6.2.2.3.7 Tuff

Tuff, when modeled as a neutron reflector, is modeled 100% saturated and treated at full density (2.359 g/cm^3) in the TAD canister MCNP calculations. The specification for Tuff is detailed in Table 21.

Table 21. Tuff Material Specification

Element/Isotope	ZAID	100% Saturated Atom Density (a/b-cm)
Si	14000.50c	1.7281E-02
Al-27	13027.50c	3.3505E-03
Fe-54	26054.60c	1.1224E-05
Fe-56	26056.60c	1.7604E-04
Fe-57	26057.60c	4.0676E-06
Fe-58	26058.60c	5.3724E-07
Mg	12000.50c	4.3900E-05
Ca	20000.50c	1.2135E-04
Na-23	11023.50c	1.5460E-03
K	19000.50c	1.3958E-03
Ti	22000.50c	1.8746E-05
P-31	15031.50c	9.5885E-06
Mn-55	25055.50c	1.3431E-05
O-16	8016.50c	4.5507E-02
H-1	1001.50c	7.8665E-03
Density = 2.359 g/cm^3		

NOTE: [a] Derivations are provided in Attachment IV, Homog_Mats.xls, sheet Tuff, of *Dimension and Material Specification for Use in Criticality Analyses* (Ref. 2.2.1).

[b] The listed materials account for 99.16 wt% of the tuff material composition. Trace impurities (e.g., Cl, F, S, etc.) that are in quantities of 0.05 wt% and less are omitted from the representative composition since they are too sparse in concentration to have any appreciable difference on the reflective properties of the tuff

Source: *Geochemistry of Repository Block* (Ref. 2.2.15), mean values (called out by *IED Geotechnical and Thermal Parameters* (Ref. 2.2.20))

6.2.2.3.8 Titanium

Titanium, when modeled as a neutron reflector, is treated at full theoretical density (4.54 g/cm^3) in the TAD canister MCNP calculations. The specification for Titanium, based on the material data provided in *CRC Handbook of Chemistry and Physics* (Ref. 2.2.11), is detailed in Table 22.

Table 22. Titanium Material Specification

Element/ Isotope	ZAID	Wt%
^{22}Ti	22000.60c	100
Density: 4.54 g/cm^3		

6.2.2.3.9 Alloy 22

Alloy 22, when modeled as a neutron reflector, is treated at full density (8.69 g/cm^3) in the TAD canister MCNP calculations. The specification for Alloy 22 is based on the specification provided in *Dimension and Material Specification for Use in Criticality Analyses* (Ref. 2.2.1), where it is designated as *SB-575 N06022*. The specification for Alloy 22 used in the TAD canister criticality safety analysis is detailed in Table 23.

Table 23. Material Specification for Alloy 22 (SB-575 N06022)

Element/Isotope	ZAID	Wt%	Element/Isotope	ZAID	Wt%
C-nat	6000.50c	0.0150	^{58}Fe	26058.60c	0.0116
Si-nat	14000.50c	0.0800	^{59}Co	27059.50c	2.5000
^{31}P	15031.50c	0.0200	^{58}Ni	28058.60c	36.8024
S-nat	16032.50c	0.0200	^{60}Ni	28060.60c	14.6621
V-nat	23000.50c	0.3500	^{61}Ni	28061.60c	0.6481
^{50}Cr	24050.60c	0.8879	^{62}Ni	28062.60c	2.0975
^{52}Cr	24052.60c	17.7863	^{64}Ni	28064.60c	0.5547
^{53}Cr	24053.60c	2.0554	Mo-nat	42000.50c	13.5000
^{54}Cr	24054.60c	0.5202	^{182}W	74182.55c	0.7877
^{55}Mn	25055.50c	0.5000	^{183}W	74183.55c	0.4278
^{54}Fe	26054.60c	0.2260	^{184}W	74184.55c	0.9209
^{56}Fe	26056.60c	3.6759	^{186}W	74186.55c	0.8636
^{57}Fe	26057.60c	0.0865	Density = 8.69 g/cm^3		

Source: *Dimension and Material Specification for Use in Criticality Analyses* (Reference 2.2.1)

6.3 CALCULATION METHODOLOGY

This section presents the methodology used to evaluate the criticality safety performance of the TAD canister-based systems under both normal and potential off-normal conditions. The calculation methodology is structured according to the operating circumstances considered; namely ‘normal conditions’ and ‘off-normal’ conditions.

6.3.1 Evaluation of Normal Conditions

All TAD canisters received and accepted into the surface and sub-surface facilities will be hermetically sealed, with a dry, intact, basket containing intact commercial spent nuclear fuel with a maximum initial enrichment of 5 wt % 235U/U. Under normal conditions, operations associated with receipt and handling of the TAD canisters in the surface facilities, in addition to operations concerned with emplacement of the TAD canisters within the sub-surface facility, will not alter these conditions.

6.3.1.1 Anticipated Surface Facility and Intra-Site Operations

Operations conducted in the surface facilities1 (which include Intra-Site operations) concern the preparation of the received TAD canisters for disposal in the Subsurface facility. These preparatory operations primarily entail:

- Receipt of transportation casks containing commercial SNF in TAD canisters (CRCF & RF);
- Upending and removal of transportation casks from their conveyance, including unbolting and removal of lids from casks (CRCF & RF);
- Transfer of the TAD canisters from their transportation cask to an aging overpack (CRCF);
- Transfer of TAD canisters in aging overpacks between the RF, WHF, CRCF, and Aging Facility (Intra-Site);
- Aging of TAD canisters in aging overpacks on an aging pad (Aging Facility);
- Receipt of loaded TAD canisters inside aging overpacks from the aging pad (CRCF);
- Transfer of canisters from transportation casks and aging overpacks into waste packages (CRCF);
- Installation and welding of the waste package inner and outer lids (CRCF); and
- Transfer of the completed waste package, using the TEV to the Subsurface facility for emplacement into the disposal drifts (Intra-Site).

Based on the abovementioned surface facility operations, it is evident that all TAD canisters will be handled individually in the surface facilities. However, it is recognized that TAD canisters could be placed within close proximity to other TAD canisters prior to loading into waste packages and emplacement in the Subsurface facility, or loading into overpacks for aging.

To demonstrate the subcriticality of the TAD canisters under the abovementioned normal conditions within the surface facilities, the PWR and BWR TAD canisters containing representative fuel assemblies (Section 6.2.1.2) are evaluated individually (i.e. as a single isolated canister) and in an infinite planar array configuration.

The single canister models are based on the models described in Section 6.2.1.1 but with incorporated close fitting full-thickness (i.e. 30 cm) reflection adjacent all surfaces of the canister. A series of reflector materials (Section 6.2.2.3) are examined for the single PWR TAD canister case to determine the limiting reflector condition. The limiting reflector material established from the single PWR TAD canister calculations is applied to the single BWR TAD canister calculation. Based on neutron mean free paths in the various reflecting materials, the

[1] Note that the WHF pool and IHF are excluded from the scope of surface facilities in this criticality safety analysis.

reflection conditions accounted for in this criticality safety calculation are considered to bound the reflections conditions that could be realized in the surface and subsurface facilities. Refer to Figure 12 through Figure 14 for a cross-section view of the PWR and BWR single canister models with incorporated close-fitting full reflectors. It should be noted that, under normal conditions, the TAD canister contents are assumed to be essentially undamaged, however, movement of the fuel assemblies within the fuel assembly compartments could potentially occur during handling. To account for potential displacement of fuel assemblies within their compartments, the normal conditions single (i.e. isolated) PWR and BWR TAD canister models are also evaluated with a hypothetical, idealized, fuel assembly configuration in which the fuel assemblies are 'bunched' by preferential displacement within their compartments. The bunched fuel assembly configurations are illustrated in Figure 17 and Figure 18 for the isolated PWR and BWR TAD canisters, respectively.

