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DISCLAIMER

CONTENTS

Page

TABLES

FIGURES

ACRONYMS, ABBREVIATIONS AND TERMS

Acronyms

ATR	Advanced Test Reactor
BSC	Bechtel SAIC Company, LLC
CD	Compact Disc
DHLW	Defense High Level Waste
DFA	Driver Fuel Assembly
DIRS	Document Input Reference System
DOE	Department of Energy
EF	Enrico Fermi
FFTF	Fast Flux Test Facility
FSV	Fort St. Vrain
GROA	Geological Repository Operational Area
HEU	Highly Enriched Uranium
HLW	High Level Waste
ITS	Important To Safety
MCNP	Monte Carlo N-Particle
MCO	Multi Canister Overpack
MOX	Mixed Oxide
QMD	Quality Management Directive
SLWBR	Shippingport Light Water Breeder Reactor
SNF	Spent Nuclear Fuel
SPWR	Shippingport Pressurized Water Reactor
SSC	Systems, Structures and Components
SRS	Savannah River Site
TRIGA	Training, Research, Isotope, General Atomics
WP	Waste Package (either 5-DHLW/DOE SNF or 2-MCO/2-DHLW variant)

Abbreviations

cm^3	cubic centimeters
cm	centimeter
eV	electron volt
ft	feet
g	grams
k_{eff}	effective neutron multiplication factor
k_{inf}	neutron multiplication factor of a system with no leakage (i.e. an infinite medium)
Δk_{eff}	numeric difference between two k_{eff} values
kg	kilogram
L	liter
vol. %	volume percent
wt. %	weight percent

Terms

ZAID	A unique nuclide identifier used by the MCNP code (Ref. 2.2.2). These identifiers generally contain the atomic number (Z), mass number (A), and data library specifier of the element or isotope of interest.

1. PURPOSE

The purpose of this calculation is to perform nuclear criticality calculations for High-Level Waste (HLW) glass to to support the criticality safety analysis of normal operations and off-normal conditions associated with the receipt, handling and loading of HLW glass canisters into 5-DHLW/DOE SNF Waste Packages (WPs) and 2-MCO/2-DHLW WPs in the surface facilities, in addition to the emplacement of loaded and sealed WPs in the sub-surface facility.

This document is intended to supplement calculations performed for DOE Spent Nuclear Fuel (SNF) canisters in a companion document *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1).

1.1 SCOPE

The criticality calculations performed and recorded in this document concern HLW glass but also include DOE SNF canisters for the purpose of performing interaction studies with HLW glass canisters.

A wide variety of HLW glass specifications are examined to account for variability in HLW glass specfications as described in Section 6.2.1.2. The calculations also consider intrusion of moderator into the HLW glass canisters.

The DOE SNF canisters examined in the interaction studies with HLW glass include the same seven representative fuel types examined in a companion document *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Section 6.1.4). The seven representative fuel types are listed in Table 1-1.

Table 1-1: Representative DOE SNF Fuel Groups for Criticality Analyses

Fuel Group	Representative Fuel Type
Mixed Oxide (MOX)	Fast Flux Test Facility (FFTF) Driver Fuel
Uranium-Zirconium Hydride (UZrH)	Training, Research, Isotope, General Atomics (TRIGA) Fuel
Mo and U-Zr Alloys	Enrico Fermi (EF) Fast Reactor Fuel
Highly Enriched Uranium (HEU) Oxide	Shippingport Pressurized Water Reactor (SPWR) Fuel
^{233}U/Th Oxide	Shippingport Light Water Breeder Reactor (SLWBR) Seed Assembly Fuel
HEU-Al	Advanced Test Reactor (ATR) Fuel
U/Th Carbide	Fort St. Vrain (FSV) Fuel

Source: Adapted from Table 1-1 of Ref. 2.2.1.

2. REFERENCES

This section details the references used in this calculation. The Document Input Reference system (DIRS) number is provided (within parenthesis) for each applicable reference.

2.1 PROCEDURES/DIRECTIVES

2.1.1 BSC 2008. *Calculations and Analyses*. EG-PRO-3DP-G04B-00037, Rev.14. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20081114.0008.

2.1.2 BSC 2008. *Preclosure Safety Analysis Process*. LS-PRO-0201, Rev. 07. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20081119.0007.

2.1.3 BSC 2008., *Software Management*. IT-PRO-0011, Rev. 10. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20080923.0003.

2.1.4 BSC 2009. *Quality Management Directive*, QA-DIR-10, Rev. 04. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20090119.0001.

2.1.5 BSC 2008. *Qualification of Software*. IT-PRO-0012, Rev. 07. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20080923.0004.

2.2 DESIGN INPUTS

2.2.1 BSC (Bechtel SAIC Company) 2008. *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF*. 000-00C-MGR0-03900-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080107.0028; ENG.20080211.0013.

