Design Analysis Cover Sheet

Complete only applicable items.

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Page: 1 Of: 21

2. DESIGN ANALYSIS TITLE: Scoping Evaluation to Explore-Rock Fall Accident Condition Analysis on Multi-Purpose Canister Waste Packages Correlated from Interlocking Basket Waste Package Design Analysis (SCPE-THA)

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14. REMARKS
This is an approved SCOPING Design Analysis. The QAP-2-0 Activity Evaluation, "Perform Criticality, Thermal, Structural, and Shielding Scoping Analysis", DI#: BB0000000-01717-2200-00026 REV 01, lists the procedural controls which are required. Therefore, this design analysis is NOT subject to the QAP-3-series procedures and does not require QAP-3-9 signatures. All information contained in this analysis is TBV and has received a technical review only.
### Design Analysis Revision Record

**Complete only applicable items.**

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Document Identifier: BBAB00000-01717-0200-00004 REV 00

Originator: Zekai Ceylan

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Draft Date: December 8, 1995
Waste Package Development
Design Analysis

Title: Scoping Evaluation to Explore - Rock Fall Accident Condition Analysis on Multi-Purpose Canister Waste Packages Correlated from Interlocking Basket Waste Package Design Analysis

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Originator: Zekai Ceylan  Technical Review: Scott M. Bennett
1. Purpose:

The objective of this analysis is to correlate the results of a rock fall analysis performed for the 12 Pressurized Water Reactor (PWR) Fuel Assembly Interlocking Basket waste package (WP) in order to determine the size of rock that can strike the Multi-Purpose Canister (MPC) waste packages without breaching the containment barriers. The purpose of this analysis is to document the models and methods used in the calculations.

2. Quality Assurance:

The quality assurance (QA) program applies to this analysis. The information in this analysis concerning disposal long-term structural parameters for the conceptual MPC WP will be used as a guide as to the possible requirements which might be used in the MPC WP design. The performance of the MPC internals will affect the proper function of the waste package and the waste package has been identified as an MGDS Q-List item important to safety (Ref. 11). The work performed for this analysis is covered by reference 5.13, Perform Criticality, Thermal, Structural, and Shielding Scoping Analysis, which is part of the WPDD QAP-2-0 Work Control evaluation documents. This QAP-2-0 evaluation determined such activities are subject to Quality Assurance Requirements and Description (QARD) (Ref. 5.12) requirements. Applicable procedural controls are listed in the evaluation.

This is a scoping design analysis. The QAP-2-0 Activity Evaluation (Ref. 5.13), "Perform Criticality, Thermal, Structural, and Shielding Scoping Analyses", lists the procedural controls which are required. Therefore, this design analysis is not subject to the QAP-3-series procedures and does not require QAP-3-9 signatures.

3. Method:

Analytical solution of a linear solid mechanics problem is introduced by making use of the conservation of energy. Basic principals of the strength of materials have been used in the formulations of area moment of inertia and bending stress relations.

4. Design Inputs:

4.1 Design Parameters:

Inertia calculations of the 12 Pressurized Water Reactor (PWR) Interlocking Basket (ILB) Waste Package including its outer barrier, inner barrier, and Spent Nuclear Fuel (SNF) basket assembly are performed according to the design sketches supplied by the waste package design team. The WP dimensions are as follows (Ref. 5.1) (see Assumption 4.3.1):
Outer barrier, outer diameter  = 1.3204 m  
Outer barrier, inner diameter  = 1.1204 m  
Inner barrier, outer diameter  = 1.1204 m  
Inner barrier, inner diameter  = 1.0804 m

Inertia calculations of the 21 PWR and 40 Boiling Water Reactor (BWR) Fuel Assembly MPC Disposal Containers are also performed according to the design sketches supplied by the waste package design team. The WP dimensions are as follows (Ref. 5.2) (see Assumption 4.3.2):

Outer barrier, outer diameter  = 1.8016 m  
Outer barrier, inner diameter  = 1.6016 m  
Inner barrier, outer diameter  = 1.6016 m  
Inner barrier, inner diameter  = 1.5616 m

Inertia calculations of the 24 BWR and 12 PWR MPC Disposal Containers are performed according to the design sketches supplied by the waste package design team. The WP dimensions are as follows (Ref. 5.3) (see Assumption 4.3.3):

Outer barrier, outer diameter  = 1.5305 m  
Outer barrier, inner diameter  = 1.3305 m  
Inner barrier, outer diameter  = 1.3305 m  
Inner barrier, inner diameter  = 1.2905 m

Inertia values for each MPC configuration are calculated by using the following dimensions (The dimensions obtained from the MPC Conceptual Design Report are converted from British Units into the SI units by using a conversion factor of 0.0254 m = 1 in.):

21 PWR MPC dimensions (Ref. 5.4):
MPC shell, outer diameter  = 1.53162 m  
MPC shell, inner diameter  = 1.48082 m  
SS Tube thickness  = 6.35 mm  
SS thickness  = 2.388 mm  
Guide thicknesses  = 9.525 mm  
AL/Boron thickness  = 6.35 mm  
SS tube inside length = 223.52 mm

40 BWR MPC dimensions (Ref. 5.4):
MPC shell, outer diameter  = 1.53162 m  
MPC shell, inner diameter  = 1.48082 m  
SS Tube thickness  = 6.35 mm
SS thickness = 2.388 mm  
Guide thicknesses = 9.525 mm  
AL/Boron thickness = 6.35 mm  
SS tube inside length = 152.4 mm

24 BWR MPC dimensions (Ref. 5.4):
MPC shell, outer diameter = 1.2603 m  
MPC shell, inner diameter = 1.2159 m  
SS Tube thickness = 6.35 mm  
SS thickness = 2.388 mm  
Guide thicknesses = 9.525 mm  
AL/Boron thickness = 6.35 mm  
SS tube inside length = 152.4 mm

12 PWR MPC dimensions (Ref. 5.4):
MPC shell, outer diameter = 1.2603 m  
MPC shell, inner diameter = 1.2159 m  
SS Tube thickness (Tube Detail A) = 2.388 mm  
.094 inch SS thickness (Tube Detail A) = 2.388 mm  
.094 inch SS thickness (Tube Detail B) = 2.388 mm  
.50 inch SS thickness (Tube Detail B) = 12.7 mm  
.25 inch SS Tube thickness (Tube detail C) = 6.35 mm  
.50 inch SS plate (Spacer detail D) = 12.7 mm  
Guide thicknesses = 9.525 mm  
AL/Boron thickness = 2.72 mm  
SS tube inside length = 228.6 mm

The elastic modulus of cast carbon steel (Ref. 5.5) is assumed for A 516 carbon steel. Since the composition of A 516 carbon steel has carbon content under 0.45% (Ref. 5.15), it can be considered as cast steel and the elastic modulus of cast carbon steel can be used for A 516 carbon steel (Assumption 4.3.12).

The elastic modulus is assumed to be the same for all materials in the calculations performed for equation 7.2. This is a simplification made in order to determine a relation between the allowable rock masses. ASTM A 516 carbon steel (Ref. 5.5) and Alloy 825 (Ref. 5.6) materials have elastic modulus of 206 GPa. Stainless Steel 316L has elastic modulus of 195 GPa. Because of the small difference, this parameter is cancelled out in equation 7.2 (Assumption 4.3.4).

Aluminum alloy 5086 (see Assumption 4.3.11):

\[ E_{Al} = 71 \, \text{GPa} \] (Ref. 5.10, ASME 1992, Section II, Part D, Subpart 2, Table TM-2)
Stainless steel 316L: Modulus of elasticity = 195 GPa (Ref. 5.10, ASME 1992, Section II, Part D, Subpart 2, Table TM-1)

The conversions from the British Units into the SI Units in the ASME Code were made by using the following conversion factors:
1 psi = 6.895 kPa, 1 lb mass = 0.4536 kg, 1 in. = 0.0254 m (Ref. 5.25).

Drop height of the rock is calculated from the given dimensions of the starter tunnel (Ref. 5.7). Figure 1 depicts the TBM starter tunnel geometry. Tunnel height has been maximized by the length measured from excavated bottom to the top surface of the tunnel. Drop height is the distance from the top surface of the WP to the bottom of the rock.

![Figure 1. TBM Starter Tunnel geometry](image)

Calculations on the Starter Tunnel (Figure 1):
Tunnel height = 9.857 - 0.152 = 9.705 m (Ref. 5.7)
\( r_1 = \) WP outer barrier radius = 0.6602 m
\( r_2 = \) Rock radius
Drop height = Tunnel height - 2\( r_1 \) = 9.705 - 2*(0.6602) = 8.3846 m

4.2 Criteria:

One of the waste package system requirements is to maintain waste containment during all...
normal handling, transportation, emplacement, and retrieval operations and, in the event of accidents or other dynamic effects, contribute to limiting dispersal of the waste. This design analysis was prepared in response to the following sections of Engineered Barrier Design Requirements Document (EBDRD) (Ref. 5.14):

3.7 ENGINEERED BARRIER SEGMENT MAJOR COMPONENT CHARACTERISTICS/REQUIREMENTS

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

3.7.1 WASTE PACKAGE SUBSYSTEM REQUIREMENTS

B. 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.

3.7.1.2 WASTE CONTAINER REQUIREMENTS

A. 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).

3.7.1.3 INTERNAL STRUCTURE REQUIREMENTS

B. 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.

The notation "TBD" in EBDRD requirements 3.7.F and 3.7.1.2.A need not be carrier to the conclusions of this analysis because the analysis is intended to quantify the resistance of the waste package to the loads described in the requirements. However, compliance can not be determined until the TBDs are removed from the requirements.

4.3 Assumptions:

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. For pre-title II design (conceptual or preliminary), assumptions are identified and documented, but they are not subject to tracking in accordance with MGDS NLP-3-15.

4.3.1 The following dimensions of the 12 PWR UCF ILB WP are obtained from the waste package development sketches (Ref. 5.1):

Outer barrier, outer diameter = 1.3204 m
Outer barrier, inner diameter = 1.1204 m
Inner barrier, outer diameter = 1.1204 m
Inner barrier, inner diameter = 1.0804 m

This assumption is used in section 4.1.

4.3.2 The following dimensions of the 21 PWR and 40 BWR MPC Disposal Containers are obtained from the waste package development sketches (Ref. 5.2):

Outer barrier, outer diameter = 1.8016 m
Outer barrier, inner diameter = 1.6016 m
Inner barrier, outer diameter = 1.6016 m
Inner barrier, inner diameter = 1.5616 m

This assumption is used in section 4.1.

4.3.3 The following dimensions of the 24 BWR and 12 PWR MPC Disposal Containers are obtained from the waste package development sketches (Ref. 5.3):

Outer barrier, outer diameter = 1.5305 m
Outer barrier, inner diameter = 1.3305 m
Inner barrier, outer diameter = 1.3305 m
Inner barrier, inner diameter = 1.2905 m

This assumption is used in section 4.1.