The canister infinite planar array configuration models are based on the non-bunched models described in Section 6.2.1.1 but include close fitting full-thickness (30 cm) reflection adjacent the upper and lower surfaces of the canister, equivalent to the axial reflection conditions considered for the single (i.e. isolated) canister calculation models. The non-bunched fuel assembly models are employed for the canister infinite planar array calculations because, based on the single canister analysis, fuel assembly bunching is inconsequential to criticality safety of the canister system (Table 24). A periodic boundary hexagonal lattice is applied directly adjacent the cylindrical surface of the canister to simulate an infinite planar array of canisters in a close packed, triangular-pitched, configuration. The space between the periodic boundary and the TAD shell represents the interstitial space between the canisters in the array. This interstitial space is evaluated as void and is separately evaluated with variable density water. Refer to Figure 14 through Figure 16 for a cross-section view of the PWR and BWR infinite planar array canister model with incorporated close-fitting full-thickness axial reflectors.

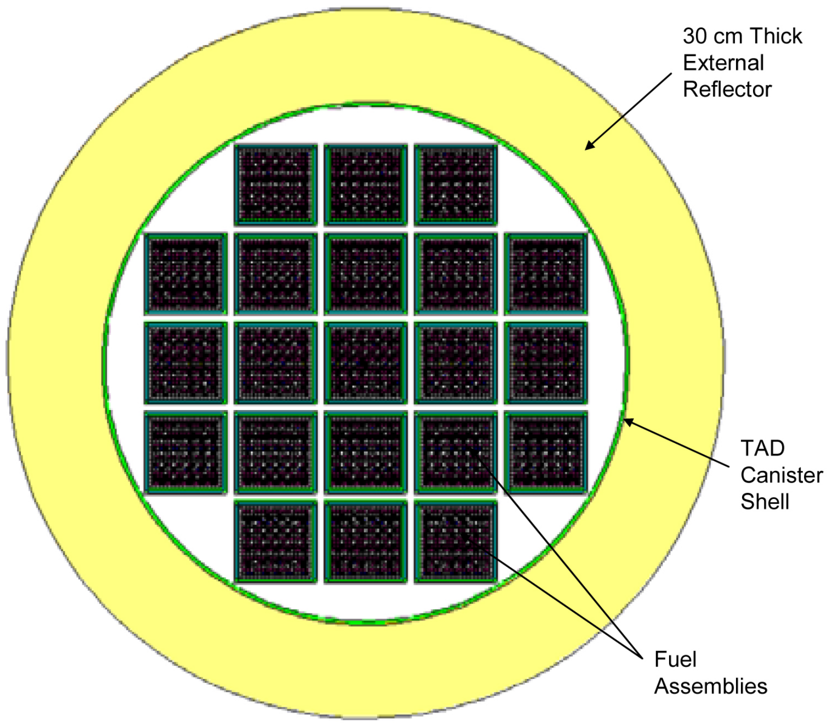

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Figure 12. Radial Cross-Section of the PWR TAD Canister MCNP Model with Radial Reflector (Fuel Assemblies Illustrated)

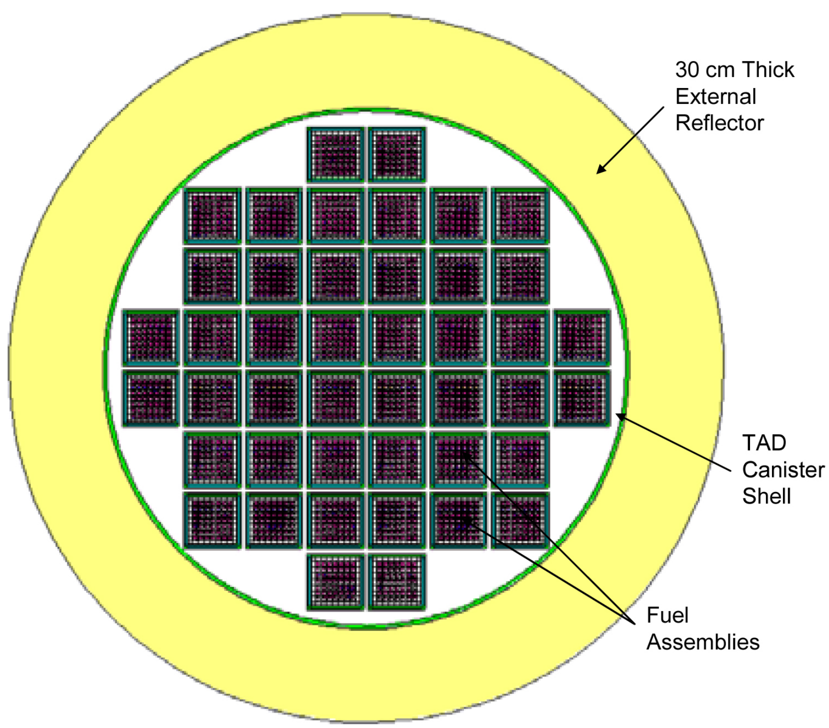

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Figure 13. Radial Cross-Section of the BWR TAD Canister MCNP Model with Radial Reflector (Fuel Assemblies Illustrated)

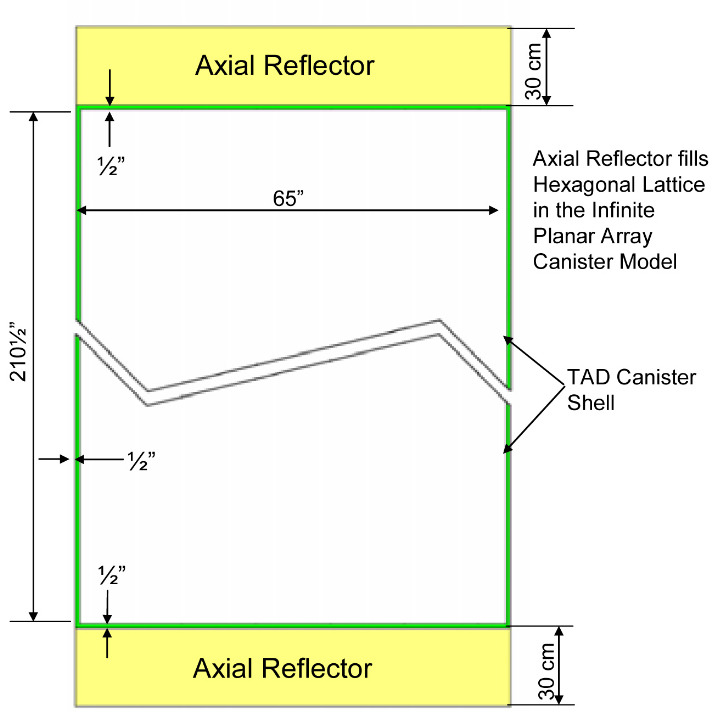

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Figure 14. Axial Cross-Section of the Single TAD Canister Models and Infinite Planar Array TAD Canister MCNP Models (Fuel Assemblies Not Illustrated)