2.2.2 MCNP V. 4B2LV.2002. WINDOWS 2000.STN: 10437-4B2LV-00 (DIRS 163407).

2.2.3 CRWMS M&O 1998. *Software Qualification Report for MCNP Version 4B2, A General Monte Carlo N-Particle Transport Code*. CSCI: 30033 V4B2LV. DI: 30033-2003, Rev. 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980622.0637 (DIRS 102836).

2.2.4 Briesmeister, J.F., ed. 1997. *MCNP-A General Monte Carlo N-Particle Transport Code*. LA-12625-M, Version 4B. Los Alamos, New Mexico: Los Alamos National Laboratory. ACC: MOL.19980624.0328 (DIRS 103897).

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 BSC 2008. *Preclosure Criticality Analysis Process Report*. TDR-DS0-NU-000001, Rev. 03. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080220.0001; ENG.20090203.0002.

2.2.7 BSC 2008. *Source Terms for HLW Glass Canisters*. 000-00C-MGR0-03500-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080130.0002.

2.3 DESIGN CONSTRAINTS

None.

2.4 DESIGN OUTPUTS

2.4.1 Preclosure Criticality Safety Analysis.

3. ASSUMPTIONS

3.1 ASSUMPTIONS REQUIRING VERIFICATION

None.

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

3.2.1 Barium Cross Section Substitution

Assumption: Since the ^{137}Ba cross section libraries are unavailable in the MCNP cross-section library, it is assumed that representing the ^{137}Ba in the Savannah River Site High-Level Waste Glass material specification as ^{138}Ba maintains similar neutronic characteristics. This treatment is entirely consistent with the treatment used in a companion document *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Section 3.2.2).

Rationale: The rationale for this assumption is that the thermal neutron capture cross-section and resonance integral of ^{137}Ba (Ref. 2.2.5, pg. 56) are greater than the thermal neutron capture cross-section and the resonance integral of ^{138}Ba (Ref. 2.2.5, pg. 56), which results in less parasitic neutron capture, and is therefore conservative with respect to criticality safety evaluations.

Use in the Calculation: This assumption is used in Table 6-1.

3.2.2 Zinc Cross Section Substitution

Assumption: Since the zinc cross section libraries are unavailable in the MCNP cross-section library, it is assumed that representing the zinc in the Savannah River Site HLW Glass material specification as aluminum maintains similar neutronic characteristics. This treatment is entirely consistent with the treatment used in a companion document *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Section 3.2.4).

Rationale: The rationale for this assumption is that the thermal neutron absorption cross-section and resonance integral for these two elements are sufficiently similar, i.e. 0.230 barns and 0.17 barns for Al, compared with 1.1 barns and 2.8 barns for Zn, respectively (Ref. 2.2.5, pg. 42 and 48). Based on the smaller thermal neutron absorption cross-section and resonance integral for Al, relative to Zn, using Al to represent Zn in the MCNP calculations results in less neutron absorption and thus represents a conservative treatment. In addition, it is noted that Zn is present in only trace quantities (Table 6-1), therefore its influence on the calculation results would be negligible, irrespective of the magnitude of its thermal neutron absorption cross-section and resonance integral.

Use in the Calculation: This assumption is used in Table 6-1.

4. METHODOLOGY

4.1 QUALITY ASSURANCE

This calculation is prepared in accordance with EG-PRO-3DP-G04B-00037, *Calculations and Analyses* (Reference 2.1.1) and LS-PRO-0201, *Preclosure Safety Analysis Process* (Reference 2.1.2). Therefore, the approved record version has a quality assurance designation of 'QA:QA'. This calculation is subject to the *Quality Management Directive* (QMD) (Reference 2.1.4).

4.2 USE OF SOFTWARE

4.2.1 MCNP

The base-lined Monte Carlo N-Particle (MCNP) code (References 2.2.2 and 2.2.3) is used in the HLW glass canister and the HLW glass canister / DOE SNF canister interaction k_{eff} (effective neutron multiplication factor) calculations. The MCNP software specification is as follows:

- Software Title: MCNP
- Version/Revision Number: Version 4B2LV
- Status/Operating System: Qualified/Microsoft Windows 2000 Service Pack 4
- Software Tracking Number: 10437-4B2LV-00
- Computer Type: Dell OPTIPLEX GX260 Workstations

The input and output files for the MCNP calculations are contained on a Compact Disc (CD) attachment to this calculation report (Attachment 2), as detailed in Attachment 1. The MCNP software has been validated as being appropriate for use in modeling a range of radiation transport problems as documented in *Software Qualification Report for MCNP Version 4B2, A General Monte Carlo N-Particle Transport Code* (Reference 2.2.3). The range of validated problems includes cases where MCNP is used to determine k_{eff} of systems containing fissile material. The use of MCNP in determining k_{eff} values is further documented in *A General Monte Carlo N-Particle Transport Code* (Reference 2.2.4). The MCNP software was obtained from Software Configuration Management in accordance with the appropriate procedure (*Software Management,* Reference 2.1.3).