4.3.4 The following materials were obtained for corresponding structural members from the waste package development sketches (Ref. 5.1):

Outer barrier: ASTM A 516 carbon steel
Inner barrier: Alloy 825

The elastic modulus is assumed to be the same for all materials in the calculations performed for equation 7.2. This is a simplification made in order to determine a relation between the allowable rock masses. ASTM A 516 carbon steel (Ref. 5.5) and Alloy 825 (Ref. 5.6) materials have elastic modulus of 206 GPa. Stainless Steel 316L has elastic modulus of 195 GPa. Because of the small difference, this parameter is cancelled out in equation 7.2.

This assumption is used in section 4.1.

4.3.5 It is assumed that all of the kinetic energy of the falling rock is imparted onto the WP as mechanical energy. Furthermore, the rock does not shatter and deflection of the rock as compared to deflection of the WP is negligible. This assumption is used in section 7.1.

4.3.6 A spherical geometry is assumed for the rock. This geometry was selected because the impact of a sphere will result in a global distribution of stress onto the WP, whereas a sharp wedge geometry would deform the pointed region of the rock as a result of the high stress concentration at the impact point. This assumption is used in section 7.1.

4.3.7 The waste package supports were conservatively assumed to be at the ends of the waste package. One finite-element from each end was selected to include horizontal and vertical displacement constraints leaving the maximum unsupported span between the outermost elements along the WP length. This assumption is used in section 7.1.

4.3.8 The basket assembly has a small contribution to the overall moment of inertia as compared to the containment barriers. Furthermore, the rock drop dynamic loading does not cause large deflection on the basket assembly. This allows the basket assembly to retain its structural integrity. Therefore, it is assumed that the basket assembly is one piece along the WP length. This assumption is used in section 7.1.
4.3.9 The rock fall height is conservatively assumed to be the same for all waste packages considered in this design analysis. The 12 PWR ILB has the smallest diameter, so the actual MPC rock fall heights are slightly less than the one calculated for the 12 PWR ILB. This assumption is used in sections 7 and 8.

4.3.10 The length and modulus of elasticity are assumed to be the same for all MPC and ILB waste packages considered in this analysis. The difference in the modulus of elasticity values of the 316L stainless steel (195 GPa, Ref. 5.10), A 516 carbon steel (206 GPa, Ref. 5.5, see Assumption 4.3.12), and Alloy 825 (206 GPa, Ref. 5.6) is negligibly small. The differences in the support spacing for the WPs are also small. Thus, these assumptions are considered to be reasonable and used in section 7.1.

4.3.11 Aluminum alloy 5086 material properties are assumed for the Aluminum-Boron. Since the Aluminum-Boron does not have significant contribution to the WP strength compared to the steel, this assumption has minor effect in the results. This assumption is used in section 4.1.

4.3.12 The elastic modulus of cast carbon steel (Ref. 5.5) is assumed for A 516 carbon steel. Since the composition of A 516 carbon steel has carbon content under 0.45% (Ref. 5.15), it can be considered as cast steel and the elastic modulus of carbon cast steel can be used for A 516 carbon steel. The physical properties of cast steel are similar to those of wrought steel (Ref. 5.5). This assumption is used in section 4.1.

4.3.13 The following simplifications are made in the drawings and dimensions which are provided in Attachments:

A small part of the outer tube structure facing the MPC shell is included in the calculations (see Attachment I, Tube Detail B). This part is negligibly small compared to the tube size. Therefore, it has almost no effect in the results.

The distances of spacers (see Spacer Detail D in Attachments III and VIII) from the neutral axis are approximated from the drawings, since these dimensions are not specified in the drawings. The horizontal members are not included in the calculations due to their negligible contribution to the overall inertia of the structure. Therefore, this assumption has almost no effect in the results.

The 12 PWR ILB waste package sketch is simplified as provided in Attachment VI, page 1. These simplifications do not have any significant effect on the results, since the dimensions are close to the ones given in the sketches (Ref. 5.1).
4.4 Codes and Standards:

N/A. Mechanical design of waste packages is not controlled by codes and standards. The standards of the American Society of Testing and Materials (ASTM), and American Iron and Steel Institute (AISI) have been used as sources of material properties for A516 Carbon Steel and 316L Stainless Steel, respectively. The modulus of elasticity for 316L was obtained from the American Society of Mechanical Engineers (ASME) 1992 Boiler and Pressure Vessel Code. The complete list of references used as sources of material properties is included in section 5.

5. References:

5.1 CRWMS/M&O, "Waste Package with Interlocking Basket Assembly (12-PWR)," BBA000000-01717-2100-15007 REV 0A.

5.2 CRWMS M&O, "MPC Disposal Container (21 PWR/40 BWR)," BBA000000-01717-2100-15020 REV 00B.

5.3 CRWMS M&O, "MPC Disposal Container (12 PWR/24 BWR)," BBA000000-01717-2100-15018 REV 00B.


5.9 F. P. Beer and E. R. Johnston, "Mechanics of Materials," Toronto, Canada,


6. Use of Computer Software:

N/A.

7. Design Analysis:

7.1 Description of Analytical Model:

The results of a nonlinear dynamic simulation of a large rock impacting a metallic multibarrier WP have been obtained in a previous design analysis (Ref. 5.8). Basic assumptions and properties of this analysis will be discussed briefly to provide a basis for correlation calculations.

A 3-D finite-element model of the 12 PWR UCF Interlocking Basket WP (including inner barrier, outer barrier, and basket assembly) has been developed in accordance with early WP
conceptual designs (Ref. 5.8). Throughout the design analysis, this WP will be referred to as the 12 UCF. In the model, it is assumed that all of the kinetic energy of the falling rock is imparted onto the WP as mechanical energy (i.e. the rock does not shatter, no heat is produced) and the deflection of the rock is negligible compared to the deflection of the WP (Assumption 4.3.5). Another important assumption is the modeling of the impacting rock as a sphere. This geometry was selected because the impact of a sphere will result in a global distribution of stress onto the WP, whereas a sharp wedge geometry would deform the pointed region of the rock as a result of the high stress concentration at the impact point (Assumption 4.3.6). It should be noted that ANSYS cannot model a perfect sphere because element surfaces are flat. In the modeling of the rock, there are small points at node locations, but their effects are minor.

The simulation of the rock impact on the WP includes both elastic and plastic deformations. Material behavior is approximated by incorporating bilinear stress-strain curves into the ANSYS WP material properties. A transient dynamic analysis solution is produced with gravitational acceleration as the only load on the system. Displacement constraints at support locations prevent vertical motion and horizontal motion normal to the axis of the WP. The support locations are at the extreme ends of the outer barrier, which in this model does not include the skirt, giving the longest unsupported length of the canister (Assumption 4.3.7).

The maximum-normal-stress theory is based on a comparison of the ultimate tensile and compressive strengths of the materials with the maximum values of tensile and compressive stresses they experience during an impact. Having evaluated the results of the finite-element analysis of the 12 UCF in accordance with the maximum-normal-stress theory, it is determined that the WP is able to withstand the maximum dynamic loading from the fall of a 19,100 kg rock through 8.4 m without breaching the containment barriers. This fall height corresponds to a rock falling from the roof of the starter tunnel, the maximum height from which a rock can fall onto the WP.

The basket assembly has a small contribution to the overall moment of inertia as compared to the containment barriers. Furthermore, the rock drop dynamic loading does not cause large deflection on the basket assembly. This allows the basket assembly to retain its structural integrity. Therefore, it is assumed that the basket assembly is one piece along the WP length (see Assumption 4.3.8).

To develop a correlation factor between the results of UCF and MPC concepts, an analytical solution is needed for the same problem. A quasi-static approach can be used to simplify the dynamic load into a static, concentrated force applied at midspan on the outer and inner barriers. Figure 2 illustrates the WP, applied force, shear force, and bending moment diagrams.
The potential energy of the rock is converted into kinetic energy by the time it falls to the top surface of the outer barrier. Assuming that total energy is spent for deflection of the inner and outer barriers, which is a conservative approach (see Assumption 4.3.5), strain energy stored in the barrier will be equal to the kinetic energy of the rock. Derivation of the strain energy relation in terms of the applied force, and stiffness of the material is presented together with the solution to the conservation of energy equation in Ref. 5.8. The following
equation is obtained from the same reference design analysis:

\[
\text{Kinetic Energy} = \text{Strain Energy}
\]

\[
\frac{1}{2} m V^2 = \left( \frac{4 \sigma I}{c L} \right)^2 \frac{L^3}{96 EI} \quad \text{(Equation 7.1)}
\]

where:
- \( m \) = mass of rock
- \( V \) = velocity of rock
- \( \sigma \) = bending stress
- \( L \) = length of basket assembly (unsupported length)
- \( E \) = modulus of elasticity of barrier materials
- \( I \) = total area moment of inertia of barriers
- \( c \) = outer barrier outer radius

If two different waste package sizes are compared in terms of their radii and area moments of inertia, equation 7.1 can be divided side by side in order to obtain the following relation:

\[
\frac{1}{2} m_1 V^2 = \left( \frac{4 \sigma I_1}{c_1 L} \right)^2 \frac{L^3}{96 EI_1} \quad \text{(Equation 7.2)}
\]

\[
\frac{1}{2} m_2 V^2 = \left( \frac{4 \sigma I_2}{c_2 L} \right)^2 \frac{L^3}{96 EI_2}
\]

Therefore,

\[
m_1 = m_2 \left( \frac{I_1}{I_2} \right) \left( \frac{c_2}{c_1} \right)^2 \quad \text{(Equation 7.3)}
\]

Note that the parameters \( V, \sigma, L, \) and \( E \) are assumed to be constant for the waste packages (Assumptions 4.3.9 and 4.3.10).
The magnitude of the maximum stress obtained from the 12 UCF will be the basis of all MPC configuration resultant stresses. The maximum allowable rock mass for each MPC configuration will be calculated to result in the maximum bending stress magnitude determined for the 12 UCF since the WP finite-element model has been developed only for the 12 UCF.

The area moment of inertia of each MPC configuration except the 40 MPC BWR has been calculated for two orientations of the basket to determine the minimum value of inertia that would result in the largest magnitude of stress on the WP. The two orientations are with the basket sides vertical and horizontal (non-rotated) and with the basket rotated 45°. Because of the complex shape of the 40 BWR when it is rotated 45°, the area moment of inertia of the 40 BWR is calculated only for 0° orientation. The resultant inertia values for each MPC configuration will be presented in the following sections.

### 7.2 Inertia Calculations:

If the structural member subjected to pure bending is made of two or more materials with different moduli of elasticity, stress can be determined by (Ref. 5.9):

\[ I = (I_{CG} + A \cdot d^2) \cdot n_{12}, \quad n_{12} = \frac{E_1}{E_2} \]

where,
- \( I_{CG} \) = area moment of inertia with respect to the axis passing through the center of gravity
- \( A \) = area
- \( d \) = distance from center of gravity to the new axis of moment of inertia
- \( n_{12} \) = ratio of the moduli of elasticity between two composite materials

\( E_1 \) (Aluminum alloy 5086) = 71 GPa (see Section 4.1)
\( E_2 \) (Stainless steel 316L) = 195 GPa (Ref. 5.10)

\[ n_{12} = \frac{195}{71} = 0.364 \]

Area moment of inertia between two rectangular shapes is given as,

\[ I = \left( b \cdot h^3 - b_1 \cdot h_1^3 \right) / 12 \]

where, \( b \) is the base, \( h \) is the height of the outer rectangle, and \( b_1 \) is the base, \( h_1 \) is the height of the inner rectangle (Ref 5.9).