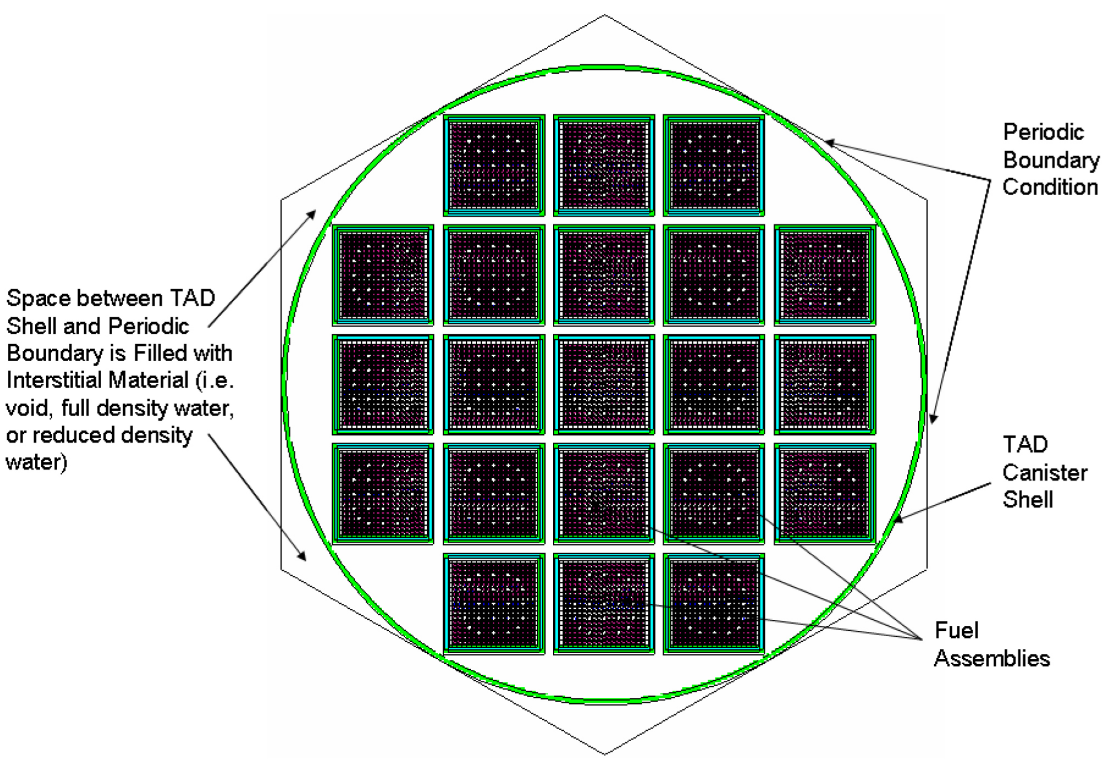

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Figure 15. Radial Cross-Section Illustration of the PWR TAD Canister MCNP Model with Periodic Boundary Condition (to Simulate an Infinite Planar Array of TAD Canisters)

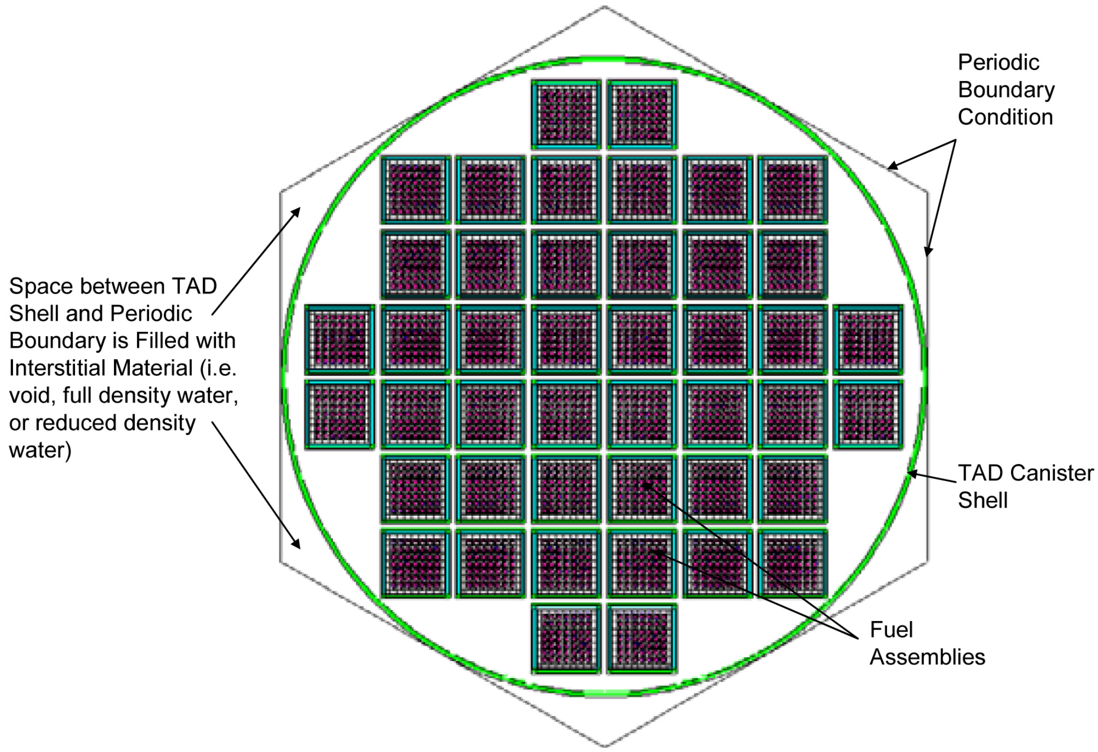

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Figure 16. Radial Cross-Section Illustration of the BWR TAD Canister MCNP Model with Periodic Boundary Condition (to Simulate an Infinite Planar Array of TAD Canisters)

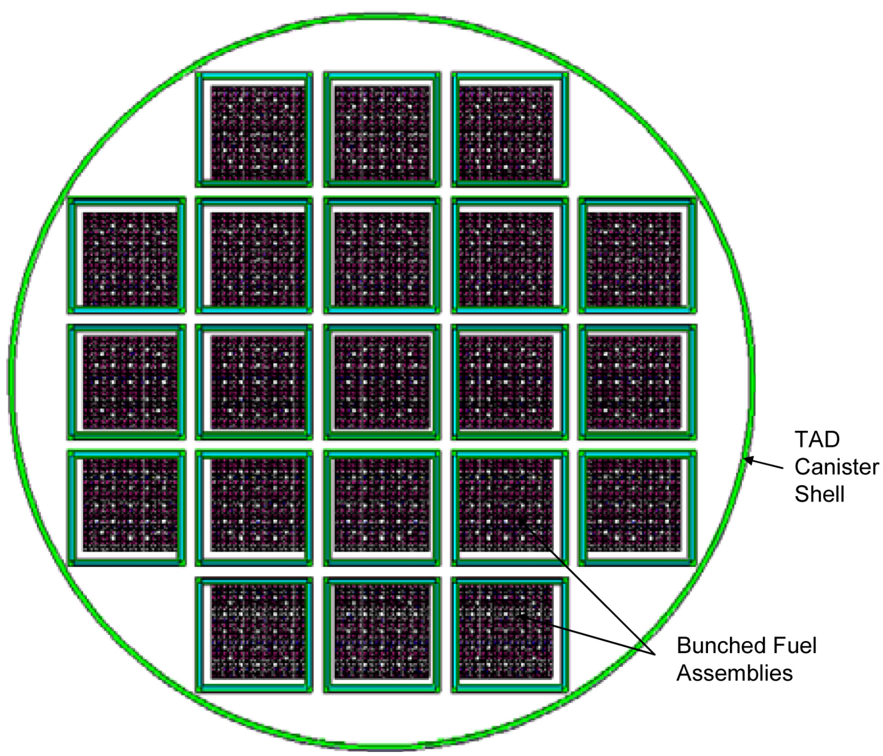

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Figure 17. Radial Cross-Section of the PWR TAD Canister MCNP Model Illustrating Maximum Fuel Assembly Bunching (Radial Reflector Not Illustrated)