The software qualification report *Software Qualification Report for MCNP Version 4B2, A General Monte Carlo N-Particle Transport Code* (Reference 2.2.3) was performed prior to the effective date of IT-PRO-0012, *Qualification of Software* (Reference 2.1.5), however, MCNP Version 4B2 was qualified software in the centralized baseline as of the effective date of IT-PRO-0012 and is therefore considered acceptable and part of the established software baseline available for level 1 usage (Paragraph 1.2.3 of IT-PRO-0012, *Qualification of Software* Reference 2.1.5).

4.2.2 EXCEL

- Software Title: Excel
- Version/Revision number: Microsoft® Excel 2003 SP-3 (on an OPTIPLEX GX620 Workstation)
- Computer Environment for Microsoft® Excel 2003: Software is installed on a DELL OPTIPLEX GX620 personal computer, running Microsoft Windows XP Professional, Version 2002, Service Pack 2.

Microsoft Excel for Windows is used in calculations and analyses to process the results of the MCNP calculations, using standard mathematical expressions and operations. It is also used to tabulate the MCNP results. The user-defined formulae, inputs, and results are documented in sufficient detail to allow an independent repetition of computations. Thus, Microsoft Excel is used only as a worksheet and not as a software routine. The use of Excel in the calculation constitutes Level 2 software usage, which does not require qualification (*Software Management*, Reference 2.1.3, Attachment 4).

The Microsoft Excel spreadsheets generated for the calculations developed in support of this document are provided in the Microsoft Excel workbooks *HLWG MCNP Results.xls* and *HHLWG MCNP Results.xls,* included in the CD file of Attachment 2. The Microsoft Excel calculations were verified by hand calculations and visual inspection. In addition, the figures used in this calculation were verified by visual inspection.

4.2.3 WINZIP

The compressed 'zip' files contained in the Compact Disc (CD) attachment of this document (Attachment 2) were created using WinZip 9.0. The zip files were verified by visual inspection. The WinZip 9.0 software specification is as follows:

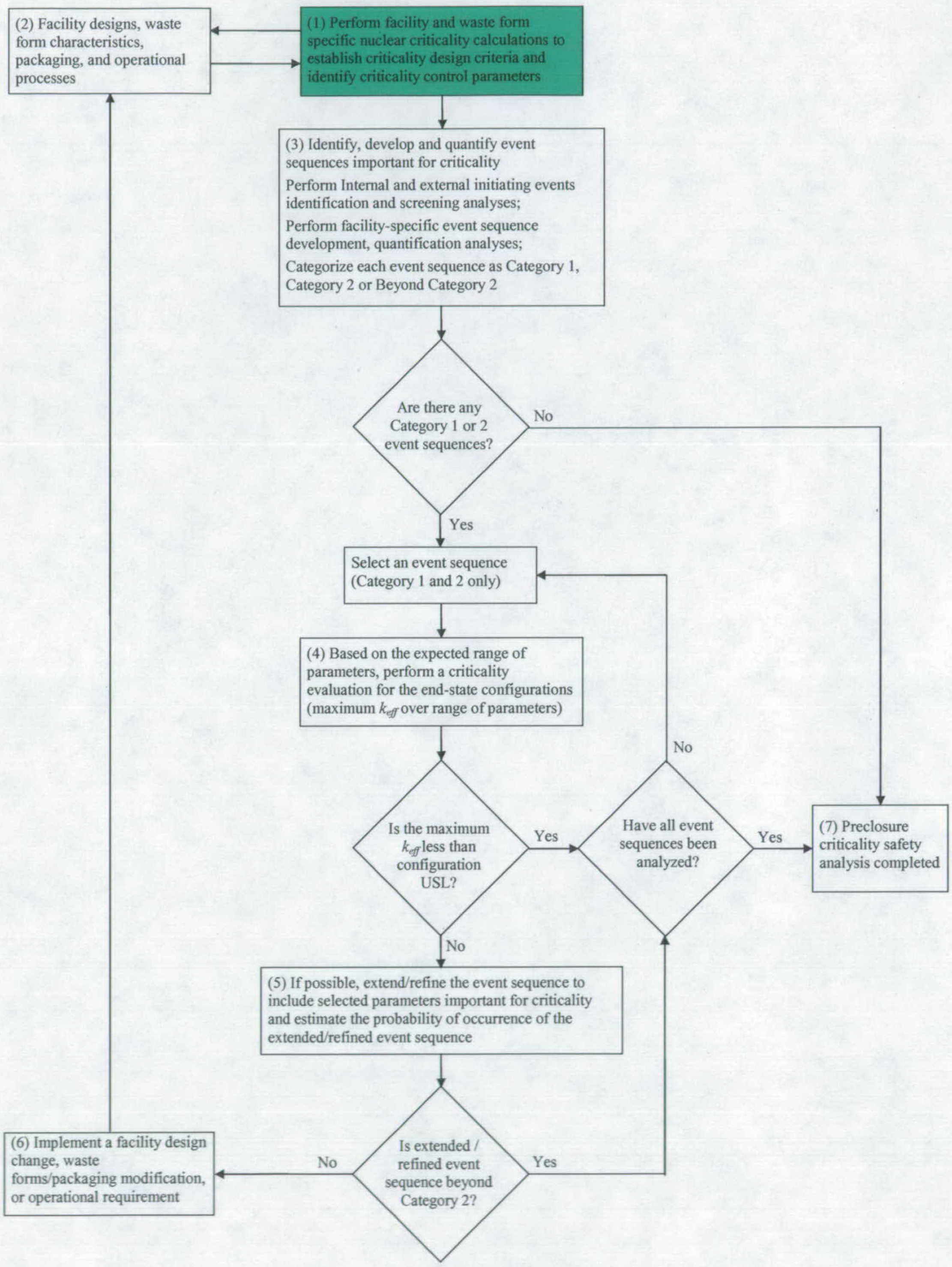
- Software Title: WinZip.
- Version/Revision number: 9.0 SR-1 (6224) (on an OPTIPLEX GX620 Workstation).
- Computer Environment for WinZip 9.0: Software is installed on a DELL OPTIPLEX GX620 personal computer, running Microsoft Windows XP Professional, Version 2002, Service Pack 2.