Area moment of inertia of a hollow circle with neutral axis through center is calculated from the following relation (Ref. 5.9):

\[ I = \pi \left( d_o^4 - d_i^4 \right) / 64 \]

where \( d_o \) is the outer diameter and \( d_i \) is the inner diameter of the circle.
Therefore, using the results provided in Attachments I through IX, the minimum inertia values are selected for $0^\circ$ and $45^\circ$ for each MPC configuration and ILB design. This is a conservative approach since the smaller inertia values result in smaller rock mass allowables.

\[
I_{12\text{ PWR ILB}} = 0.0934849 \text{ m}^4 \quad \text{(see Attachment VI)}
\]

\[
I_{21\text{ PWR MPC}} = 0.292833 \text{ m}^4 \quad \text{(see Attachment I)}
\]

\[
I_{40\text{ BWR MPC}} = 0.302559 \text{ m}^4 \quad \text{(see Attachment II)}
\]

\[
I_{24\text{ BWR MPC}} = 0.1661517 \text{ m}^4 \quad \text{(see Attachment IV)}
\]

\[
I_{12\text{ PWR MPC}} = 0.1634392 \text{ m}^4 \quad \text{(see Attachment VIII)}
\]

### 7.3 Rock Mass Calculations:

Equation 7.3 can be used to calculate the allowable rock masses for each MPC design (also see Section 7.2).

Therefore, \( m_1 = m_2 \left( \frac{I_1}{I_2} \right) \left( \frac{c_2}{c_1} \right)^2 \) and

\[
m_{21\text{ PWR MPC}} = 19100 \times \left( \frac{0.292833}{0.0934849} \right) \times \left( \frac{0.6602}{0.9008} \right)^2 = 32100 \text{ kg}
\]

\[
m_{40\text{ BWR MPC}} = 19100 \times \left( \frac{0.302559}{0.0934849} \right) \times \left( \frac{0.6602}{0.9008} \right)^2 = 33200 \text{ kg}
\]

\[
m_{24\text{ BWR MPC}} = 19100 \times \left( \frac{0.1661517}{0.0934849} \right) \times \left( \frac{0.6602}{0.76525} \right)^2 = 25200 \text{ kg}
\]

\[
m_{12\text{ PWR MPC}} = 19100 \times \left( \frac{0.1634392}{0.0934849} \right) \times \left( \frac{0.6602}{0.76525} \right)^2 = 24800 \text{ kg}
\]

### 8. Conclusions:

#### 8.1 21 PWR MPC WP Barrier Response to Rock Fall Accident

The analytical model assumes that the normal stress varies linearly with the distance from the neutral surface. A compressive normal stress state is active above the neutral axis, and a tensile normal stress state is active below the neutral axis. Furthermore, the magnitudes of maximum compressive and tensile stresses are identical due to the symmetric geometry of the WP cross-sectional area with respect to the plane passing through the center of the WP.

The finite-element evaluations are based on a slightly different mechanism of impact and proceeding stress distribution on the finite-element model. Plastic deformation in a material...
leads to a nonlinear stress profile across the material thickness. The impacted region of the WP experiences high stress concentration due to localized plastic deformation. Since the analytical formulations will be used only for correlating the results of the finite element analysis performed on the 12 UCF with MPC configurations, the accuracy of the finite-element method will be reflected on the MPC configuration results.

Moment of inertia calculations of the 0° rotated 21 PWR configuration result in a value of 0.2928 m⁴ (see Sec. 7.2). The modulus of elasticity, WP length, and the impact velocity of the rock are substituted into the energy equation together with this moment of inertia value. The rock fall height is conservatively assumed to be the same for the 21 PWR as it was for the 12 UCF, 8.4 m (Assumption 4.3.9). The mass of the falling rock is varied to produce a resultant stress magnitude previously determined as the limit for not causing any breach on the 12 UCF. This process is simplified by the use of equation 7.3 (also see Sec. 7.3). The critical rock mass is determined as 32,100 kg for the 21 PWR configuration (see Sec. 7.3).

### 8.2 40 BWR MPC WP Barrier Response to Rock Fall Accident

The total area moment of inertia of the 40 BWR is calculated as 0.3026 m⁴ (see Sec. 7.2). The rock fall height is conservatively assumed to be the same for the 40 BWR as it was for the 12 UCF, 8.4 m (see Assumption 4.3.9). Having the inertia and outer radius values substituted into the equation 7.3, the critical mass of the rock is determined as 33,200 kg (see Sec. 7.3).

When the results of the 21 PWR are compared to the 40 BWR configuration in terms of inertia and critical rock mass values, it is observed that the maximum allowable rock mass increases as the area moment of inertia of the WP becomes larger. Due to the fact that there is a small difference in the moment of inertia values between the 21 PWR and the 40 BWR WPs, the difference in the calculated critical mass values is also very small.

In conclusion, deformation patterns and stress distributions due to the rock fall accident scenario for the 21 PWR are considered to be the limiting results since the moment of inertia of the 21 PWR is slightly lower than the moment of inertia of the 40 BWR configuration.

### 8.3 24 BWR MPC WP Barrier Response to Rock Fall Accident

The MPC disposal container and MPC shell inner and outer diameters are smaller for the small (75-ton) MPC configurations than for the large (125-ton) MPC configurations. Considerably smaller moment of inertia values are calculated as a result. Analytically derived conservation of energy equations indicate that any change in the moment of inertia value is inversely proportional to the maximum stress magnitude created on the WP due to the rock drop loading condition. Thus, the maximum rock mass values are expected to be smaller for
the small MPC WPs than for the large MPC WPs.

The rock fall height is conservatively assumed to be the same for the 24 BWR as it was for the 12 UCF, 8.4 m (see Assumption 4.3.9). The moment of inertia for the 24 BWR is 0.1662 m$^4$ (see Sec. 7.2). When incorporated into the equation 7.3, the critical rock mass is determined as 25,200 kg (see Sec. 7.3).

8.4 12 PWR MPC WP Barrier Response to Rock Fall Accident

Inertia calculations of the 45° rotated 12 PWR configuration resulted in a value of 0.1634 m$^4$ (see Sec. 7.2). The rock fall height is conservatively assumed to be the same for the 12 PWR as it was for the 12 UCF, 8.4 m (see Assumption 4.3.9). The inertia and radius values have been substituted into equation 7.3. Thus, the critical rock mass is determined as 24,800 kg for the 12 PWR (see Sec. 7.3).

It is noted that a smaller inertia value of the 12 PWR compared to the 24 BWR results in a smaller critical rock mass for the 12 PWR. This result is consistent with the previous discussion of the 21 PWR and the 40 BWR configurations in Section 8.2.

It is concluded that the limiting MPC WP configuration is the 12 PWR with a critical rock mass of 24,800 kg.

9. Attachments:

The drawings and dimensions in all attachments are obtained from Ref. 5.4. The following attachments are presented in this section:

Attachment I (5 pages): Inertia calculations on MPC 125-Ton 21 PWR configuration.
Attachment II (6 pages): Inertia calculations on MPC 125-Ton 40 BWR configuration.
Attachment III (7 pages): Inertia calculations on MPC 75-Ton 12 PWR configuration.
Attachment IV (5 pages): Inertia calculations on MPC 75-Ton 24 BWR configuration.
Attachment V (1 page): Inertia calculations on 12 PWR ILB waste package.
Attachment VI (2 pages): Inertia calculations on 12 PWR ILB waste package (45° rotated).
Attachment VII (8 pages): Inertia calculations on MPC 125-Ton 21 PWR waste package (45° rotated).
Attachment VIII (9 pages): Inertia calculations on MPC 75-Ton 12 PWR configuration (45° rotated).
Attachment IX (6 pages): Inertia calculations on MPC 75-Ton 24 BWR configuration (45° rotated).
Inertia Calculations on MPC 125-Ton 21 PWR Configuration

The regions of inertia calculations are numbered in the below figure. The figure on the right shows the tube detail A. All dimensions are in metric units.

Tube Detail A (Typical 9 Inside Tubes) (see Assumption 4.3.13):

\[
I_4 = \frac{((253.75)^4 - (248.92)^4)}{12} + \frac{((236.22)^4 - (223.52)^4)}{12} \\
+ \frac{((253.75)^2 - (248.92)^2) * (253.75)^2}{12} + \frac{((236.22)^2 - (223.52)^2) * (253.75)^2}{12} \\
= 609.3 \times 10^6 \text{ mm}^4
\]

Borated aluminum plate can also be incorporated into the inertia calculations:

\[
I_{4\text{B/A0}} = \frac{((248.92)^4 - (236.22)^4)}{12} + ((248.92)^2 - (236.22)^2) * 0.364 \\
= 166.4 \times 10^6 \text{ mm}^4
\]
Tube Detail B (Typical 12 Outside Tubes):

\[ I_s = I_4 - \left( \frac{bh^3}{12} + A \cdot d^3 \right) \]
\[ = 609.3 \cdot 10^6 - \left( (2.39) \cdot (253.75)^3 / 12 + (2.39) \cdot (253.75) \cdot (253.75)^2 \right) \]
\[ = 567 \cdot 10^6 \text{ mm}^4 \]

Borated aluminum part:

\[ I_{s(\text{B/AB})} = I_{s(\text{B/AB})} - \left( \frac{bh^3}{12} + A \cdot d^3 \right) \cdot 0.364 \]
\[ = 166.4 \cdot 10^6 - \left( (6.35) \cdot (248.92)^3 / 12 + (6.35) \cdot (248.92) \cdot (253.75)^2 \right) \cdot 0.364 \]
\[ = 126.4 \cdot 10^6 \text{ mm}^4 \]
\[ I_2 = \frac{(253.75)^4 - (248.92)^4}{12} + \frac{(236.22)^4 - (223.52)^4}{12} + \frac{(253.75)^2 - (248.92)^2}{12} \cdot (507.49)^2 + \frac{(236.22)^2 - (223.52)^2}{12} \cdot (507.49)^2 - (253.75) \cdot (2.39)^3 / 12 - (253.75) \cdot (2.39) \cdot (633.17)^2 \]
\[ = 1962.9 \cdot 10^6 \text{ mm}^4 \]

Borated aluminum part:
\[ I_{2B/AD} = \frac{((248.92)^4 - (236.22)^4)}{12} + \frac{(248.92)^2 - (236.22)^2}{12} \cdot (507.49)^2 - (248.92) \cdot (6.35)^3 / 12 - (248.92) \cdot (6.35) \cdot (633.17)^2 \cdot 0.364 \]
\[ = 368.9 \cdot 10^6 \text{ mm}^4 \]