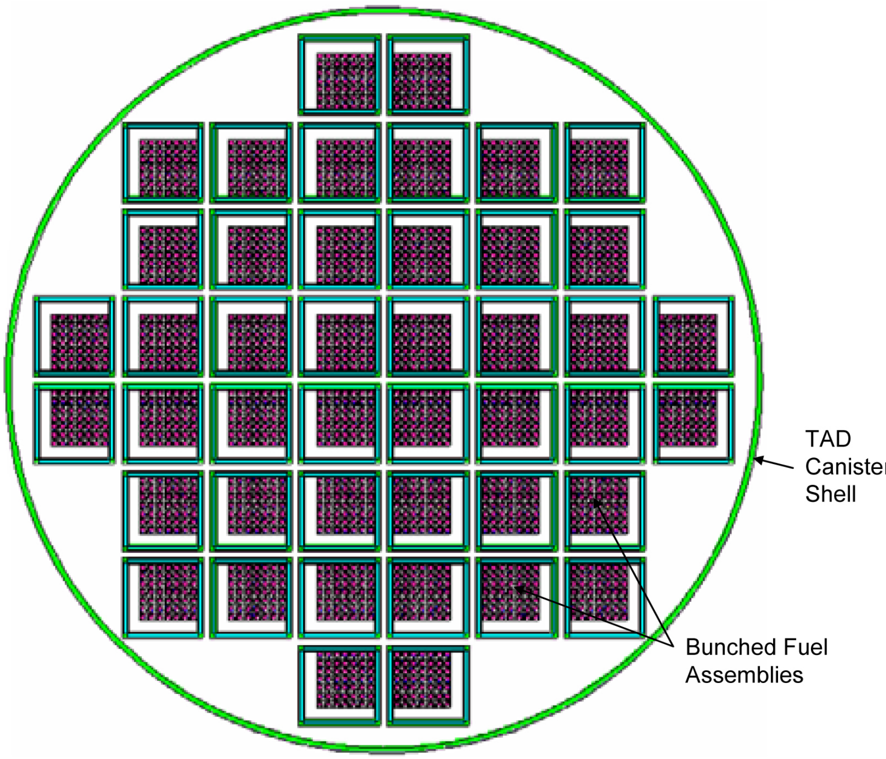

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Figure 18. Radial Cross-Section of the BWR TAD Canister MCNP Model Illustrating Maximum Fuel Assembly Bunching (Radial Reflector Not Illustrated)

6.3.1.2 Anticipated Subsurface Facility Operations

Operations conducted in the Subsurface facility concern the receipt and placement of loaded, sealed, waste packages containing CSNF, DOE SNF, naval SNF and HLW glass. The analysis of sealed waste packages positioned in the Subsurface facility emplacement drifts is performed in this document for waste packages containing TAD canister-based systems. Analysis of sealed waste packages containing DOE SNF canisters is contained in a separate analysis. Analysis of sealed waste packages containing naval SNF is provided in the Naval Nuclear Propulsion Program Technical Support Document.

Within the Subsurface facility, TAD canisters (sealed in their waste package) are arranged in a continuous row within the emplacement drifts. Due to their emplacement configuration (which only provides for close proximity between adjacent canisters, axially), it is expected that there is little neutron interaction between each TAD canister, and thus, it is expected that the reactivity of a single fully reflected TAD canister will be very similar to the reactivity of a fully reflected continuous row of TAD canisters positioned in an emplacement drift.

To demonstrate the subcriticality of the TAD canisters under the abovementioned normal conditions within the sub-surface facility, the PWR TAD canisters containing representative fuel assemblies (Section 6.2.1.2) are evaluated in an emplacement configuration. The single canister models described in Section 6.2.1.1 are employed for this analysis, but with modification to apply a mirror boundary condition to the axial ends of the canister, and to incorporate a close fitting full-thickness (30 cm) reflector adjacent the cylindrical surface of the canister. Similar to the surface facility calculations, a series of reflector materials (Section 6.2.2.3) are examined to determine the limiting reflection condition associated with emplaced TAD canisters. The limiting reflector material established from the PWR TAD canister emplacement configuration calculation is applied to the BWR TAD canister emplacement configuration calculation. Owing to the range of full (i.e. 30 cm thick) close fitting reflectors considered, and the mirror boundary condition used at the axial ends of the canister, the TAD canister emplacement models are considered to bound the actual conditions that could be realized in the Subsurface facility. Refer to Figure 19 for a cross-section view of the PWR and BWR TAD canister models with the incorporated close-fitting full-thickness radial reflector and axial mirror boundary condition.