4.3 ANALYSIS PROCESS

This calculation is performed in accordance with the criticality safety analysis process described in the *Preclosure Criticality Analysis Process Report* (Reference 2.2.6, Figure 3-1). Refer to Section 6 for a discussion of the methodology used for the calculations presented in this document.

The key elements of the criticality safety analysis process are detailed in Figure 4-1. The calculations reported in this document specifically address function (1), highlighted in Figure 4-1. This is accomplished by determining the k_{eff} of HLW glass and HLW glass canister / DOE

SNF canister interaction models under a variety of conditions. The results of these calculations aid in establishing criticality safety design criteria, and aid in identifying design and process parameters that are important to the criticality safety of the surface and sub-surface facilities.



Source: Ref. 2.2.6, Figure 3-1

Figure 4-1: Preclosure Criticality Safety Process Flow Diagram

5. LIST OF ATTACHMENTS

Attachment #	Title	Number of Pages
1	Compact Disc Listing	2
2	One Compact Disc	N/A

6. BODY OF CALCULATION

This section provides a detailed description of the waste forms examined, describes their representation in the criticality safety models, and details the specific MCNP calculations undertaken to provide an understanding of system behavior and to identify potential limits. The following structure is used:

- Section 6.1 summarizes the waste forms examined; and
- Section 6.2 describes the explicit representation of the waste forms in the MCNP calculation models generated to examine bounding normal conditions and to establish the conditions under which the examined waste forms remain safely subcritical under potential off-normal conditions.

6.1 WASTE FORM DESCRIPTION

This section details the waste forms included in the scope of this document (Section 1.1). References are provided for physical descriptions, including geometry data, material lists and material compositions.

Two waste form types are examined; HLW glass canisters and DOE SNF canisters. The HLW glass canisters are the primary focus of this document, with the DOE SNF canisters being examined only in the context of interaction with HLW glass.

6.1.1 HLW Glass Canisters

The HLW glass canisters are fully described in a companion document *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Section 6.1.4). The HLW glass canisters consist of two design variants; short and long canisters. The short and long HLW glass canisters are identical except for their length, which is ~300 cm and ~449 cm for the short and long canisters, respectively. The HLW glass canisters have an outer diameter of ~61 cm, with a ~1 cm thick stainless steel wall. The material compositions and material densities relevant to HLW glass canisters (and their HLW glass content) are provided in *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Section 6.1.4 and Attachment 1).

6.1.2 DOE SNF Canisters

The DOE SNF canisters are fully described in a companion document *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Section 6.1.3). The seven DOE SNF canisters examined in this document are listed in Table 1-1. A brief description of each DOE SNF canister is provided in subsequent sub-sections.

6.1.2.1 ATR DOE SNF Canister

The ATR DOE SNF canister is fully described in a companion document *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Section 6.1.3.1). The ATR DOE SNF canister consists of a standardized long, cylindrical, DOE SNF canister with an outer length and outer diameter of ~457 cm and ~46 cm, respectively. The canister is constructed of stainless steel, with a wall thickness of ~1 cm. The ATR DOE SNF canister contains three fuel baskets in a stacked configuration. Each fuel basket is composed of orthogonally arranged nickel-gadolinium alloy basket plates ~1 cm thick. The orthogonally arranged plates within each fuel basket serve to create ten (10) locations/positions for ATR fuel elements, providing a total canister capacity of thrity (30) ATR fuel elements. The material compositions and material densities relevant to ATR DOE SNF canisters (and their content) are provided in *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Table 6-4, Table 6-6, Table 6-7, Table 6-8 and Attachment 1).