Detail C Guides (Typical 4 Places):
\[ I_c = \frac{(733.2)^2 \cdot (9.53)^3}{12} + (733.2) \cdot (9.53) \cdot (639.13)^2 + 2 \cdot ((9.53)^3 \cdot (85.39)^3 / 12 + (9.53) \cdot (85.39) \cdot (681.825)^2) \]
\[ = 3611.8 \cdot 10^6 \text{ mm}^4 \]
Detail D Guides (Typical 4 Places):

\[ I_D = \frac{(236.7)^2 \times (9.53)^2}{12} + \frac{(236.7) \times (9.53) \times (385.38)^2}{12} + \frac{(9.53)^2 \times (227.17)^3}{12} + \frac{(9.53) \times (227.17) \times (503.73)^2}{12} \]
\[ = 893.68 \times 10^4 \text{ mm}^4 \]

Detail C (vertical structures):

\[ I_{CV} = \frac{(9.53)^2 \times (366.6)^3}{12} + \frac{(9.53) \times (366.6) \times (183.3)^2}{12} + \frac{(85.39)^2 \times (9.53)^3}{12} + \frac{(85.39) \times (9.53) \times (249)^2}{12} \]
\[ = 206.97 \times 10^4 \text{ mm}^4 \]

Therefore,

\[ I_{total} = (1962.9 + 368.9) \times 10^6 / 2 = 1165.9 \times 10^6 \text{ mm}^4 \]
\[ I_{2total} = (1962.9 + 368.9) \times 10^6 = 2331.8 \times 10^6 \text{ mm}^4 \]
\[ I_{\text{total}} = (609.3 + 166.4) \times 10^6 / 2 = 387.85 \times 10^6 \text{ mm}^4 \]
\[ I_{\text{total}} = (609.3 + 166.4) \times 10^6 = 775.7 \times 10^6 \text{ mm}^4 \]
\[ I_{\text{total}} = (567 + 126.4) \times 10^6 = 693.4 \times 10^6 \text{ mm}^4 \]
\[ I_{\text{total}} = (((253.75)^4 - (248.92)^4) / 12 + ((236.22)^4 - (223.52)^4) / 12) / 4 \]
\[ + (((248.92)^4 - (236.22)^4) / 12) \times 0.364) / 4 \]
\[ = 24.76 \times 10^6 \text{ mm}^4 \]
\[ I_{\text{total}} = I_6 * 2 = 49.52 \times 10^6 \text{ mm}^4 \]
\[ I_{\text{total}} = 49.52 \times 10^6 - (2.39) * (253.75)^3 / 12 - ((6.35) * (253.75)^3 / 12) * 0.364 \]
\[ = 43.12 \times 10^6 \text{ mm}^4 \]
\[ I_C / 2 = 1805.9 \times 10^6 \text{ mm}^4 \]
\[ I_D = 893.68 \times 10^6 \text{ mm}^4 \]
\[ I_{CV} = 206.97 \times 10^6 \text{ mm}^4 \]

\[ I (\text{inner structure total inertia}) = (8378.6 \times 10^6) * 4 = 33514.4 \times 10^6 \text{ mm}^4 \]

\[ I_{\text{MPC shell}} = \pi * (d^4 - d_t^4) / 64 = \pi * ((1531.62)^4 - (1480.82)^4) / 64 = 34094.34 \times 10^6 \text{ mm}^4 \]

\[ I_{\text{MPC Disposal Container}} = \pi * ((1801.6)^4 - (1561.6)^4) / 64 = 225224.27 \times 10^6 \text{ mm}^4 \]

\[ I_{\text{overall}} = 292833 \times 10^6 \text{ mm}^4 \]
Inertia Calculations on MPC 125-Ton 40 BWR Configuration

\[ I_{1A} = \frac{((182.58)^4 - (177.8)^4)}{12} + \frac{((165.1)^4 - (152.4)^4)}{12} \\
+ \frac{((182.58)^3 - (177.8)^3) * (91.29)^2 + ((165.1)^3 - (152.4)^3) * (91.29)^2}{12} \\
= 74.2 \times 10^6 \text{ mm}^4 \]
Attachment II : BBAB00000-01717-0200-00004 REV 00

\[
I_{1B} = \frac{(182.58)^4 - (177.8)^4}{12} + \frac{(165.1)^4 - (152.4)^4}{12} + \frac{(182.58)^2 - (177.8)^2}{12} \cdot (273.87)^2 + \frac{(165.1)^2 - (152.4)^2}{12} \cdot (273.87)^2 \\
= 457.9 \cdot 10^6 \text{ mm}^4
\]

\[
I_{1C} = \frac{(182.58)^4 - (177.8)^4}{12} + \frac{(165.1)^4 - (152.4)^4}{12} + \frac{(182.58)^2 - (177.8)^2}{12} \cdot (456.45)^2 + \frac{(165.1)^2 - (152.4)^2}{12} \cdot (456.45)^2 \\
= 1225.3 \cdot 10^6 \text{ mm}^4
\]

\[
I_{\text{total}} = 2 \cdot 5 \cdot (1757.4 \cdot 10^6) = 17574 \cdot 10^6 \text{ mm}^4
\]

Borated aluminum part:

\[
I_{1A(B/Al)} = \frac{((177.8)^4 - (165.1)^4)}{12} + \frac{(177.8)^2 - (165.1)^2}{12} \cdot (91.29)^2 \cdot 0.364 \\
= 21 \cdot 10^6 \text{ mm}^4
\]

\[
I_{1B(B/Al)} = \frac{((177.8)^4 - (165.1)^4)}{12} + \frac{(177.8)^2 - (165.1)^2}{12} \cdot (273.87)^2 \cdot 0.364 \\
= 126.7 \cdot 10^6 \text{ mm}^4
\]

\[
I_{1C(B/Al)} = \frac{((177.8)^4 - (165.1)^4)}{12} + \frac{(177.8)^2 - (165.1)^2}{12} \cdot (456.45)^2 \cdot 0.364 \\
= 338 \cdot 10^6 \text{ mm}^4
\]

\[
I_{\text{total}} = 2 \cdot 5 \cdot (485.7 \cdot 10^6) = 4857 \cdot 10^6 \text{ mm}^4
\]

Tube Detail B (Typical 10 Outside Tubes):

\[
I_{2A} = 74.2 \cdot 10^6 - (2.39) \cdot (182.58)^3 / 12 - (2.39) \cdot (182.58) \cdot (91.3)^2 \\
= 69.4 \cdot 10^6 \text{ mm}^4
\]

\[
I_{2B} = 457.9 \cdot 10^6 - (2.39) \cdot (182.58)^3 / 12 - (2.39) \cdot (182.58) \cdot (273.9)^2 \\
= 423.95 \cdot 10^6 \text{ mm}^4
\]

\[
I_{\text{total}} = 4 \cdot (493.35 \cdot 10^6) = 1973.4 \cdot 10^6 \text{ mm}^4
\]
I_{3A} = \frac{((182.58)^4 - (177.8)^4)}{12} + \frac{((165.1)^4 - (152.4)^4)}{12} + \frac{((182.58)^2 - (177.8)^2)^2}{12} + \frac{((165.1)^2 - (152.4)^2)^2}{12} - (182.58)^2 * (2.39)^3 / 12 - (182.58) * (2.39) * (729.1)^2
\hspace{1cm} = 2144.2 * 10^6 \text{ mm}^4
I_{\text{total}} = 2 * (2144.2 * 10^6) = 4288.4 * 10^6 \text{ mm}^4

Borated aluminum parts in tube detail B:

I_{2\text{A}(B/A)} = 21 * 10^6 - \frac{(6.35) * (182.58)^3}{12} + (6.35) * (182.58) * (91.3)^2 * 0.364
\hspace{1cm} = 16.3 * 10^6 \text{ mm}^4

I_{2\text{B}(B/A)} = 126.7 * 10^6 - \frac{(6.35) * (182.58)^3}{12} + (6.35) * (182.58) * (273.9)^2 * 0.364
\hspace{1cm} = 93.8 * 10^6 \text{ mm}^4
I_{\text{total}} = 4 * (16.3 * 10^6 + 93.8 * 10^6) = 440.4 * 10^6 \text{ mm}^4

I_{3\text{A}(B/A)} = \frac{((177.8)^4 - (165.1)^4)}{12} + \frac{((177.8)^2 - (165.1)^2)^2}{12} - (182.58)^2 * (6.35)^3 / 12 - (182.58) * (6.35) * (729.1)^2 * 0.364
\hspace{1cm} = 430.7 * 10^6 \text{ mm}^4
I_{\text{total}} = 2 * (430.7 * 10^6) = 861.4 * 10^6 \text{ mm}^4
Detail C Guides (Typical 4 Places):

\[ I_1 = \frac{(161.1 \times (9.5)^3)}{12} + \frac{(161.1 \times (9.5) \times (377.85)^2)}{12} = 218.5 \times 10^6 \text{ mm}^4 \]
\[ I_2 = \frac{(9.5 \times (197.1)^3)}{12} + \frac{(9.5 \times (197.1) \times (471.6)^2)}{12} = 422.5 \times 10^6 \text{ mm}^4 \]
\[ I_3 = \frac{(184.4 \times (9.5)^3)}{12} + \frac{(184.4 \times (9.5) \times (561)^2)}{12} = 551.3 \times 10^6 \text{ mm}^4 \]
\[ I_4 = \frac{(9.5 \times (130.3)^3)}{12} + \frac{(9.5 \times (130.3) \times (621.3)^2)}{12} = 479.6 \times 10^6 \text{ mm}^4 \]
\[ I_5 = \frac{(162.7 \times (9.5)^3)}{12} + \frac{(162.7 \times (9.5) \times (561)^2)}{12} = 486.5 \times 10^6 \text{ mm}^4 \]
\[ I_6 = \frac{(9.5 \times (177.3)^3)}{12} + \frac{(9.5 \times (177.3) \times (644.8)^2)}{12} = 704.7 \times 10^6 \text{ mm}^4 \]
\[ I = 2863.1 \times 10^6 \text{ mm}^4 \]
\[ I_{\text{total}} = 4 \times (2863.1 \times 10^6) = 11452.4 \times 10^6 \text{ mm}^4 \]
Detail D Guides (Typical 2 Places):

\[ I_1 = (9.5) \times (170.9)^3 / 12 + (9.5) \times (170.9) \times (273.3)^2 = 125.2 \times 10^6 \text{ mm}^4 \]

\[ I_2 = (78) \times (9.5)^3 / 12 + (78) \times (9.5) \times (183.1)^2 = 24.8 \times 10^6 \text{ mm}^4 \]

\[ I_3 = (9.5) \times (173.6)^3 / 12 + (9.5) \times (173.6) \times (91.6)^2 = 18 \times 10^6 \text{ mm}^4 \]

\[ I_4 = ((102.2) \times (9.5)^3 / 12) / 2 = 0.004 \times 10^6 \text{ mm}^4 \]

\[ I = 168 \times 10^6 \text{ mm}^4 \]

\[ I_{total} = 4 \times (168 \times 10^6) = 672 \times 10^6 \text{ mm}^4 \]

