7. RESULTS AND CONCLUSIONS

This section presents the results of, and draws conclusions from, the MCNP criticality safety calculations performed in support of the criticality safety demonstration of the TAD canister-based systems, under both normal conditions and potential off-normal conditions. The following structure is used:

- Section 7.1 presents the results of the MCNP calculations performed in support of demonstrating the criticality safety of the PWR and BWR TAD canister systems in the surface and sub-surface facilities, under both normal conditions and potential off-normal conditions; and
- Section 7.2 draws conclusions from the results of the normal condition and potential off-normal condition calculations, and identifies the limits on system parameters that are necessary to ensure the subcriticality of the TAD canister-based systems under all foreseeable conditions in the surface and Subsurface facilities.

7.1 RESULTS

7.1.1 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. 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 Subsurface facility, will not alter these conditions.

7.1.1.1 Surface Facilities and Intra-Site Operations

The criticality safety process for evaluating the TAD canister-based systems under normal conditions in the surface facilities (including Intra-Site operations) is described in detail in Section 6.3.1.1.

The results of the single PWR TAD canister calculations performed based on the process defined in Section 6.3.1.1 are presented in Figure 25.

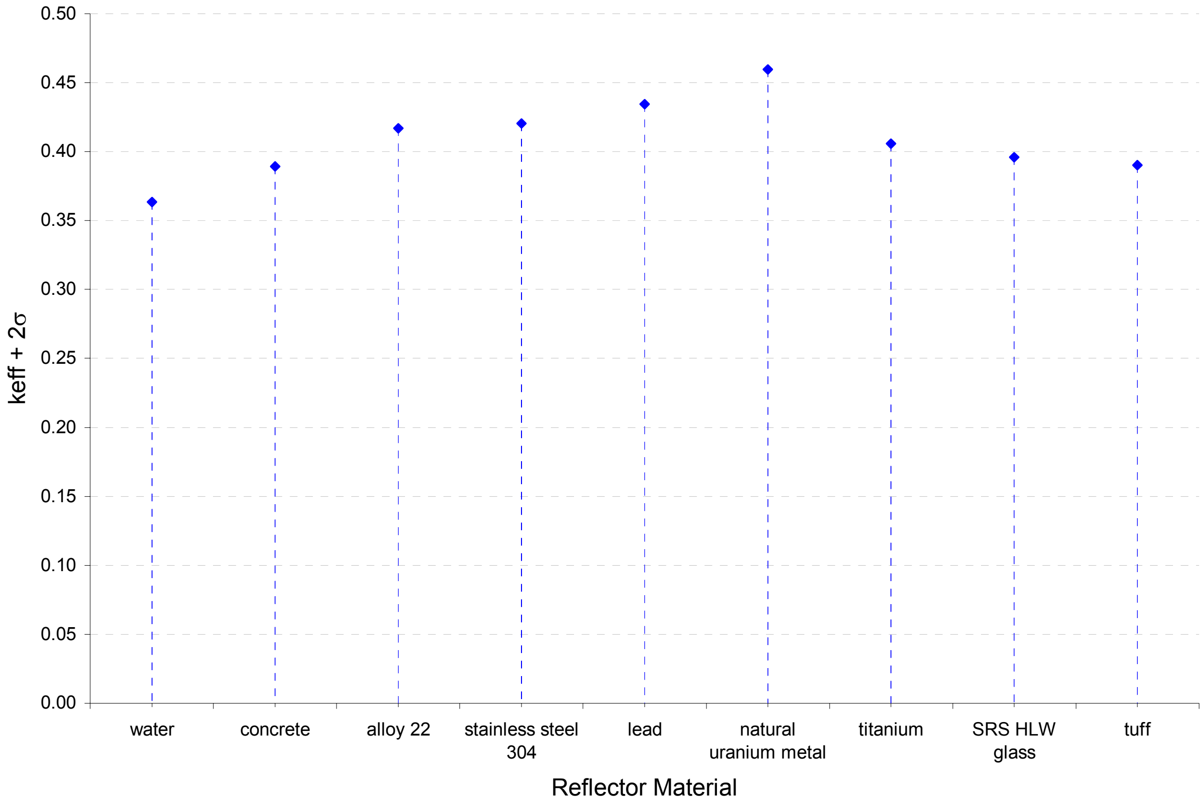

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Figure 25. Variation of k_{eff} +2σ with Close Fitting Full-Thickness (I.E. 30 Cm) Reflector Material, for a Single Undamaged Dry PWR TAD Canister Containing Intact, Undamaged, Representative CSNF

The results of the single PWR and BWR TAD canister calculations, with the limiting reflector material established in Figure 25, are detailed in Table 24. The results of the fuel assembly bunching calculations (which utilized the same limiting reflector material) are also presented.

Table 24. Comparison of k_{eff} +2σ Values ffor Single Undamaged Dry PWR and BWR TAD Canisters Containing Intact, Undamaged, Representative CSNF, and with Close Fitting Full-Thickness (I.E. 30 Cm) Natural Uranium Metal Reflection

TAD Canister Variant	**Close Fitting 30 cm Thick Reflector Material**	**Fuel Assembly Configuration in the TAD Canister Compartments**	**k_{eff} +2σ**
PWR	Natural uranium metal	Centered	0.45829
PWR	Natural uranium metal	Bunched	0.46165
BWR	Natural uranium metal	Centered	0.45107
BWR	Natural uranium metal	Bunched	0.45001

Based on the results presented in Table 24, it is seen that under normal (i.e. dry, undamaged and intact) conditions substantial margin exists between the computed peak k_{eff} +2σ value and the USL value of 0.92 (Section 3.1.1). Furthermore, it is seen from the results that fuel assembly bunching results in a negligible change in the established peak k_{eff} +2σ value, relative to the un-bunched scenario. Thus any potential displacement of fuel assemblies within their compartments is inconsequential to criticality safety of the canister system under dry conditions.

The results of the calculations performed to evaluate an infinite planar array of PWR TAD canisters are presented in Figure 26.

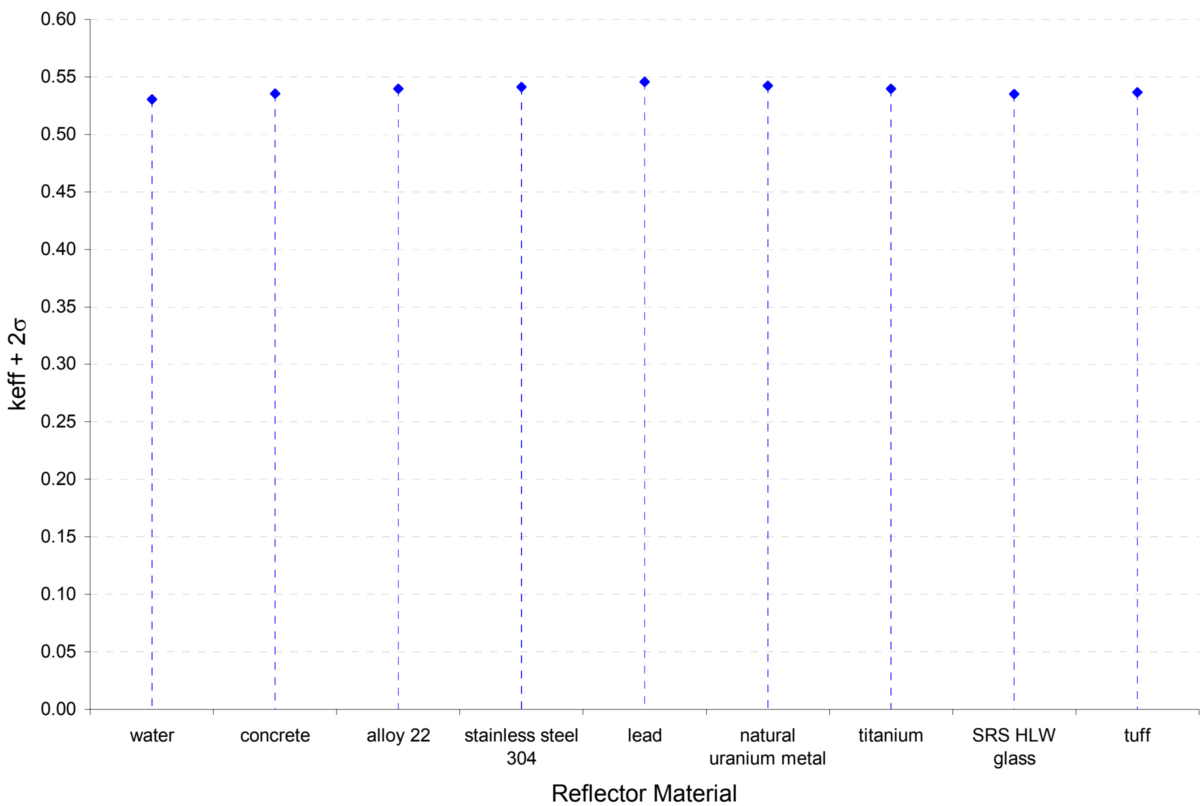

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Figure 26. Variation of k_{eff} +2σ with Close Fitting Full-Thickness (I.E. 30 Cm) Axial Reflector Material, For Infinite Planar Array of Undamaged Dry PWR TAD Canisters, in Close Packed Triangular-Pitched Configuration, and with Each TAD Canister Containing Intact, Undamaged, Representative CSNF.

Based on the presented results in Figure 26, it is seen that the peak k_{eff} +2σ value is observed when the infinite planar array of PWR TAD canisters are axially reflected with lead, stainless steel or natural uranium metal. Of these three limiting materials, stainless steel is the only material that could credibly be available in sufficient quantity to axially reflect an entire array of TAD canisters. Therefore, a stainless steel axial reflector is applied to the MCNP model of an infinite planar array of BWR TAD canisters. The result of the calculation performed to evaluate an infinite planar array of BWR TAD canisters is detailed in Table 25, along with the equivalent case from the PWR TAD canister calculation.

Table 25. Comparison of k_{eff} +2σ Values For Infinite Planar Array Of Undamaged Dry PWR And BWR TAD Canisters In Close Packed Triangular-Pitched Configuration With Full-Thickness (I.E. 30 Cm) Stainless Steel Axial Reflector, and with Each TAD Canister Containing Intact, Undamaged, Representative CSNF

TAD Canister Variant	Close Fitting 30 cm Thick Axial Reflector Material	TAD Canister Surface-Surface Spacing (cm)	k_{eff} +2σ
PWR	Stainless Steel 304	0.0	0.54104
BWR	Stainless Steel 304	0.0	0.51201

From the results presented in Table 25, it is seen that under normal (i.e. dry, undamaged and intact) conditions, substantial margin exists between the computed peak k_{eff} +2σ value and the USL value of 0.92 (Section 3.1.1). Furthermore, examination of the results in Table 24 and Table 25, reveals that, under normal (i.e. dry, undamaged and intact) conditions, the TAD canisters are slightly more reactive in an array configuration, and that the PWR TAD canisters represent the limiting canister system, from a criticality safety viewpoint.

To confirm the expectation that the presence of moderator in the interstitial space between the TAD canisters in the canister infinite planar array scenario would reduce the calculated peak k_{eff} +2σ value, a further series of calculations are performed. From the trend established in Figure 27, it is seen that the presence of moderator external to, and between, the TAD canisters results in a decrease in the system reactivity. This trend is understood when realizing that the neutron absorption cross-section of iron (the predominant constituent element of steel) is highly susceptible to the incident neutron energy, increasing sharply with progressive softening of the neutron spectrum.

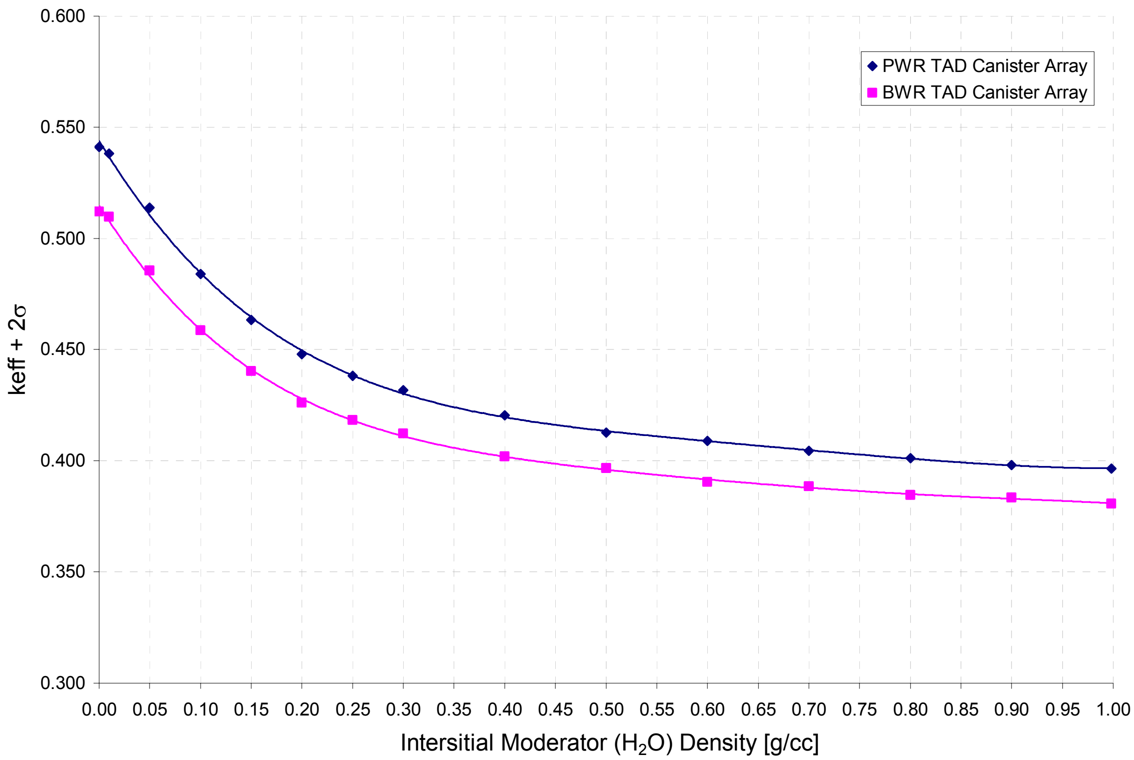

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Figure 27. Variation of k_{eff} +2σ for Infinite Planar Array Of Undamaged Dry TAD Canisters In Close Packed Triangular-Pitched Configuration With Full-Thickness (I.E. 30 Cm) Stainless Steel Axial Reflector, with Each TAD Canister Containing Intact, Undamaged, Representative CSNF, and with Variable Density H2O Moderator Situated in the Interstitial Space Between Each TAD Canister

7.1.1.2 Subsurface Facility

The criticality safety process for evaluating the TAD canister-based systems under normal conditions in the Subsurface facility is described in detail in Section 6.3.1.2.

The results of the PWR TAD canister emplacement configuration calculations performed based on the process defined in Section 6.3.1.2 are presented in Figure 28. The results of the PWR and BWR TAD canister emplacement configuration calculations, with the limiting reflector material established in Figure 28, are detailed in Table 26.

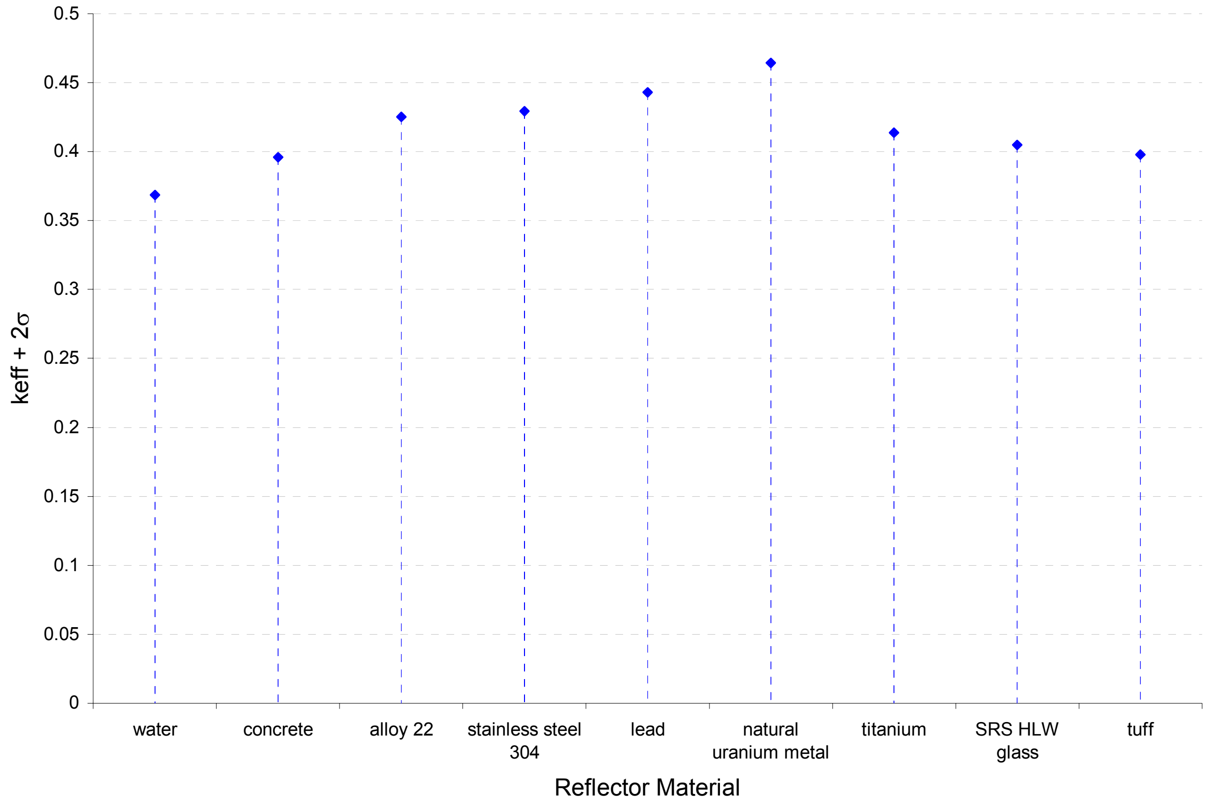

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Figure 28. Variation of k_{eff} +2σ with Close Fitting Full-Thickness (I.E. 30 Cm) Reflector Material, for Infinitely Long Row (Drift) of Undamaged Dry PWR TAD Canisters, Containing Intact, Undamaged, Representative CSNF

Table 26. Comparison of k_{eff} +2σ Values for Infinitely Long Row (Drift) of Undamaged Dry PWR TAD Canisters, Containing Intact, Undamaged, Representative CSNF, and with Close Fitting Full-Thickness (I.E. 30 Cm) Natural Uranium Metal Reflection Applied to Cylindrical Surface of Canisters

TAD Canister Variant	**Close Fitting 30 cm Thick Reflector Material**	**k_{eff} +2σ**
PWR	Natural Uranium Metal	0.46441
BWR	Natural Uranium Metal	0.45161

Based on the results presented in Table 26, it is seen that under normal conditions (i.e. emplacement of dry, undamaged and intact canisters containing intact, undamaged, CSNF), substantial margin exists between the computed peak k_{eff} +2σ value and the USL value of 0.92 (Section 3.1.1). As expected, the results demonstrate that the reactivity of the TAD canister emplacement configuration is essentially equivalent to the reactivity of a single fully reflected canister.

7.1.2 Potential Off-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. Deviation(s) from normal operating conditions in the surface facilities could potentially result in off-normal conditions that promote a compromise to the integrity, desiccation and geometry of the TAD canisters, their basket structure and their CSNF payload. Further to these potential facility-based off-normal conditions, 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.

7.1.2.1 Surface Facilities and Intra-Site Operations

7.1.2.1.1 Detailed Parametric Study

7.1.2.1.1.1 Potential Off-Normal Scenario 1

Potential Off-Normal Scenario 1 considers:

- 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.

The results of the potential off-normal scenario 1 calculations are presented in Figure 38 though Figure 43 (Attachment I) for the PWR TAD canister, and Figure 44 though Figure 49 (Attachment II), for the BWR TAD canister. An interpolation of the raw results, to establish the maximum safe moderator volume as a function of the basket/fuel assembly damage condition, is presented in Figure 29 and Figure 30 for the PWR and BWR TAD canisters, respectively.

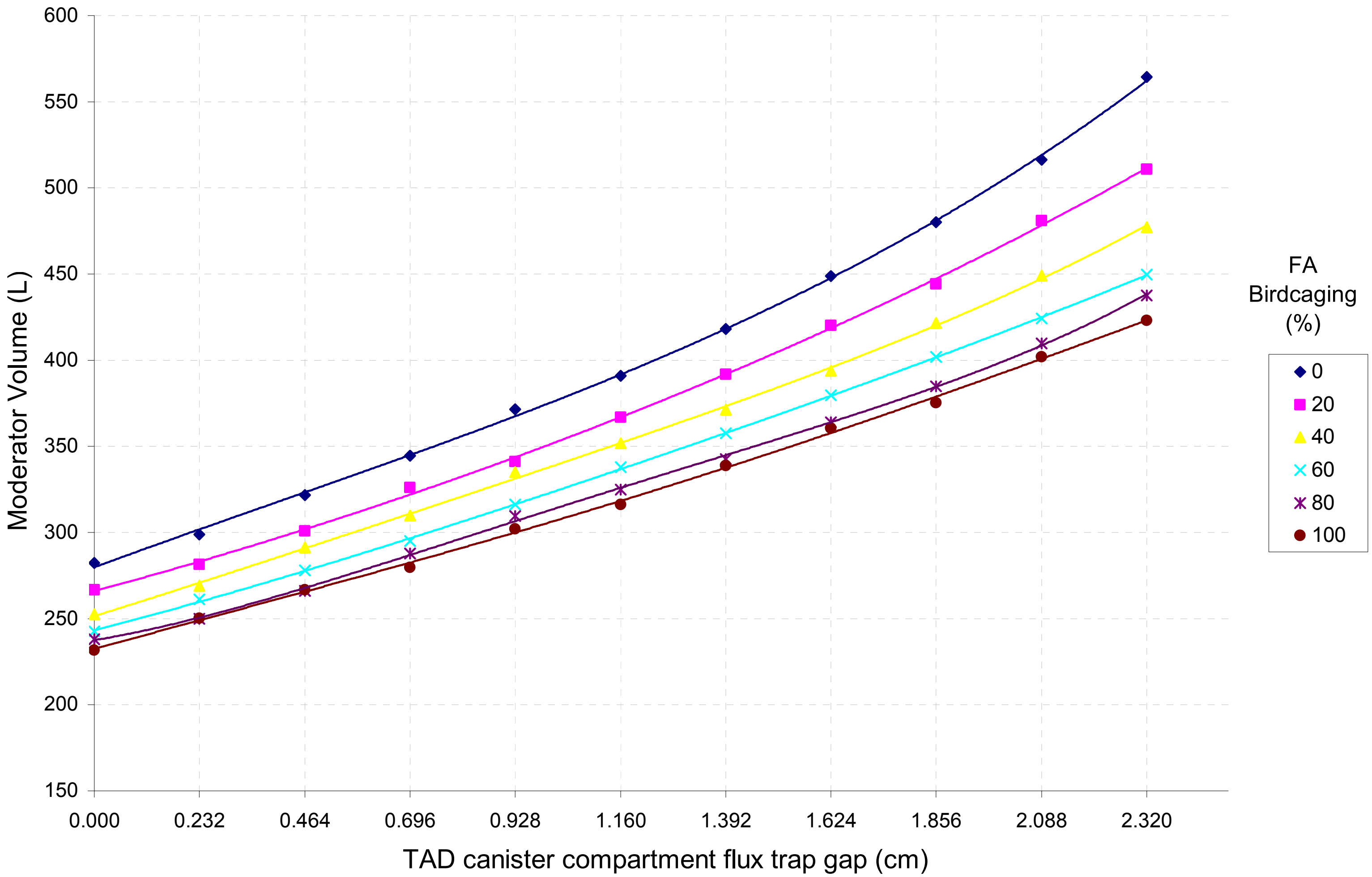

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Figure 29. Maximum Safe Moderator (H_2O) Volume as Function of Fuel Assembly Birdcaging, and Compartment Flux Trap Gap, for Single Damaged, Partially Flooded PWR TAD Canister with 30cm Thick Close Fitting Steel Reflector

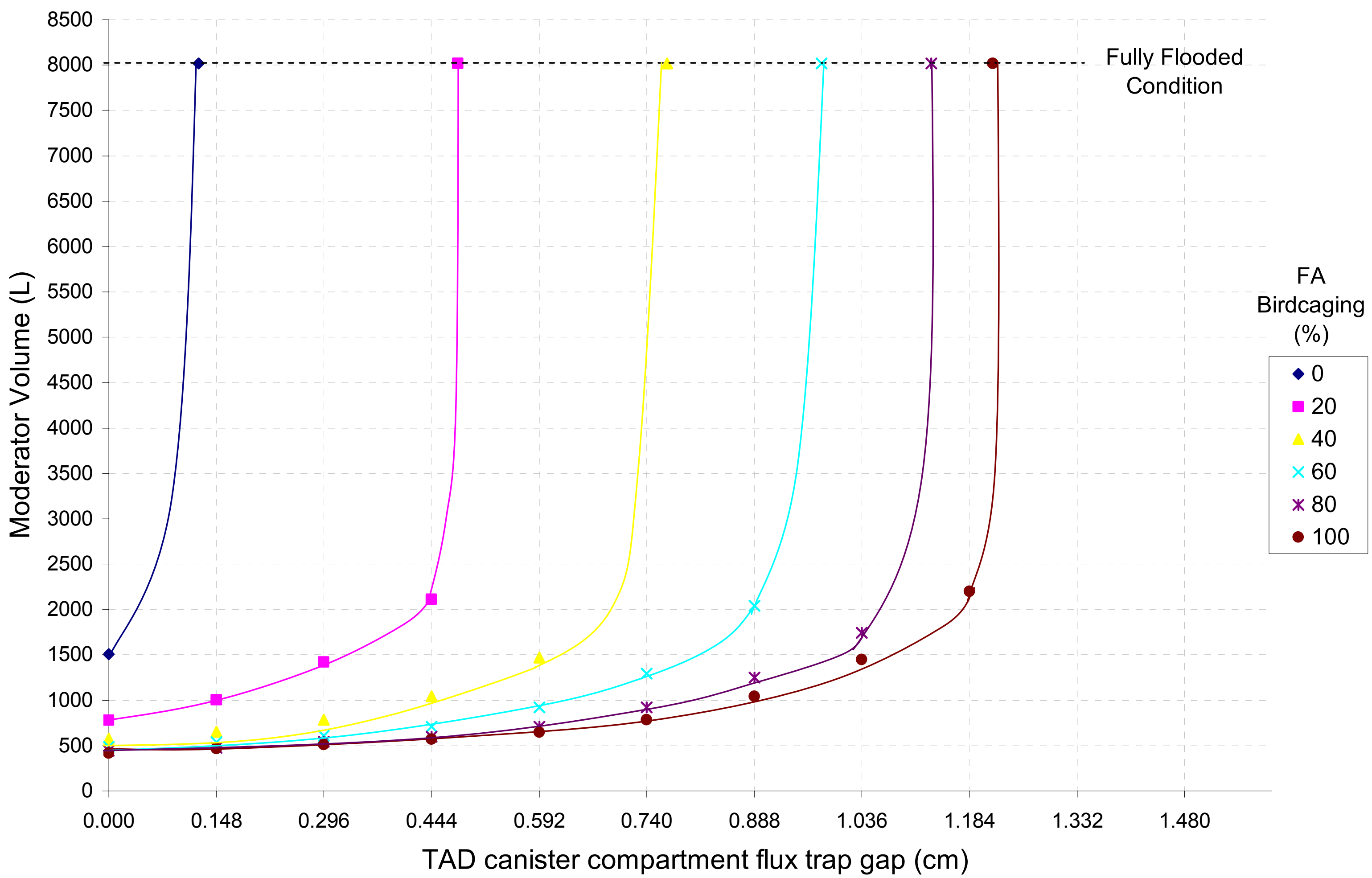

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Figure 30. Maximum Safe Moderator (H_2O) Volume as Function of Fuel Assembly Birdcaging, and Compartment Flux Trap Gap, for Single Damaged, Partially Flooded BWR TAD Canister with 30cm Thick Close Fitting Steel Reflector

7.1.2.1.1.2 Potential Off-Normal Scenario 2

Potential Off-Normal Scenario 2 considers:

- 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.

The results of the potential off-normal scenario 2 calculations are presented in Figure 50 though Figure 60 (Attachment II) for the PWR TAD canister, and Figure 61 though Figure 71 (Attachment II), for the BWR TAD canister. An interpolation of the raw results, to establish the maximum safe moderator volume as a function of the basket damage condition and neutron absorber content, is presented in Figure 29 and Figure 30 for the PWR and BWR TAD canister, respectively.