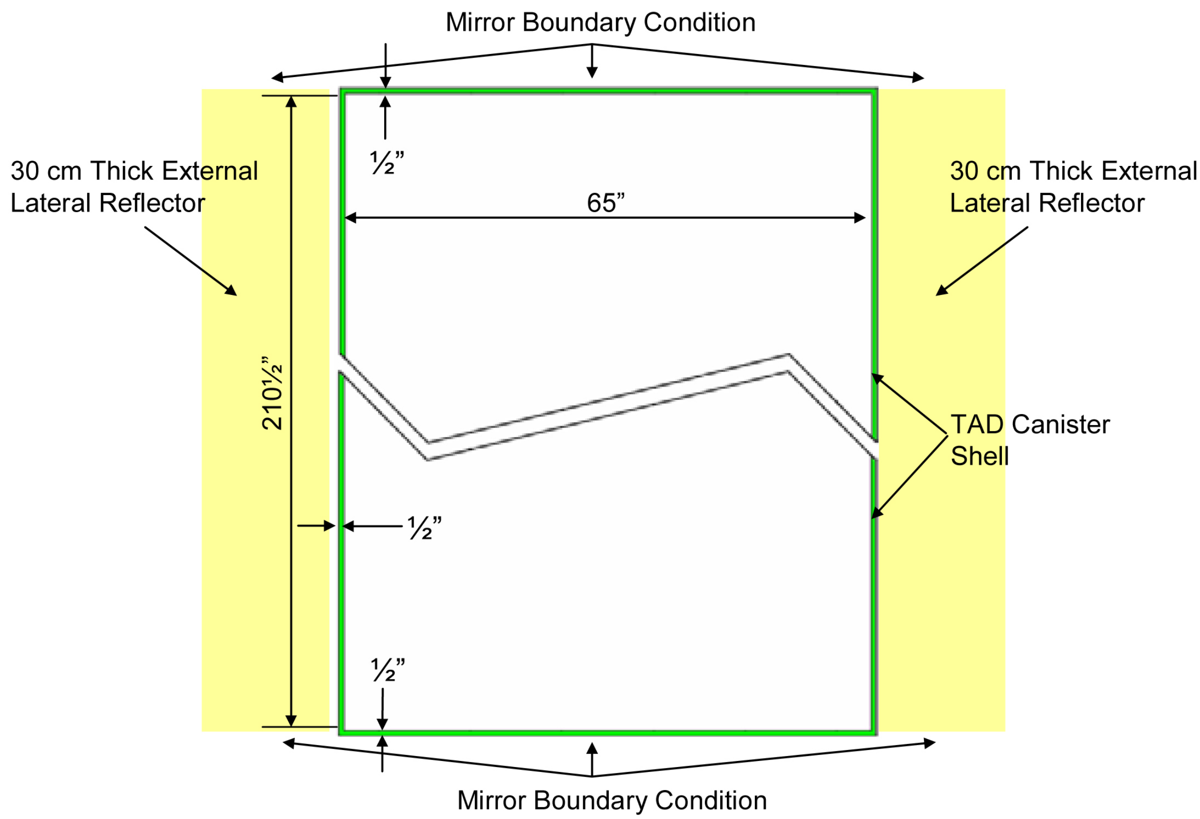

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Figure 19. Axial Cross-Section of the Emplacement Configuration TAD Canister MCNP Models (Fuel Assemblies Not Illustrated)

6.3.2 Evaluation of Off-Normal Conditions

All TAD canisters received and accepted into the surface and Subsurface facilities will be hermetically sealed, with a dry, intact, basket containing intact commercial spent nuclear fuel with a maximum initial enrichment of 5 wt % 235U/U. The realization of off-normal conditions within the surface facilities could potentially result in a compromise to the integrity, desiccation and geometry of the TAD canisters, their basket structure and their CSNF payload. Furthermore, manufacturing errors could potentially result in received TAD canisters containing improper quantities of borated stainless steel, or reduced boron content in the borated stainless steel panels associated with the TAD canister basket.

6.3.2.1 Surface Facilities and Intra-Site Operations

The scope of normal operations pertinent to the surface facilities is summarized in Section 6.3.1. Any deviation from the scope of normal operations (e.g. dropping of a TAD canister during transfer into a shielding cask or waste package) could potentially erode the significant criticality safety margin established for normal operations (Section 7.1).

Under off-normal conditions it is postulated that the integrity, desiccation and geometry of the TAD canisters located in their sealed waste packages is compromised. To characterize the system behavior and response to changes in properties (such as geometry, moderation and neutron absorber content), a comprehensive analysis of the TAD canisters is performed. This sub-section defines the systematic method employed for this off-normal condition analysis.

The key aspects of the off-normal conditions analysis involve postulated damage to the TAD canister resulting in:

1. Deformation of the TAD canister shell, coincident with a release of liquid moderator within the vicinity of the canister, leading to a progressive entrainment of moderator into the canister cavity (depicted in Figure 21);

2. Deformation of the TAD canister basket structure, leading to a progressive closure of the fuel compartment flux trap gap (depicted in Figure 22 and Figure 23);

3. Deformation of the fuel assemblies positioned in the TAD canister fuel compartments, resulting in a progressive expansion of the fuel pin pitch, often termed 'birdcaging' (depicted in Figure 22 and Figure 23); and

4. Deformation of the fuel assemblies positioned in the TAD canister fuel compartments, to the extent that there is a progressive release of fuel into the canister cavity (depicted in Figure 24).

In addition to the postulated TAD canister damage scenarios, the off-normal conditions analysis considers:

5. Manufacturing errors resulting in a reduction in the boron content of the borated stainless steel panels associated with the canister basket structure.

The four abovementioned facility-based off-normal scenarios (items 1 through 4) are very conservative approximations of the damage that could potentially be realized in the event of accidental release of the TAD canister-based systems during handling.

Because the TAD canister systems are maneuvered vertically, it is considered unlikely that a horizontal or near horizontal drop could occur. A horizontal drop could cause the fuel assembly compartments to congregate, i.e. could cause a reduction in the compartment flux trap gap. However, the horizontal impact that would be necessary to promote such conditions would also be expected to cause the pins within each fuel assembly to bunch together. Since LWR fuel assemblies are typically under moderated, a reduction in pin pitch would be expected to reduce k_{eff}. Refer to Figure 20 for an illustration of the type of damage that would be considered representative[1] of a horizontal impact event.

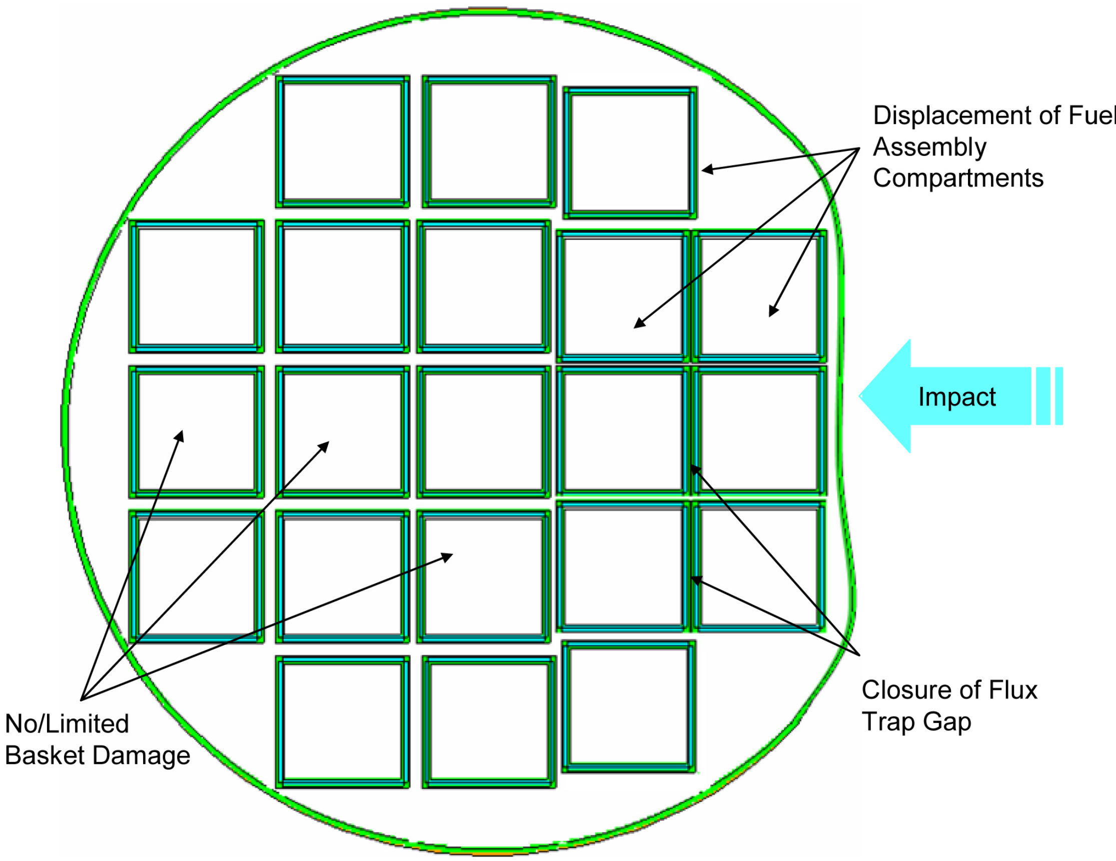

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Figure 20. Radial Cross-Section Sketch of a Damaged PWR TAD Canister Depicting Basket Damage Considered Representative of a Horizontal Impact Event