Detail E Guides (Typical 2 Places):

\[ I_E = (160.6) \times (6.35)^3 / 12 + (160.6) \times (6.35) \times (741.5)^2 = 560.7 \times 10^6 \text{ mm}^4 \]

\[ I_{total} = 2 \times (560.7 \times 10^6) = 1121.4 \times 10^6 \text{ mm}^4 \]
I (inner structure total inertia) = (17574 + 4857 + 1973.4 + 4288.4 + 440.4 + 861.4 + 11452.4 + 672 + 1121.4) * 10^6 = 43240.4 * 10^6 mm^4

I_{MPC \text{ shell}} = 34094.34 * 10^6 \text{ mm}^4

I_{MPC \text{ Disposal Container}} = 225224.27 * 10^6 \text{ mm}^4

I_{overall} = 302559 * 10^6 \text{ mm}^4
Inertia Calculations on MPC 75-Ton 12 PWR Configuration

$D_0 = 1260.35$

$D_1 = 1215.9$

\[\text{Lengths and dimensions}\]

\[\text{Dimensions in meters}\]

\[\text{N.A.}\]
Tube Detail A (Typical 12 Places):

\[ I_1 = \frac{((233.4)^4 - (228.6)^4)}{12} + \frac{((233.4)^2 - (228.6)^2) \cdot (150.8)^2}{12} \]
\[ + \frac{(2.39) \cdot (238.5)^3}{12} + \frac{(2.39) \cdot (238.5) \cdot (153.4)^2}{12} \]
\[ + \frac{(236.1) \cdot (2.39)^3}{12} + \frac{(236.1) \cdot (2.39) \cdot (271.4)^2}{12} \]
\[ = 127.8 \cdot 10^6 \text{ mm}^4 \]

\[ I_{\text{total}} = 8 \cdot (127.8 \cdot 10^6) = 1022.4 \cdot 10^6 \text{ mm}^4 \]

Borated aluminum part:

\[ I_{(B/Al)} = \frac{(2.72) \cdot (236.1)^3}{12} + \frac{(2.72) \cdot (236.1) \cdot (152.2)^2}{12} \]
\[ + \frac{(233.4) \cdot (2.72)^3}{12} + \frac{(233.4) \cdot (2.72) \cdot (268.8)^2}{12} \cdot 0.364 \]
\[ = 23.2 \cdot 10^6 \text{ mm}^4 \]

\[ I_{(B/Al)} = 8 \cdot (23.2 \cdot 10^6) = 185.6 \cdot 10^6 \text{ mm}^4 \]

![Diagram of Tube Detail A](image_url)
**Detail B (Typical 4 Places):**

\[
I = \frac{(560.6) \times (2.39)^3}{12} + (560.6) \times (2.39) \times (32.9)^2 \\
+ \frac{(588.4) \times (12.7)^3}{12} + (588.4) \times (12.7) \times (19.1)^2 \\
+ (2.39) \times (569.3)^3 / 12 + (2.39) \times (569.3) \times (310)^2 \\
+ (12.7) \times (575.7)^3 / 12 + (12.7) \times (575.7) \times (313.3)^2 \\
= 1091.4 \times 10^6 \text{ mm}^4 \\
I_{\text{total}} = 4 \times (1091.4 \times 10^6) = 4365.6 \times 10^6 \text{ mm}^4
\]

**Borated aluminum part:**

\[
I_{\text{B/Al}} = \frac{(6.35) \times (569.3)^3}{12} + (6.35) \times (569.3) \times (310)^2 \\
+ (560.6) \times (6.35)^3 / 12 + (560.6) \times (6.35) \times (28.36)^2 \times 0.364 \\
= 163.1 \times 10^6 \text{ mm}^4 \\
I_{\text{B/Al, total}} = 4 \times (163.1 \times 10^6) = 652.4 \times 10^6 \text{ mm}^4
\]
Detail E (Typical 8 Places):

\[
I_H = (204.7) \times (9.5)^3 / 12 + (204.7) \times (9.5) \times (548.8)^2 \\
+ (9.5) \times (63.4)^3 / 12 + (9.5) \times (63.4) \times (575.8)^2 \\
= 785.6 \times 10^6 \text{ mm}^4 \\
I_{H\text{total}} = 4 \times (785.6 \times 10^6) = 3142.4 \times 10^6 \text{ mm}^4
\]

\[
I_V = (53.9) \times (9.5)^3 / 12 + (53.9) \times (9.5) \times (46.8)^2 \\
+ (9.5) \times (214.2)^3 / 12 + (9.5) \times (214.2) \times (149.1)^2 \\
= 54.1 \times 10^6 \text{ mm}^4 \\
I_{V\text{total}} = 4 \times (54.1 \times 10^6) = 216.4 \times 10^6 \text{ mm}^4
\]
Detail F (Typical 4 Places):

\[ I = \frac{(246.7)(9.5)^2}{12} + \frac{(246.7)(9.5)(285.3)^2}{12} + \frac{(9.5)(256.2)^3}{12} + \frac{(9.5)(256.2)(408.6)^2}{12} \]
\[ = 610.4 \times 10^6 \text{ mm}^4 \]
\[ I_{\text{total}} = 4 \times (610.4 \times 10^6) = 2441.6 \times 10^6 \text{ mm}^4 \]

Box Spar Spacer Detail C (Typical 8 Places):

\[ I_H = 4 \times \frac{(6.35)(25)^3}{12} + (6.35)(25)(285.1)^2 \]
\[ = 51.6 \times 10^6 \text{ mm}^4 \]
\[ I_{\text{total}} = 4 \times (51.6 \times 10^6) = 206.4 \times 10^6 \text{ mm}^4 \]
\[ I_v = (25) \times (6.35)^3 / 12 \times 4 + (25) \times (6.35) \times (37.3)^2 + (25) \times (6.35) \times (114.6)^2 \\
+ (25) \times (6.35) \times (192)^2 + (25) \times (6.35) \times (269.3)^2 \]
\[ = 19.7 \times 10^6 \text{ mm}^4 \]
\[ I_{\text{Total}} = 4 \times (19.7 \times 10^6) = 78.8 \times 10^6 \text{ mm}^4 \]

Spacer Detail D (Typical 20 Places) (see Assumption 4.3.13):

\[ I = ((25.4)^4 / 12) \times 5 + (25.4)^2 \times (548.9)^2 + (25.4)^2 \times (417)^2 \\
+ (25.4)^2 \times (285.3)^2 + (25.4)^2 \times (153.4)^2 + (25.4)^2 \times (25.4)^2 \\
= 374.8 \times 10^6 \text{ mm}^4 \]
\[ I_{\text{Total}} = 2 \times (374.8 \times 10^6) = 749.6 \times 10^6 \text{ mm}^4 \]
I (inner structure total inertia) = (1022.4 + 185.6 + 2247.6 + 251.6 + 4365.6 + 652.4
+ 3142.4 + 216.4 + 2441.6 + 206.4 + 78.8 + 749.6) * 10^6 = 15560.5 * 10^6 mm^4

\[ I_{\text{MPC shell}} = \pi * \frac{((1260.35)^4 - (1215.9)^4)}{64} = 16570.5 * 10^6 \text{ mm}^4 \]

\[ I_{\text{MPC Disposal Container}} = \pi * \frac{((1530.5)^4 - (1290.5)^4)}{64} = 133196.4 * 10^6 \text{ mm}^4 \]

\[ I_{\text{overall}} = 165327.4 * 10^6 \text{ mm}^4 \]
Inertia Calculations on MPC 75-Ton 24 BWR Configuration

\[ D_0 = 1260.3 \]
\[ D_i = 1215.9 \]

6.35 SS Tube
6.35 B. At. Plate
2.39 SS Plate
Tube Detail A (Typical 16 Inside Tubes):

\[ I_1 = \frac{((182.6)^4 - (177.82)^4)}{12} + \frac{((182.6)^2 - (177.82)^2) * (91.3)^2}{12} + \frac{((165.1)^4 - (152.4)^4)}{12} + \frac{((165.1)^2 - (152.4)^2) * (91.3)^2}{12} \]

\[ I_{\text{total}} = 8 \times (74.3 \times 10^6) = 594.4 \times 10^6 \text{ mm}^4 \]

Borated aluminum part:

\[ I_{1(B/A)} = \frac{((177.8)^4 - (165.1)^4)}{12} + \frac{((177.8)^2 - (165.1)^2) * (91.3)^2}{12} \times 0.364 \]

\[ I_{1(B/A)_{\text{total}}} = 8 \times (21 \times 10^6) = 168 \times 10^6 \text{ mm}^4 \]

\[ I_2 = \frac{((182.6)^4 - (177.82)^4)}{12} + \frac{((182.6)^2 - (177.82)^2) * (273.9)^2}{12} + \frac{((165.1)^4 - (152.4)^4)}{12} + \frac{((165.1)^2 - (152.4)^2) * (273.9)^2}{12} \]

\[ I_{\text{total}} = 8 \times (458 \times 10^6) = 3664 \times 10^6 \text{ mm}^4 \]

Borated aluminum part:

\[ I_{3(B/A)} = \frac{((177.8)^4 - (165.1)^4)}{12} + \frac{((177.8)^2 - (165.1)^2) * (273.9)^2}{12} \times 0.364 \]

\[ I_{3(B/A)_{\text{total}}} = 8 \times (126 \times 10^6) = 1014 \times 10^6 \text{ mm}^4 \]
Tube Detail B (Typical 8 Outside Tubes):

\[ I_2 = \left( \left( 165.1 \right)^4 - \left( 152.4 \right)^4 \right) / 12 + \left( \left( 165.1 \right)^2 - \left( 152.4 \right)^2 \right) * (91.3)^2 \]
\[ + (2.39) * (182.6)^3 / 12 + (2.39) * (182.6) * (91.3)^2 \]
\[ + (171.4) * (2.39)^3 / 12 + (171.4) * (2.39) * (181.4)^2 \]
\[ + (171.4) * (2.39)^3 / 12 + (171.4) * (2.39) * (1.2)^2 \]
\[ = 68.9 * 10^6 \text{ mm}^4 \]
\[ I_{total} = 4 * (68.9 * 10^6) = 275.6 * 10^6 \text{ mm}^4 \]

Borated aluminum part:

\[ I_{2B/AD} = \left( \left( 165.1 \right) * (6.35)^3 \right) / 12 + (165.1) * (6.35) * (177)^2 \]
\[ + (6.35) * (177.8)^3 / 12 + (6.35) * (177.8) * (91.3)^2 \]
\[ + (165.1) * (6.35)^3 / 12 + (165.1) * (6.35) * (1.2)^2 \] * 0.364
\[ = 16.5 * 10^6 \text{ mm}^4 \]
\[ I_{2B/AD_{total}} = 4 * (16.5 * 10^6) = 66 * 10^6 \text{ mm}^4 \]

\[ I_4 = \left( \left( 165.1 \right)^4 - \left( 152.4 \right)^4 \right) / 12 + \left( \left( 165.1 \right)^2 - \left( 152.4 \right)^2 \right) * (456.5)^2 \]
\[ + ((2.39) * (173.8)^3 / 12 + (2.39) * (173.8) * (452.1)^2) * 2 \]
\[ + (177.8) * (2.39)^3 / 12 + (177.8) * (2.39) * (366.4)^2 \]
\[ = 1086.2 * 10^6 \text{ mm}^4 \]
\[ I_{total} = 4 * (1086.2 * 10^6) = 4344.8 * 10^6 \text{ mm}^4 \]
Borated aluminum part:

\[
I_{(B/A)0} = \left( (6.35)^3 \times (171.4)^3 / 12 + (6.35) \times (171.4) \times (453.3)^2 \times 2 \right. \\
+ (165.1) \times (6.35)^3 / 12 + (165.1) \times (6.35) \times (370.8)^2 \times 0.364 \\
= 217.4 \times 10^6 \text{ mm}^4 \\
I_{(B/A)\text{total}} = 4 \times (217.4 \times 10^6) = 869.6 \times 10^6 \text{ mm}^4
\]