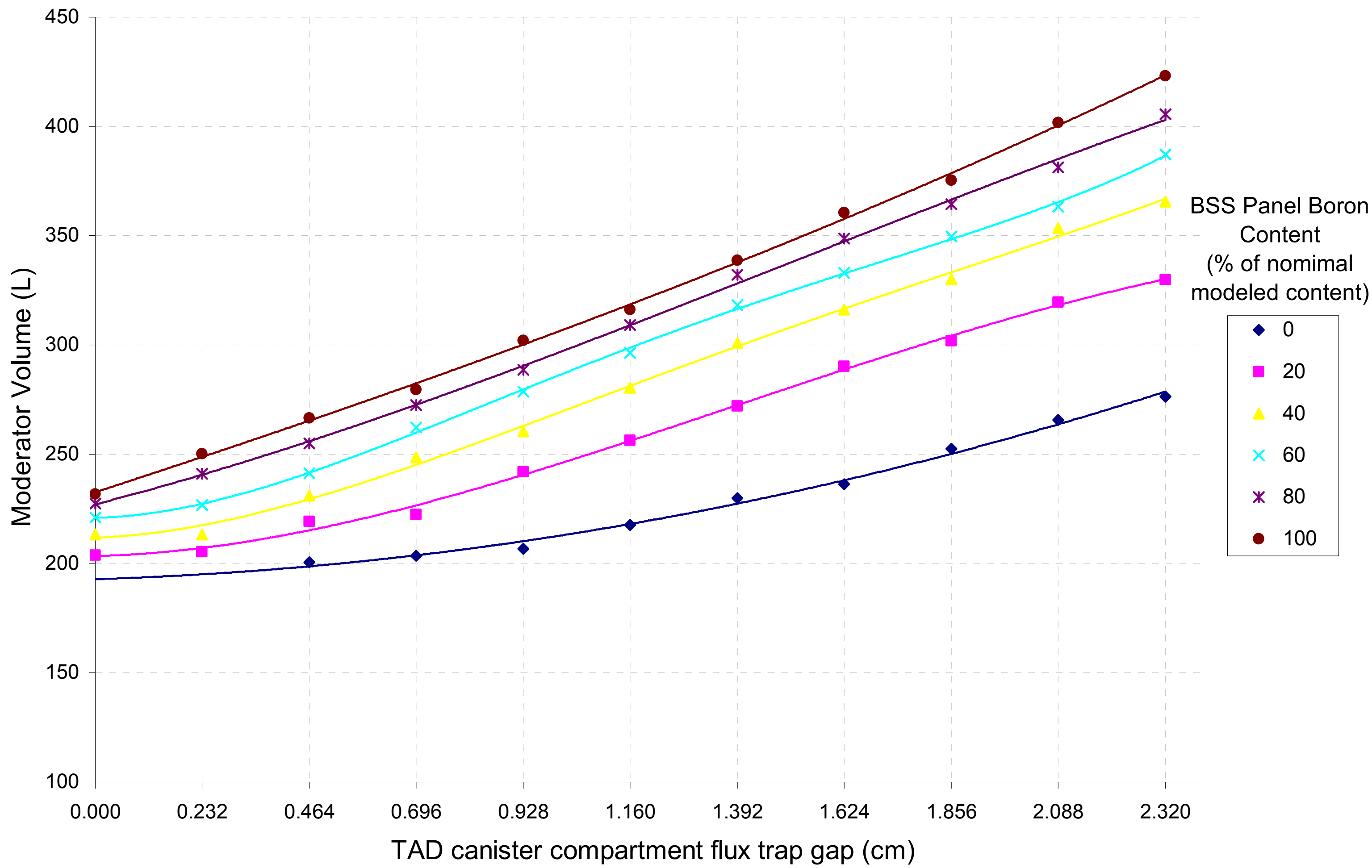

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Figure 31. Maximum Safe Moderator (H_2O) Volume as Function of Canister BSS Panel Boron Content and Compartment Flux Trap Gap, for Single Damaged, Partially Flooded PWR TAD Canister with 30cm Thick Close Fitting Steel Reflector

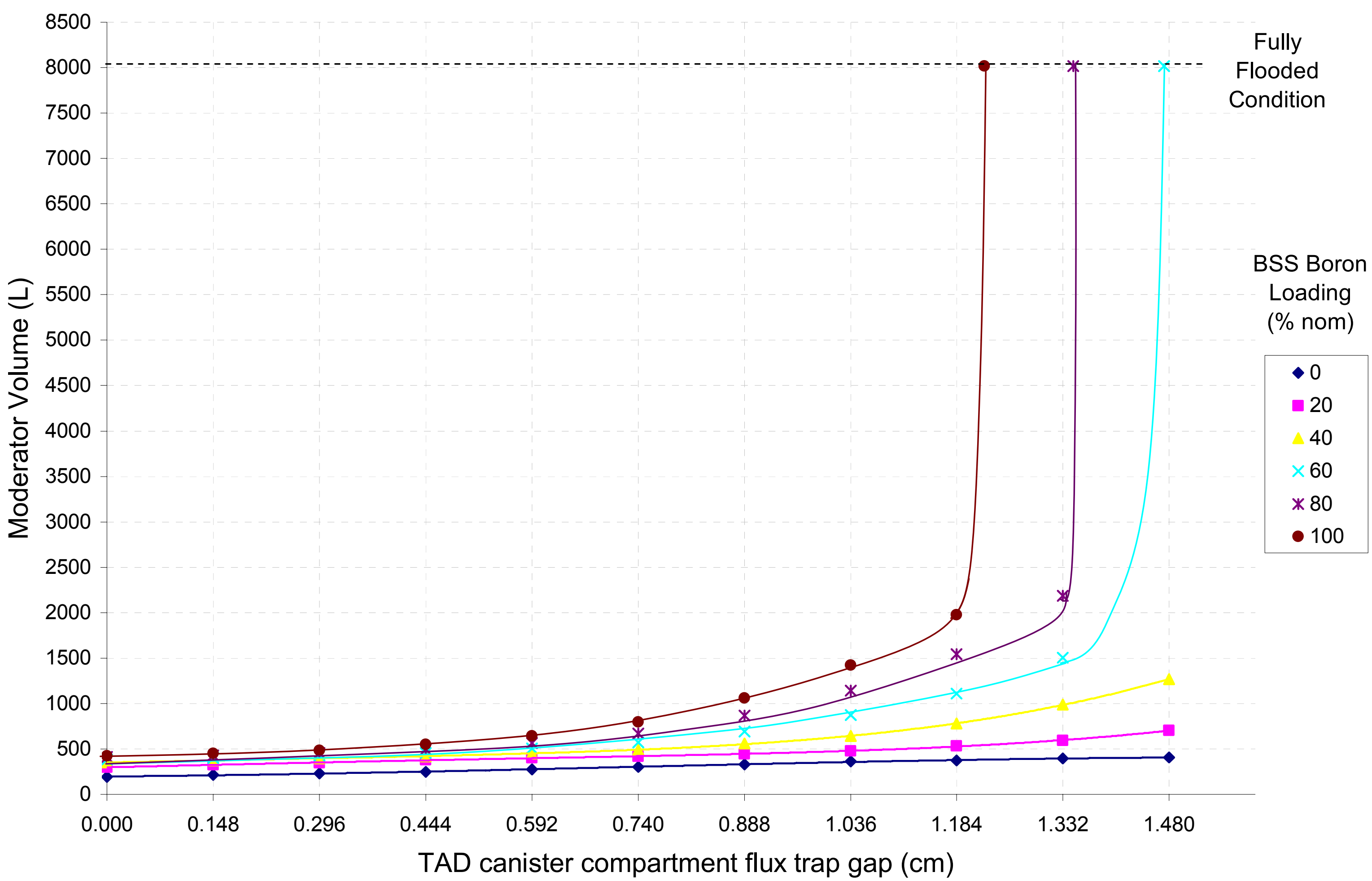

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Figure 32. Maximum Safe Moderator (H_2O) Volume as Function of Canister BSS Panel Boron Content and Compartment Flux Trap Gap, for Single Damaged, Partially Flooded BWR TAD Canister with 30cm Thick Close Fitting Steel Reflector

7.1.2.1.1.3 Potential Off-Normal Scenario 3

Potential Off-Normal Scenario 3 considers:

- 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.

The results of the precursor potential off-normal scenario 3 calculation (to establish the optimum fuel-water sludge concentration for an unconstrained moderator volume scenario) are presented in Figure 33. The data is based on a model of the PWR TAD canister with no basket or fuel damage, but with an entrained moderator volume of 500 liters, into which 5% of the total mass of fuel contained within the canister is homogenized at the base of the canister. Based on the results presented in Figure 33, it is seen that a reactivity peak is observed with an optimum fuel-water sludge concentration of approximately 1.2 g(UO_2)/cc.

The results of the main potential off-normal scenario 3 calculations are presented in Figure 72 though Figure 77 (Attachment III) for the 1% fuel release fraction scenario, Figure 78 though Figure 83 (Attachment III) for the 3% fuel release fraction scenario, and Figure 84 though Figure 89 (Attachment III) for the 5% fuel release fraction scenario. An interpolation of the raw results, to establish the maximum safe moderator volume as a function of the basket/fuel assembly damage condition and fuel release fraction considered, is presented in Figure 34. For comparison purposes, the results of the potential off-normal scenario 1 calculations are also presented, which correspond to the 'no fuel release' scenario.

Based on the trends established in Figure 34 it is seen that the maximum safe moderator volume is significantly more sensitive to damage scenarios that promote flux trap gap closure, than scenarios that lead to fuel assembly birdcaging. The relative insensitivity of fuel assembly birdgcaging on the maximum safe moderator volume is more clearly emphasized in Figure 35. From Figure 35 it is also seen that the maximum safe moderator volume becomes less sensitive to the fuel release fraction considered, as the canister compartment flux trap gap is reduced.

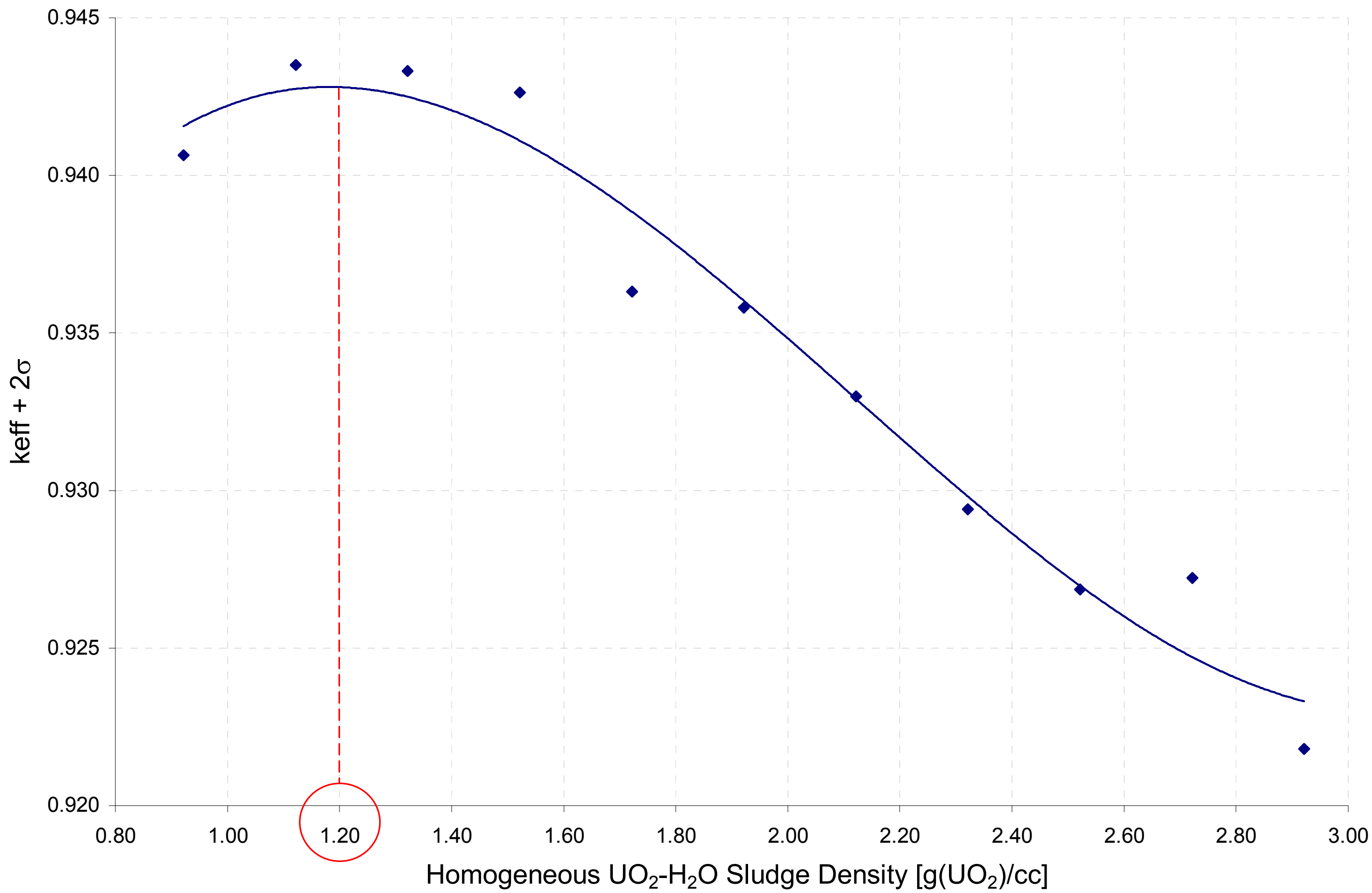

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Figure 33. Variation of k_{eff} +2σ with Variation of Density of Homogeneous UO2-H2O Sludge (Based on 5% Fuel Release Positioned at Base of TAD Canister), for Single Undamaged, Partially Flooded PWR TAD Canister with 30cm Thick Close Fitting Steel Reflector

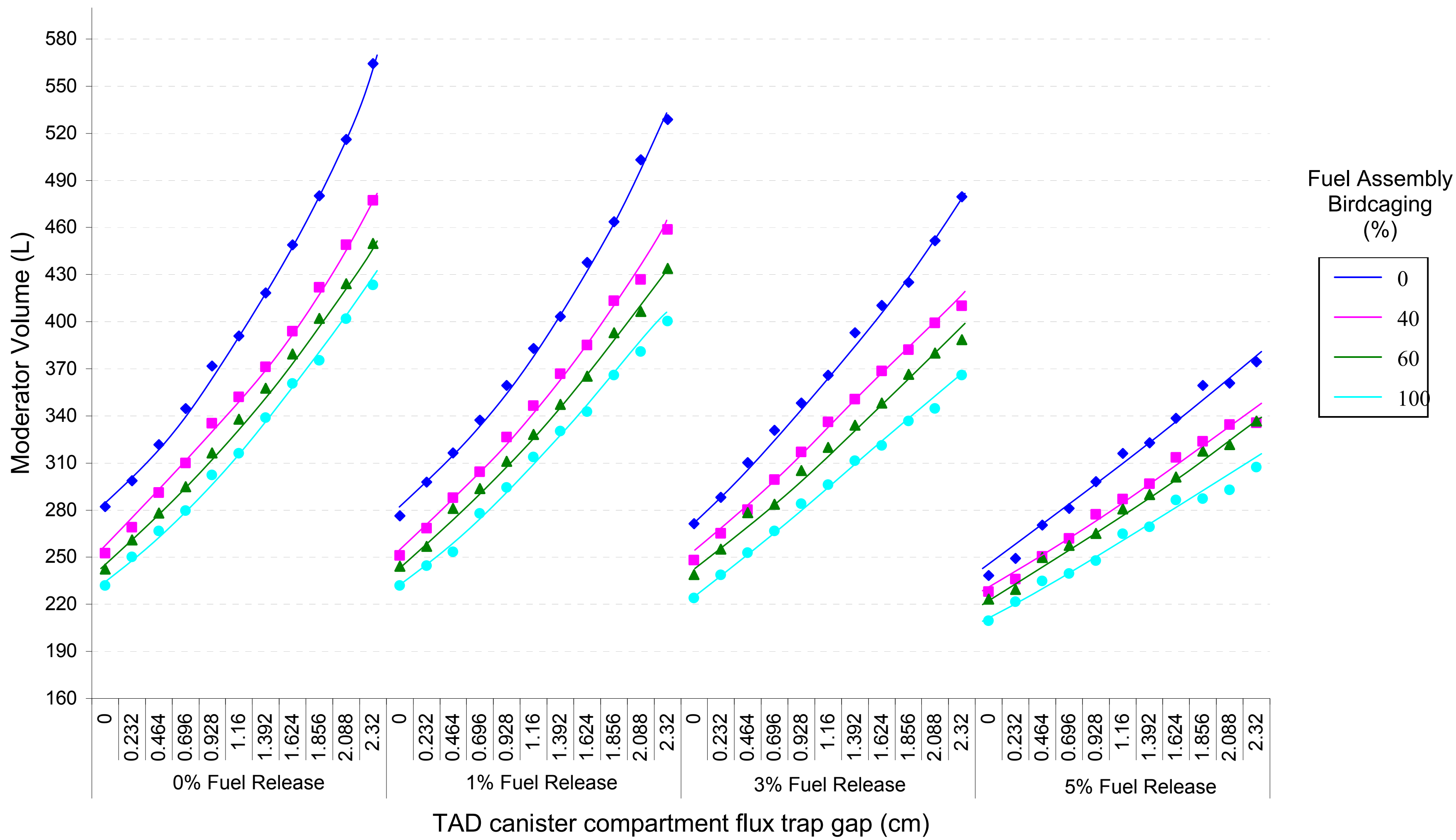

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Figure 34. Maximum Safe Moderator (H_2O) Volume as Function of Fuel Assembly Birdcaging, Compartment Flux Trap Gap and Fuel Release Fraction, for Single Damaged, Partially Flooded PWR TAD Canister with 30cm Thick Close Fitting Steel Reflector

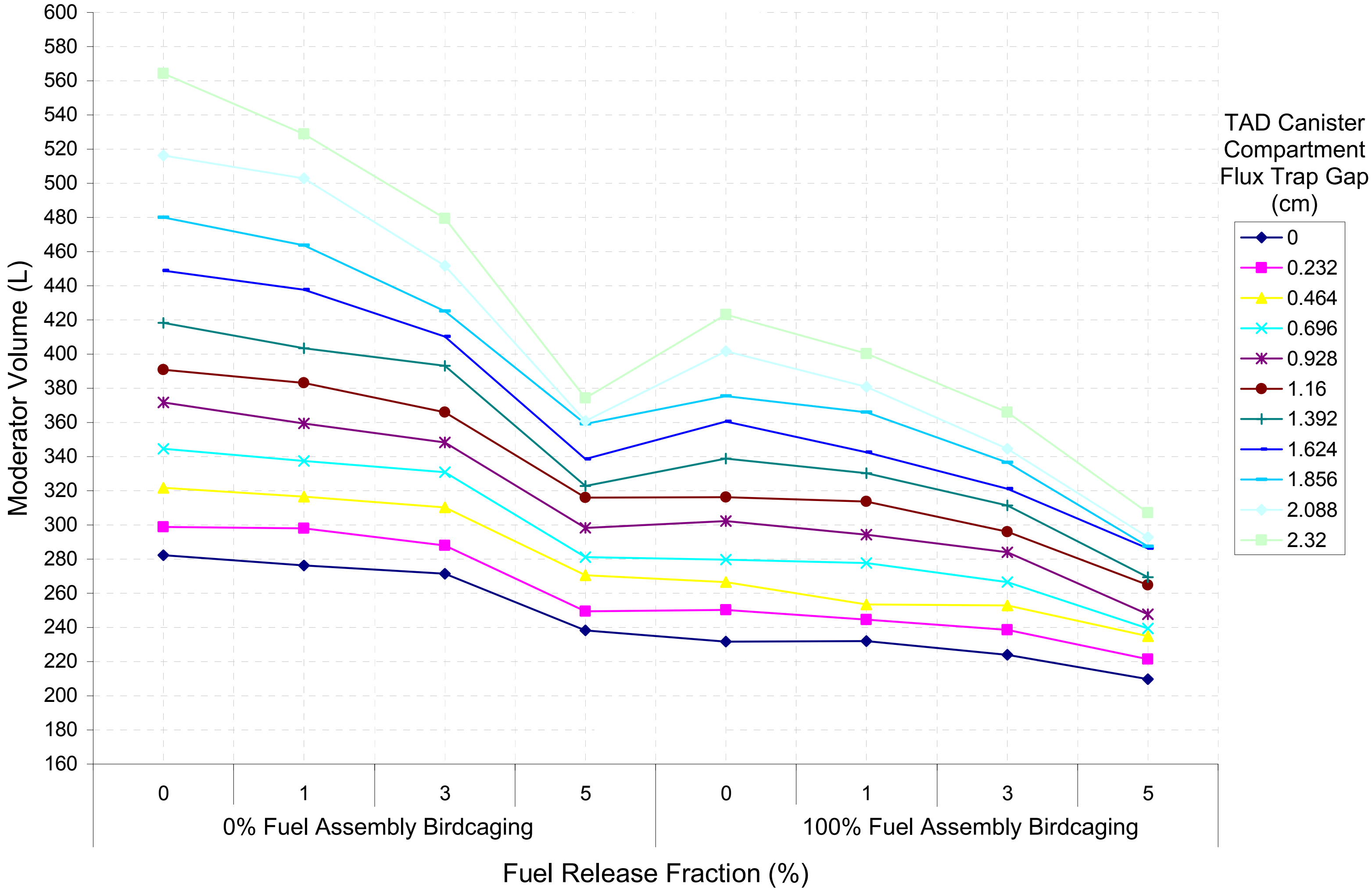

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Figure 35. Maximum Safe Moderator (H_2O) Volume as Function of Fuel Assembly Birdcaging, Compartment Flux Trap Gap and Fuel Release Fraction, for Single Damaged, Partially Flooded PWR TAD Canister with 30cm Thick Close Fitting Steel Reflector

7.1.2.1.2 Ancillary Study

The ancillary potential off-normal conditions analysis supplements the detailed parametric study described in Section 6.3.2.1.1 and evaluated in Section 7.1.2.1.1. The ancillary study quantifies the effectiveness of various reflecting media, which could differ from the trend established in the normal conditions analysis due to the presence of moderator in the off-normal conditions models. The ancillary analysis also investigates the effect of grouping **multiple** damaged TAD canisters within an array, in addition to the effect of intrusion of an alternate moderator (hydraulic fluid) into the canister cavity.

7.1.2.1.2.1 Reflecting Media

The results of the calculations performed for single PWR and BWR TAD canisters exhibiting maximum fuel assembly birdcaging, complete compartment flux trap gap closure, and partial entrainment of water moderator are presented in Figure 36 and Figure 37. It is seen from the results presented that stainless steel is amongst the most onerous reflector materials for damaged, partially moderated, TAD canisters. Based on the very small change in k_{eff} (< 1%) between the worst case reflector material (full theoretical density lead) and stainless steel, the detailed potential off-normal conditions calculations reported in Section 7.1.2.1.1 (which are based on a 30 cm thick close-fitting stainless steel reflector) are considered to bound reflection conditions achievable for TAD canisters within the surface facilities.

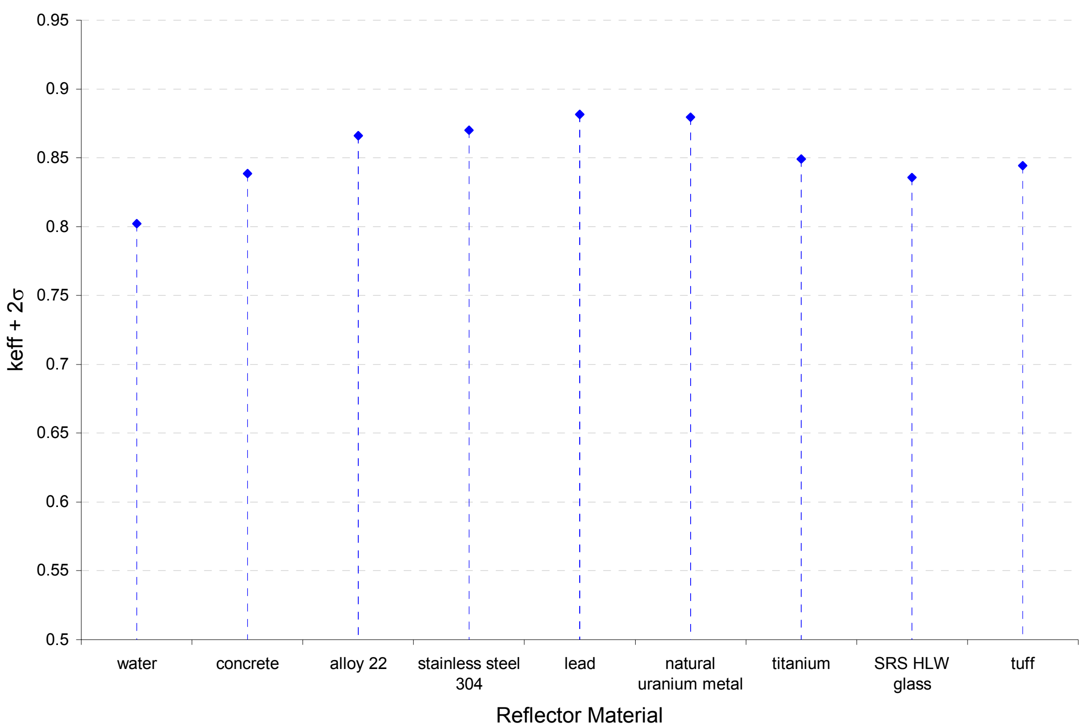

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Figure 36. Variation of keff +2σ with Close Fitting Full-Thickness (I.E. 30 cm) Reflector Material, for Single Damaged (Maximum Flux Trap Gap Collapse) and Partially Flooded (200 Liters Water Moderator) PWR TAD Canister Containing Intact, Damaged (Maximum Fuel Assembly Birdcaging), Representative CSNF

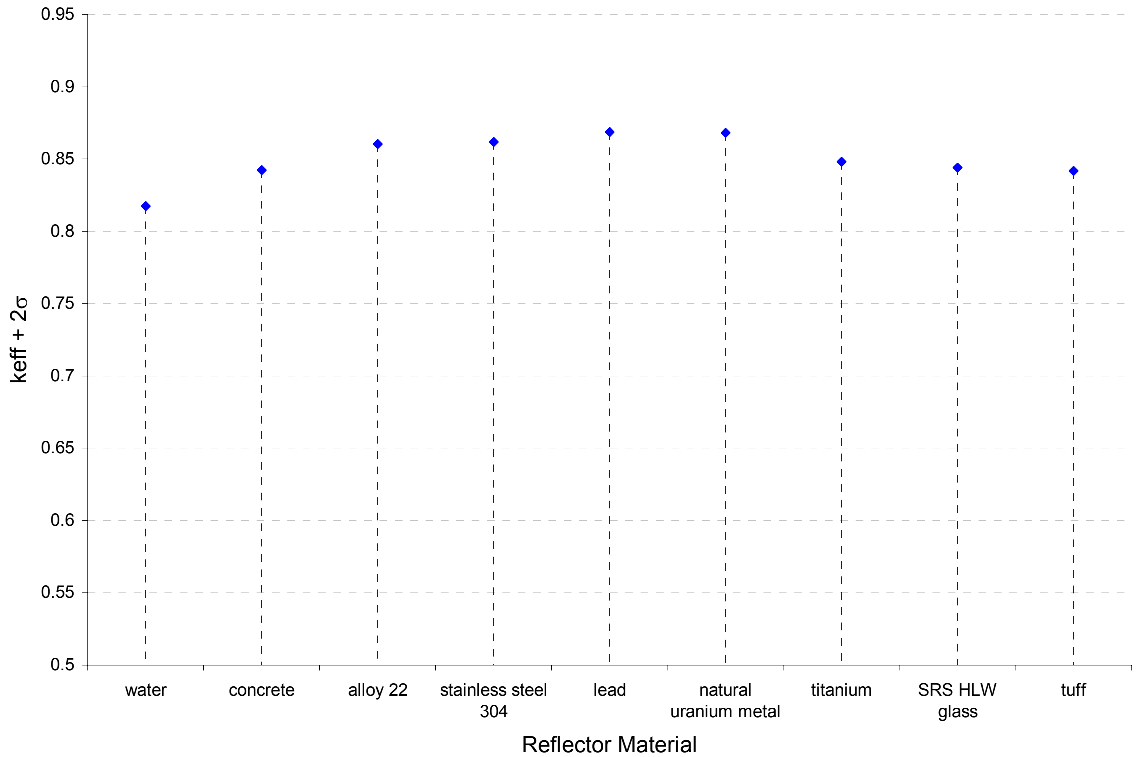

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Figure 37. Variation of k_{eff} +2σ with Close Fitting Full-Thickness (I.E. 30 cm) Reflector Material, for Single Damaged (Maximum Flux Trap Gap Collapse) and Partially Flooded (300 Liters Water Moderator) BWR TAD Canister Containing Intact, Damaged (Maximum Fuel Assembly Birdcaging), Representative CSNF

7.1.2.1.2.2 Damaged Canister Array

The results of the calculations performed for an infinite planar array of TAD canisters, with each canister exhibiting maximum fuel assembly birdcaging and complete compartment flux trap gap closure, are presented in Table 27. The corresponding water moderator content of each canister in the array is included in the table. For comparison, the equivalent results for the single canister calculations (**Potential Off-Normal Scenario 1**) reported in Section 7.1.2.1.1 are presented. It is seen from Table 27 that there is a negligible difference between the calculated values of k_{eff} +2σ for a single fully reflected damaged canister and an infinite planar array of damaged canisters.