An increase in pin pitch, up to and including a condition where the fuel pins just fit within the fuel compartments, is often referred to as 'birdcaging', and is considered to arise from an axial impact. For the TAD canister-based systems, an axial, i.e. end-on impact, could occur in the event of a vertically orientated drop/impact during handling. A further consequence of an axial impact is the potential for the release of fuel into the canister cavity, resultant from rupture of fuel pins. A very conservative treatment of this condition is to assume that the fuel debris collects in a localized region of the canister cavity where liquid moderator has coincidentally entrained, and subsequently mixes forming a homogeneous fuel and moderator mixture, with an optimum fuel concentration. A homogeneous representation of the assumed fuel-water sludge is appropriate because any significant impact event that would cause a significant release of fuel (via physical rupture of fuel pins) would be expected to result in disintegration of the fuel pellets

[1] Note that Figure 20 portrays the characteristic pattern of basket damage resultant from a horizontal drop, and does not reflect the actual off-normal configurations analyzed in the criticality safety calculations. Refer to the Figures provided in Section 6.3.2.1.1 for illustration of the actual MCNP models.

released. Furthermore, considering the very limited space available within the TAD canister cavity, the realization of an optimum concentration condition would naturally require the fuel debris to consist of fine particles. Whole pellets or large pellet fragments would simply lack the mobility necessary to form the optimum concentration conditions considered in the calculations, due to the physical impediment afforded by the intact fuel and basket structure within the canister cavity.

On the basis that the TAD canister systems are maneuvered vertically during handling, it is unlikely that a horizontal impact could occur, and thus it is unlikely that collapse of the flux trap gap between fuel assembly compartments could occur. Flux trap gap collapse in conjunction with fuel assembly birdcaging would require concurrent significant horizontal and vertical impacts. Clearly, consideration of fuel assembly birdcaging in conjunction with collapse of the flux trap gap between fuel assembly compartments represents a very conservative model of off-normal conditions.

To characterize the behavior of the TAD canister-based systems under the five potential off-normal conditions outlined above, a comprehensive parametric study is performed for both the PWR and BWR TAD canisters, with each canister variant containing a representative fuel assembly (Section 6.2.1.2). The parametric study is split into two components; a detailed parametric study and an ancillary study. The detailed parametric study is based on a single (i.e. isolated) TAD canister, and considers moderator intrusion, basket deformation, fuel deformation, fuel release and neutron absorber reduction. The ancillary analysis supplements the detailed parametric study and includes evaluation of the effect of intrusion of an alternate moderator (hydraulic fluid), in addition to the effect of grouping multiple damaged TAD canisters within an array.

6.3.2.1.1 Detailed Parametric Study

Similar to the evaluation of normal conditions, the single canister off-normal conditions model (upon which the detailed parametric study is based) incorporates close fitting full-thickness (30 cm) reflection adjacent all surfaces of the canister. A series of reflector materials (Section 6.2.2.3) are examined to determine the limiting reflection condition. Unlike the normal conditions analysis, the limiting reflector material is established, independently, for both the PWR TAD canister and the BWR TAD canister calculation. Examination of alternate reflectors is performed for the off-normal conditions analysis (rather than using the worst-case reflector established from the normal conditions analysis) in recognition of softening of the neutron spectrum from moderation of the canister contents.

The detailed TAD canister off-normal conditions calculations are structured into three scenarios, as follows:

Potential Off-Normal Scenario 1

- Progressive canister basket deformation (i.e. flux trap gap collapse),
- Progressive fuel assembly deformation (i.e. birdcaging), and
- Progressive flooding of the TAD canister with water.

Potential Off-Normal Scenario 2

- Progressive canister basket deformation (i.e. flux trap gap collapse),
- Maximum fuel assembly deformation (i.e. birdcaging),
- Progressive reduction of the neutron absorber content of the canister basket, and
- Progressive flooding of the TAD canister with water.

Potential Off-Normal Scenario 3

- Progressive canister basket deformation (i.e. flux trap gap collapse),
- Progressive fuel assembly deformation (i.e. birdcaging),
- Progressive fuel release (i.e. fuel break-up), and
- Progressive flooding of the TAD canister with water.

6.3.2.1.1.1 Potential Off-Normal Scenario 1

Potential off-normal scenario 1 is based on progressive degrees of canister basket deformation (i.e. flux trap gap collapse), fuel assembly deformation (i.e. birdcaging), and progressive flooding of the TAD canister (from the base upwards) with water moderator. It is noted that only vertically orientated TAD canister arrangements (as opposed to horizontal arrangements) are considered for all moderator intrusion cases to minimize the volume of water required to exceed the USL.

The height of the modeled water moderator region at the base of the canister cavity is dependent on the total moderator volume considered and the available volume per unit height within the canister cavity. The height of the water moderator region is calculated according to the following method:

1. The available volume per unit height within the canister is established by calculating the cross-sectional area of the canister cavity and subtracting the volume per unit height of structure contained within the canister cavity (i.e. fuel, and basket material).

2. The height of the moderator region is determined by dividing the moderator volume by the "available volume per unit height" derived in step 1.

The specific moderator height values used in the MCNP calculations are listed in the Microsoft Excel spreadsheet *tad_canister_calculations.xls*, included in the DVD file of Attachment V. A graphic illustration of the MCNP model showing a water moderated region is provided in Figure 21.

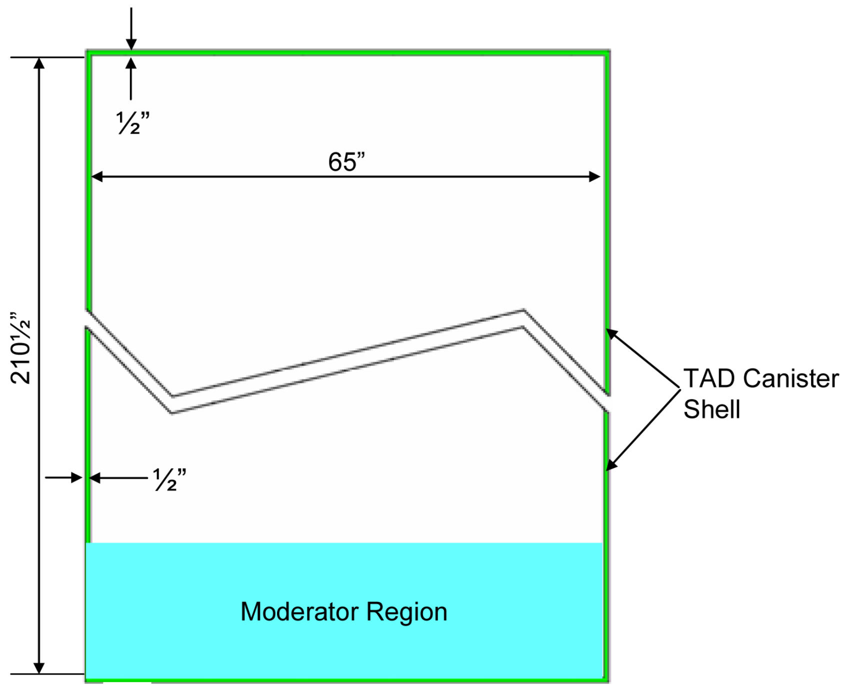

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Figure 21. Axial Cross-Section of the TAD Canister MCNP Model Depicting Moderator Intrusion (Fuel Assemblies Not Illustrated)

6.3.2.1.1.2 Potential Off-Normal Scenario 2

Potential off-normal scenario 2 is based on progressive degrees of canister basket deformation (i.e. flux trap gap collapse), maximum fuel assembly deformation (i.e. birdcaging), reduction of the neutron absorber content of the basket borated stainless steel panels, and progressive flooding of the TAD canister (from the base upwards) with water. The height of the modeled water moderator region at the base of the canister cavity is calculated according to the method described for potential off-normal scenario 1 above.