Detail C (Typical 4 Places):

\[
I_H = \left( (184.4)^3 \times (9.5)^3 / 12 + (184.4) \times (9.5) \times (551.7)^2 \times 2 \right. \\
+ (9.5) \times (61.3)^3 / 12 + (9.5) \times (61.3) \times (577.6)^2 \\
= 1260.9 \times 10^6 \text{ mm}^4 \\
I_{H\text{total}} = 2 \times (1260.9 \times 10^6) = 2521.8 \times 10^6 \text{ mm}^4
\]

\[
I_V = (9.5) \times (378.4)^3 / 12 + (51.8) \times (9.5)^3 = 42.9 \times 10^6 \text{ mm}^4 \\
I_{V\text{total}} = 2 \times (42.9 \times 10^6) = 85.8 \times 10^6 \text{ mm}^4
\]
Detail D (Typical 4 Places):

\[
I = (9.5) \times (202.3)^3 / 12 + (9.5) \times (202.3) \times (393.1)^2 \\
+ (192.8) \times (9.5)^3 / 12 + (192.8) \times (9.5) \times (296.8)^2 \\
+ (9.5) \times (91.3)^3 / 12 + (9.5) \times (91.3) \times (347.1)^2 \\
+ (9.5) \times (101.5)^3 / 12 + (9.5) \times (101.5) \times (241.3)^2 \\
+ (192.3) \times (9.5)^3 / 12 + (192.3) \times (9.5) \times (195.3)^2 \\
= 696.7 \times 10^6 \text{ mm}^4
\]

\[
I_{\text{total}} = 4 \times (696.7 \times 10^6) = 2786.8 \times 10^6 \text{ mm}^4
\]

I (inner structure total inertia) = (594.4 + 168 + 3664 + 1008 + 275.6 + 66 + 4344.8 + 869.6 + 2521.8 + 85.8 + 2786.8) \times 10^6 = 16384.8 \times 10^6 \text{ mm}^4

\[
I_{\text{MPC shell}} = 16570.5 \times 10^6 \text{ mm}^4
\]

\[
I_{\text{MPC Disposal Container}} = 133196.4 \times 10^6 \text{ mm}^4
\]

\[
I_{\text{overall}} = 166151.7 \times 10^6 \text{ mm}^4
\]
Inertia Calculations on 12 PWR ILB Waste Package

\[
I_1 = \frac{(235.6) \times (20)^3}{12} + \frac{(235.6) \times (20) \times (471.2)^2}{12} = 1046.36 \times 10^6 \text{ mm}^4
\]

\[
I_2 = \frac{(20) \times (215.6)^3}{12} + \frac{(20) \times (215.6) \times (353.4)^2}{12} = 555.24 \times 10^6 \text{ mm}^4
\]

\[
I_3 = \frac{(471.2) \times (20)^3}{12} + \frac{(471.2) \times (20) \times (235.6)^2}{12} = 523.42 \times 10^6 \text{ mm}^4
\]

\[
I_4 = \frac{(20) \times (215.6)^3}{12} + \frac{(20) \times (215.6) \times (117.8)^2}{12} = 76.54 \times 10^6 \text{ mm}^4
\]

\[
I_5 = I_4 = 76.54 \times 10^6 \text{ mm}^4
\]

\[
I_6 = \frac{(10) \times (540.2)^3}{12} + \frac{(10) \times (540.2) \times (270.1)^2}{12} = 525.46 \times 10^6 \text{ mm}
\]

\[
I_7 = \frac{(530.2) \times (10)^3}{12} + \frac{(530.2) \times (10) \times (5)^2}{12} = 0.18 \times 10^6 \text{ mm}^4
\]

\[
I_{\text{total}} = 2803.74 \times 10^6 \text{ mm}^4
\]

\[
I_{\text{inner structure total inertia}} = 4 \times (2803.74 \times 10^6) = 11214.96 \times 10^6 \text{ mm}^4
\]

\[
I_{\text{inner and outer barriers}} = \frac{\pi \times ((1320.4)^4 - 1080.4)^4}{64} = 82326.11 \times 10^6 \text{ mm}^4
\]

\[
I_{\text{overall}} = 93541.1 \times 10^6 \text{ mm}^4
\]
Inertia Calculations on 12 PWR ILB Waste Package (45 degree rotated)

The following relation is used to determine the area moment of inertia of a rectangular shape with respect to an axis rotated by an angle $z$:

$$I = \frac{(b^3 \cdot h \cdot \sin^2(z) + b \cdot h^3 \cdot \cos^2(z))}{12}$$

(Ref. 5.16)

Let $z = 45$ degrees, therefore,

$$I = \frac{(b^3 \cdot h + b \cdot h^3) \cdot 0.5}{12}$$

The 12 PWR ILB waste package sketch is simplified as given in below figure. These simplifications do not have any significant effect on the results, since the dimensions are close to the ones given in the sketches (Ref. 5.1) (Assumption 4.3.13).
\[
I_1 = ((540.2)^3 \times (20) + (540.2) \times (20)^3) \times \frac{0.5}{12} + (540.2) \times (20) \times (191)^2
= 525.69 \times 10^6 \text{ mm}^4
\]

\[
I_2 = ((245.6)^3 \times (20) + (245.6) \times (20)^3) \times \frac{0.5}{12} + (245.6) \times (20) \times (416.48)^2
= 864.44 \times 10^6 \text{ mm}^4
\]

\[
I_3 = ((245.6)^3 \times (20) + (245.6) \times (20)^3) \times \frac{0.5}{12} + (245.6) \times (20) \times (86.83)^2
= 49.46 \times 10^6 \text{ mm}^4
\]

\[
I_4 = ((215.6)^3 \times (20) + (215.6) \times (20)^3) \times \frac{0.5}{12} + (215.6) \times (20) \times (416.48)^2
= 756.36 \times 10^6 \text{ mm}^4
\]

\[
I_5 = ((215.6)^3 \times (20) + (215.6) \times (20)^3) \times \frac{0.5}{12} + (215.6) \times (20) \times (249.9)^2
= 277.7 \times 10^6 \text{ mm}^4
\]

\[
I_6 = I_5 = 277.7 \times 10^6 \text{ mm}^4
\]

\[
I_7 = ((225.6)^3 \times (20) + (225.6) \times (20)^3) \times \frac{0.5}{12} + (225.6) \times (20) \times (79.76)^2
= 38.35 \times 10^6 \text{ mm}^4
\]

I (inner structure) = 4 \times (2789.7 \times 10^6) = 11158.8 \times 10^6 \text{ mm}^4

I (inner and outer barriers) = \pi \times ((1320.4)^4 - (1080.4)^4) / 64 = 82326.11 \times 10^6 \text{ mm}^4

I_{\text{overall}} = 93484.9 \times 10^6 \text{ mm}^4
Inertia Calculations on 125-Ton MPC 21 PWR Configuration (45 degree rotated)

The following figure shows the numbers assigned to each section in order to calculate area moments of inertia.
Tube Detail B (Typical 12 Outside Tubes):

\[ I_1 = \frac{((253.75)^4 - (248.92)^4)}{12} + \frac{((236.22)^4 - (223.52)^4)}{12} + \frac{((236.22)^2 - (223.52)^2)}{12} \cdot (538.3)^2 \]
- \[ ((2.39)^3 \cdot (253.75) + (2.39) \cdot (253.75)^3) \cdot 0.5 \times 12 - (2.39) \cdot (253.75) \cdot (627.16)^2 \]
\[ = 2232.24 \times 10^6 \text{ mm}^4 \]

Borated aluminum part:

\[ I_{I(B/A)} = \frac{((248.92)^4 - (236.22)^4)}{12} + (248.92)^2 - (236.22)^2) \cdot (538.3)^2 \]
- \[ ((6.35)^3 \cdot (248.92) + (6.35) \cdot (248.92)^3) \cdot 0.5 \times 12 \]
- \[ (6.35) \cdot (248.92) \cdot (624.1)^2 \times 0.364 \]
\[ = 446.3 \times 10^6 \text{ mm}^4 \]

\[ I_{\text{total}} = 2678.54 \times 10^6 \text{ mm}^4 \]
I_2 = \frac{((253.75)^4 - (248.92)^4)}{12} + \frac{((236.22)^4 - (223.52)^4)}{12} \\
+ \frac{((253.75)^2 - (248.92)^2) \times (358.86)^2}{12} + ((236.22)^2 - (223.52)^2) \times (358.86)^2 \\
- ((2.39)^3 \times (253.75) + (2.39) \times (253.75)^3) \times 0.5 / 12 \\
- (2.39) \times (253.75) \times (447.73)^2 \\
= 1018.4 \times 10^6 \text{ mm}^4

Borated aluminum:

I_{ZB/AO} = \frac{((248.92)^4 - (236.22)^4)}{12} + ((248.92)^2 - (236.22)^2) \times (358.86)^2 \\
- ((6.35)^3 \times (248.92) + (6.35) \times (248.92)^3) \times 0.5 / 12 \\
- (6.35) \times (248.92) \times (444.67)^2 \times 0.364 \\
= 195.57 \times 10^6 \text{ mm}^4 \\
I_{\text{total}} = 1214 \times 10^6 \text{ mm}^4
\[ I_3 = \frac{(253.75)^4 - (248.92)^4}{12} + \frac{(236.22)^4 - (223.52)^4}{12} + \frac{(253.75)^2 - (248.92)^2}{12} \cdot (179.43)^2 + \frac{(236.22)^2 - (223.52)^2}{12} \cdot (179.43)^2 - \frac{(2.39)^3 \cdot (253.75) + (2.39) \cdot (253.75)^3}{12} - (2.39) \cdot (253.75) \cdot (268.3)^3 \cdot 0.5 / 12 = 297.9 \times 10^6 \text{ mm}^4 \]

Borated aluminum:

\[ I_{3_{\text{AD}}} = \frac{((248.92)^4 - (236.22)^4)}{12} + \frac{(248.92)^2 - (236.22)^2}{12} \cdot (179.43)^2 - \frac{(6.35)^3 \cdot (248.92) + (6.35) \cdot (248.92)^3}{12} - (6.35) \cdot (248.92) \cdot (265.24)^3 \cdot 0.364 = 52.25 \times 10^6 \text{ mm}^4 \]

\[ I_{3_{\text{total}}} = 350.15 \times 10^6 \text{ mm}^4 \]
Tube Detail A (Typical 9 Inside Tubes):