7.1.2.1.2.3 Hydraulic Fluid Moderator

The result of the calculation performed for a single PWR TAD canister exhibiting maximum fuel assembly birdcaging, complete compartment flux trap gap closure, and entrainment of 200 liters of Polysiloxane fluid is presented in Table 28. For comparison, the equivalent result based on a 200 liter water moderator content (reported for **Potential Off-Normal Scenario 1** in Section 7.1.2.1.1) is presented. It is seen from Table 28 that there is a significant reduction in the calculated value of k_{eff} +2σ when the modeled water moderator is substituted for an equivalent volume of polysiloxane fluid.

Table 27. Comparison of k_{eff} +2σ Values for Damaged PWR and BWR TAD Canisters, with Each TAD Canister Containing Water Moderator and Intact, Representative CSNF, with Maximum Fuel Assembly Birdcaging and Complete Canister Compartment Flux Trap Gap Closure

TAD Canister Variant	Canister Model	TAD Canister Surface-Surface Spacing (cm)	Degree of FA Birdcaging (%)	Flux Trap Gap (cm)	Boron loading in BSS (%)	30 cm Thick Reflector Material	Water Moderator Volume (L)	k_{eff} +2σ
PWR	Infinite Planar Array	0.0	100	0.0	100	Stainless Steel 304 (axially)	200	0.87603
PWR	Single Fully Reflected	N/A	100	0.0	100	Stainless Steel 304 (axially/radially)	200	0.87012
BWR	Infinite Planar Array	0.0	100	0.0	100	Stainless Steel 304 (axially)	300	0.8636
BWR	Single Fully Reflected	N/A	100	0.0	100	Stainless Steel 304 (axially/ radially)	300	0.86187

Table 28. Comparison of k_{eff} +2σ Values for Single Fully Reflected Damaged PWR TAD Canister Containing 200 Liters of Water or Polysiloxane Moderator and Intact, Representative CSNF, with Maximum Fuel Assembly Birdcaging and Complete Canister Compartment Flux Trap Gap Closure

TAD Canister Variant	Degree of FA Birdcaging (%)	Flux Trap Gap (cm)	Boron loading in BSS (%)	30 cm Thick Reflector Material	Moderator	Moderator Volume (L)	k_{eff} +2σ
PWR	100	0.0	100	Stainless Steel 304 (axially)	Polysiloxane	200	0.75775
PWR	100	0.0	100	Stainless Steel 304 (axially/ radially)	Water	200	0.87012

7.1.2.2 Subsurface Facility

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 subcriticality of sealed waste packages positioned in the Subsurface facility emplacement drifts is demonstrated in Section 7.1.1.2 for waste packages containing TAD canister-based systems that conform to a normal (i.e. dry, undamaged and intact) condition. In the event of deviation(s) from normal conditions occurring subsequent to emplacement, but prior to permanent closure of the Subsurface facility, the integrity, desiccation and geometry of the TAD canisters located in their sealed waste packages could be compromised. However, based on the results of the calculations reported in Section 7.1.1.2, the reactivity of the TAD canisters in an emplacement configuration is essentially equivalent to the reactivity of a single fully reflected TAD canister. Because this trait is a result of the large length of the TAD canisters (which is essentially infinite from a neutron transport viewpoint), it is confidently judged that the established trait is independent of the canister condition considered (i.e. normal condition versus off-normal condition). Therefore, the Subsurface facility under off-normal conditions may be bounded by the single damaged TAD canister analysis reported in Section 7.1.2.1.

7.2 CONCLUSIONS

The results of the MCNP criticality safety calculations described in this document are presented in Section 7.1. Based on the results presented attributes of the TAD canister-based systems that are important to ensuring their subcriticality are established. These attributes can be categorized according to the criticality control parameter that is impacted. Based on the categorization presented below, it is seen that **Moderation** control is the underlying criticality control parameter for TAD canister-based systems containing CSNF with a maximum initial enrichment of 5 wt. % ^{235}U/U. However, **Geometry** and **Neutron Absorber** control are also important because the design of the canister basket, including the associated neutron absorber panels, directly influence the maximum moderator volume that can be safely tolerated inside the TAD canister cavity in the event of a canister breach. On this basis, it is convenient to define the moderation limits for the PWR and BWR TAD canisters according to the geometry and neutron absorber condition prevalent. In this respect, the maximum safe moderator limits for the TAD canister-based systems, and their associated range of applicability (i.e. **Geometry** and **Neutron Absorber** condition), are detailed in Table 29. For clarity, 'conditions' are used to correlate physical conditions with corresponding moderator limits. It is noted that the moderator limits provided in Table 29 correspond to the limiting volumes derived from the PWR TAD canister calculations. Consequently, the established limits bound the actual maximum safe moderator volumes for the BWR TAD canister.

Geometry

Under all normal conditions the TAD canister systems feature dry intact CSNF, held within a dry intact basket. Based on these dry (i.e. unmoderated) conditions, substantial margin exists between the computed peak k_{eff} +2σ value (in the region of 0.5, Section 7.1.1) and the USL value of 0.92 (Section 3.1.1). Owing to the relatively low fissile enrichment of CSNF, any rearrangement of CSNF or basket material due to a process upset involving damage of a canister, but not including moderation of its content, will not result in an unsafe condition. However, for process upsets involving damage of a canister including its breach and subsequent introduction of moderator, the geometry of the CSNF and basket material is important. In this respect, the geometry of the canister basket and CSNF directly influence the established moderation limits tolerable for the PWR and BWR TAD canisters.

Neutron Absorber

Under normal conditions the TAD canisters are completely dry, which results in a hard neutron spectrum. Under these dry, unmoderated conditions, the borated stainless steel neutron absorber panels associated with the TAD canister basket structure provide very limited neutron absorption, to the extent that their complete omission will not result in an unsafe condition. For the same reason, under potential off-normal conditions resulting in moderation of the canister content coincident with collapse of the canister fuel compartment flux trap gap, the effectiveness of the neutron absorber panels is significantly diminished. This trait is understood when it is realized that reduction in the TAD canister fuel compartment flux trap gap results in reduced neutron moderation (i.e. a harder neutron spectrum), and thus reduced neutron absorption. Consequent to the above analysis, it is seen that the neutron absorber panels associated with the TAD canisters are important to criticality safety in situations involving moderation (or partial moderation) of the TAD canister cavity. However, based on the calculation results documented, it is seen that under a complete loss of moderation control (e.g. full flooding of the TAD canister cavity), the provision of neutron absorber control is insufficient to ensure subcriticality for the PWR TAD canister design (with no basket/fuel damage) and is insufficient to ensure subcriticality for the BWR TAD canister design (with just minor basket/fuel damage). Therefore, neutron absorber control is important to criticality safety, but only in the context of influencing the moderation limits tolerable for the PWR and BWR TAD canisters.

Moderation

Under all normal conditions the TAD canister systems feature dry intact CSNF, held within a dry intact basket. Based on these dry (i.e. unmoderated) conditions, substantial margin exists between the computed peak k_{eff} +2σ value (in the region of 0.5, Section 7.1.1) and the USL value of 0.92 (Section 3.1.1). However, under potential off-normal conditions involving moderation (or partial moderation) of the TAD canister cavity, the USL could be exceeded. This is especially true for the PWR TAD canister, which exceeds the USL with only partial moderation and no basket/fuel damage. Consequently, moderation control is essential to preserving the subcriticality of the TAD canister-based systems in the surface and Subsurface facilities examined in this document.

Interaction

The infinite planar array configuration considered for undamaged TAD canisters in the criticality safety analysis bounds any foreseen neutron interaction conditions that could be realized in the surface facilities under normal conditions. Furthermore, the ‘infinite row’ configuration considered for TAD canisters in the criticality safety emplacement models bounds any foreseen neutron interaction conditions that could be realized in the sub-surface facility.

Although coincident damage of multiple TAD canisters is considered extremely unlikely (because canisters are handled individually), the ancillary criticality safety analysis reported in this document includes a model of an infinite planar array configuration of damaged TAD canisters. The calculation results demonstrate that an infinite planar array of damaged canisters is essentially equivalent to a single, fully reflected, damaged canister, with regards to the maximum safe moderator volume. Consequently, the established moderator limits reported in this document bound conditions under which multiple TAD canisters are simultaneously damaged and subject to moderator intrusion.

Based on the above discussion, interaction control is not important to ensuring the subcriticality of the TAD canister-based systems in the surface and Subsurface facilities examined in this document.

Reflection

The effect of reflection on the fuel assemblies is considered in the criticality safety calculations reported in this document. For all calculations performed, close fitting full-thickness (i.e. 30 cm) reflection is considered. In addition, a comprehensive range of reflector materials (Section 6.2.3.3) are examined to determine the limiting reflector condition. Consequently, the reflection conditions accounted for the criticality safety calculations are considered to bound any foreseen reflections conditions that could be realized in the surface and subsurface facilities examined in this document. Therefore, reflection control is not important to ensuring the subcriticality of the TAD canister-based systems in the surface and sub-surface facilities examined in this document.

Waste Form Characteristics

The characteristics of CSNF and the canisters in which it is transported, packaged, and stored, are fixed prior to the time of acceptance into the repository. This calculation considered bounding waste form parameters (summarized below). Therefore, waste form characteristics are bounded and do not need to be controlled. The specific bounding waste form parameters employed in this calculation include:

- 5 wt% enriched ^{235}U fresh fuel (i.e., maximum CSNF enrichment and no credit for burnup);
- UO_2 density of 10.751 g/cm^3, i.e., 98% of full theoretical density;
- Use of full assembly length as active fuel length;
- No burnable poison;
- No credit for the presence of ^{234}U or ^{236}U absorbers;
- Fuel pellet stack modeled as a simple cylinder with no density correction for dished ends;
- Gap between fuel and clad filled with unborated water; and
- Simplified fuel assembly model neglecting spacer grids and end fittings.

Table 29. Summary of Calculated Maximum Safe Moderator Limits for TAD Canister-Based Systems and their Associated Range of Applicability

TAD Canister Condition	Criticality Control Parameter					Ref.
	Neutron Absorber	Geometry			Moderation	
	Absorber Reduction (%)	Degree of FA Birdcaging (%)	Flux Trap Gap Collapse (%)	Fuel Release Fraction (%)	Max. Safe Moderator Volume (L)	
Handling of an undamaged TAD canister	N/A	N/A	N/A	N/A	564	Figure 29
Staging of multiple undamaged TAD canisters	N/A	N/A	N/A	N/A	~564[d]	Figure 29
Emplacement of undamaged TAD canisters in the Subsurface facility	N/A	N/A	N/A	N/A	>564[e]	Figure 29
Axial impact resulting in FA birdcaging	N/A	0% 50% 100%	N/A [a]	N/A	564 463 423	Figure 29
Axial impact resulting in fuel release	N/A	N/A	N/A [a]	0% 1% 3% 5%	564 529 480 374	Figure 35
Axial impact resulting in FA birdcaging and fuel release	N/A	100%	N/A [a]	0% 1% 3% 5%	423 400 366 307	Figure 35
Horizontal impact resulting in flux trap gap collapse	N/A	N/A [b]	0% 50% 100%	N/A [c]	564 391 282	Figure 29
Concurrent horizontal and axial impacts resulting in maximum damage, without fuel release	N/A	100%	100%	N/A	232	Figure 29
Concurrent horizontal and axial impacts resulting in maximum damage, with fuel release	N/A	100%	100%	0% 1% 3% 5%	232 232 224 210	Figure 35
Receipt of a TAD canister with reduced neutron absorber content, with a subsequent axial impact, resulting in FA birdcaging	0% 50% 100%	100%	N/A [a]	N/A	423 376 276	Figure 31
Receipt of a TAD canister with reduced neutron absorber content, with subsequent concurrent horizontal and axial impacts resulting in maximum	0% 50% 100%	100%	100%	N/A [c]	232 217 192	Figure 31

TAD Canister Condition	Criticality Control Parameter					Ref.
	Neutron Absorber	Geometry			Moderation	
	Absorber Reduction (%)	Degree of FA Birdcaging (%)	Flux Trap Gap Collapse (%)	Fuel Release Fraction (%)	Max. Safe Moderator Volume (L)	
damage, without fuel release						

NOTES: [a] Flux trap gap collapse is considered to arise from a horizontal impact. An end-on impact, resultant from a vertical drop, would not be expected to cause a reduction in the flux trap gap. Refer to Figure 20 for an illustration of expected damage resultant from a horizontal impact.

[b] Fuel assembly birdcaging refers to a condition where there is an increase in fuel pin pitch, and is considered to arise from an axial impact. A horizontal impact would be expected to have an opposite effect; i.e. reduce pin pitch. Refer to Figure 20 for an illustration of expected damage resultant from a horizontal impact.

[c] Fuel break-up and release in the canister cavity is considered to arise from an end-on impact. A horizontal impact is considered to result in basket deformation and potential reduction in pin pitch but is not considered to result in fuel release.

[d] The results of the criticality safety calculations performed for the damaged canister array (Table 27) demonstrate that for partially flooded canisters, the canister array model is practically equivalent to the single fully reflected damaged canister model, with regards to the maximum safe moderator volume. Therefore, it is confidently judged that an array of undamaged, but partially flooded, canisters is equivalent to a single fully reflected undamaged, but partially flooded, canister.

[e] Although not explicitly analyzed, the maximum safe moderator volume per canister for canisters in an emplacement configuration is considered to be significantly greater than the maximum safe moderator volume established for a single fully reflected canister, due to the horizontal configuration of canisters in the sub-surface emplacement drifts.

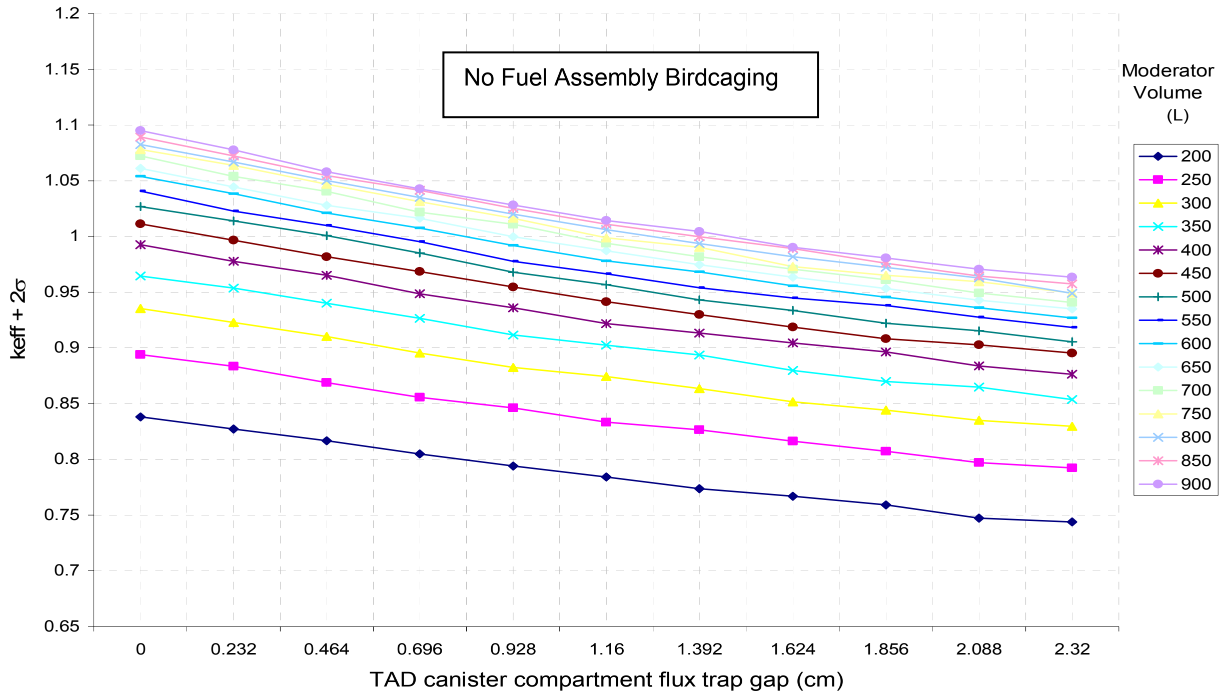
Source: Original

ATTACHMENT I: POTENTIAL OFF-NORMAL SCENARIO 1 RESULTS

Potential Off-Normal Scenario 1 considers:

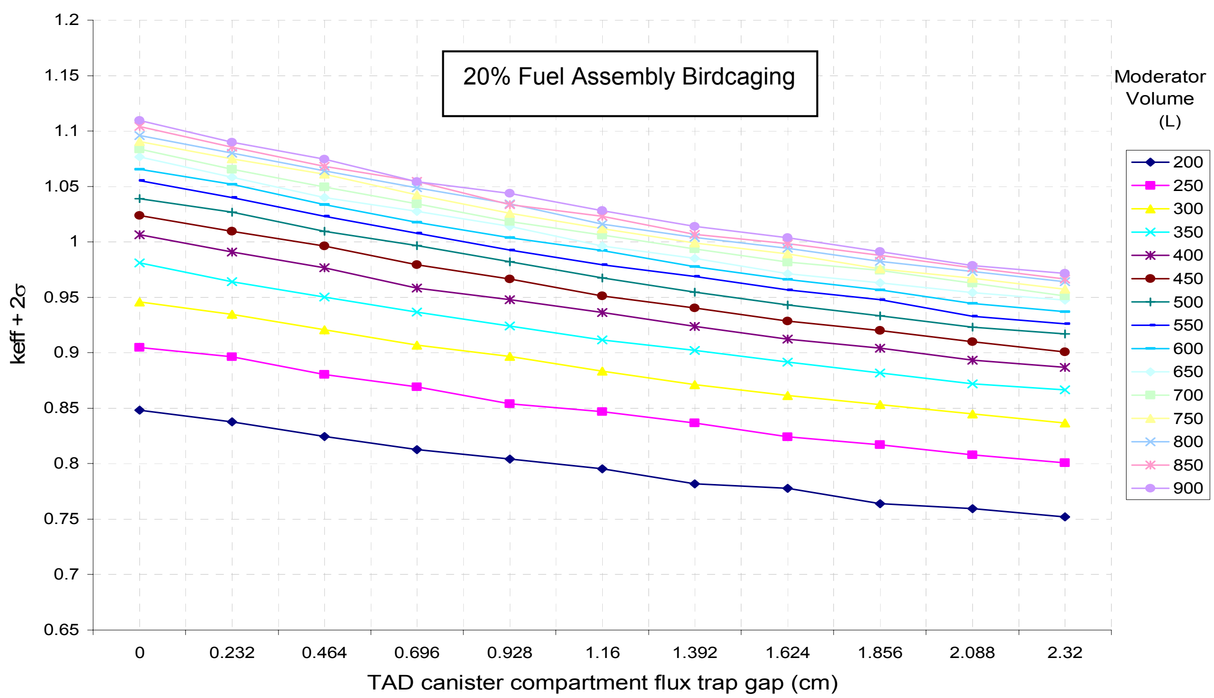
- Progressive canister basket deformation (i.e. flux trap gap collapse),
- Progressive fuel assembly deformation (i.e. birdcaging), and
- Progressive flooding of the TAD canister with water.

The results of the potential off-normal scenario 1 calculations are presented in Figure 38 though Figure 43 of this attachment for the PWR TAD canister, and Figure 44 though Figure 49 of this attachment, for the BWR TAD canister. An interpolation of the presented results, to establish the maximum safe moderator volume as a function of the basket/fuel assembly damage condition, is performed in the body of this document (Figure 29 and Figure 30 for the PWR and BWR TAD canister, respectively).



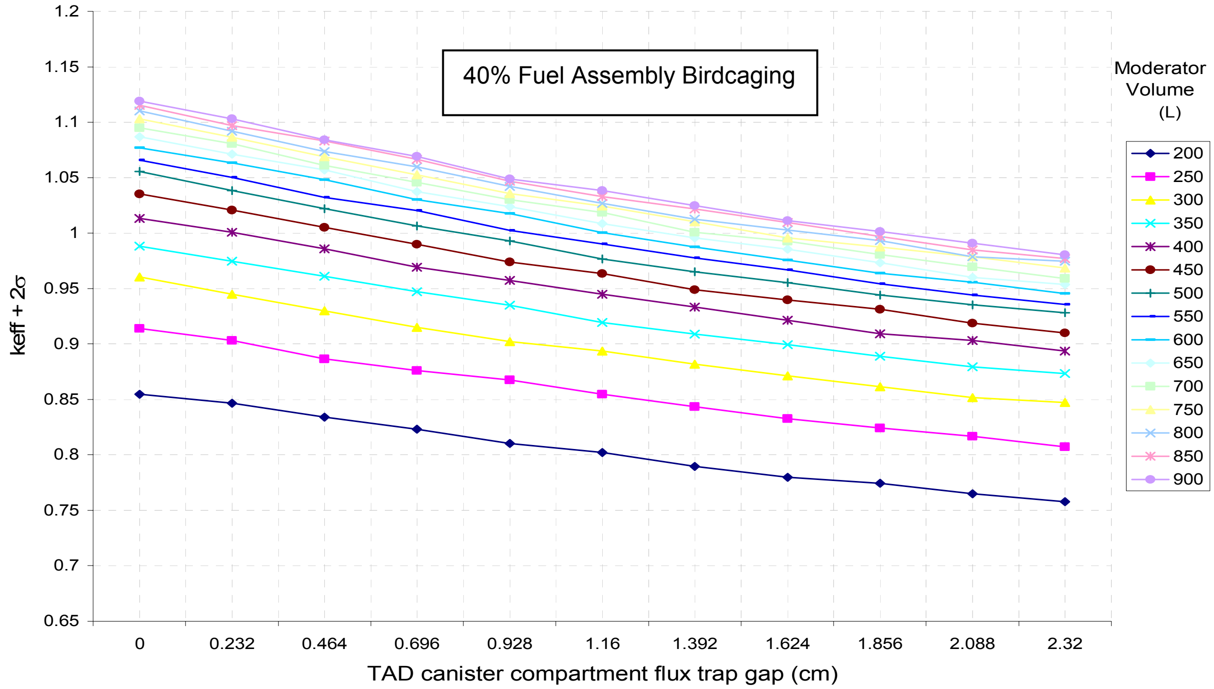
Source: Original

Figure 38. Variation of k_{eff} +2σ for Single Damaged and Partially Flooded PWR TAD Canister (With 30cm Thick Steel Reflector) Containing Intact Representative CSNF with No Fuel Deformation (0% Birdcaging)



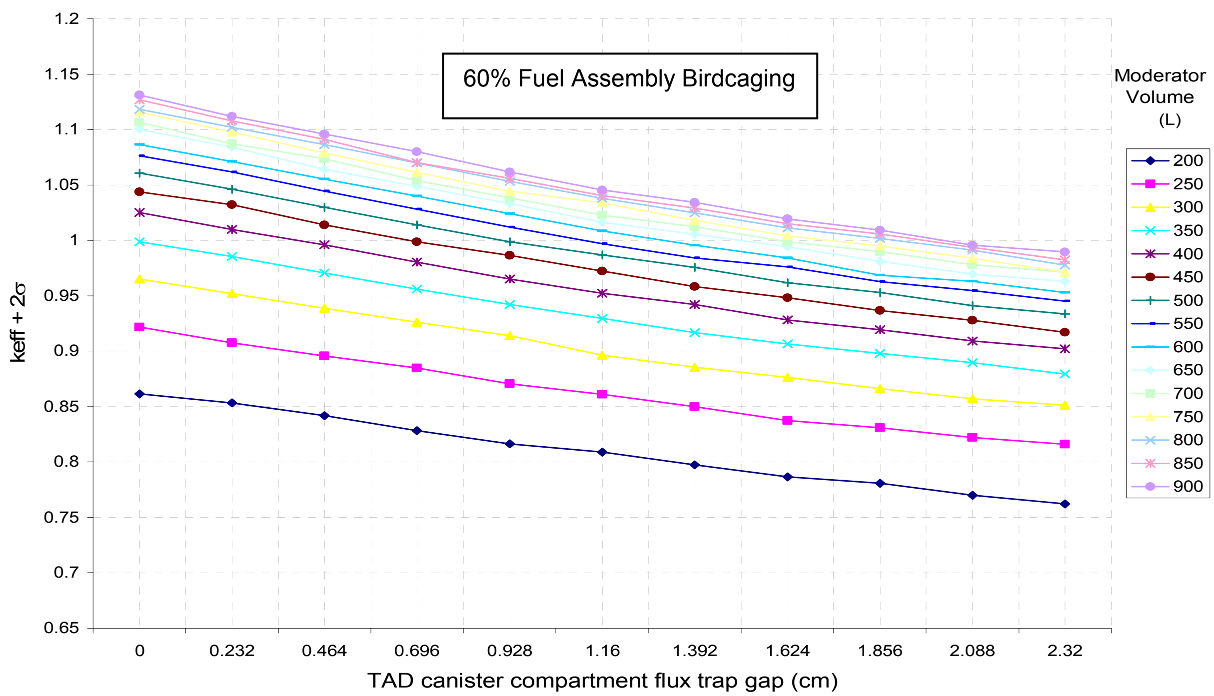
Source: Original

Figure 39. Variation of k_{eff} +2σ for Single Damaged and Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Partial Fuel Deformation (20% Birdcaging)



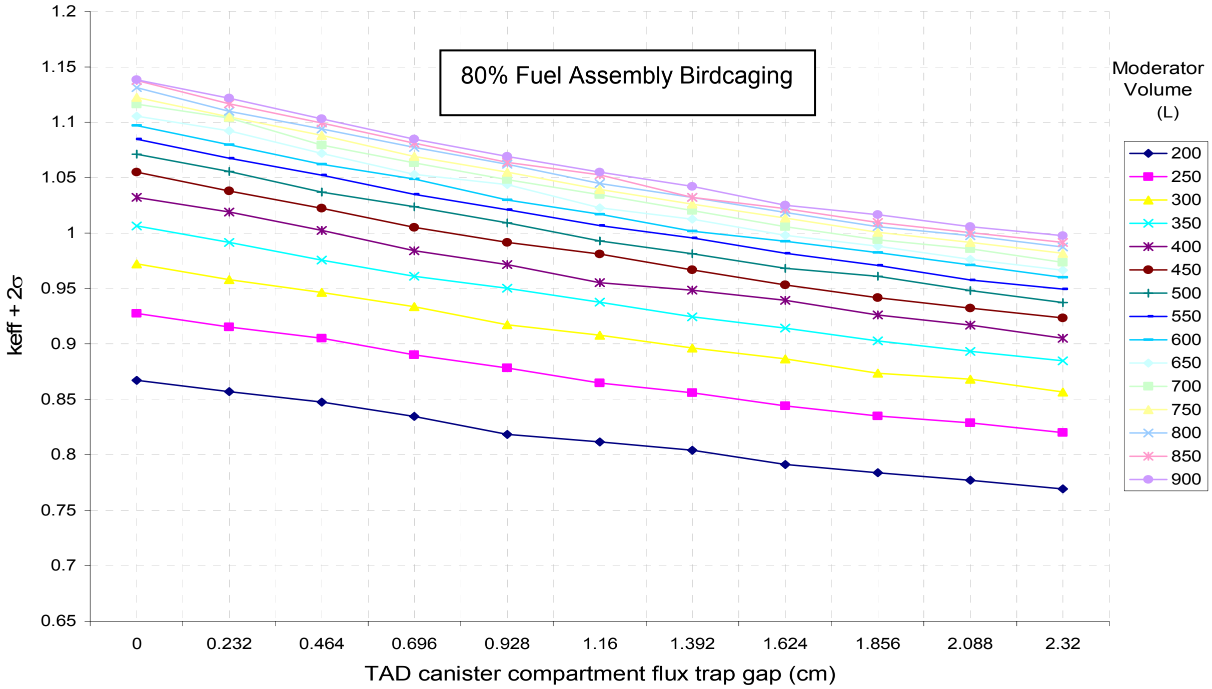
Source: Original

Figure 40. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Partial Fuel Deformation (40% Birdcaging)



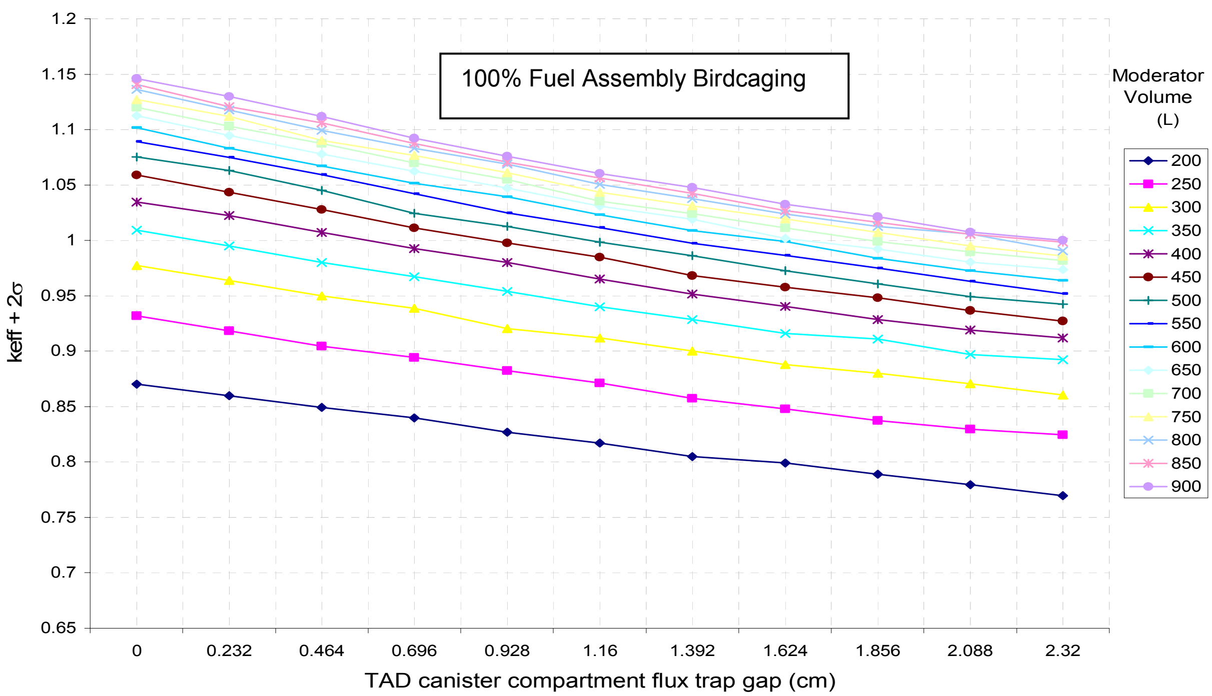
Source: Original

Figure 41. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Partial Fuel Deformation (60% Birdcaging)