6.1.2.2 EF DOE SNF Canister

The EF DOE SNF canister is fully described in a companion document *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Section 6.1.3.2). The EF DOE SNF canister consists of a standardized short, cylindrical, DOE SNF canister with an outer length and outer diameter of ~300 cm and ~46 cm, respectively. The canister is constructed of stainless steel, with a wall thickness of ~1 cm. The EF DOE SNF canister contains two stacked fuel baskets, each composed of twelve cylindrical tubes constructed of ~1 cm thick nickel-gadolinium alloy, providing a total twenty-four (24) locations for EF fuel elements per canister. The material compositions and material densities relevant to EF DOE SNF canisters (and their content) are provided in *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Table 6-5, Table 6-9, Table 6-10 and Attachment 1).

6.1.2.3 FFTF DOE SNF Canister

The FFTF DOE SNF canister is fully described in a companion document *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Section 6.1.3.3). The FFTF DOE SNF canister consists of a standardized long, cylindrical, DOE SNF canister with an outer length and outer diameter of ~457 cm and ~46 cm, respectively. The canister is constructed of stainless steel, with a wall thickness of ~1 cm. The FFTF DOE SNF canister contains a fuel basket that consists of a cylindrical center tube, or basket tube, and five divider plates, or spokes, extending radially from the center tube to the inside wall of the DOE SNF canister. The basket center tube and divider plates are composed of ~1 cm thick nickel-gadolinium alloy. The basket center tube is used to accommodate a single Ident-69 canister, containing loose fuel pins from dissassembled FFTF assemblies. The remaining five basket locations created by the basket divider plates provide peripheral positions for up to five, intact, standard driver fuel assemblies (DFAs). The material compositions and material densities relevant to FFTF DOE SNF canisters (and their content) are provided in *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Table 6-4, Table 6-11, Table 6-12, Table 6-13 and Attachment 1).

6.1.2.4 FSV DOE SNF Canister

The FSV DOE SNF canister is fully described in a companion document *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Section 6.1.3.4). The FSV DOE SNF canister consists of a standardized long, cylindrical, DOE SNF canister with an outer length and outer diameter of ~457 cm and ~46 cm, respectively. The canister is constructed of stainless steel, with a wall thickness of ~1 cm. The FSV DOE SNF canister contains five stacked FSV fuel elements, each consisting of an hexagonal graphite prism loaded with fuel compacts. The material compositions and material densities relevant to FSV DOE SNF canisters (and their content) are provided in *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Table 6-4, Table 6-14, Table 6-15 and Attachment 1).

6.1.2.5 SLWBR DOE SNF Canister

The SLWBR DOE SNF canister is fully described in a companion document *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Section 6.1.3.5). The SLWBR DOE SNF canister consists of a standardized long, cylindrical, DOE SNF canister with an outer length and outer diameter of ~457 cm and ~46 cm, respectively. The canister is constructed of stainless steel, with a wall thickness of ~1 cm. The SLWBR DOE SNF canister contains a single rectangular fuel basket structure composed of ~1 cm thick stainless steel plates, providing a single position for one SLWBR fuel assembly. The material compositions and material densities relevant to SLWBR DOE SNF canisters (and their content) are provided in *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Table 6-4, Table 6-16, Table 6-17, Table 6-18, Table 6-19 and Attachment 1).

6.1.2.6 SPWR DOE SNF Canister

The SPWR DOE SNF canister is fully described in a companion document *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Section 6.1.3.6). The SPWR DOE SNF canister consists of a standardized long, cylindrical, DOE SNF canister with an outer length and outer diameter of ~457 cm and ~46 cm, respectively. The canister is constructed of stainless steel, with a wall thickness of ~1 cm. The SPWR DOE SNF canister contains a single rectangular fuel basket structure composed of ~1 cm thick stainless steel plates, providing a single position for one SPWR fuel assembly. The material compositions and material densities relevant to SPWR DOE SNF canisters (and their content) are provided in *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Table 6-4, Table 6-20, Table 6-21, Table 6-22 and Attachment 1).