This part has the same geometry with $I_3$ except one side of the square. Thus, the moment of inertia is directly calculated from $I_3$ as,

$$I_4 = 343.2 \times 10^6 \text{ mm}^4$$

Borated aluminum:

$$I_{4(B\text{/A}0)} = 94.2 \times 10^6 \text{ mm}^4$$

$$I_{4\text{total}} = 437.4 \times 10^6 \text{ mm}^4$$

$$\begin{align*}
I_3 &= \frac{(((253.75)^4 - (248.92)^4)}{12} + \frac{((236.22)^4 - (223.52)^4)}{12} + \frac{((253.75)^2 - (248.92)^2) \cdot (358.86)^2 + ((236.22)^2 - (223.52)^2) \cdot (358.86)^2}{2} 
\end{align*}$$
= 570.8 \times 10^6 \text{ mm}

Borated aluminum:

\[ I_{5\text{B/AD}} = \frac{((248.92)^4 - (236.22)^4)}{12} + \frac{((248.92)^2 - (236.22)^2)}{12} \times (358.86)^2 \times 0.364 \times \frac{1}{2} \]

= 155.4 \times 10^6 \text{ mm}

\[ I_{5\text{total}} = 726.2 \times 10^6 \text{ mm} \]

\[ I_6 = \frac{((253.75)^4 - (248.92)^4)}{12} + \frac{((236.22)^4 - (223.52)^4)}{12} \times \frac{1}{4} \]

= 19.26 \times 10^6 \text{ mm}

Borated aluminum:

\[ I_{5\text{B/AD}} = \frac{((248.92)^4 - (236.22)^4)}{12} \times 0.364 \times \frac{1}{4} \]

= 5.5 \times 10^6 \text{ mm}

\[ I_{6\text{total}} = 24.76 \times 10^6 \text{ mm} \]

\[ I_7 = 2 \times I_6 = 49.52 \times 10^6 \text{ mm} \]
Detail D Guides (Typical 4 Places):

\[ I_4 = \frac{((236.7)^3 \times (9.53) + (236.7) \times (9.53)^3) \times 0.5}{12} + (236.7) \times (9.53) \times (720.2)^2 \]
\[ = 1175.3 \times 10^6 \text{ mm} \]

\[ I_9 = ((236.7)^3 \times (9.53) + (236.7) \times (9.53)^3) \times 0.5 / 12 + (236.7) \times (9.53) \times (83.6)^2 \]
\[ = 21 \times 10^6 \text{ mm} \]

\[ I_{10} = ((9.53)^3 \times (733.2) + (9.53) \times (733.2)^3) \times 0.5 / 12 + (9.53) \times (733.2) \times (451.3)^2 \]
\[ + ((94.92)^3 \times (9.53) + (94.92) \times (9.53)^3) \times 0.5 / 12 + (94.92) \times (9.53) \times (398)^2 \]
\[ + ((94.92)^3 \times (9.53) + (94.92) \times (9.53)^3) \times 0.5 / 12 + (94.92) \times (9.53) \times (577.43)^2 \]
\[ I = 2025.25 \times 10^6 \text{ mm} \]

\[ \text{I (inner structure)} = 4 \times (8702.12 \times 10^6) = 34808.5 \times 10^6 \text{ mm} \]

\[ I_{\text{MPC shell}} = 34094.34 \times 10^6 \text{ mm}^4 \]

\[ I_{\text{MPC Disposal Container}} = 225224.27 \times 10^6 \text{ mm}^4 \]

\[ I_{\text{overall}} = 294127.1 \times 10^6 \text{ mm}^4 \]
Inertia Calculations on MPC 75-Ton 12 PWR Configuration (45 degree rotated)

The following figure shows the numbers assigned to each section in order to calculate area moments of inertia.
\[
I_1 = \frac{((243.61)^4 - (238.82)^4)}{12} + \frac{((243.61)^2 - (238.82)^2) * (406.86)^2}{12} \cdot 0.364 \cdot \frac{1}{2} \\
= 589.3 \cdot 10^6 \text{ mm}^4
\]

Borated aluminum:
\[
I_{1(B/A)} = \frac{((238.82)^4 - (233.4)^4)}{12} + \frac{((238.82)^2 - (233.4)^2) * (406.86)^2}{12} \cdot 0.364 \cdot \frac{1}{2} \\
= 81.44 \cdot 10^6 \text{ mm}^4
\]

\[
I_{\text{total}} = 4 \cdot (670.74 \cdot 10^6) = 2682.96 \cdot 10^6 \text{ mm}^4
\]
I_2 = ((233.4)^4 - (228.6)^4) / 12 + ((233.4)^2 - (228.6)^2) * (190)^2 
+ ((243.61)^4 - (238.82)^4) / 12 + ((243.61)^2 - (238.82)^2) * (190)^2 
- (((2.39)^3 * (243.61) + (2.39) * (243.61)^3) * 0.5 / 12 + (2.39) * (243.61) * (275.3)^2) * 2
= 114.47 \times 10^6 \text{ mm}^4

Borated Aluminum:
I_{2B/\phi} = (((238.82)^4 - (233.4)^4) / 12 + ((238.82)^2 - (233.4)^2) * (190)^2 
+ ((2.72)^3 * (238.82) + (2.72) * (238.82)^3) * 0.5 / 12 
+ (2.72) * (238.82) * (273.5)^2) * 2) * 0.364 
= 5.8 \times 10^6 \text{ mm}^4

I_{\text{total}} = 4 * (120.27 \times 10^6) = 481.1 \times 10^6 \text{ mm}^4
\[I_3 = \frac{((233.4)^4 - (228.6)^4)}{12} + \frac{((233.4)^2 - (228.6)^2) \cdot (209.7)^2}{12} + \frac{((243.61)^4 - (238.82)^4)}{12} + \frac{((243.61)^2 - (238.82)^2) \cdot (209.7)^2}{12} - \frac{((2.39)^3 \cdot (243.61) + (2.39) \cdot (243.61)^3)}{2} \cdot 0.5 / 12 + (2.39) \cdot (243.61) \cdot (124.4)^2} \cdot 0.5 / 12 + (2.39) \cdot (243.61) \cdot (124.4)^2) \cdot 2 \]

\[= 220.4 \cdot 10^6 \text{ mm}^4\]

Borated Aluminum:
\[I_{3/B/AD} = \frac{((238.82)^4 - (233.4)^4)}{12} + \frac{((238.82)^2 - (233.4)^2) \cdot (209.7)^2}{12} - \frac{((2.72)^3 \cdot (238.82) + (2.72) \cdot (238.82)^3)}{0.5 / 12} + (2.72) \cdot (238.82) \cdot (126.2)^2) \cdot 2 \cdot 0.364 \]
\[= 40.97 \cdot 10^6 \text{ mm}^4\]

\[I_{3\text{total}} = 2 \cdot (261.37 \cdot 10^6) = 522.74 \cdot 10^6 \text{ mm}^4\]

\[I_4 = \frac{((243.61)^4 - (238.82)^4)}{12} \cdot 1/2 \cdot 1/12 + \frac{((233.4)^4 - (228.6)^4)}{12} \]
\[= 30.93 \cdot 10^6 \text{ mm}^4\]

Borated Aluminum:
\[I_{4/B/AD} = \frac{((238.82)^4 - (233.4)^4)}{12} \cdot 1/2 \cdot 1/12 \cdot 0.364 \]
\[= 4.3 \cdot 10^6 \text{ mm}^4\]

\[I_{4\text{total}} = 2 \cdot (35.23 \cdot 10^6) = 70.46 \cdot 10^6 \text{ mm}^4\]
Detail B (Typical 4 Places):

\[ I_1 = ((575.7)^3 \times (12.7) + (575.7) \times (12.7)^3) \times 0.5 / 12 + (575.7) \times (12.7) \times (235)^2 \]
\[ = 504.79 \times 10^6 \text{ mm}^4 \]

\[ I_3 = ((569.3)^3 \times (2.39) + (569.3) \times (2.39)^3) \times 0.5 / 12 + (569.3) \times (2.39) \times (242.5)^2 \]
\[ = 98.4 \times 10^6 \text{ mm}^4 \]

\[ I_4 = ((12.7)^3 \times (588.4) + (12.7) \times (588.4)^3) \times 0.5 / 12 + (12.7) \times (588.4) \times (230.48)^2 \]
\[ = 504.8 \times 10^6 \text{ mm}^4 \]

\[ I_6 = ((2.39)^3 \times (560.6) + (2.39) \times (560.6)^3) \times 0.5 / 12 + (2.39) \times (560.6) \times (245.64)^2 \]
\[ = 98.39 \times 10^6 \text{ mm}^4 \]

Borated Aluminum:

\[ I_2 = (((569.3)^3 \times (6.35) + (569.3) \times (6.35)^3) \times 0.5 / 12 \]
\[ + (569.3) \times (6.35) \times (239.4)^2) \times 0.364 \]
\[ = 93.19 \times 10^6 \text{ mm}^4 \]
\[ I_5 = \left( (6.35)^3 \times (560.6) + (6.35) \times (560.6)^3 \right) \times 0.5 / 12 \\
+ (6.35) \times (560.6) \times (242.55)^2 \times 0.364 \\
= 93.2 \times 10^6 \text{ mm}^4 \]

\[ I_{\text{total}} = 2 \times (1392.77 \times 10^6) = 2785.54 \times 10^6 \text{ mm}^4 \]

Detail F (Typical 4 Places):

Vertical symmetry:
\[ I_1 = ((246.7)^3 \times (9.5) + (246.7) \times (9.5)^3) \times 0.5 / 12 + (246.7) \times (9.5) \times (494)^2 \\
= 577.89 \times 10^6 \text{ mm}^4 \]

\[ I_2 = ((9.5)^3 \times (256.2) + (9.5) \times (256.2)^3) \times 0.5 / 12 + (9.5) \times (256.2) \times (490.7)^2 \\
= 592.7 \times 10^6 \text{ mm}^4 \]

\[ I_{\text{total}} = 2 \times (1170.59 \times 10^6) = 2341.18 \times 10^6 \text{ mm}^4 \]
Horizontal Symmetry:
\[ I_1 = (256.2)^3 \times (9.5) + (256.2) \times (9.5)^3 \times 0.5 \div 12 + (256.2) \times (9.5) \times (87.22)^2 \]
\[ = 25.18 \times 10^6 \text{ mm}^4 \]

\[ I_2 = (9.5)^3 \times (246.7) + (9.5) \times (246.7)^3 \times 0.5 \div 12 + (9.5) \times (246.7) \times (90.6)^2 \]
\[ = 25.18 \times 10^6 \text{ mm}^4 \]

\[ I_{\text{total}} = 2 \times (50.36 \times 10^6) = 100.72 \times 10^6 \text{ mm}^4 \]