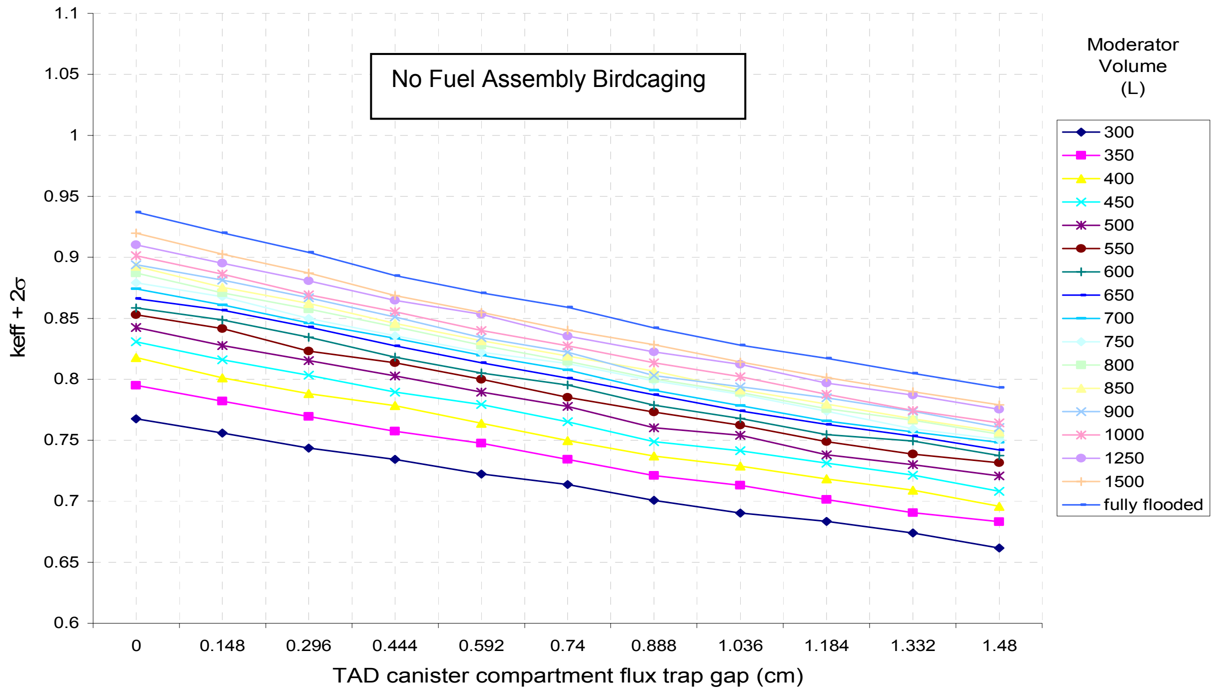
Source: Original

Figure 42. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded PWR TAD Canister (With 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Partial Fuel Deformation (80% Birdcaging)



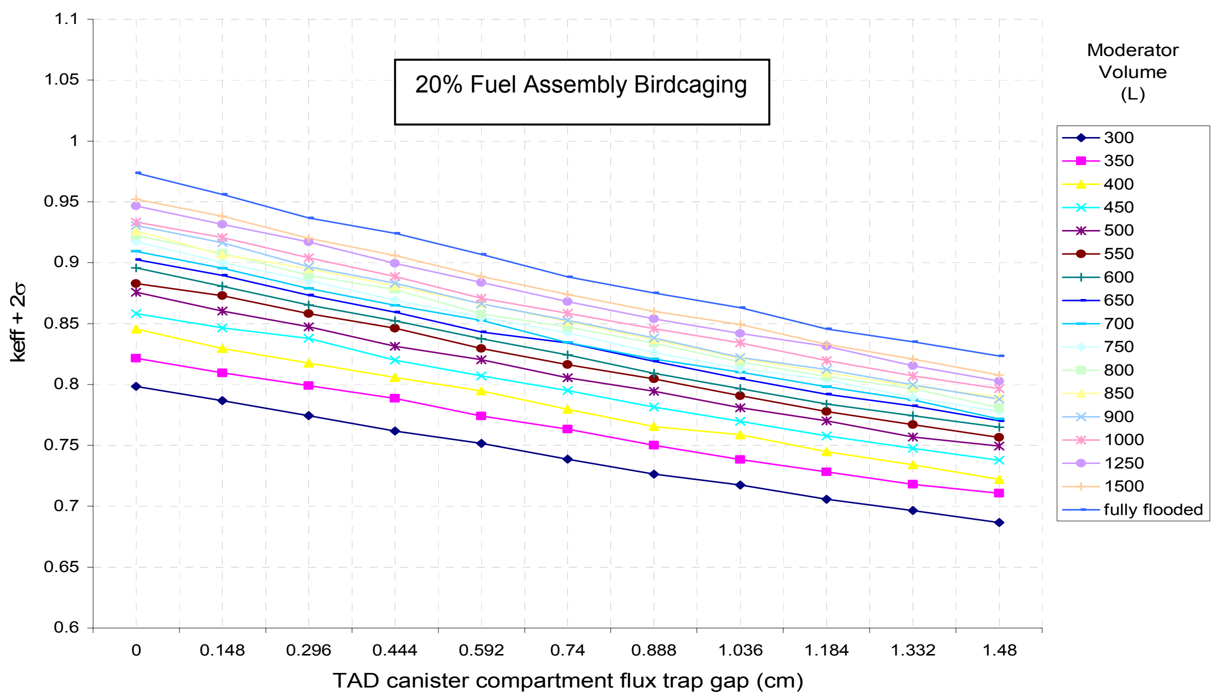
Source: Original

Figure 43. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (100% Birdcaging)



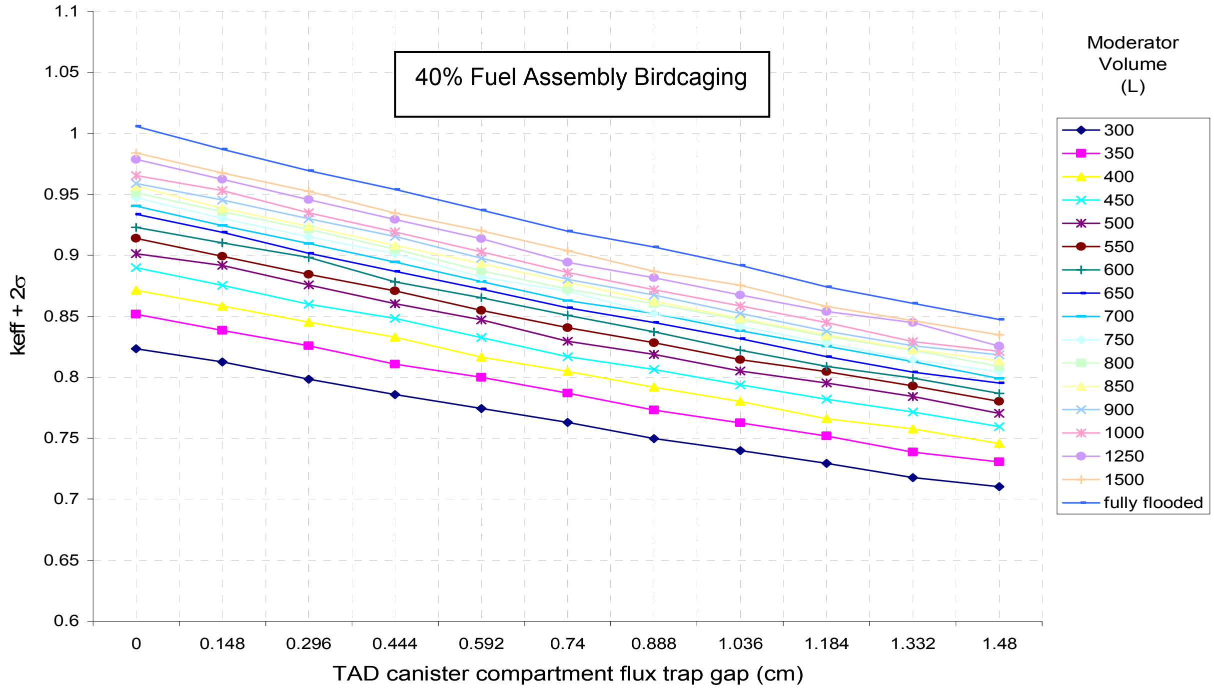
Source: Original

Figure 44. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded BWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with No Fuel Deformation (0% Birdcaging)



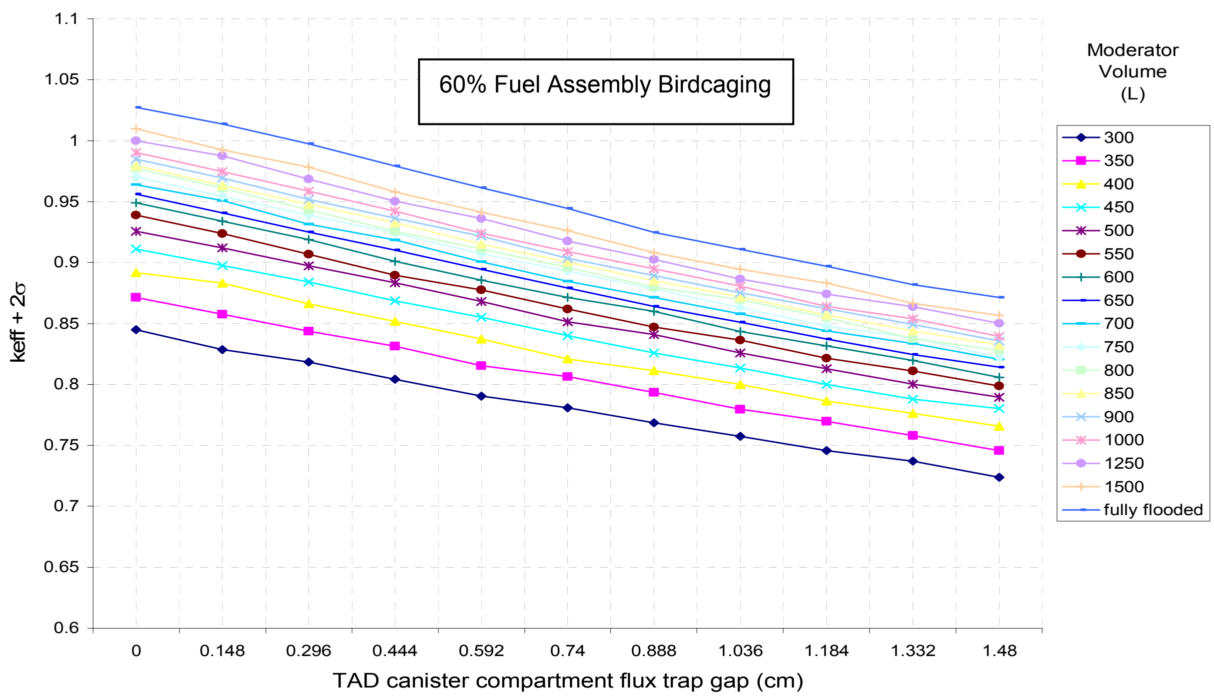
Source: Original

Figure 45. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded BWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Partial Fuel Deformation (20% Birdcaging)



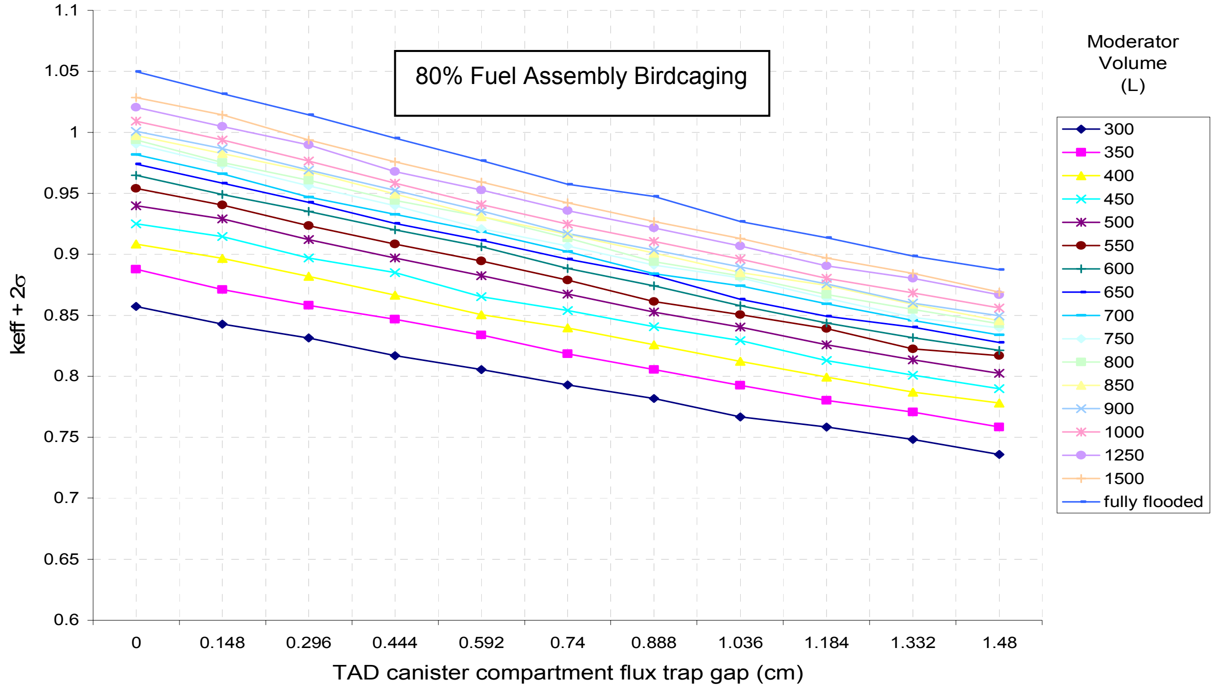
Source: Original

Figure 46. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded BWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Partial Fuel Deformation (40% Birdcaging)



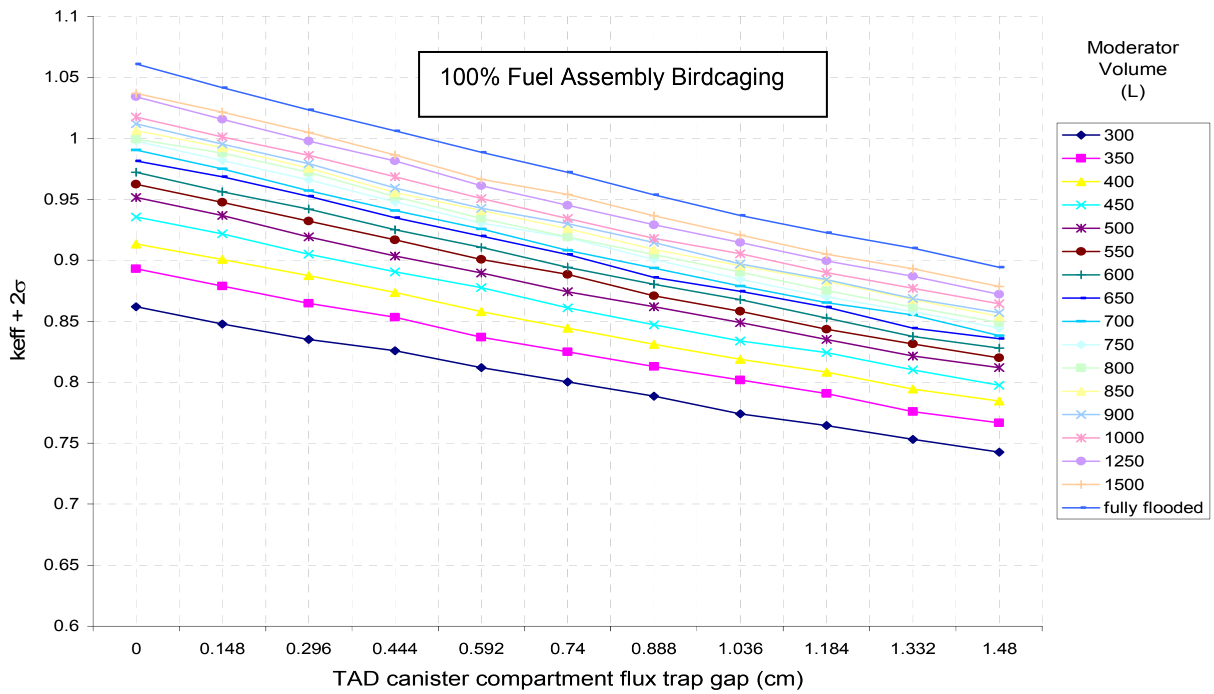
Source: Original

Figure 47. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded BWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Partial Fuel Deformation (60% Birdcaging)



Source: Original

Figure 48. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded BWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Partial Fuel Deformation (80% Birdcaging)



Source: Original

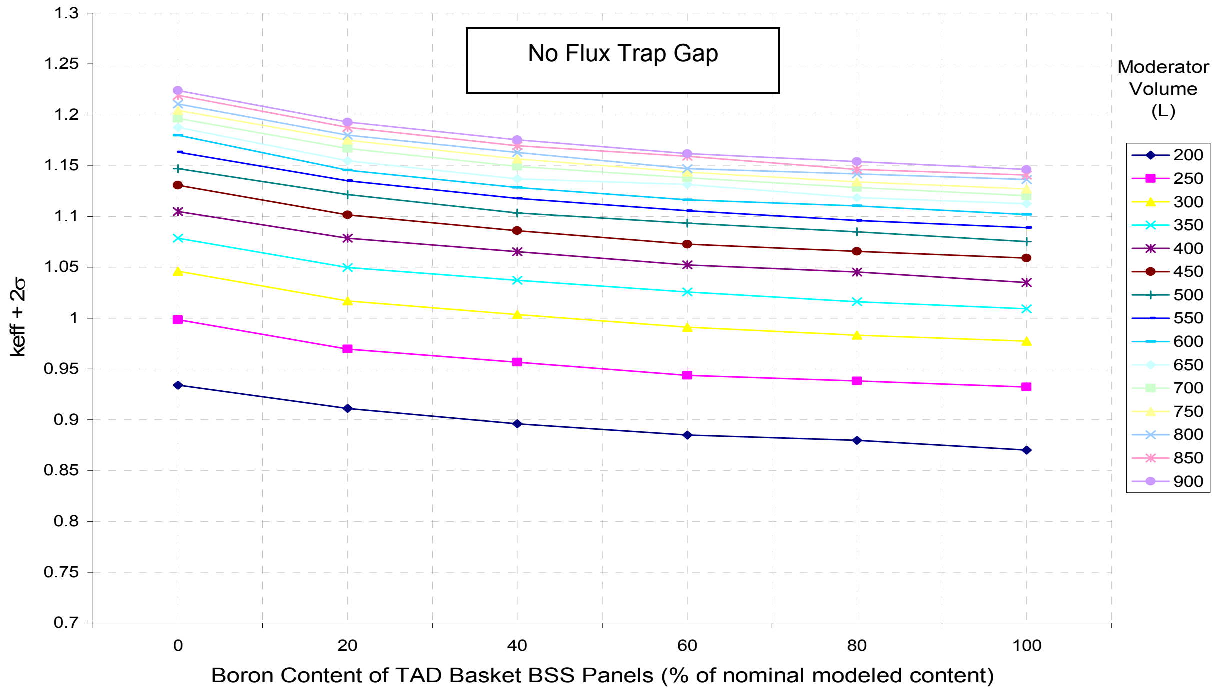
Figure 49. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded BWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (100% Birdcaging)

ATTACHMENT II: POTENTIAL OFF-NORMAL SCENARIO 2 RESULTS

Potential Off-Normal Scenario 2 considers:

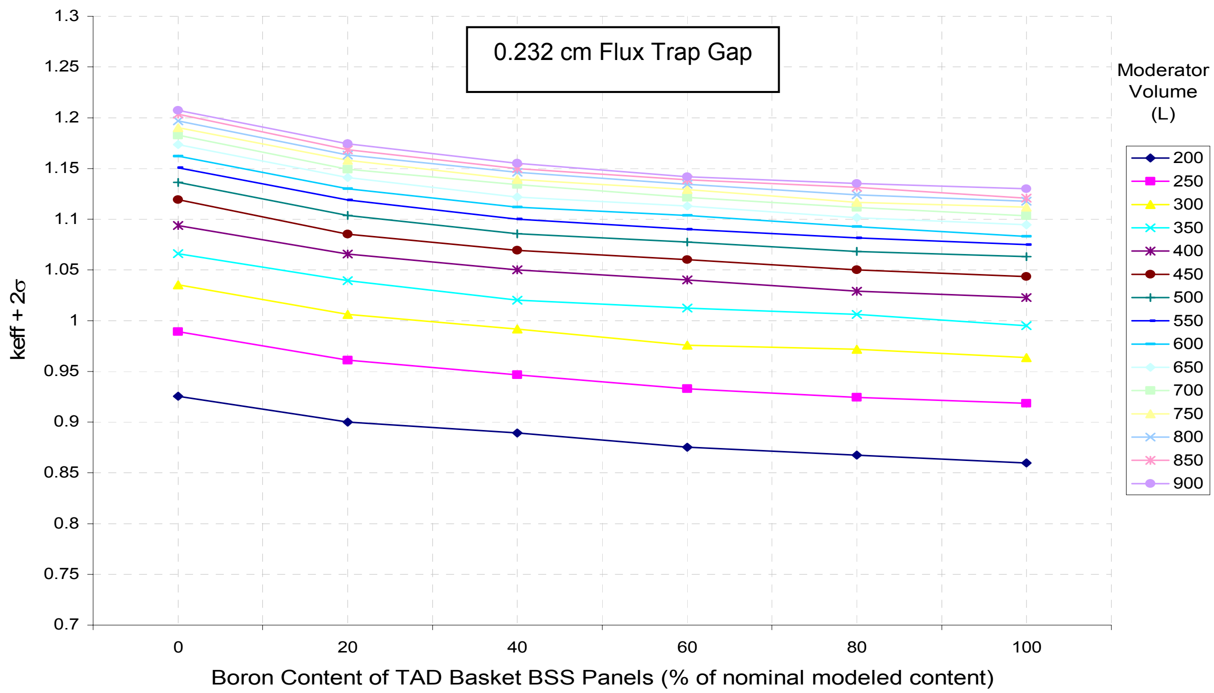
- Progressive canister basket deformation (i.e. flux trap gap collapse),
- Maximum fuel assembly deformation (i.e. birdcaging),
- Progressive reduction of the neutron absorber content of the canister basket, and
- Progressive flooding of the TAD canister with water.

The results of the potential off-normal scenario 2 calculations are presented in Figure 50 though Figure 60 of this attachment for the PWR TAD canister, and Figure 61 though Figure 71 of this attachment, for the BWR TAD canister. An interpolation of the raw results, to establish the maximum safe moderator volume as a function of the basket damage condition and neutron absorber content, is performed in the body of this document (Figure 29 and Figure 30 for the PWR and BWR TAD canister, respectively).



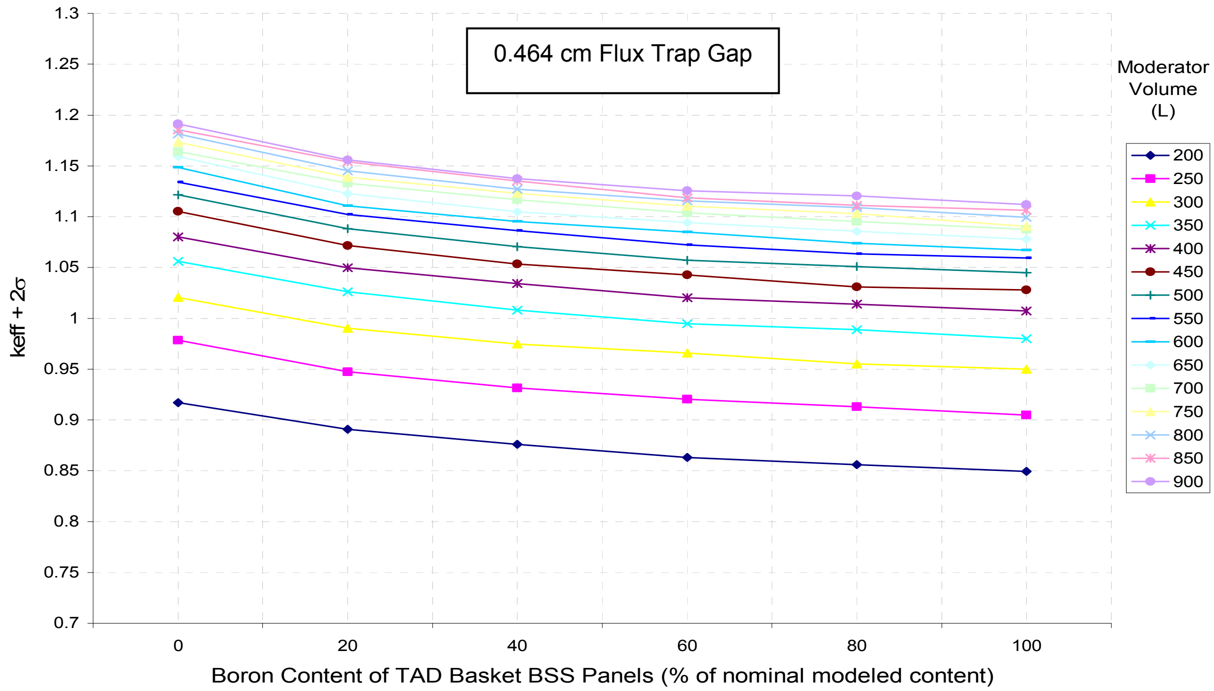
Source: Original

Figure 50. Variation of k_{eff} +2σ for Single Maximum Damaged (No Flux Trap Gap) and Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



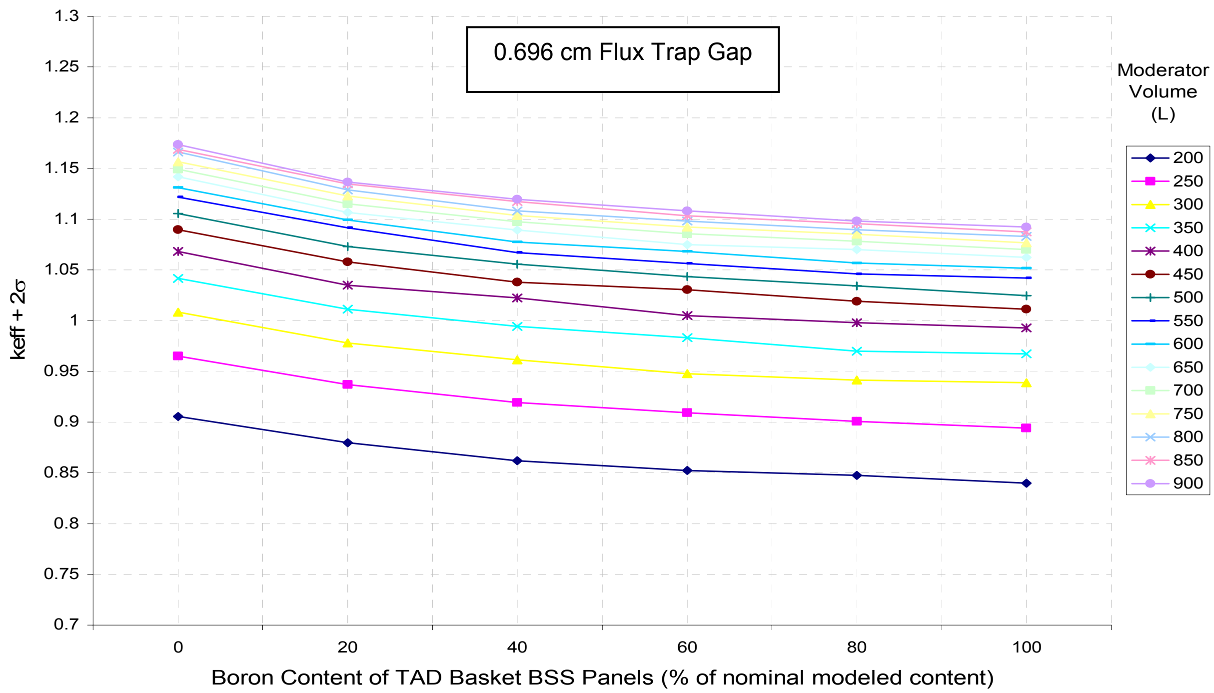
Source: Original

Figure 51. Variation of k_{eff} +2σ for Single Partially Damaged (0.232 Cm Flux Trap Gap) and Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