No variation of fuel assembly deformation (i.e. birdcaging) is considered for off-normal scenario 2 because the effect of this type of damage is relatively insensitive to changes in the neutron absorber content of the borated stainless steel panels (Section 7.1.2.1.1.3, paragraph 4). Conversely, closure of the flux trap gap directly influences the neutron absorbed worth of the borated stainless steel panels, since this type of damage directly affects the thermalization of neutrons traversing the inter-compartment gaps.

6.3.2.1.1.3 Potential Off-Normal Scenario 3

Potential off-normal scenario 3 is based on progressive degrees of canister basket deformation (i.e. flux trap gap collapse), fuel assembly deformation (i.e. birdcaging), fuel release (i.e. fuel break-up resulting in formation of an optimum fuel-water sludge at the base of the canister cavity), and progressive flooding of the TAD canister (from the base upwards) with water. Refer to Figure 22 through Figure 24 for a graphic illustration of these particular damage conditions.

The evaluation of potential off-normal scenario 3 is restricted to the PWR TAD canister only, because the results of off-normal scenarios 1 and 2 (Section 7.1.2) conclusively prove that the PWR TAD canister is more restrictive than the BWR TAD canister in terms of the maximum tolerable damage and moderation combinations.

From the description of the potential off-normal scenario models (see for example the bulleted list at the beginning of Section 6.3.2.1.1), it is seen that the off-normal scenario 1 and 3 models differ only in the absence and presence of a fuel-water sludge, respectively. Therefore, in developing the potential off-normal scenario 3 models, the MCNP models employed for the potential off-normal scenario 1 calculations are modified to provide a region containing an optimum concentration fuel-water sludge. This is achieved by segregating the water moderated region at the base of the canister into a fuel-water sludge region and an excess water region (modeled directly above the fuel-water sludge region). An illustration of this configuration is provided in Figure 24.

The height of the fuel-sludge region is varied in the MCNP calculations to account for the specific fuel-release fraction considered (i.e., 1, 3, or 5 wt%), while the height of the excess water moderator region is independently varied. The total volume of water within the TAD canister is calculated by adding the volume of water in the excess water region (determined using the method established for potential off-normal scenario 1) to the volume of water present in the fuel-water sludge region. The volume of water associated with the fuel-water sludge region is determined by subtracting the volume of the fuel debris and intact components (e.g. fuel in rods, basket, etc.) displacing the fuel-water sludge from the total volume of the fuel-water sludge region. The specific fuel-water sludge height and excess water moderator height values used in the MCNP calculations are listed in the Microsoft Excel spreadsheet *tad_canister_calculations.xls*, included in the DVD file of Attachment V.

For all calculations performed for off-normal scenario 3, the fuel-water sludge at the base of the canister cavity is modeled at optimum concentration given the moderator volume constraints imposed. For example, for scenarios involving relatively large quantities of entrained moderator, the fuel-water sludge is modeled at optimum concentration, and the excess moderator is modeled directly above the fuel-water sludge region. However, for cases with a relatively small volume of entrained moderator, the fuel-water sludge is modeled at the optimum concentration corresponding to the available moderator volume within the canister. For these relatively small moderator volume cases, this is typically the minimum concentration possible. Thus, while the actual concentration modeled may deviate depending on the moderator volume considered in the calculation, the modeled concentration is always optimized (i.e. is the most reactive uniform concentration possible).

The optimum fuel-water sludge concentration used in the detailed calculations is determined in a separate precursor calculation by modeling a fully loaded TAD canister with representative commercial fuel, and adding a fixed mass of UO_2 as a fuel-water sludge. The optimum concentration of the fuel-water sludge is established by varying the concentration of UO_2 in the fuel-water sludge. It is noted that no intact fuel is removed from the model to offset the fuel release fraction considered. This approach is considered conservative on account of an overall increase in total fuel mass (resultant from the addition of fuel associated with the fuel-water sludge).