Detail E (Typical 8 Places):
First placement mode:
\[ I_1 = ((53.9)^3 \times (9.5) + (53.9) \times (9.5)^3) \times 0.5 \div 12 + (53.9) \times (9.5) \times (443.5)^2 \]
\[ = 100.8 \times 10^6 \text{ mm}^4 \]

\[ I_2 = ((9.5)^3 \times (214.2) + (9.5) \times (214.2)^3) \times 0.5 \div 12 + (9.5) \times (214.2) \times (524.6)^2 \]
\[ = 563.9 \times 10^6 \text{ mm}^4 \]

\[ I_{\text{total}} = 4 \times (664.7 \times 10^6) = 2658.8 \times 10^6 \text{ mm}^4 \]
Second placement mode:

\[ I_1 = ((9.5)^3 \times 214.2 + (9.5) \times (214.2)^3) \times 0.5 / 12 + (9.5) \times (214.2) \times (288.2)^2 \]
\[ = 172.9 \times 10^6 \text{ mm}^4 \]

\[ I_2 = ((53.9)^3 \times (9.5) + (53.9) \times (9.5)^3) \times 0.5 / 12 + (53.9) \times (9.5) \times (383)^2 \]
\[ = 75.18 \times 10^6 \text{ mm}^4 \]

\[ I_{\text{total}} = 4 \times (248.08 \times 10^6) = 992.32 \times 10^6 \text{ mm}^4 \]
Spacer Detail D (Typical 20 Places) (see Assumption 4.3.13):

\[ I = (25.4)^4 \times 5 \times \frac{1}{12} + (25.4)^2 \times ((388.13)^2 + (294.86)^2 + (201.74)^2) \\
+ (108.47)^2 + (26.94)^2) \\
= 187.77 \times 10^6 \text{ mm}^4 \]

\[ I_{\text{total}} = 4 \times (187.77 \times 10^6) = 751.08 \times 10^6 \text{ mm}^4 \]

Box Spar Spacer Detail C (Typical 8 Places):

\[ I = (((25) \times (6.35)^3 + (25)^3 \times (6.35)) \times 0.5 / 12) \times 8 + (6.35) \times (25) \times ((11.1)^2 \\
+ (65.79)^2 + (120.48)^2 + (175.17)^2 + (228.1)^2 + (282.78)^2 + (337.47)^2 + (392.16)^2) \\
= 71.36 \times 10^6 \text{ mm}^4 \]

\[ I_{\text{total}} = 4 \times (71.36 \times 10^6) = 285.44 \times 10^6 \text{ mm}^4 \]

\[ I (\text{inner structure}) = 13672.3 \times 10^6 \text{ mm} \]

\[ I_{\text{MPC shell}} = 16570.5 \times 10^6 \text{ mm}^4 \]

\[ I_{\text{MPC disposal container}} = 133196.4 \times 10^6 \text{ mm}^4 \]

\[ I_{\text{overall}} = 163439.2 \times 10^6 \text{ mm}^4 \]
Inertia Calculations on MPC 75-Ton 24 BWR Configuration (45 degree rotated)

The following figure shows the numbers assigned to each section in order to calculate area moments of inertia.
Tube Detail B (Typical 8 Outside Tubes):

\[ I_1 = \frac{(165.1^4 - 152.4^4)}{12} + \frac{(165.1^2 - 152.4^2)(387.35)^2}{12} \]
\[ + \frac{(182.6^4 - 177.8^4)}{12} + \frac{(182.6^2 - 177.8^2)(387.35)^2}{12} \]
\[ - \frac{(2.39)^3(182.6) + (2.39)(182.6^3)}{12} \quad 0.5 / 12 \]
\[ - \frac{(2.39)(182.6)(451.06)^2}{12} = 801.49 \times 10^6 \text{ mm}^4 \]

Borated Aluminum:

\[ I_{(B/A)} = \frac{((177.8)^4 - (165.1)^4)}{12} + \frac{(177.8)^2 - (165.1)^2)(387.35)^2}{12} \]
\[ - \frac{(6.35)^3(177.8) + (6.35)(177.8^3)}{12} \quad 0.5 / 12 \]
\[ - \frac{(6.35)(177.8)(447.97)^2}{12} \times 0.364 = 162.6 \times 10^6 \text{ mm}^4 \]

\[ I_{\text{local}} = 4 \times (964.09 \times 10^6) = 3856.36 \times 10^6 \text{ mm}^4 \]

\[ I_3 = \frac{(165.1^4 - 152.4^4)}{12} + \frac{(165.1^2 - 152.4^2)(258.23)^2}{12} \]
\[ + \frac{(182.6^4 - 177.8^4)}{12} + \frac{(182.6^2 - 177.8^2)(258.23)^2}{12} \]
\[ - \frac{(2.39)^3(182.6) + (2.39)(182.6^3)}{12} \quad 0.5 / 12 \]
Borated Aluminum:

\[ I_{\text{Borated Aluminum}} = \frac{((177.8)^4 - (165.1)^4)}{12} + \frac{((177.8)^2 - (165.1)^2) \times (258.23)^2}{12} + \frac{(6.35)^3 \times (177.8) + (6.35) \times (177.8)^3}{12} \times 0.5 \]
\[ = 71.16 \times 10^6 \text{ mm}^4 \]

\[ I_{\text{Total}} = 4 \times (435.89 \times 10^6) = 1743.56 \times 10^6 \text{ mm}^4 \]

**Tube Detail A (Typical 16 Inside Tubes):**

\[ I_2 = \frac{((182.6)^4 - (177.8)^4)}{12} + \frac{((182.6)^2 - (177.8)^2) \times (387.35)^2}{12} + \frac{((165.1)^4 - (152.4)^4)}{12} + \frac{((165.1)^2 - (152.4)^2) \times (387.35)^2}{12} \]
\[ = 890.88 \times 10^6 \text{ mm}^4 \]

\[ I_{\text{Borated Aluminum}} = \frac{((177.8)^4 - (165.1)^4)}{12} + \frac{((177.8)^2 - (165.1)^2) \times (387.35)^2}{12} \times 0.364 \]
\[ = 245.6 \times 10^6 \text{ mm}^4 \]
\[ I_{2\text{total}} = 2 \times (1136.48 \times 10^6) = 2272.96 \times 10^6 \text{ mm}^4 \]
\[ I_4 = \frac{((182.6)^4 - (177.8)^4)}{12} + \frac{((182.6)^2 - (177.8)^2)^2}{(258.23)^2} \]
\[ + \frac{((165.1)^4 - (152.4)^4)}{12} + \frac{((165.1)^2 - (152.4)^2)^2}{(258.23)^2} \]
\[ = 410.56 \times 10^6 \text{ mm}^4 \]
\[ I_{4(\text{B/AD})} = \frac{((177.8)^4 - (165.1)^4)}{12} + \frac{((177.8)^2 - (165.1)^2)^2}{(258.23)^2} \times 0.364 \]
\[ = 113.48 \times 10^6 \text{ mm}^4 \]
\[ I_{4\text{total}} = 4 \times (524.04 \times 10^6) = 2096.16 \times 10^6 \text{ mm}^4 \]
\[ I_5 = \frac{((182.6)^4 - (177.8)^4)}{12} + \frac{((182.6)^2 - (177.8)^2)^2}{(129.12)^2} \]
\[ + \frac{((165.1)^4 - (152.4)^4)}{12} + \frac{((165.1)^2 - (152.4)^2)^2}{(129.12)^2} \]
\[ = 122.39 \times 10^6 \text{ mm}^4 \]
\[ I_{5(\text{B/AD})} = \frac{((177.8)^4 - (165.1)^4)}{12} + \frac{((177.8)^2 - (165.1)^2)^2}{(129.12)^2} \times 0.364 \]
\[ = 34.2 \times 10^6 \text{ mm}^4 \]
\[ I_{5\text{total}} = 6 \times (156.59 \times 10^6) = 939.54 \times 10^6 \text{ mm}^4 \]
\[ I_6 = 9.36 \times 10^6 + 16.96 \times 10^6 = 26.32 \times 10^6 \text{ mm}^4 \]
\[ I_{6(\text{B/AD})} = (21.36 \times 10^6) \times 0.364 = 7.77 \times 10^6 \text{ mm}^4 \]
\[ I_{6\text{total}} = 4 \times (34.09 \times 10^6) = 136.36 \times 10^6 \text{ mm}^4 \]
Detail D (Typical 4 Places):

\[ I_1 = ((202.3) \times (9.5)^3 + (202.3)^3 \times (9.5)) \times 0.5 / 12 + (202.3) \times (9.5) \times (473.38)^2 \]
\[ = 433.95 \times 10^6 \text{ mm}^4 \]

\[ I_2 = ((9.5) \times (192.8)^3 + (9.5)^3 \times (192.8)) \times 0.5 / 12 + (9.5) \times (192.8) \times (483.46)^2 \]
\[ = 430.95 \times 10^6 \text{ mm}^4 \]

\[ I_3 = (9.5)^4 \times 1/12 + (9.5)^2 \times (477)^2 = 20.54 \times 10^6 \text{ mm}^4 \]

\[ I_{\text{total}} = ((433.95 \times 10^6 + 430.95 \times 10^6) \times 2 - 20.54 \times 10^6) \times 2 \]
\[ = 3418.52 \times 10^6 \text{ mm}^4 \]

\[ \text{Detail C (Typical 4 Places)}: \]

\[ I_1 = ((9.5) \times (378.4)^3 + (9.5)^3 \times (378.4)) \times 0.5 / 12 + (9.5) \times (378.4) \times (395.37)^2 \]
\[ = 583.4 \times 10^6 \text{ mm}^4 \]

\[ I_2 = ((51.8) \times (9.5)^3 + (51.8)^3 \times (9.5)) \times 0.5 / 12 + (51.8) \times (9.5) \times (417)^2 \]
\[ = 85.63 \times 10^6 \text{ mm}^4 \]

\[ I_{\text{total}} = 4 \times (669 \times 10^6) = 2676 \times 10^6 \text{ mm}^4 \]
Detail D (continued):

\[ I_1 = \left( (9.5) * (92)^3 + (9.5)^3 * (92) \right) / 12 + (9.5) * (92) * (35.88)^2 \]
\[ = 1.44 * 10^6 \text{ mm}^4 \]

\[ I_2 = \left( (202.3) * (9.5)^3 + (202.3)^3 * (9.5) \right) / 12 + (202.3) * (9.5) * (140)^2 \]
\[ = 40.95 * 10^6 \text{ mm}^4 \]

\[ I_3 = \left( (9.5) * (91.3)^3 + (9.5)^3 * (91.3) \right) / 12 + (9.5) * (91.3) * (35.64)^2 \]
\[ = 1.4 * 10^6 \text{ mm}^4 \]

\[ I_{\text{total}} = 4 * (43.79 * 10^6) = 175.16 * 10^6 \text{ mm}^4 \]

\[ I \text{ (inner structure)} = 17314.62 * 10^6 \text{ mm} \]

\[ I_{\text{MPC shell}} = 16570.5 * 10^6 \text{ mm}^4 \]

\[ I_{\text{MPC Disposal Container}} = 133196.4 * 10^6 \text{ mm}^4 \]

\[ I_{\text{overall}} = 167081.5 * 10^6 \text{ mm}^4 \]