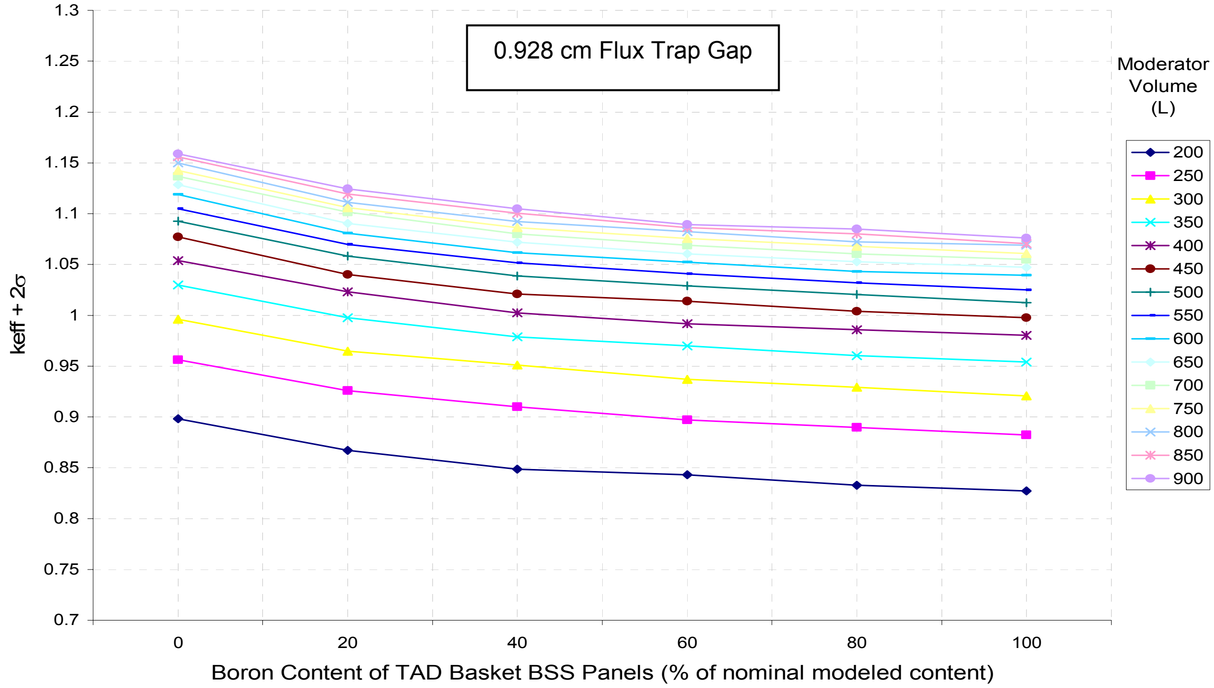
Source: Original

Figure 52. Variation of k_{eff} +2σ for Single Partially Damaged (0.464 Cm Flux Trap Gap) and Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



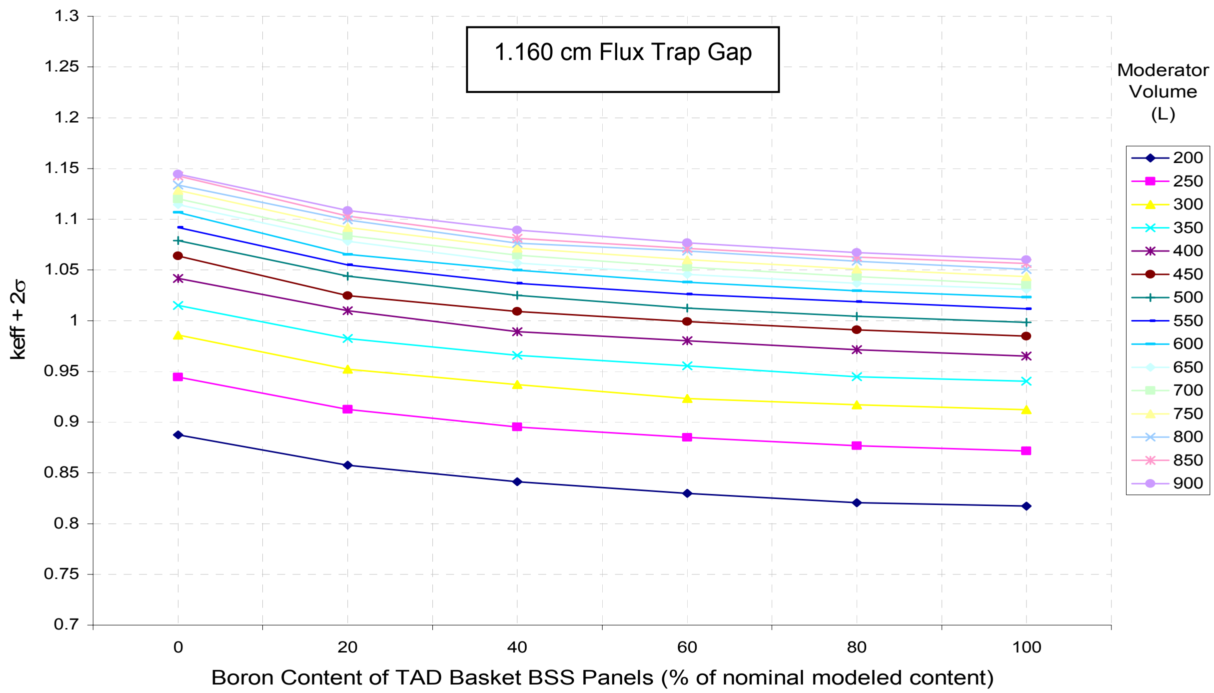
Source: Original

Figure 53. Variation of k_{eff} +2σ for Single Partially Damaged (0.696 Cm Flux Trap Gap) and Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



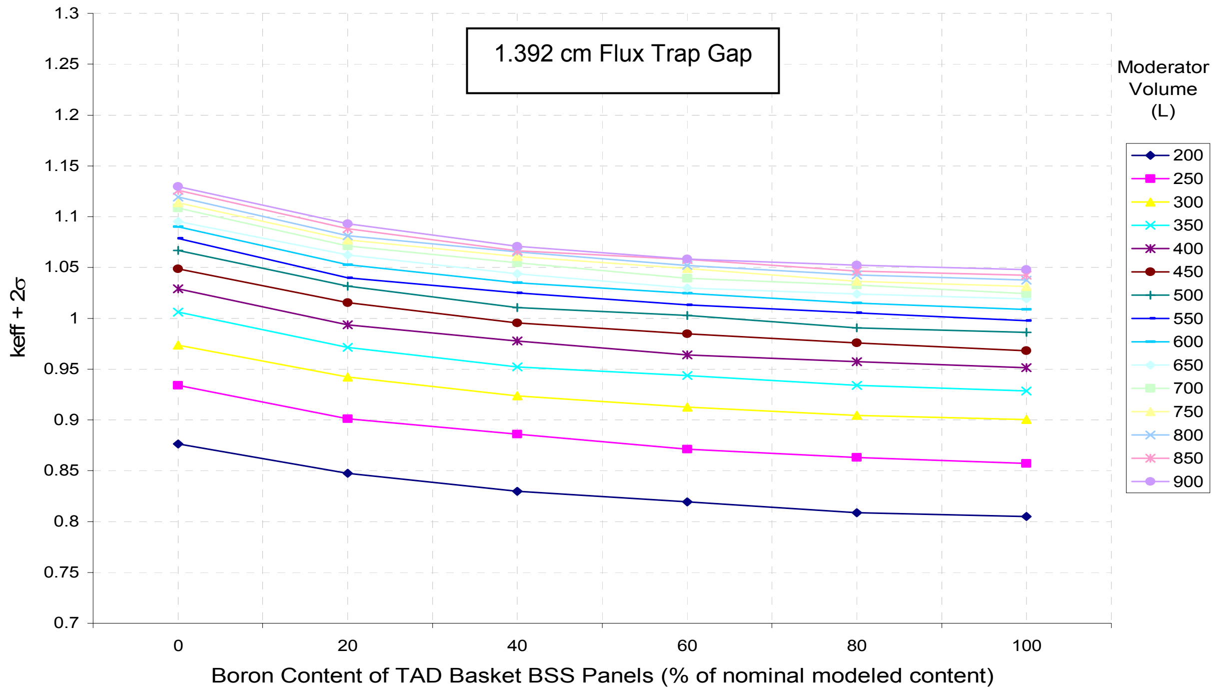
Source: Original

Figure 54. Variation of k_{eff} +2σ for Single Partially Damaged (0.928 Cm Flux Trap Gap) and Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



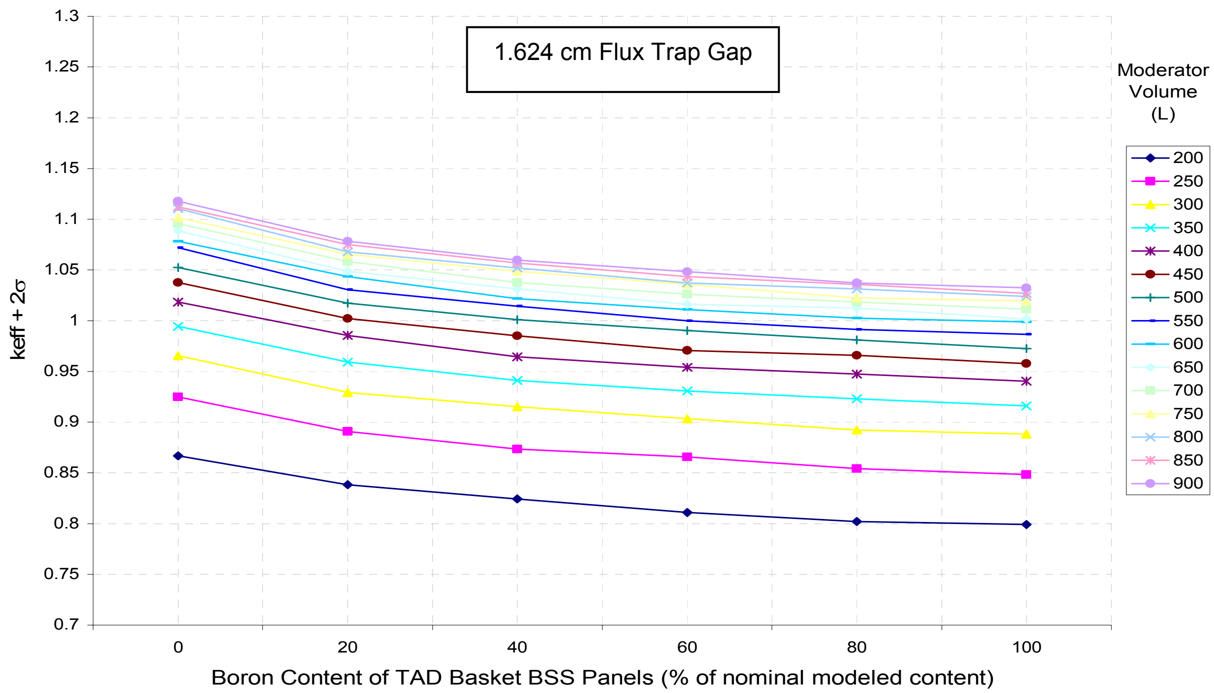
Source: Original

Figure 55. Variation of k_{eff} +2σ for Single Partially Damaged (1.160 Cm Flux Trap Gap) and Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



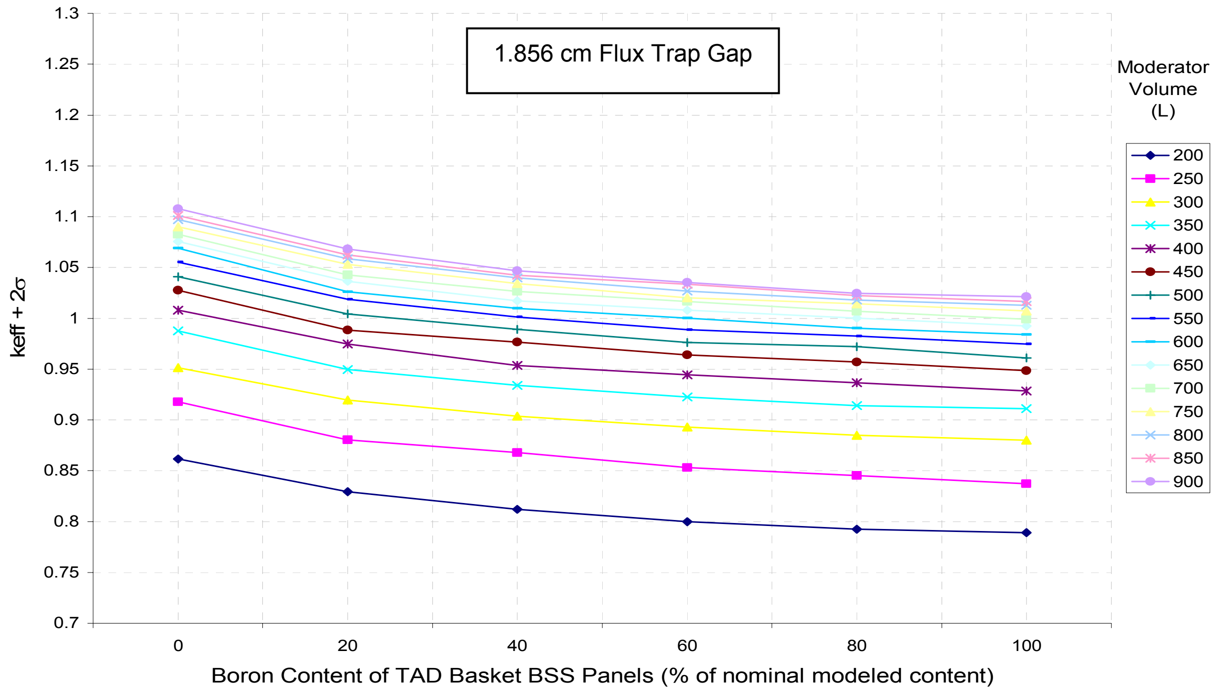
Source: Original

Figure 56. Variation of k_{eff} +2σ for Single Partially Damaged (1.392 Cm Flux Trap Gap) and Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



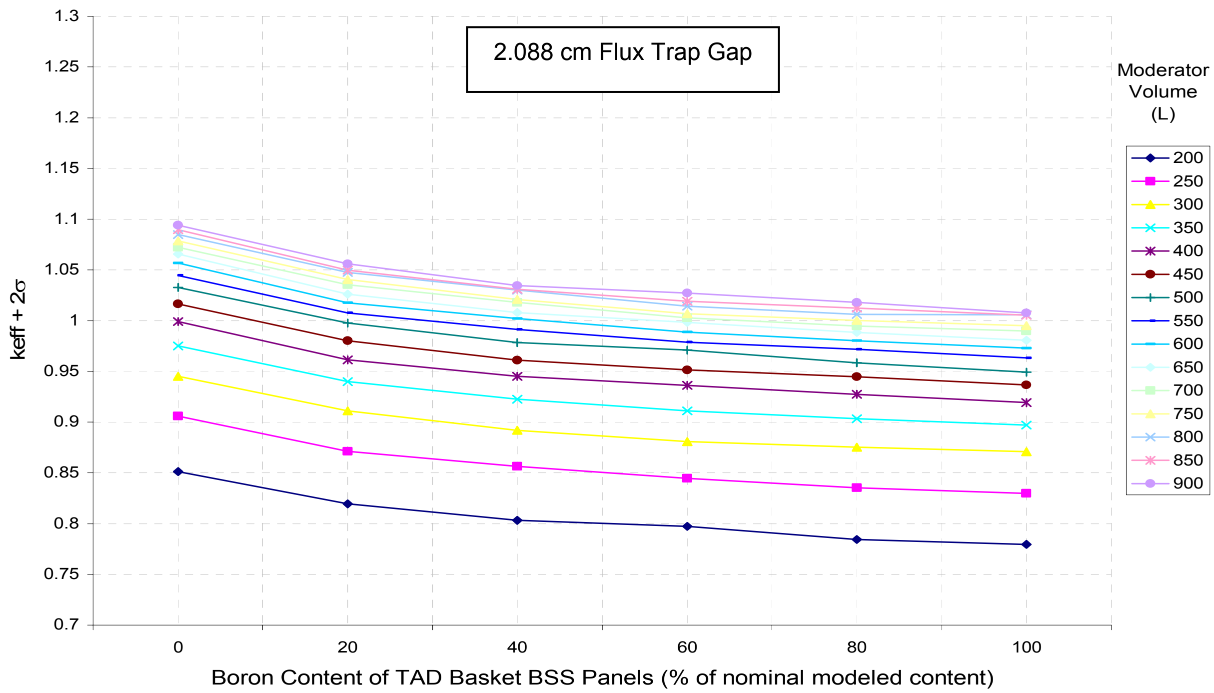
Source: Original

Figure 57. Variation of k_{eff} +2σ for Single Partially Damaged (1.624 Cm Flux Trap Gap) and Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



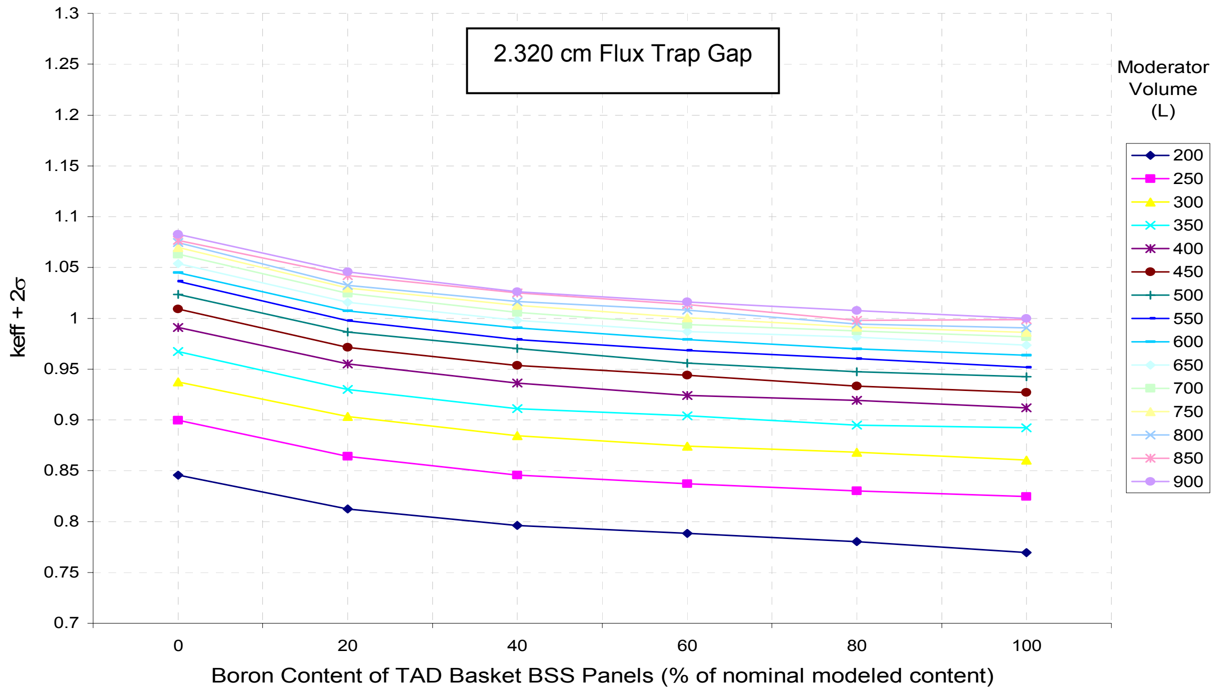
Source: Original

Figure 58. Variation of k_{eff} +2σ for Single Partially Damaged (1.856 Cm Flux Trap Gap) and Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



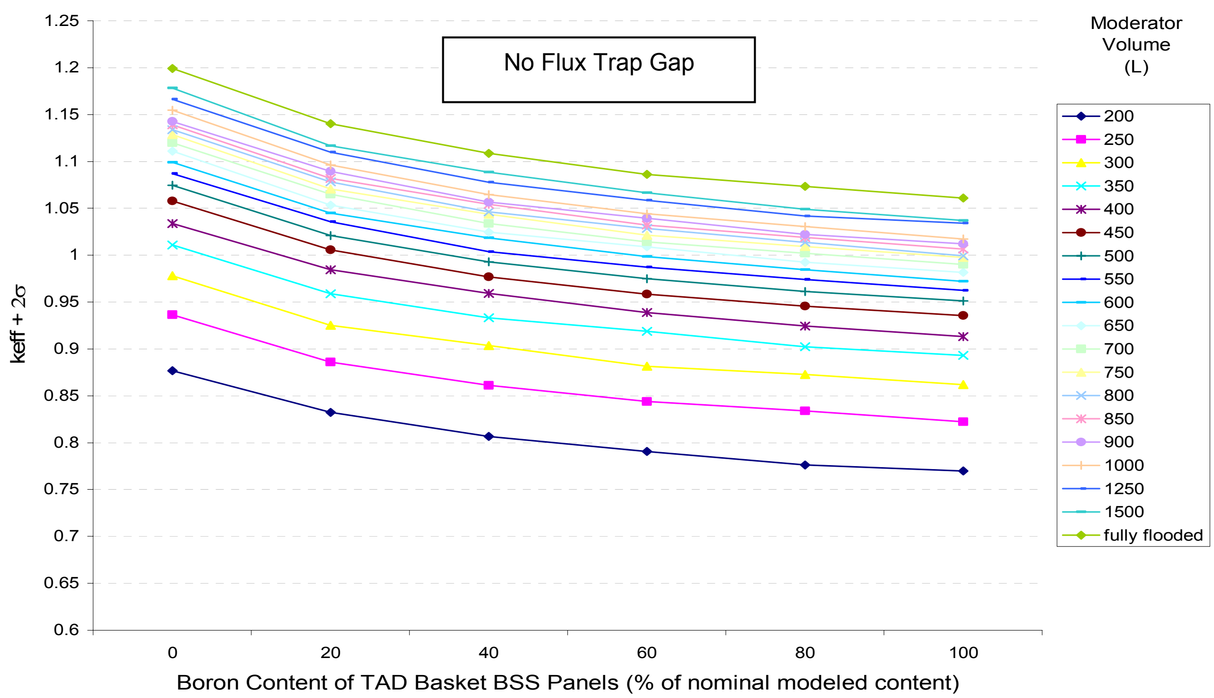
Source: Original

Figure 59. Variation of k_{eff} +2σ for Single Partially Damaged (2.088 Cm Flux Trap Gap) and Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



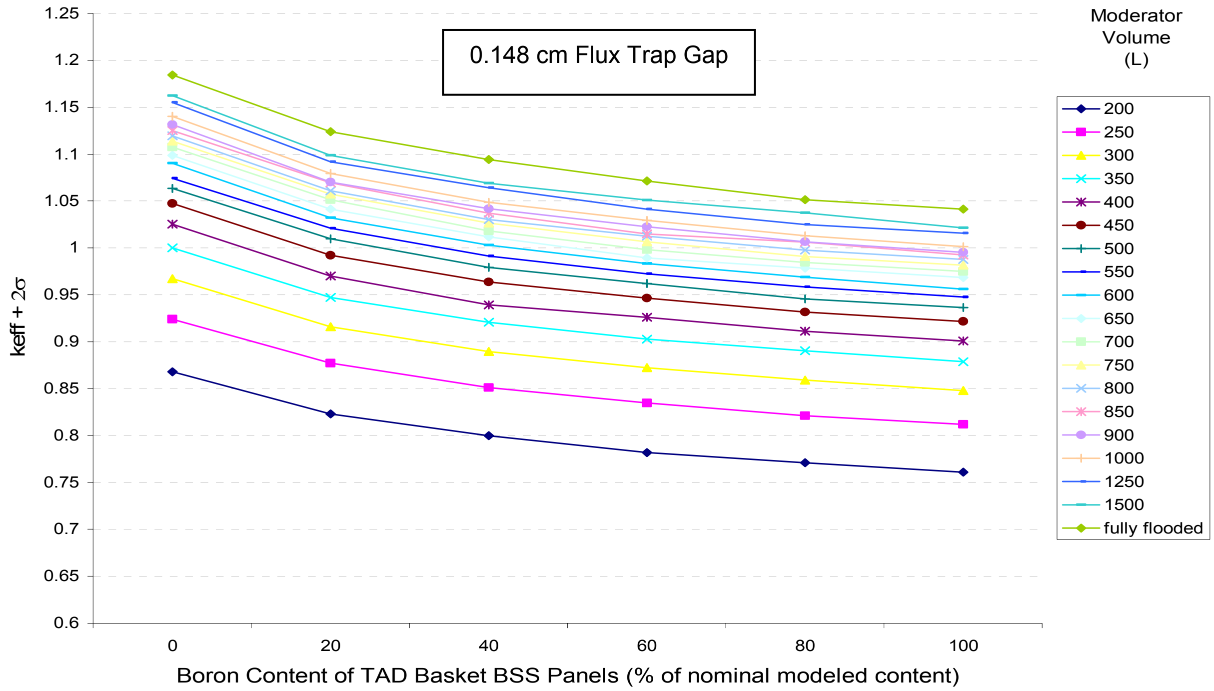
Source: Original

Figure 60. Variation of k_{eff} +2σ for Single Partially Damaged (2.320 Cm Flux Trap Gap) and Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



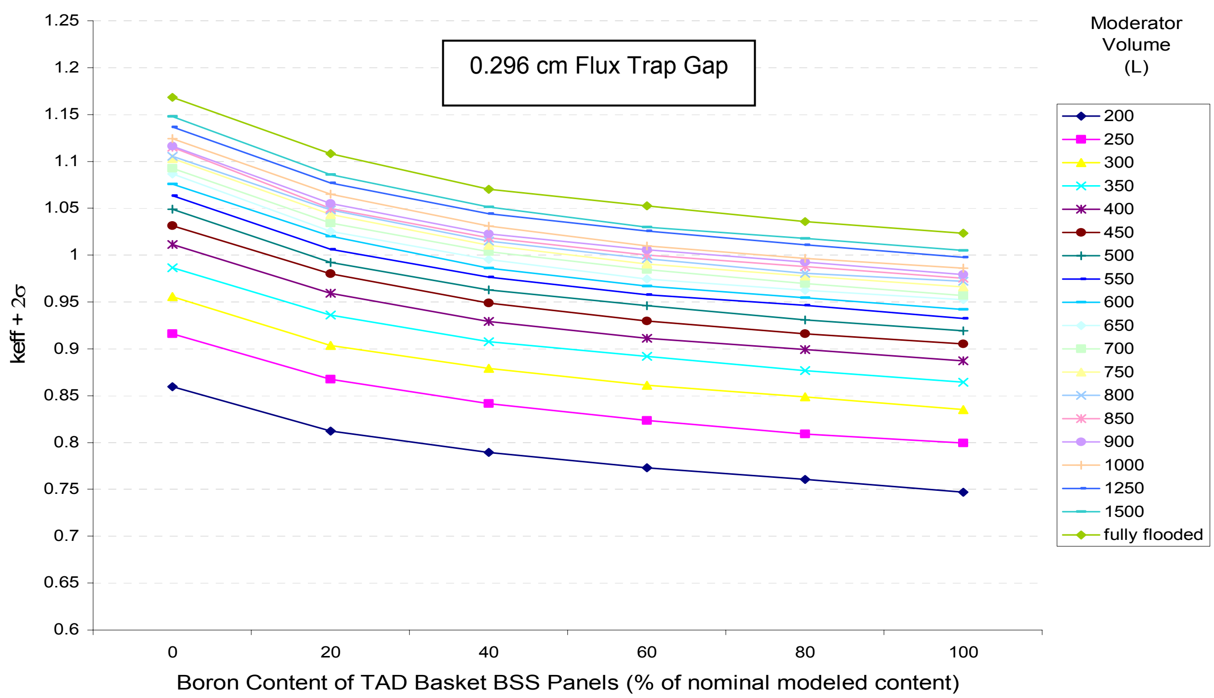
Source: Original

Figure 61. Variation of k_{eff} +2σ for Single Maximum Damaged (No Flux Trap Gap) and Partially Flooded BWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