6.1.2.7 TRIGA DOE SNF Canister

The TRIGA DOE SNF canister is fully described in a companion document *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Section 6.1.3.7). The TRIGA DOE SNF canister consists of a standardized short, cylindrical, DOE SNF canister with an outer length and outer diameter of ~300 cm and ~46 cm, respectively. The canister is constructed of stainless steel, with a wall thickness of ~1 cm. The TRIGA DOE SNF canister contains three stacked fuel baskets, each composed of thirty-one (31) fuel tubes constructed of ~1 cm thick nickel-gadolinium alloy, providing a total ninety-three (93) locations for TRIGA fuel elements per canister. The material compositions and material densities relevant to TRIGA DOE SNF canisters (and their content) are provided in *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Table 6-5, Table 6-23, Table 6-24, Table 6-25 and Attachment 1).

6.2 CALCULATION DESCRIPTION

This section describes the representation of the DOE waste forms examined in the MCNP calculations. Based on the purpose and scope of this document (Sections 1 and 1.1, respectively), two sets of calculations are performed:

- HLW glass canister calculations; and
- HLW glass canister / DOE SNF canister interaction calculations.

6.2.1 HLW Glass Canister Calculations

6.2.1.1 Geometry Representation

To bound all normal and potentially off-normal configurations of HLW glass canisters in the surface and subsurface facilities, a single conservative model is used. The model used consists of a simple geometry (sphere) of HLW glass with a mirror boundary condition, which has the effect of simulating an infinite medium of HLW glass, commonly referred to as an 'infinite sea'. This representation bounds any configuration and quantity of HLW glass canisters in addition to any potential reflection conditions. Based on this model, design dimensions and HLW glass canister design variants (e.g., long or short length canister variants) are unimportant.

6.2.1.2 Material Specification

A wide range of material specifications are considered for the HLW glass modeled in the calculations described in this document in order to evaluate, and potentially bound, the variety of HLW glass waste forms that could be received in the surface facilities. The wide range of material specifications examined can be grouped into two categories as follows:

- HLW glass; and
- Hypothetical HLW glass.

6.2.1.2.1 HLW Glass

The material specification (i.e. composition and density) used to represent HLW glass in the MCNP calculations is based on the Savannah River Site (SRS) HLW glass specification used in *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Table A1-17). The SRS HLW glass specification is used as the *nominal* material specification for HLW glass in the MCNP calculations, to represent normal (i.e. expected) conditions. The SRS HLW glass specification is provided in Table 6-1.

To address normal deviations in the composition and density of HLW glass (e.g. receipt of HLW glass with a fissile concentration that is disparate to SRS HLW glass) a wide variety of alternate material specifications are considered based on perturbations of the nominal SRS HLW glass specification. The approach used is to consider perturbations associated with fissile concentration and water content, as described below. It is noted that examination of the water content perturbation is performed to address potential event sequences associated with handling upsets in conjunction with intusion of moderator into HLW glass canisters.

6.2.1.2.2 HLW Glass Fissile Concentration

To establish the effect of the fissile concentration on the reactivity of HLW glass, the total fissile concentration (i.e., $^{235}U+^{239}Pu+^{241}Pu$ mass fractions) within the HLW glass composition is varied from the nominal value of ~ 0.51 g/L (Table 6-2) to a value approximately three orders of magnitude greater (500 g/L). The multiplier used to adjust the HLW glass non-fissile element/isotope weight fractions (see Table 6-2) to account for an increase in fissile concentration is provided in the formula below. The fissile concentration range and intermediate concentration values examined for HLW glass in the MCNP calculations (based on a dry HLW glass composition) are detailed in Table 6-2. Note that the density of the HLW glass is assumed to remain constant with only the weight fractions changing.

$$Non\ Fissile\ Concentration\ Multiplier = \frac{MW_T - MW_T(fissile)}{NW_T - NW_T(fissile)}$$

where,

MW_T	=	the total weight of nuclides in the modeled HLW glass specification.
$MW_T(fissile)$	=	the total weight of fissile nuclides in the modeled HLW glass specification.
NW_T	=	the total weight of nuclides in the nominal HLW glass specification, i.e. the total weight of nuclides provided in the SRS HLW glass specificaiton (Table 6-1).
$NW_T(fissile)$	=	the total weight of fissile nuclides in the nominal HLW glass specification, i.e. the total weight of fissile nuclides provided in the SRS HLW glass specificaiton (Table 6-1).

6.2.1.2.3 HLW Glass Water Content

To establish whether the presence of water or moisture within or around the HLW glass can increase its reactivity, water is progressively added to the HLW glass composition. A range of water fractions is considered between 0 vol. % to 50 vol. %. The multiplier used to adjust the HLW glass element/isotope weight fractions (see Table 6-2) to account for the addition of water to the HLW glass composition is provided in the formula below. The water volume fraction range and intermediate values examined for HLW glass in the MCNP calculations are detailed in Table 6-3.

$$H_2O\ Addition\ Multiplier = 1 - \frac{VF_{H_2O}\,\rho_{H_2O}}{\left(VF_{H_2O}\,\rho_{H_2O}\right) + \left(\left(1 - VF_{H_2O}\right)\rho_{HLWG}\right)}$$

where,

VF_{H2O}	=	the volume fraction of water in the HLW glass mixture (expressed as a decimal).
ρ_{H2O}	=	the density of water.

