waste packages the skirt failure is acceptable because a failure in this region will not cause loss of radionuclide containment.

9. ATTACHMENTS

N/A. There are no attachments included for this document.