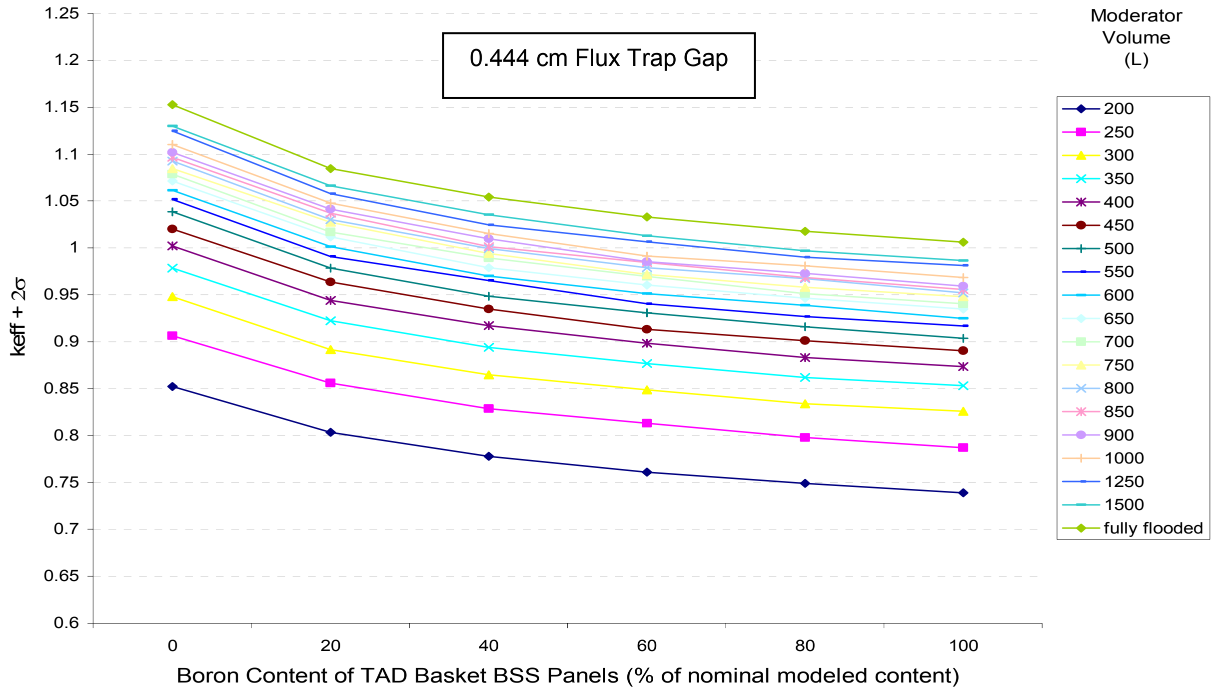
Source: Original

Figure 62. Variation of k_{eff} +2σ for Single Partially Damaged (0.148 Cm Flux Trap Gap) and Partially Flooded BWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



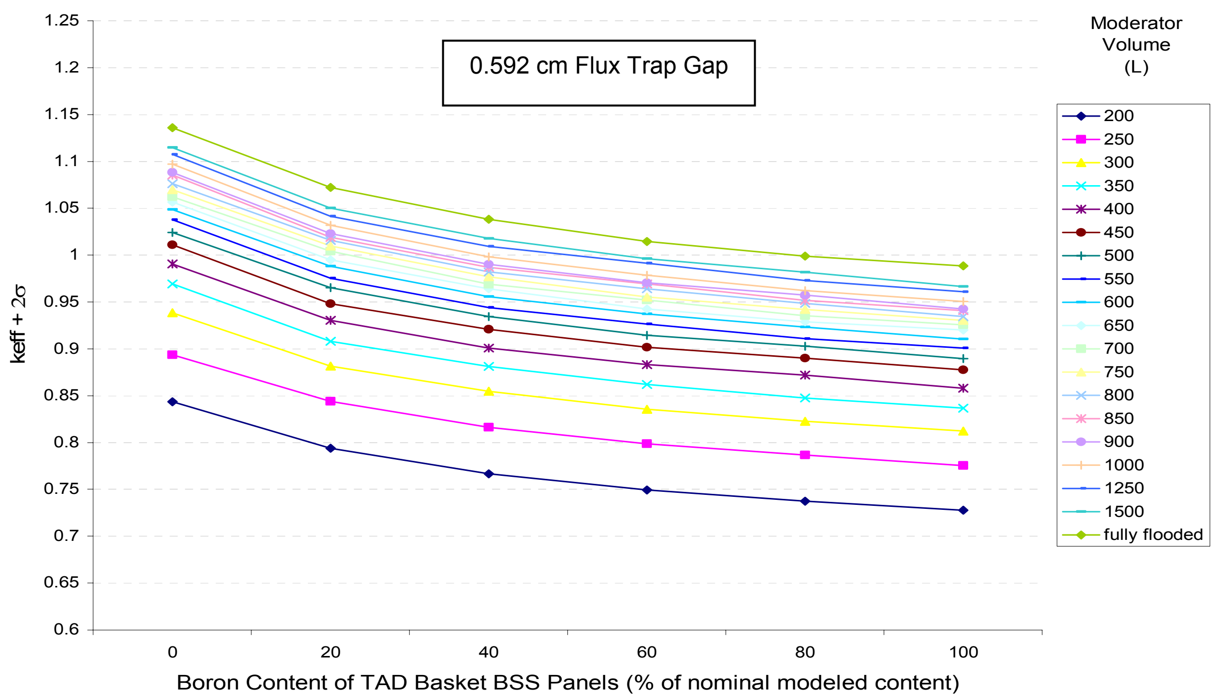
Source: Original

Figure 63. Variation of k_{eff} +2σ for Single Partially Damaged (0.296 Cm Flux Trap Gap) and Partially Flooded BWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



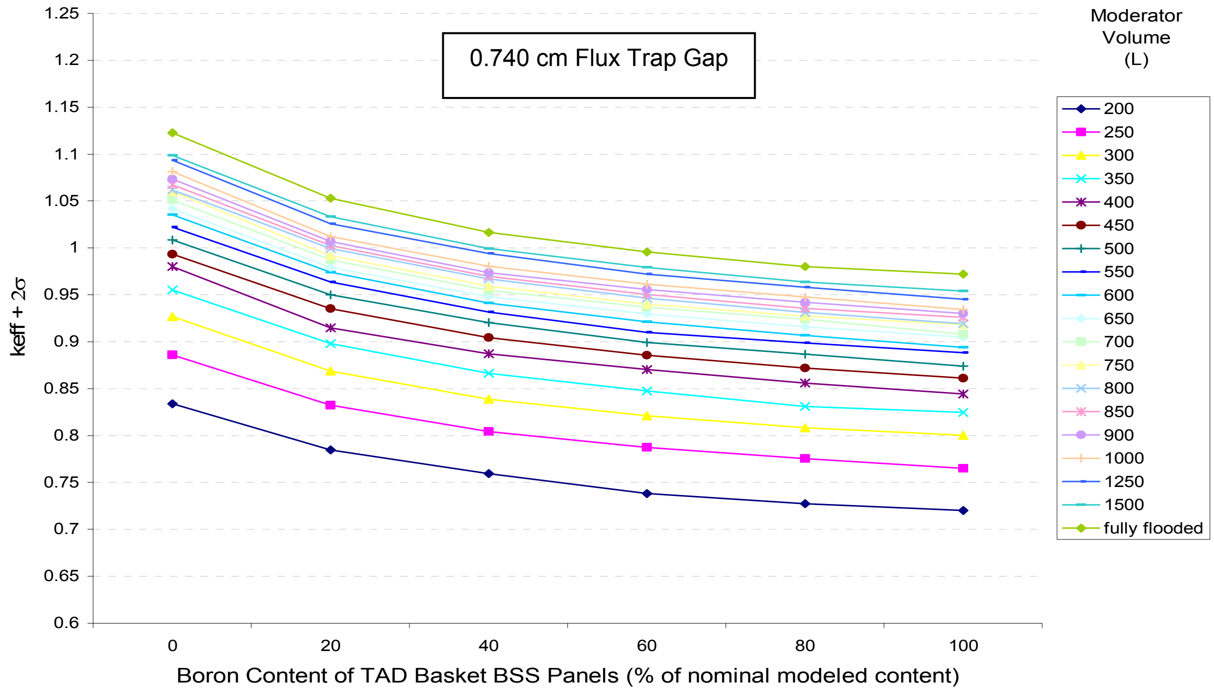
Source: Original

Figure 64. Variation of k_{eff} +2σ for Single Partially Damaged (0.444 Cm Flux Trap Gap) and Partially Flooded BWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



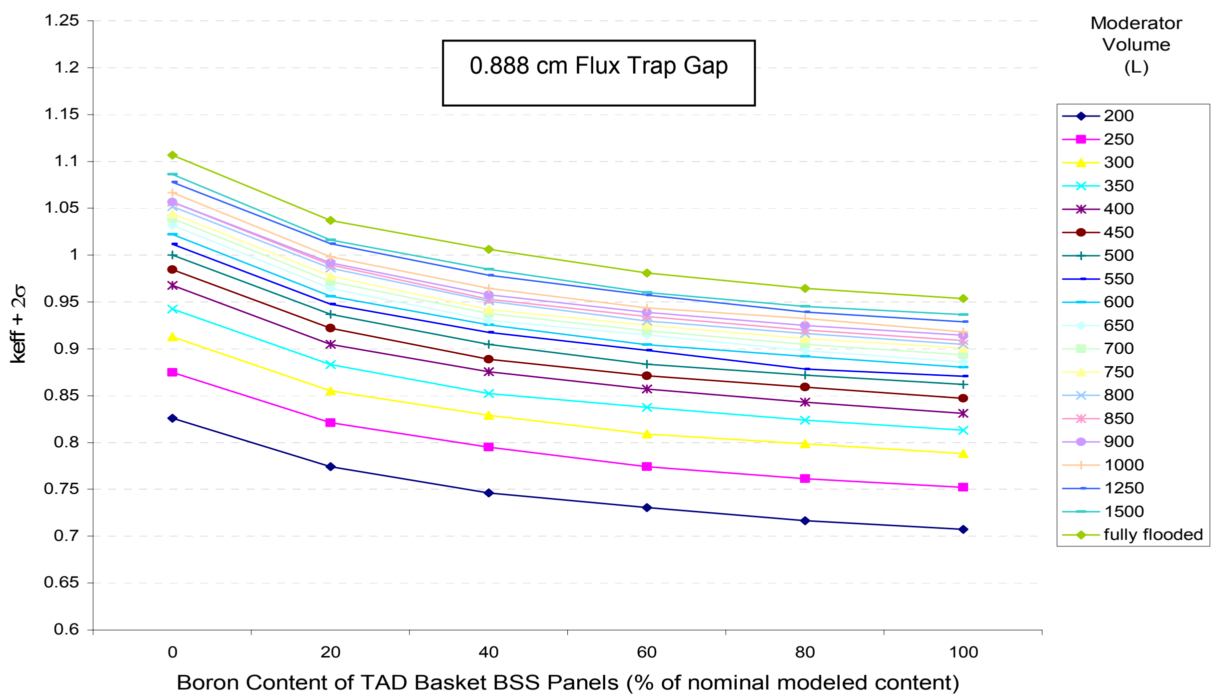
Source: Original

Figure 65. Variation of k_{eff} +2σ for Single Partially Damaged (0.592 Cm Flux Trap Gap) and Partially Flooded BWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



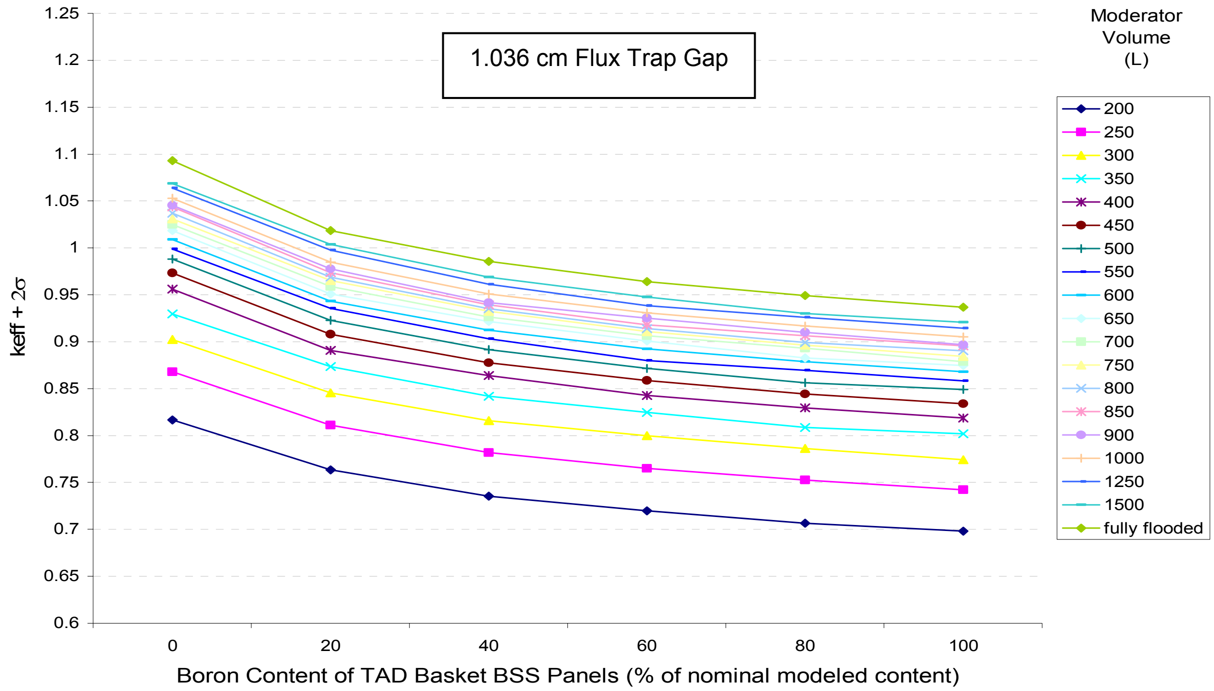
Source: Original

Figure 66. Variation of k_{eff} +2σ for Single Partially Damaged (0.740 Cm Flux Trap Gap) and Partially Flooded BWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



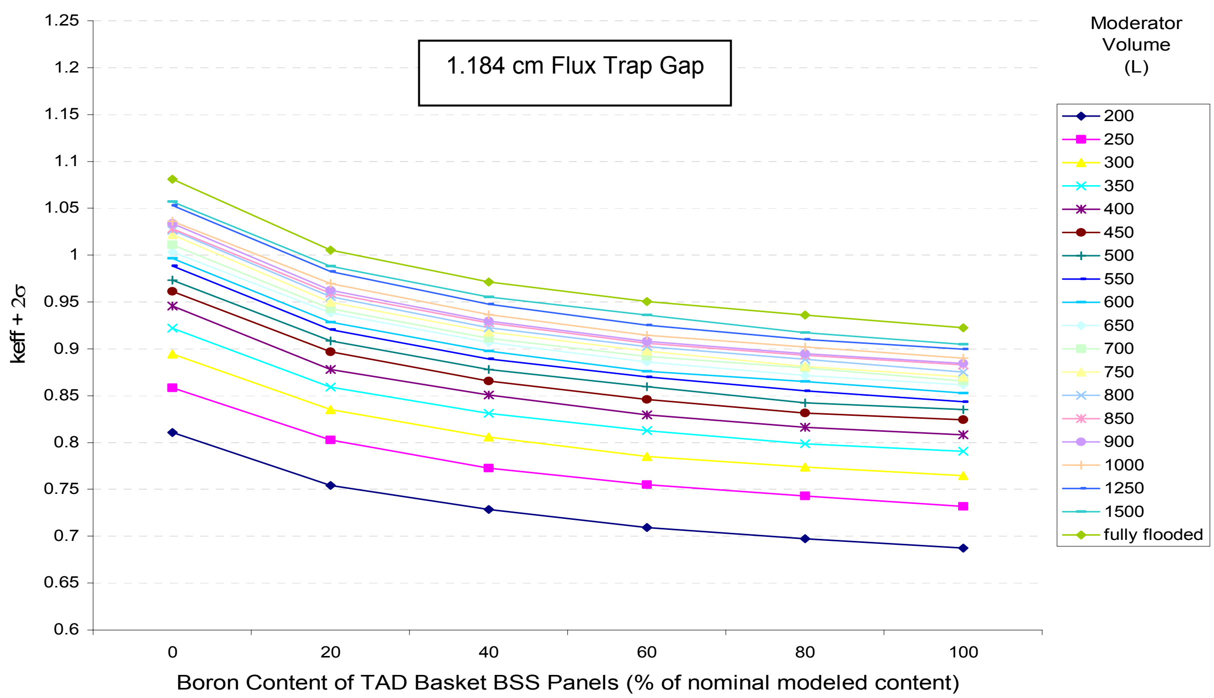
Source: Original

Figure 67. Variation of k_{eff} +2σ for Single Partially Damaged (0.888 Cm Flux Trap Gap) and Partially Flooded BWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



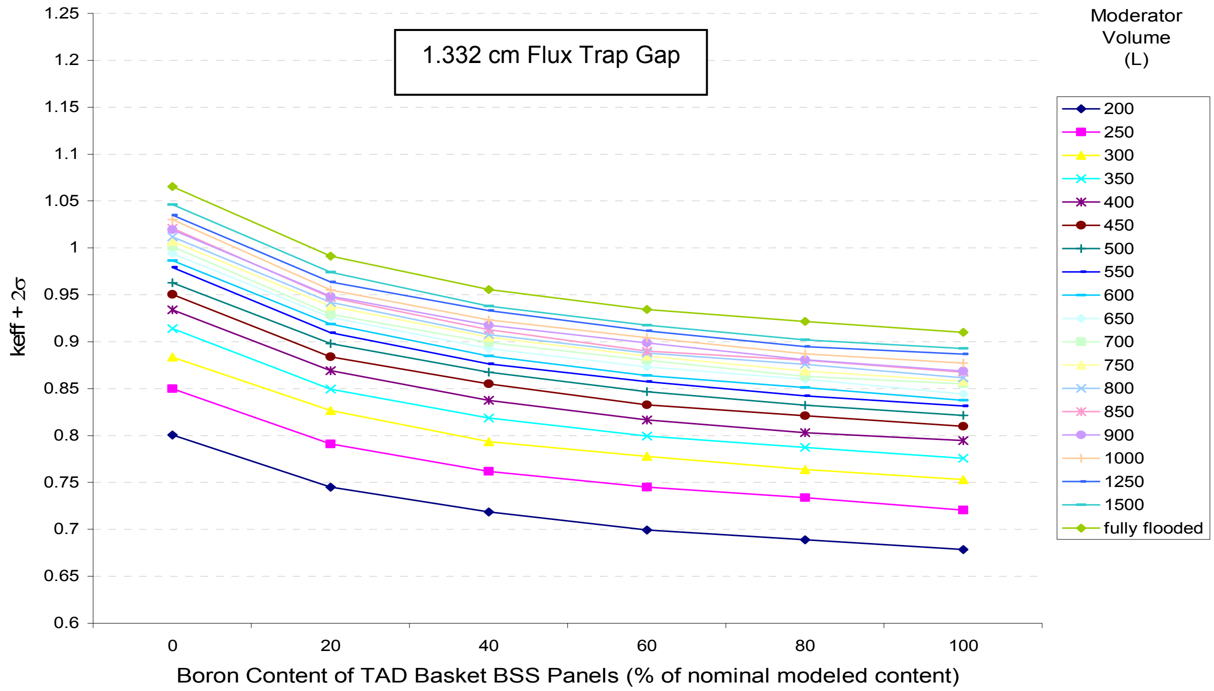
Source: Original

Figure 68. Variation of k_{eff} +2σ for Single Partially Damaged (1.036 Cm Flux Trap Gap) and Partially Flooded BWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



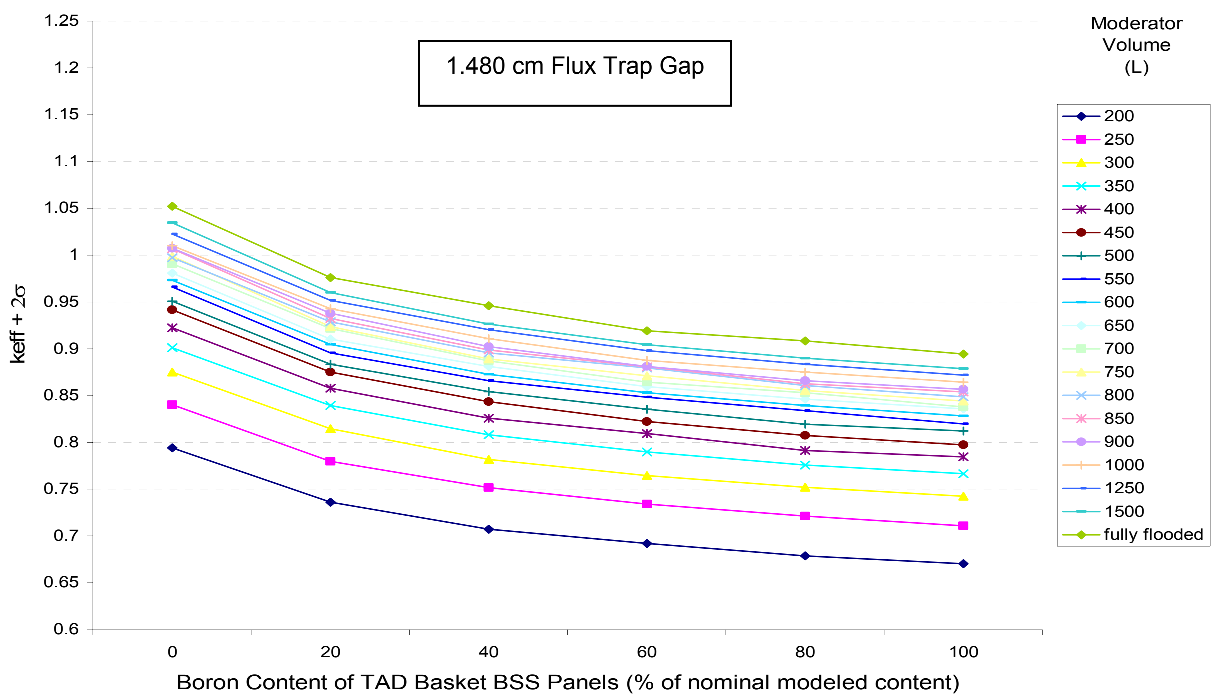
Source: Original

Figure 69. Variation of k_{eff} +2σ for Single Partially Damaged (1.184 Cm Flux Trap Gap) and Partially Flooded BWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



Source: Original

Figure 70. Variation of k_{eff} +2σ for Single Partially Damaged (1.332 Cm Flux Trap Gap) and Partially Flooded BWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)



Source: Original

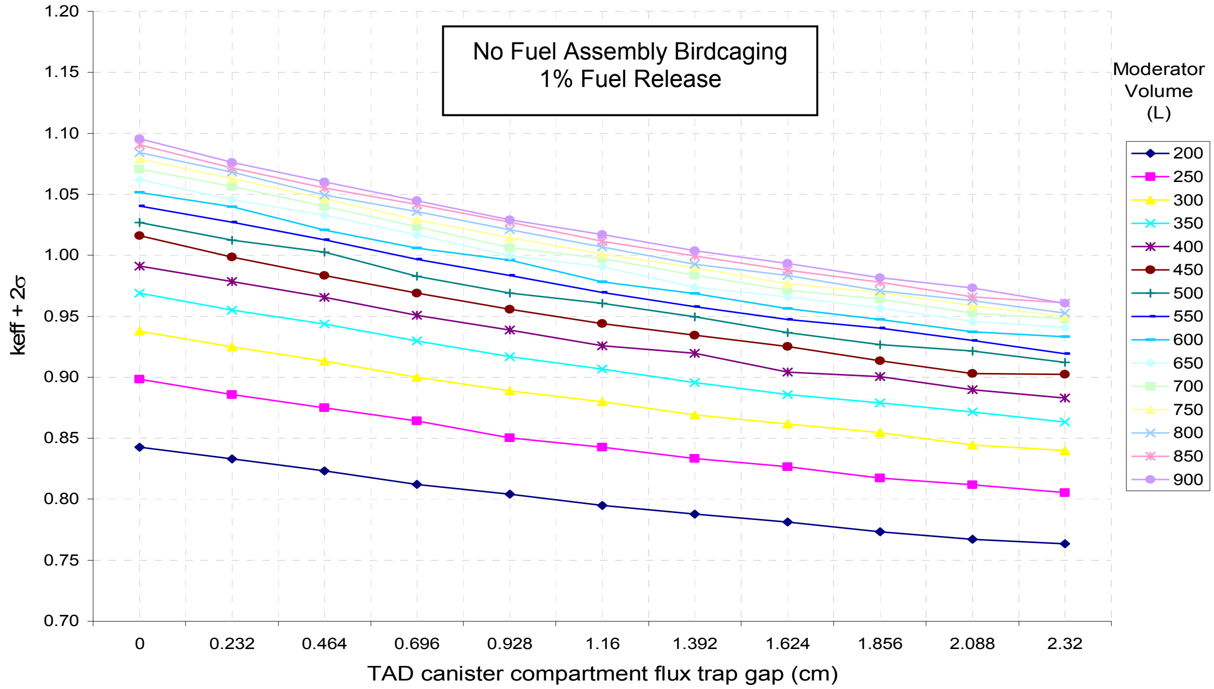
Figure 71. Variation of k_{eff} +2σ for Single Partially Damaged (1.480 Cm Flux Trap Gap) and Partially Flooded BWR TAD Canister (with 30cm Thick Steel Reflector) Containing Intact Representative CSNF with Maximum Fuel Deformation (I.E. 100% Birdcaging)

ATTACHMENT III: POTENTIAL OFF-NORMAL SCENARIO 3 RESULTS

Potential Off-Normal Scenario 3 considers:

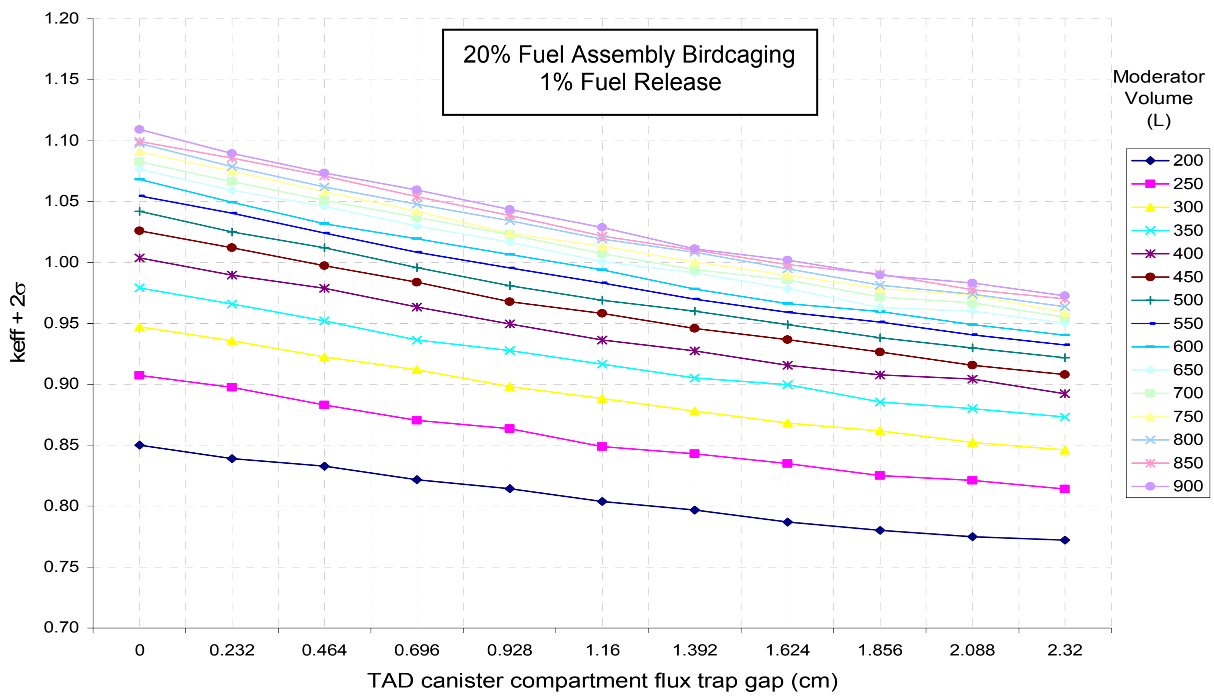
- Progressive canister basket deformation (i.e. flux trap gap collapse),
- Progressive fuel assembly deformation (i.e. birdcaging),
- Progressive fuel release (i.e. fuel break-up), and
- Progressive flooding of the TAD canister with water.

The results of the potential off-normal scenario 3 calculations are presented in Figure 72 though Figure 77 of this attachment for the 1% fuel release fraction scenario, Figure 78 though Figure 83 of this attachment for the 3% fuel release fraction scenario, and Figure 84 though Figure 89 of this attachment for the 5% fuel release fraction scenario. An interpolation of the presented results, to establish the maximum safe moderator volume as a function of the basket/fuel assembly damage condition and fuel release fraction considered, is performed in the body of this document (Figure 34).