ρ_{HLWG} = the nominal density of the HLW glass, corresponding to a dry composition.

Table 6-1: Material Specifications for Savannah River Site High-Level Waste Glass

Element/Isotope	ZAID	wt. %	Element/Isotope	ZAID	wt. %
Li-6	3006.50c	0.0960	P	15031.50c	0.0141
Li-7	3007.55c	1.3804	Cr-50	24050.60c	0.0035
B-10	5010.50c	0.5918	Cr-52	24052.60c	0.0691
B-11	5011.56c	2.6189	Cr-53	24053.60c	0.0080
O	8016.50c	44.7700	Cr-54	24054.60c	0.0020
F	9019.50c	0.0319	Cu	29000.50c	0.1526
Na	11023.50c	8.6284	Ag	47000.55c	0.0503
Mg	12000.50c	0.8248	Ba-137 [a]	56138.50c	0.1127
Al [b]	13027.50c	2.3318	Pb	82000.50c	0.0610
Si	14000.50c	21.8880	Cl	17000.50c	0.1159
S	16000.60c	0.1295	Th-232	90232.50c	0.1856
K	19000.50c	2.9887	Cs-133	55133.50c	0.0409
Ca	20000.50c	0.6619	Cs-135	55135.50c	0.0052
Ti	22000.50c	0.5968	U-234	92234.50c	0.0003
Mn	25055.50c	1.5577	U-235	92235.50c	0.0044
Fe-54	26054.60c	0.4176	U-236	92236.50c	0.0010
Fe-56	26056.60c	6.7919	U-238	92238.50c	1.8666
Fe-57	26057.60c	0.1597	Zn	13027.50c [b]	0.0646
Fe-58	26058.60c	0.0215	Pu-238	94238.50c	0.0052
Ni-58	28058.60c	0.4939	Pu-239	94239.55c	0.0124
Ni-60	28060.60c	0.1968	Pu-240	94240.50c	0.0023
Ni-61	28061.60c	0.0087	Pu-241	94241.50c	0.0010
Ni-62	28062.60c	0.0281	Pu-242	94242.50c	0.0002
Ni-64	28064.60c	0.0074	Density = 2.85 g/cm^3 at 25 °C, 2.69 g/cm^3 at 825 °C		

NOTES: [a] Ba-137 cross-section data unavailable; therefore substituted as Ba-138 (Refer to Assumption 3.2.1).
[b] Zn cross-section data unavailable; therefore substituted *as Al-27 (*Refer to Assumption 3.2.2*).* Thus, the total wt. % modeled for Al is 2.3964 (i.e. 2.3318+0.0646).

Source: Ref. 2.2.1, Table A1-17

Table 6-2: Fissile Concentration Values Examined for Dry HLW Glass in the MCNP Calculations

Fissile Concentration modeled [g/L]	Ratio to nominal SRS HLW glass fissile concentration value	Element/Isotope	ZAID	wt. %
0.5073	1.000	U-235	92235.50c	0.0044
		Pu-239	94239.55c	0.0124
		Pu-241	94241.50c	0.0010
5.0000	9.856	U-235	92235.50c	0.0434
		Pu-239	94239.55c	0.1222
		Pu-241	94241.50c	0.0099
50.0000	98.561	U-235	92235.50c	0.4337
		Pu-239	94239.55c	1.2222
		Pu-241	94241.50c	0.0986
100.0000	197.122	U-235	92235.50c	0.8673
		Pu-239	94239.55c	2.4443
		Pu-241	94241.50c	0.1971
150.0000	295.683	U-235	92235.50c	1.3010
		Pu-239	94239.55c	3.6665
		Pu-241	94241.50c	0.2957
200.0000	394.244	U-235	92235.50c	1.7347
		Pu-239	94239.55c	4.8886
		Pu-241	94241.50c	0.3942
250.0000	492.805	U-235	92235.50c	2.1683
		Pu-239	94239.55c	6.1108
		Pu-241	94241.50c	0.4928
300.0000	591.366	U-235	92235.50c	2.6020
		Pu-239	94239.55c	7.3329
		Pu-241	94241.50c	0.5914
350.0000	689.927	U-235	92235.50c	3.0357
		Pu-239	94239.55c	8.5551
		Pu-241	94241.50c	0.6899
400.0000	788.488	U-235	92235.50c	3.4693
		Pu-239	94239.55c	9.7773
		Pu-241	94241.50c	0.7885
450.0000	887.049	U-235	92235.50c	3.9030
		Pu-239	94239.55c	10.9990
		Pu-241	94241.50c	0.8871
500.0000	985.610	U-235	92235.50c	4.3367
		Pu-239	94239.55c	12.2220
		Pu-241	94241.50c	0.9856