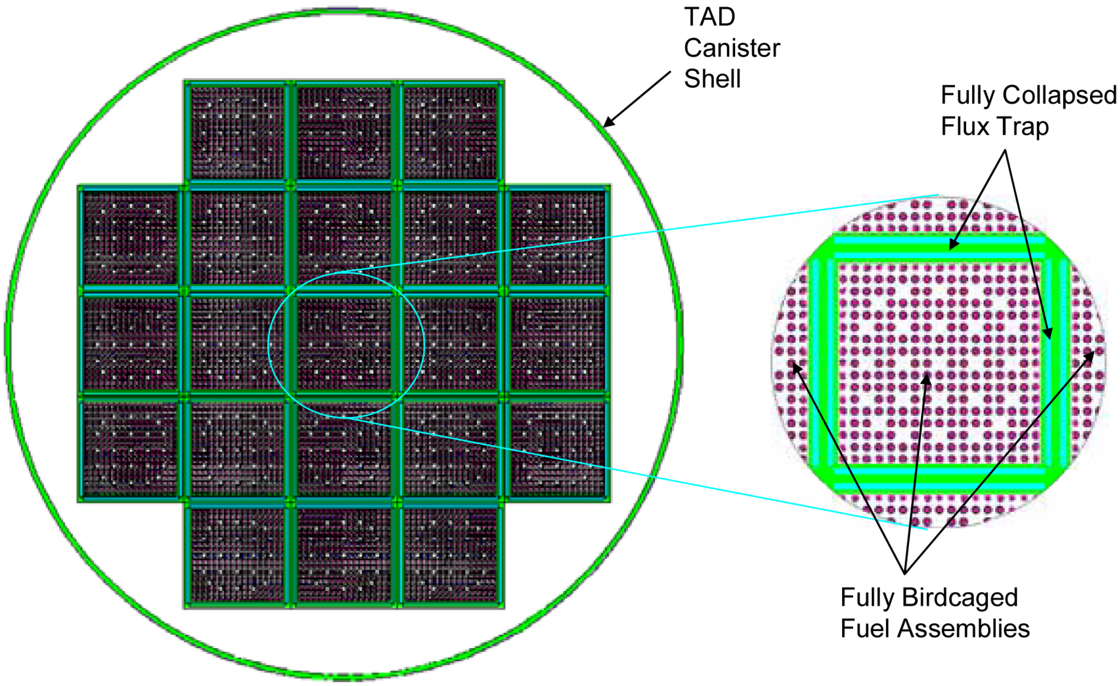

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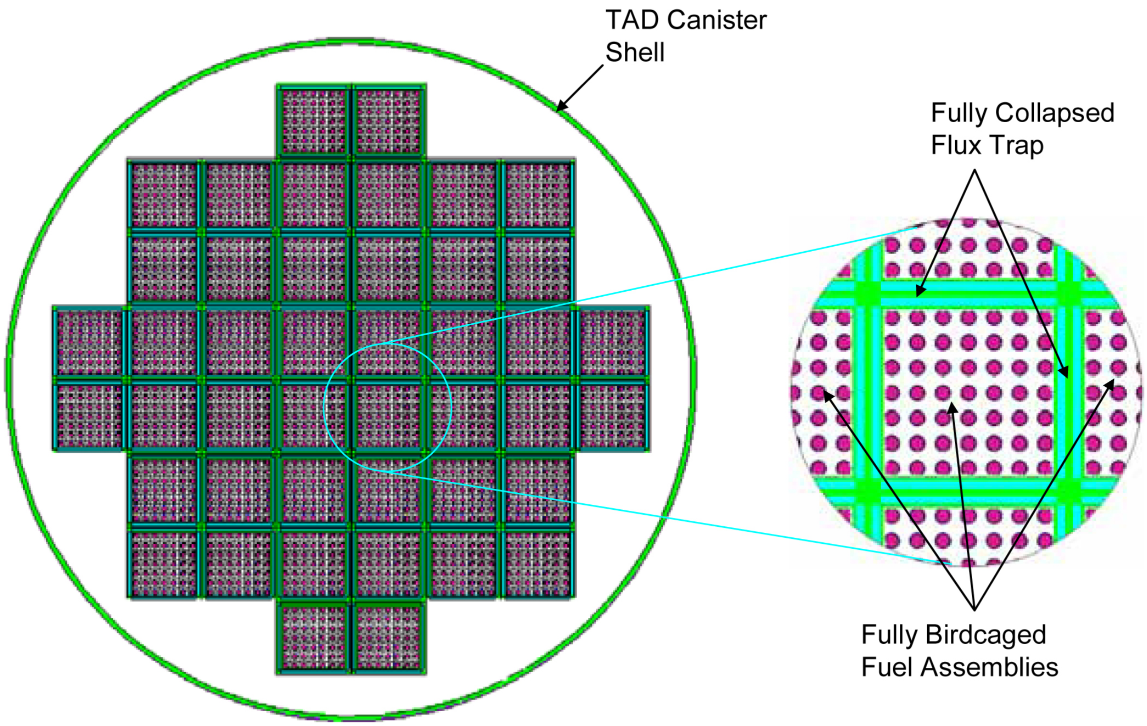
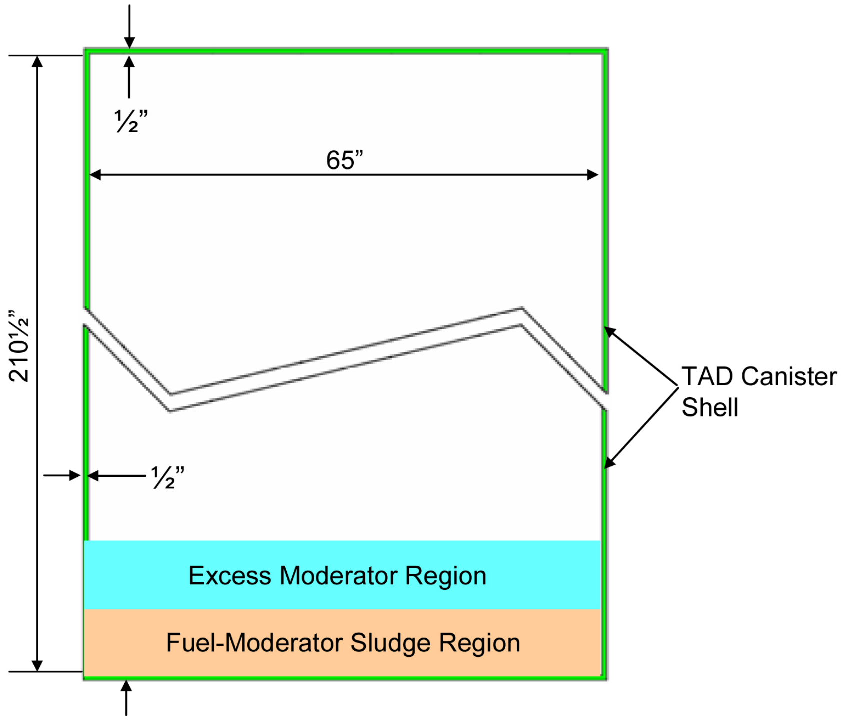
Figure 22. Radial Cross-Section of the PWR TAD Canister MCNP Model Depicting Maximum Flux Trap Gap Collapse and Maximum Fuel Assembly Birdcaging



Source: Original

Figure 23. Radial Cross-Section of the BWR TAD Canister MCNP Model Depicting Maximum Flux Trap Gap Collapse and Maximum Fuel Assembly Birdcaging



Source: Original

Figure 24. Axial Cross-Section of the TAD Canister MCNP Model Depicting Moderator Intrusion in Conjunction with Fuel Release (Fuel Assemblies Not Illustrated)

6.3.2.1.2 Ancillary Study

The ancillary potential off-normal conditions analysis supplements the detailed parametric study described in Section 6.3.2.1.1 (which is based on damage of a single canister only), and includes evaluation of the effectiveness of various reflecting media on the moderator limits established in the preceding detailed analysis. In addition, the ancillary analysis establishes the effect of grouping **multiple** damaged TAD canisters within an array, and quantifies the effect of intrusion of an alternate moderator (hydraulic fluid) into the canister cavity.

6.3.2.1.2.1 Reflecting Media

Based on the results of the normal conditions analyses (Section 7.1.1), it is expected that stainless steel represents one of the most onerous reflector materials from a criticality safety viewpoint. To confirm this expectation under potential off-normal conditions involving damage to the TAD canister in conjunction with damage and partial moderation of its contents, the worst case off-normal conditions model from potential off-normal scenario 1 (Section 6.3.2.1.1.1) is re-evaluated with alternate close-fitting 30 cm thick reflector materials. A series of reflector materials (Section 6.2.2.3) are examined for both the PWR and BWR TAD canisters.

6.3.2.1.2.2 Damaged Canister Array

The model of the infinite planar array of damage TAD canisters is based on the maximum damaged single canister condition (i.e. maximum fuel assembly birdcaging and complete collapse of the canister compartment flux trap gap). Similar to the evaluation of an infinite planar array of TAD canisters under normal conditions (Section 6.3.1.1), a hexagonal lattice with a periodic boundary condition is modeled directly adjacent the cylindrical surface of the canister to simulate an infinite planar array of canisters in a close package, triangular-pitched, configuration. The interstitial space between the canisters in the array (i.e. the space between the periodic boundary and the TAD shell) is modeled as void[1]. A close fitting full-thickness (30 cm) reflector is included adjacent the upper and lower surfaces of the canister, with a series of reflector materials (Section 6.2.2.3) examined to determine the limiting reflection condition. Note that the examination of alternate reflectors is re-performed for the off-normal conditions analysis (rather than using the worst-case reflector established from the normal conditions analysis) in recognition of softening of the neutron spectrum from moderation of the canister contents.

6.3.2.1.2.3 Hydraulic Fluid Moderator

The detailed off-normal conditions study described in Section 6.3.2.1.1 considers only water as a potential moderator. To evaluate the effect on the established maximum safe moderator quantities in the event of entrainment of an alternate moderator (hydraulic fluid), the limiting (i.e. worst-case) intact fuel off-normal conditions model for the PWR TAD canister is re-evaluated with an equivalent volume of polysiloxane fluid, which is a representative hydraulic fluid (refer to Section 3.2.5 for details).

[1] The presence of water in the interstitial space between TAD canisters in a planar array configuration results in a reduction in k_{eff} (Figure 27).