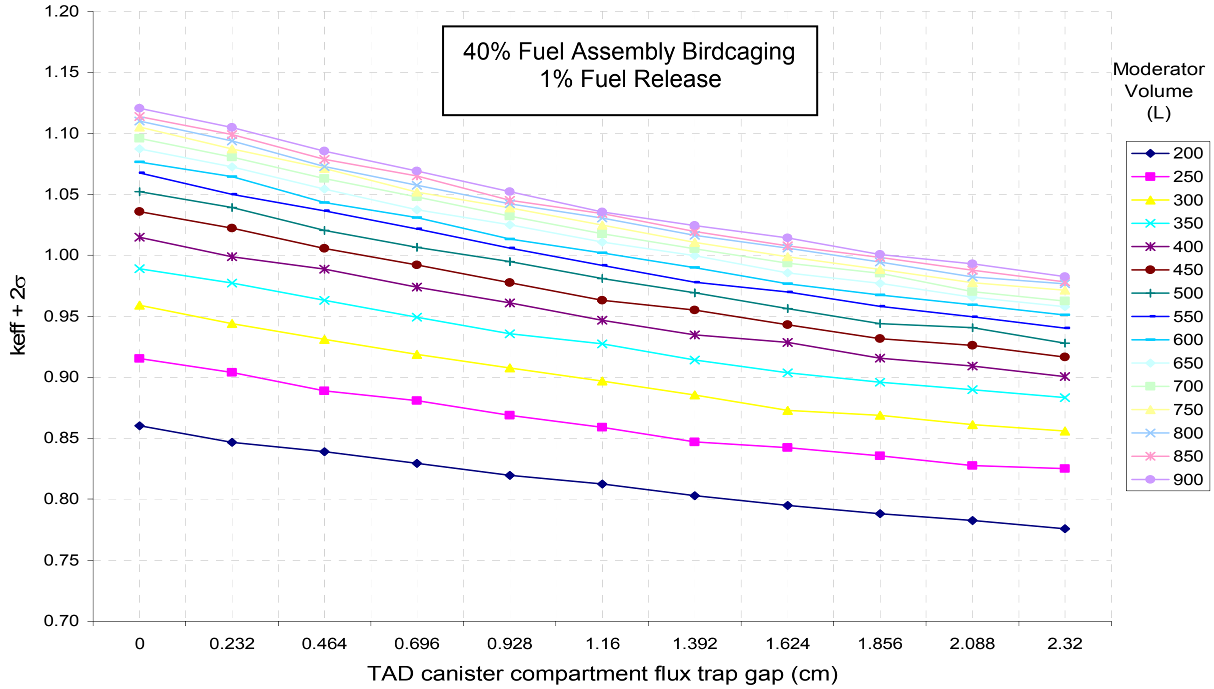
Source: Original

Figure 72. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Representative CSNF with No Fuel Deformation (0% Birdcaging) and 1% Fuel Release



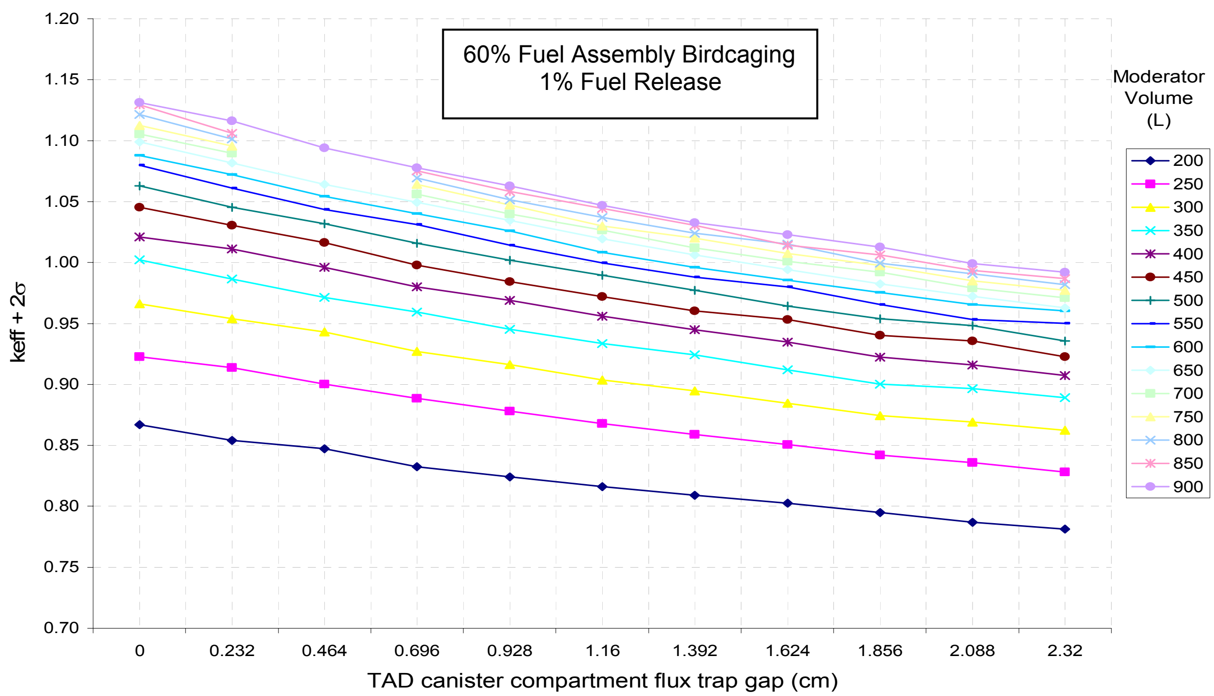
Source: Original

Figure 73. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Representative CSNF with Partial Fuel Deformation (20% Birdcaging) and 1% Fuel Release



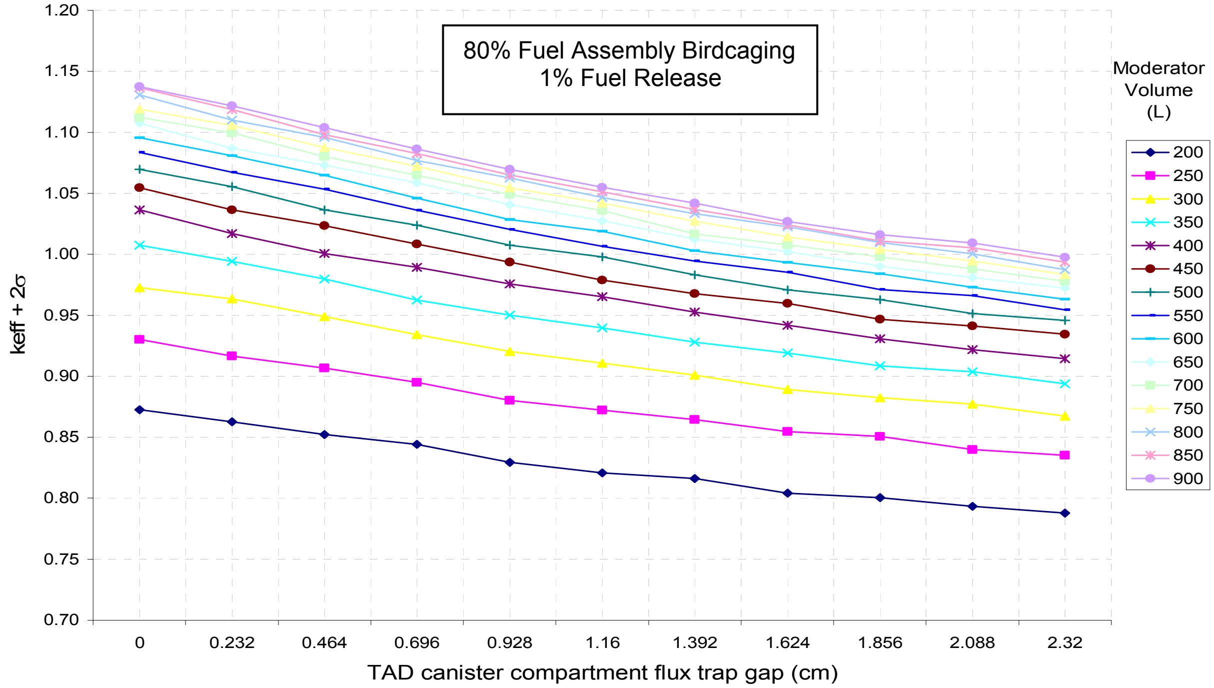
Source: Original

Figure 74. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Representative CSNF with Partial Fuel Deformation (40% Birdcaging) and 1% Fuel Release



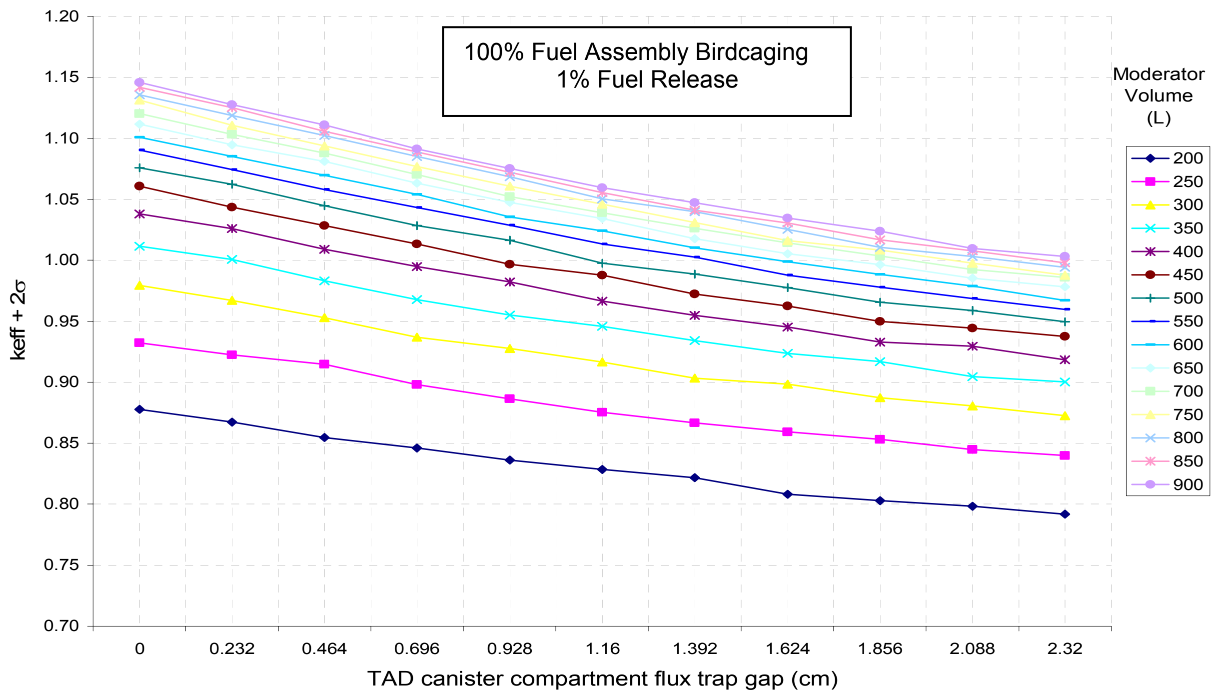
Source: Original

Figure 75. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Representative CSNF with Partial Fuel Deformation (60% Birdcaging) and 1% Fuel Release



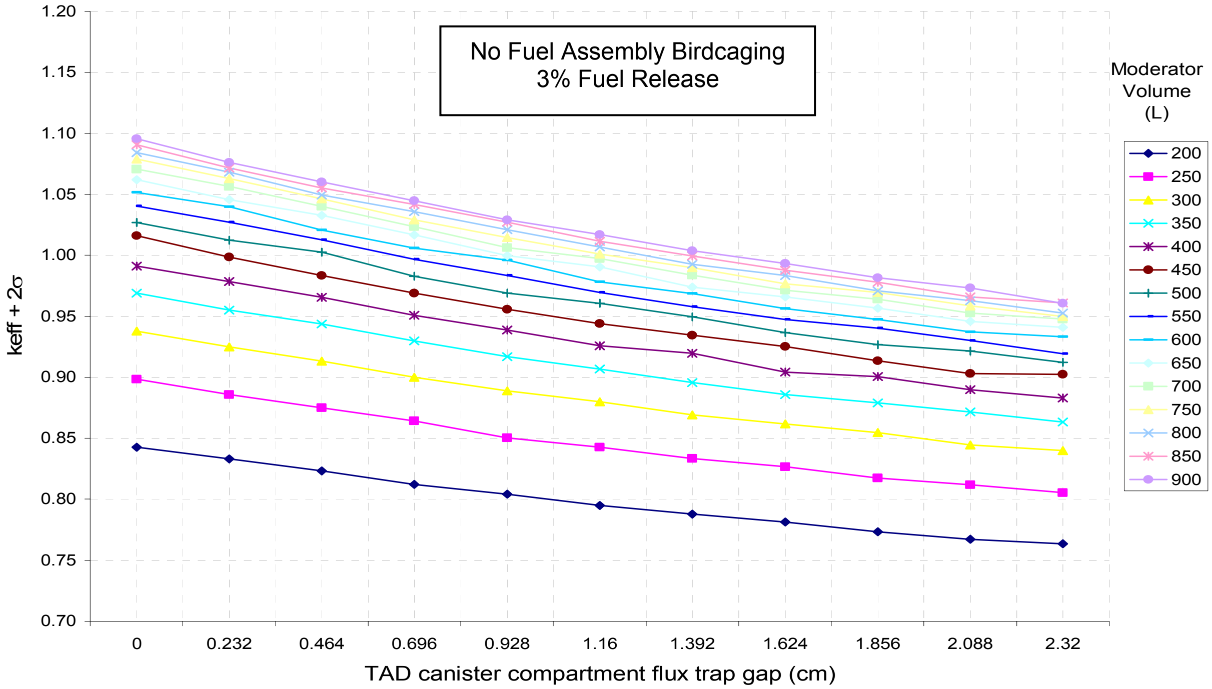
Source: Original

Figure 76. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Representative CSNF with Partial Fuel Deformation (80% Birdcaging) and 1% Fuel Release



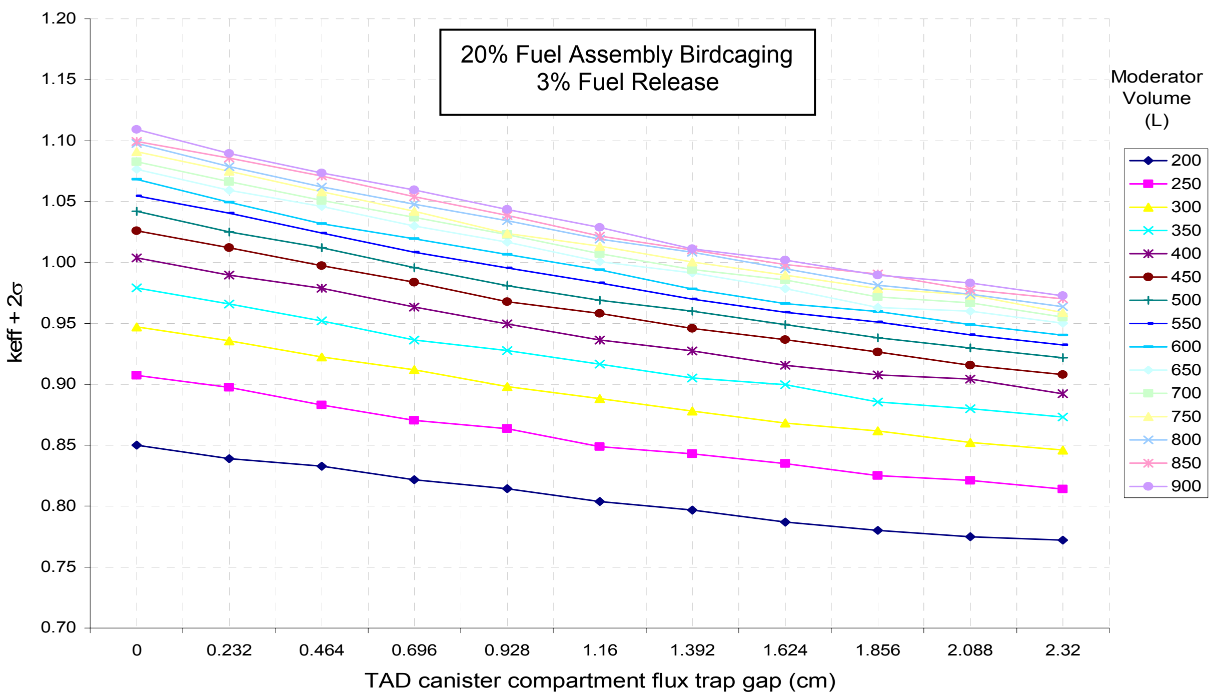
Source: Original

Figure 77. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Representative CSNF with Maximum Fuel Deformation (100% Birdcaging) and 1% Fuel Release



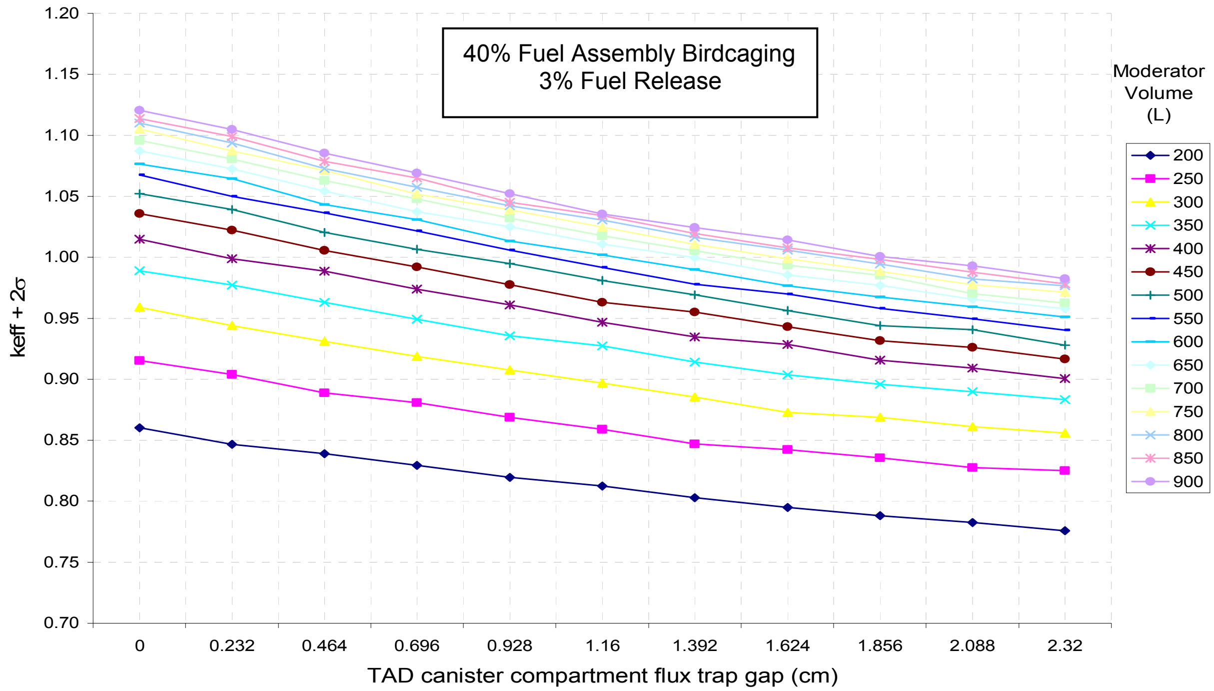
Source: Original

Figure 78. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Representative CSNF with No Fuel Deformation (0% Birdcaging) and 3% Fuel Release



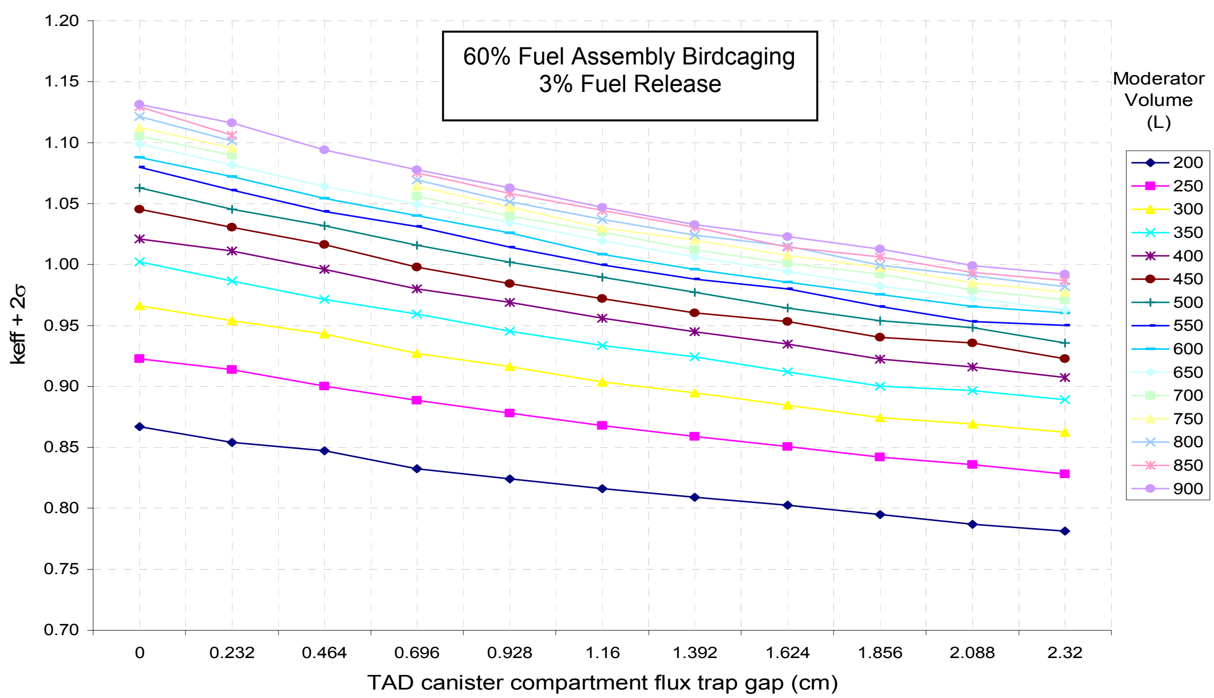
Source: Original

Figure 79. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Representative CSNF with Partial Fuel Deformation (20% Birdcaging) and 3% Fuel Release



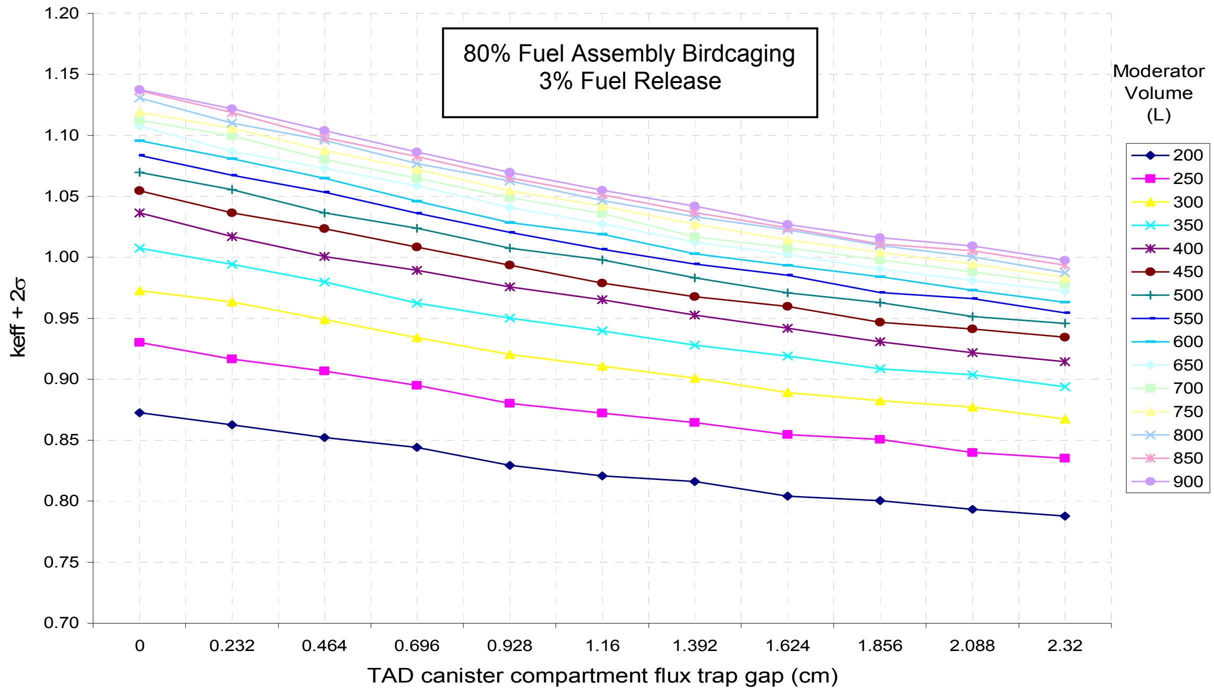
Source: Original

Figure 80. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Representative CSNF with Partial Fuel Deformation (40% Birdcaging) and 3% Fuel Release



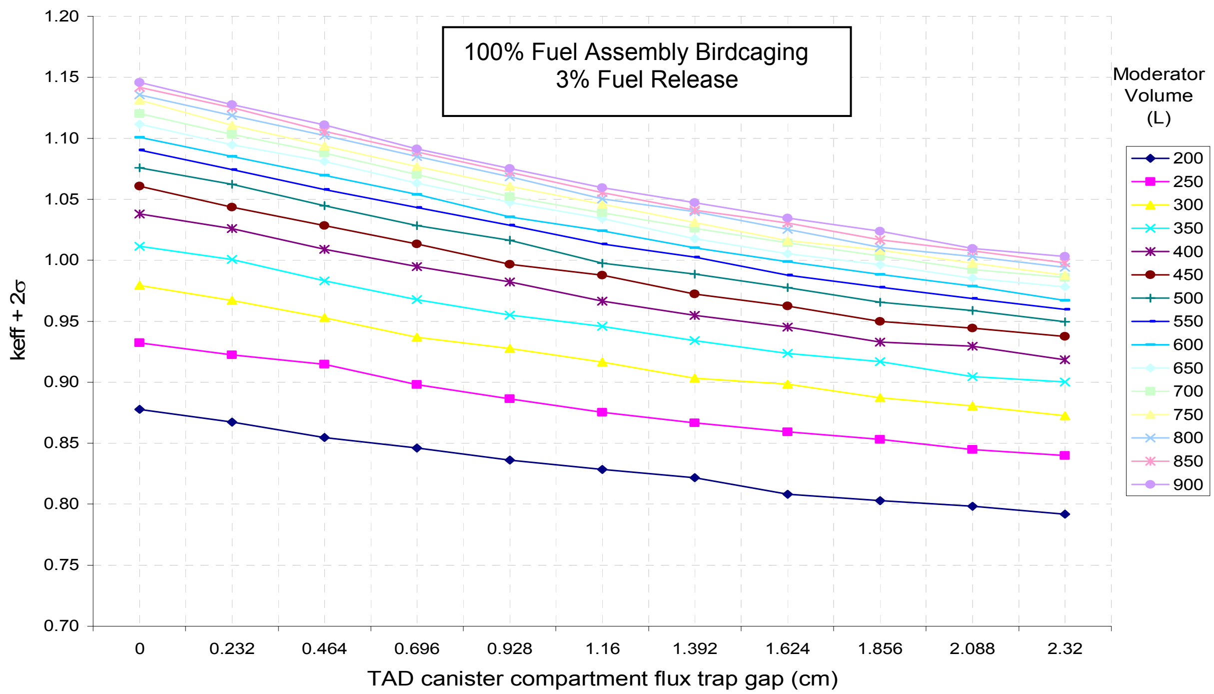
Source: Original

Figure 81. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Representative CSNF with Partial Fuel Deformation (60% Birdcaging) and 3% Fuel Release



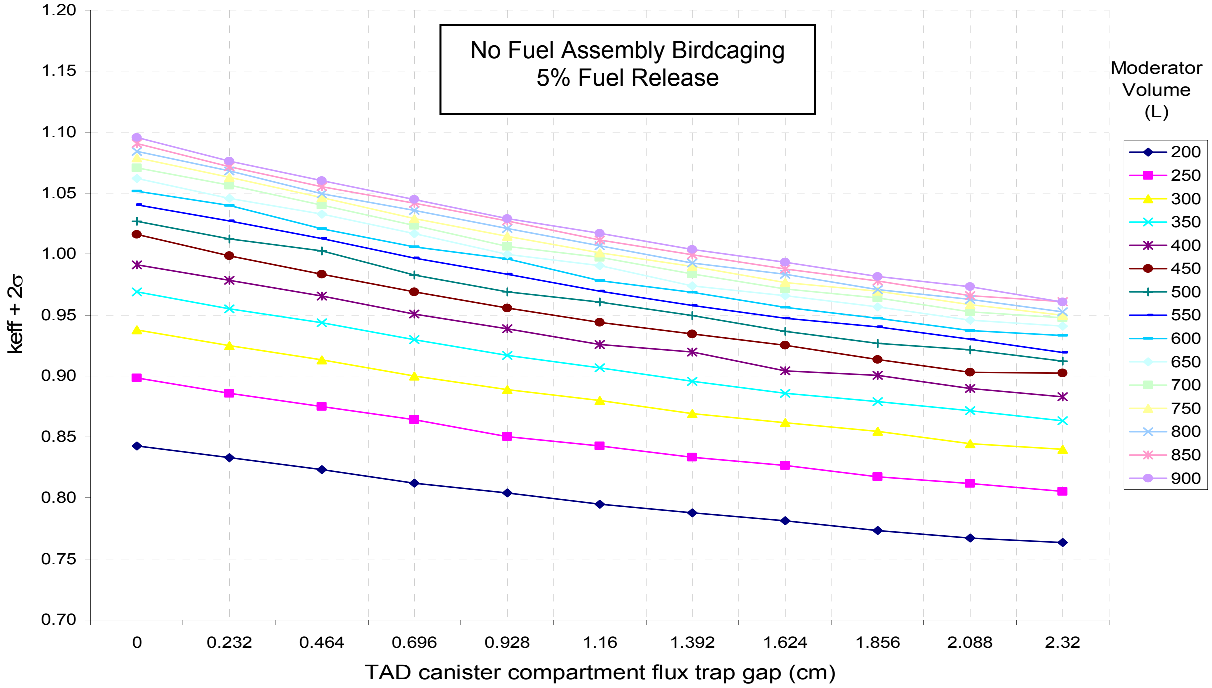
Source: Original

Figure 82. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Representative CSNF with Partial Fuel Deformation (80% Birdcaging) and 3% Fuel Release



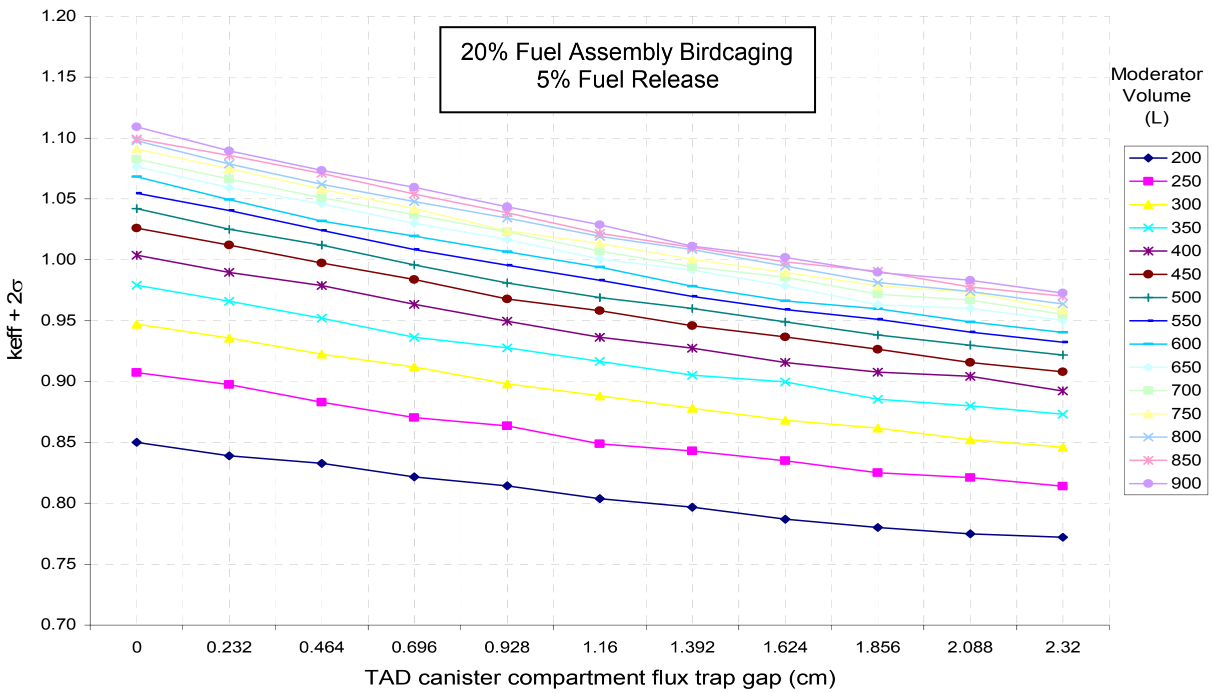
Source: Original

Figure 83. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Representative CSNF with Maximum Fuel Deformation (100% Birdcaging) and 3% Fuel Release



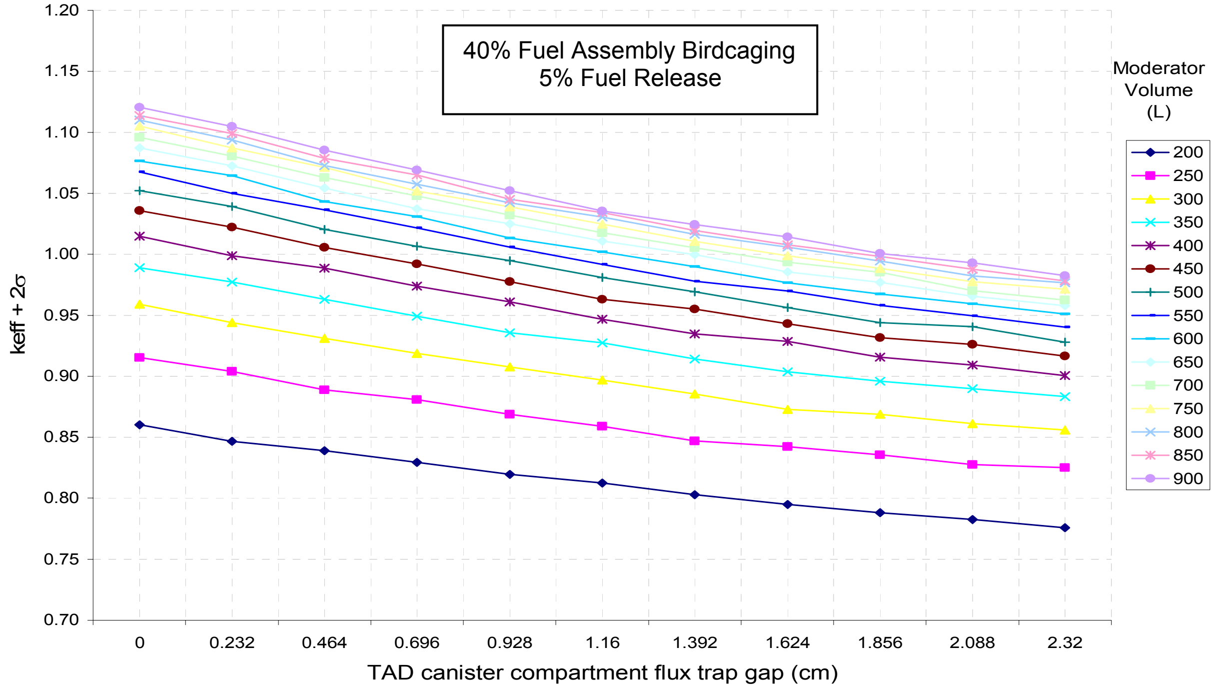
Source: Original

Figure 84. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Representative CSNF with No Fuel Deformation (0% Birdcaging) and 5% Fuel Release



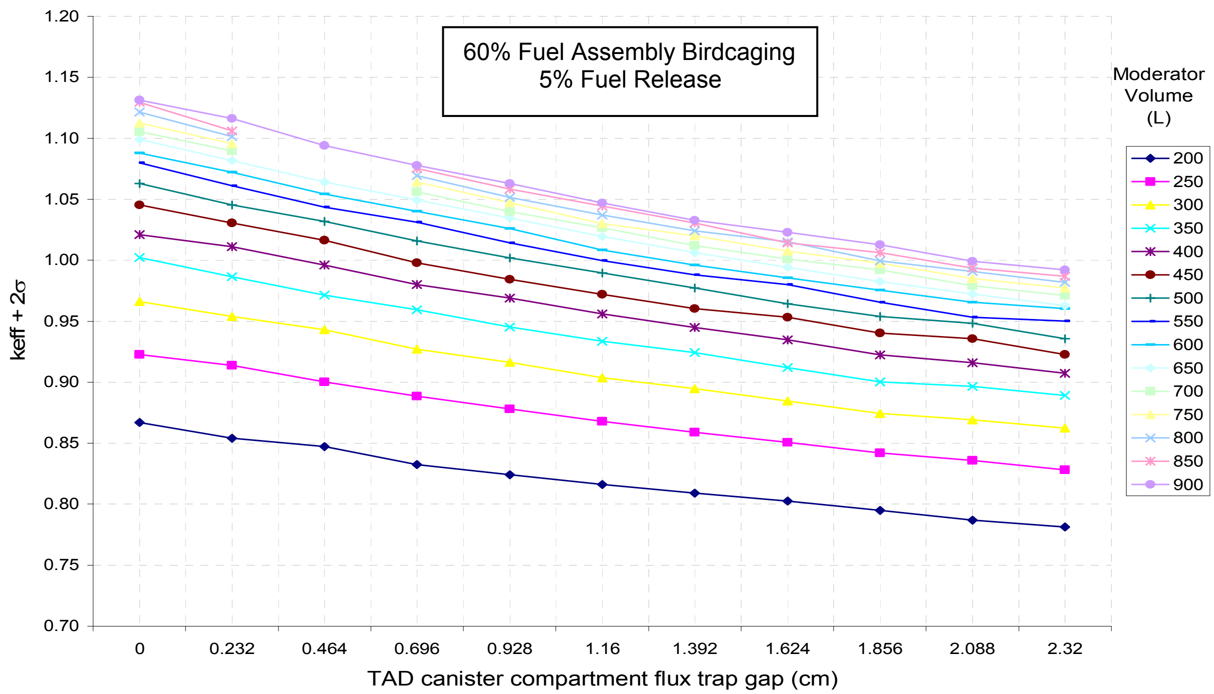
Source: Original

Figure 85. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Representative CSNF with Partial Fuel Deformation (20% Birdcaging) and 5% Fuel Release



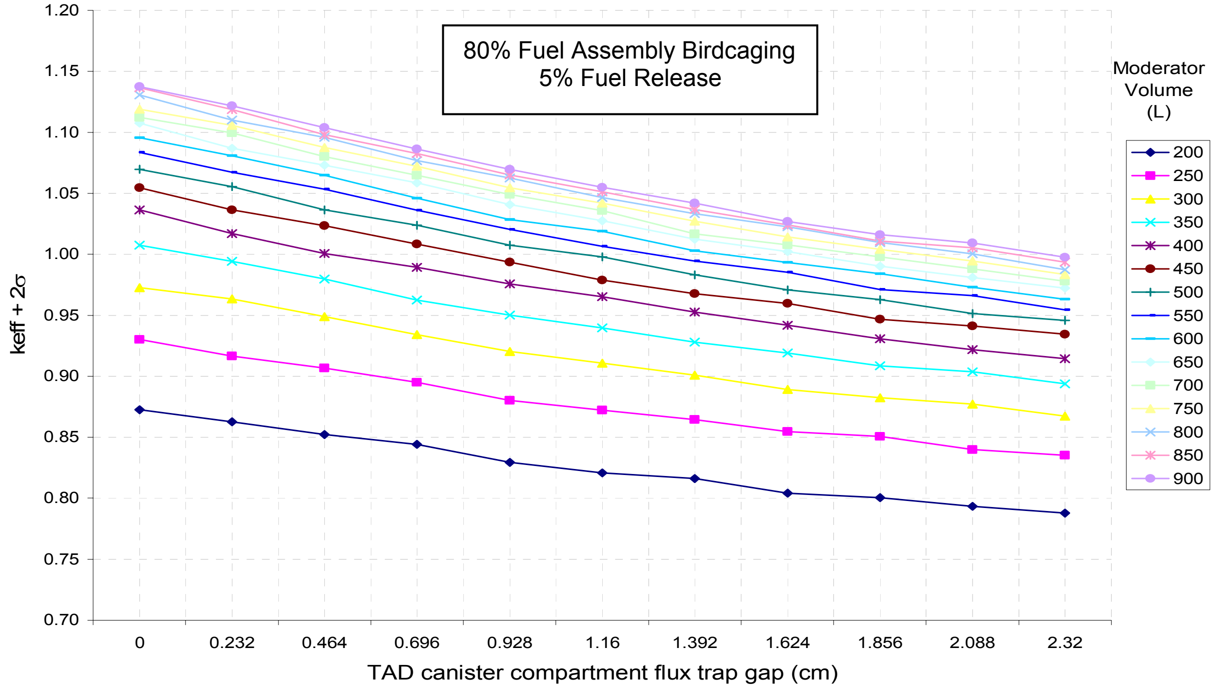
Source: Original

Figure 86. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Representative CSNF with Partial Fuel Deformation (40% Birdcaging) and 5% Fuel Release



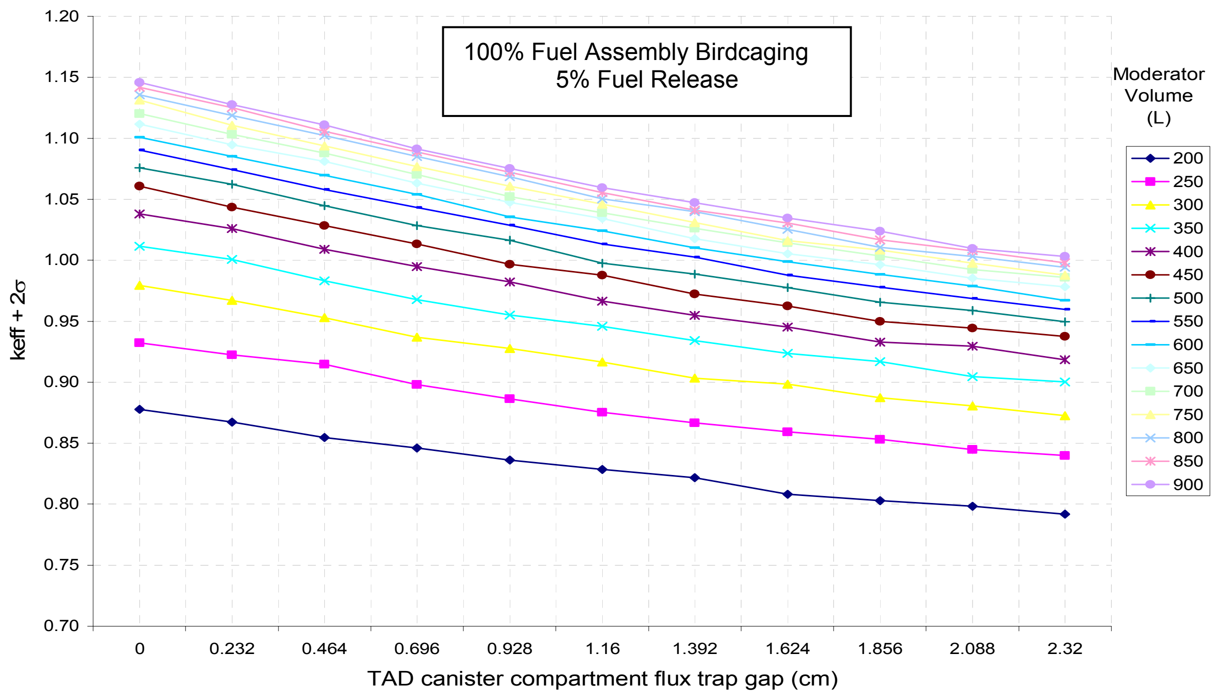
Source: Original

Figure 87. Variation of k_{eff} +2σ for a Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Representative CSNF with Partial Fuel Deformation (60% Birdcaging) and 5% Fuel Release



Source: Original

Figure 88. Variation of k_{eff} +2σ for Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Representative CSNF with Partial Fuel Deformation (80% Birdcaging) and 5% Fuel Release



Source: Original

Figure 89. Variation of k_{eff} +2σ for a Single Damaged, Partially Flooded PWR TAD Canister (with 30cm Thick Steel Reflector) Containing Representative CSNF with Maximum Fuel Deformation (100% Birdcaging) and 5% Fuel Release

ATTACHMENT IV: ATTACHMENT DIGITAL VIDEO DISC LISTING

This attachment contains a listing and description of the files contained on the attachment Digital Video Disc (DVD) of this report (Attachment V). The zip archives were created using WINZIP 9.0. The attributes of all files contained on the DVD are as follows:

Filename	File Size (bytes)	File Date	File Time	Description
tad_mcnp_inputs.zip	30,403,000	8/24/07	15:48	Winzip file containing all MCNP input files relevant to this document
tad_mcnp_outputs.zip	3,135,938,000	8/24/07	16:03	Winzip file containing all MCNP output files relevant to this document
tad_canister_calculations.xls	5,960,000	8/28/07	10:32	Microsoft Excel workbook containing all data analysis (i.e. MCNP results processing) relevant to this document
aencf.txt	516,000	7/4/07	18:21	Text file containing MCNP results of the Average Energy of Neutrons Lost to Fission
bwr_calc1_results.txt	1,000	6/6/07	17:05	Text file containing MCNP k-eff results
bwr_calc2_results.txt	1,000	6/6/07	17:05	Text file containing MCNP k-eff results
bwr_calc3_results.txt	1,000	5/21/07	11:23	Text file containing MCNP k-eff results
bwr_calc4_results.txt	3,000	5/21/07	11:25	Text file containing MCNP k-eff results
bwr_calc5_results.txt	1,000	7/02/07	15:19	Text file containing MCNP k-eff results
bwr_calc6_results.txt	201,000	7/04/07	10:03	Text file containing MCNP k-eff results
bwr_calc7_results.txt	2,000	7/02/07	09:10	Text file containing MCNP k-eff results
bwr_calc9_results.txt	228,000	7/04/07	10:05	Text file containing MCNP k-eff results
bwr_calc10_results.txt	2,000	5/21/07	13:40	Text file containing MCNP k-eff results
bwr_calc11_results.txt	2,000	5/21/07	11:20	Text file containing MCNP k-eff results
pwr_calc1_results.txt	2,000	7/02/07	09:08	Text file containing MCNP k-eff results
pwr_calc2_results.txt	2,000	7/02/07	09:06	Text file containing MCNP k-eff results
pwr_calc3_results.txt	2,000	7/02/07	09:12	Text file containing MCNP k-eff results
pwr_calc4_results.txt	3,000	5/21/07	11:22	Text file containing MCNP k-eff results
pwr_calc5_results.txt	1,000	7/02/07	09:05	Text file containing MCNP k-eff results
pwr_calc6_results.txt	195,000	5/21/07	11:36	Text file containing MCNP k-eff results
pwr_calc7_results.txt	2,000	7/02/07	09:10	Text file containing MCNP k-eff results
pwr_calc8_results.txt	3,000	7/04/07	09:46	Text file containing MCNP k-eff results
pwr_calc9_results.txt	205,000	5/21/07	13:30	Text file containing MCNP k-eff results
pwr_calc10_results.txt	2,000	5/21/07	11:35	Text file containing MCNP k-eff results
pwr_calc11_results.txt	1,000	6/6/07	17:03	Text file containing MCNP k-eff results
pwr_calc13_results.txt	1,000	6/6/07	17:04	Text file containing MCNP k-eff results
pwr_calc14_results.txt	568,000	7/04/07	11:52	Text file containing MCNP k-eff results
k_{eff} _all_calcs.txt	1,364,000	7/05/07	13:38	Text file containing MCNP k-eff results
k_{eff} _all_bwr_tad_calcs.txt	434,000	7/05/07	13:45	Text file containing MCNP k-eff results
k_{eff} _all_pwr_tad_calcs.txt	931,000	7/05/07	13:44	Text file containing MCNP k-eff results

There are 7426 total files contained in the zip archive file *tad_mcnp_inputs.zip,* and 7426 total files contained in the zip archive file *tad_mcnp_outputs.zip*. Files suffixed "_in" are input files, whereas files suffixed "_ino" denote output files. Including 1 Microsoft Excel workbook and 27 text files, the DVD contains a total of 14880 files.

BSC

Calculation/Analysis Change Notice

Complete only applicable items.

1. QA:QA
2. Page 1 of 2

3. Document Identifier: 000-00C-MGR0-03600-000	4. Rev.: 00A	5. CACN: 001
6. Title: Nuclear Criticality Calculations for Canister-Based Facilities - Commercial SNF		
7. Reason for Change: Typographical errors were noted subsequent to document issue. These errors are identified in CR 11857.		
8. Supersedes Change Notice: ☐ Yes If, Yes, CACN No.: ______ ☒ No		

9. Change Impact:

Inputs Changed:	☐ Yes	☒ No	Results Impacted:	☐ Yes	☒ No
Assumptions Changed:	☐ Yes	☒ No	Design Impacted:	☐ Yes	☒ No

10. Description of Change:

The typographical errors noted subsequent to document issue are listed in a table on page 2. For each typographical error listed, a description is provided of the associated correction.

The typographical errors listed in page 2 have no impact on the document assumptions, calculations, results and conclusions.

11. REVIEWS AND APPROVAL

Printed Name	Signature	Date
11a. Originator: B. A. Matthews	[signature]	03/11/2008
11b. Checker: J. C. Ryman	JC Ryman	03/11/2008
11c. EGS: A. A. Alsaed	[signature]	3/11/2008
11d. DEM: M. R. Wisenburg	[signature]	3/11/2008
11e. Design Authority: B. Rusinko	B Rusinko	3/11/08

Item	Typographical Error Description	Typographical Error Correction
1	Reference 2.1.3 is not included in the DIRS report for the document.	Reference 2.1.3 is included in Section 2.1 (Procedures/Directives) but should have been included in Section 2.2 (Design Input). In addition, Reference 2.1.3 should have been included in the DIRS report for the document. The DIRS entries for Reference 2.1.3 (DIRS number 182214) should have been: • Document Input: BSC (Bechtel SAIC Company) 2007. Preclosure Criticality Analysis Process Report. TDR-DS0-NU-000001 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20071023.0011. • Specifically used from: Figure 3-1 • Specifically used in: Section 4.3, Figure 4-1 • Input Description: Reference for the preclosure criticality safety analysis process • Input usage: Indirect Input • Input category: N/A • Q status: N/A • TBV/TBD status: N/A
2	The DIRS number is not included in Section 2.2 for Reference 2.2.19.	The DIRS number for Reference 2.2.19 is 163407. This number should have been listed at the end of the reference listing for Reference 2.2.19 in Section 2.2.
3	There is a reference to footnote 3 in Table 1, however no footnote 3 exists.	Footnote "3" is actually footnote "c", which is included at the end of the table. The penultimate row of the table (column 1) should have cited footnote "c" instead of footnote "3".
4	The "U mass – M_U (kg per assembly)" value in column 3 of Table 3 is missing.	The U Mass (kg per assembly) for the 7x7 assembly type evaluated is not used. Instead the actual UO_2 mass, listed in column 3 of the penultimate row of the table, is used. Therefore, the missing data in column 3 of row 4 is intentional. However, the erroneous reference to footnote "a" in this otherwise empty cell should have been deleted and, for clarity, the cell should have included the words "Not Used". As a related matter, the penultimate row of the table (column 3) should have cited footnote "a" instead of footnote "(1)".
5	The title of Section 3.2.6 should read "Zinc Cross Section Substitution".	The title of Section 3.2.6 currently reads "Aluminum Cross Section Substitution". The title of Section 3.2.6 should have read "Zinc Cross Section Substitution".
6	The isotope "^{1238}U" in Table 18 should read "^{238}U".	Table 18 incorrectly lists Uranium-238 as "^{1238}U". The isotope should have been listed as "^{238}U".
7	The "Confirmation Status" section of Sections 3.1.1 and 3.1.2 incorrectly refer to the title of Reference 2.1.7 as "Desktop Information for Using CalTrac"	The correct title of Reference 2.1.7 is "Desktop Information for Using CalcTrac" (i.e. "CalcTrac" should have been used instead of "CalTrac").
8	The title of Ref. 2.1.5 in Section 4.1 is incorrectly stated.	In section 4.1, the title of Ref. 2.1.5 should read "Quality Management Directive" instead of "Quality Assurance Requirements and Description". Also, "(QARD)" should have been deleted.
9	The text "Ref. 2.2.2" in Section 4.2.1 should be included in parenthesis.	The penultimate sentence of the 2nd paragraph of section 4.2.1 should have included "Ref. 2.2.2" in parenthesis; i.e. "(Ref. 2.2.2)".
10	The title of Ref. 2.1.3 in Section 4.3 is incorrectly stated.	In Section 4.3, the title of Ref. 2.1.3 should read "Preclosure Criticality Analysis Process Report" instead of "Preclosure Criticality Analysis Report".

BSC

Calculation/Analysis Change Notice

Complete only applicable items.

1. QA: QA
2. Page 1 of 4

3. Document Identifier:	4. Rev.:	5. CACN:
000-00C-MGR0-03600-000	00A	002

6. Title:
Nuclear Criticality Calculations for Canister-Based Facilities – Commercial SNF

7. Reason for Change:
Typographical errors were noted subsequent to the issue of CACN 001. These errors are identified in the extent of condition description of CR 11857.

8. Supersedes Change Notice: ☐ Yes If, Yes, CACN No.: ______ ☒ No

9. Change Impact:

Inputs Changed:	☐ Yes	☒ No	Results Impacted:	☐ Yes	☒ No
Assumptions Changed:	☐ Yes	☒ No	Design Impacted:	☐ Yes	☒ No

10. Description of Change:
Table 21 has a description of footnotes a and b below the table, but the body of the table includes no references to the footnotes. The corrections are as follows:

1) The source for Table 21 is changed to Table 1 of *Dimension and Material Specification for Use in Criticality Analyses* (Ref. 2.2.1)
2) Footnotes a and b are deleted from Table 21 because the footnote information is given in the calculation referenced as the source for Table 21.
3) Reference 2.2.15 is changed to "Not used."
4) Reference 2.2.20 is deleted.
5) The DIRS should not have included DIRS reference numbers 162015 (Ref. 2.2.15) and 179928 (Ref. 2.2.20).

All corrections to the document are indicated with change bars on the attached replacements for pages 20, 21, and 59.

The typographical errors in Table 21 and the corrections have no impact on the document assumptions, calculations, results, and conclusions.

11. REVIEWS AND APPROVAL

Printed Name	Signature	Date
11a. Originator: J. C. Ryman	J. C. Ryman	5/15/2008
11b. Checker: W. G. Rhoden	W. G. Rhoden	5/15/2008
11c. EGS: A. A. Alsaed	AAlsaed	5/15/2008
11d. DEM: D. Beckman	T. Dunn for D. Beckman	5/15/2008
11e. Design Authority: B. E. Rusinko	BRusinko	5/15/08

2.2.5 Baum, E.M.; Knox, H.D.; and Miller, T.R. 2002. *Nuclides and Isotopes.* 16th edition. [Schenectady, New York]: Knolls Atomic Power Laboratory. TIC: 255130. (DIRS 175238).

2.2.6 DOE (U.S. Department of Energy) 2007. *Transportation, Aging, and Disposal Canister System Performance Specification.* WMO-TADCS-000001, Rev. 0. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20070614.0007 (DIRS 181403).

2.2.7 ASTM A 887-89 (Re-approved 2004). 2004. *Standard Specification for Borated Stainless Steel Plate, Sheet, and Strip for Nuclear Application.* West Conshohocken, Pennsylvania: American Society for Testing and Materials. TIC: 258746 (DIRS 178058).

2.2.8 NRC (U.S. Nuclear Regulatory Commission) 2000. *Standard Review Plan for Spent Fuel Dry Storage Facilities.* NUREG-1567. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 247929 (DIRS 149756).

2.2.9 DOE (U.S. Department of Energy) 1987. Appendix 2A Physical Descriptions of LWR Fuel Assemblies. Volume 3 of Characteristics of Spent Fuel, High-Level Waste, and Other Radioactive Wastes Which May Require Long-Term Isolation DOE/RW-0184. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: HQX.19880405.0024 (DIRS 132333).

2.2.10 CRWMS M&O 1998. *Summary Report of Commercial Reactor Criticality Data for McGuire Unit 1.* B00000000-01717-5705-00063 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980622.0079 (DIRS 106022).

2.2.11 Lide, D.R., ed. 2006. *CRC Handbook of Chemistry and Physics.* 87th Edition. Boca Raton, Florida: CRC Press. TIC: 258634 (DIRS 178081).

2.2.12 Gelest, Inc. 2004. *Gelest Silicone Fluids: Stable, Inert Media.* Morrisville, Pennsylvania: Gelest, Inc. TIC: 256122 (DIRS 169915).

2.2.13 CRWMS M&O 1999 *DOE SRS HLW Glass Chemical Composition.* BBA000000-01717-0210-00038 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990215.0397 (DIRS 102140).

2.2.14 Stout, R.B. and Leider, H.R., eds. 1991. *Preliminary Waste Form Characteristics Report* Version 1.0. Livermore, California: Lawrence Livermore National Laboratory. ACC: MOL.19940726.0118 (DIRS 102813).

2.2.15 Not used.

2.2.16 ASTM A 240/A 240M-06c. 2006. Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications West Conshohocken, Pennsylvania: American Society for Testing and Materials. TIC: 259153 (DIRS 179346).

2.2.17 Larsen, N.H.; Parkos, G.R.; and Raza, O. 1976. *Core Design and Operating Data for Cycles 1 and 2 of Quad Cities 1.* EPRI NP-240. Palo Alto, California: Electric Power Research Institute. TIC: 237267. (DIRS 146576).

2.2.18 BSC (Bechtel SAIC Company) 2005. *CSNF Assembly Type Sensitivity Evaluation for Pre- and Postclosure Criticality Analysis.* CAL-DSU-NU-000013 REV 00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20050525.0006 (DIRS 175046).

2.2.19 MCNP V. 4B2LV.2002. WINDOWS 2000.STN: 10437-4B2LV-00.

It is noted that Reference 2.2.9 is "QA-NA" but is used as "direct input" based on the context of its use (i.e. "data" only). This reference is suitable for its intended use in this document because the data refers to fuel assembly characteristics that are representative of the broader CSNF assembly population.

It is also noted that References 2.2.12 and 2.2.17 are "inputs from outside sources". These references are suitable for their intended use in this document because the data is considered representative and the safety limits established in this document are considered insensitive to the exact values used.

2.3 DESIGN CONSTRAINTS

None.

2.4 DESIGN OUTPUTS

2.4.1 Preclosure Criticality Safety Analysis.

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		

Source: Table 1 of *Dimension and Material Specification for Use in Criticality Analyses* (Ref. 2.2.1)

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		