Source: Original

Note: Weight fractions are based on a dry HLW glass composition (i.e. no water content)

Table 6-3: Water Volume Fractions Examined for Dry HLW Glass in the MCNP Calculations

HLW Glass Water Volume Fraction (vol. %)	Multiplier used to adjust the HLW glass element/isotope weight fractions (see Table 6-1) to account for H_2O addition
1	0.9965
5	0.9819
10	0.9625
15	0.9418
20	0.9195
25	0.8955
30	0.8695
35	0.8413
40	0.8107
45	0.7773
50	0.7406

Source: Original

6.2.1.2.4 Hypothetical HLW Glass

The hypothetical HLW glass material specification category is not based on any particular HLW glass specification and is intended to provide a basis to generically evaluate any potential HLW glass composition.

The hypothetical HLW glass material composition comprises only PuO_2, H_2O, SiO_2 and B_2O_3. This set of compounds represents only fissile material (PuO_2), moderator (H_2O) and principal HLW glass constituents (note that SiO_2 and B_2O_3 are basic constituents of BoroSilicate glass). The concentration of each of these four compounds is independently varied as part of a large parametric study to determine k_{inf} (which represents the k_{eff} of an unlimited amount of HLW glass in any configuration) as a function of the concentration of each compound in the hypothetical HLW glass material. The concentration range examined for each compound represented in the hypothetical HLW glass material specification is detailed in Table 6-4. Note that the compound concentration values detailed in Table 6-4 were varied independently; i.e., all permutations were examined in the MCNP calculations.

Table 6-4: Hypothetical High-Level Waste Glass Constituent Compound Concentrations Examined in the MCNP Calculations

Hypothetical HLW Glass Compound Concentration (g/cc)			
PuO_2 [a,d]	B_2O_3 [b,d]	SiO_2 [c,d]	H_2O [d]
0.001	0.0	0.2	0.0
0.003	0.1	0.6	0.025
0.005	0.2	1.0	0.05
0.007	0.3	1.4	0.075
0.009	0.4	1.8	0.1
0.01	0.5	2.2	0.2
0.02	0.6		0.4
0.04			0.6
0.06			0.8
0.08			0.99821
0.1			
0.2			
0.3			
0.4			
0.5			

NOTES: [a] Pu is represented by ^{239}Pu in the MCNP calculations.
[b] B is represented by natural boron in the MCNP calculations.
[c] Si is represented by natural silicon in the MCNP calculations.
[d] O is represented by ^{16}O in the MCNP calculations.

Source: Original

Table 6-5 provides the weight fractions for SiO_2 and B_2O_3 in HLW glass types expected to be handled in the Geological Repository Operational Area (GROA) along with the expected density of each HLW glass type. Compound concentrations in (g/cc) are also provided in Table 6-5 for correlation with the analyzed ranges provided in Table 6-4. Additional information concerning these waste forms is provided in *Source Terms for HLW Glass Canisters* (Reference 2.2.7, Section 6).

Table 6-5: HLW Types Expected to be Received and Handled in the GROA

HLW type	Compound Weight Fraction (wt.%)		Compound Concentration (g/cc)		Density (g/cc)
	B_2O_3	SiO_2	B_2O_3	SiO_2	
Hanford	6.16 [a]	31.63 [a]	0.173	0.889	2.811 [b]
Savannah River Site	6.94 [c]	54.39 [c]	0.183	1.436	2.64 [d]
West Valley Demonstration Project	12.97 [e]	41.22 [e]	0.344 [i]	1.092 [i]	2.6 to 2.7 [f]
Idaho National Laboratory	10.94 [g]	54.87 [g]	0.274	1.372	2.5 [h]

Source: [a] Ref. 2.2.7, Table 2
[b] Ref. 2.2.7, pg. 20
[c] Ref. 2.2.7, Table 6
[d] Ref. 2.2.7, pg. 25
[e] Ref. 2.2.7, Table 10
[f] Ref. 2.2.7, pg. 29
[g] Ref. 2.2.7, Table 14
[h] Ref. 2.2.7, 34
[i] Based on a HLW glass density of 2.65 g/cc

The formulae developed and used to compute the weight fraction of each nuclide in the hypotheical HLW glass mixtures specified in Table 6-4 are provided below. The formula for computing the hypotheical HLW glass mixture density is also provided below. These formulae were used to generate the hypotheical HLW glass material density and nuclide weight fractions in the MCNP calcualtions.

$$^{239}Pu_{wt\ frac} = \frac{C_{PuO_2}}{\rho_{hhlw}}\left(\frac{^{239}Pu_{at\ wt}}{^{239}Pu_{at\ wt} + 2\left(^{16}O_{at\ wt}\right)}\right)$$

$$^{10}B_{wt\ frac} = \frac{C_{B_2O_3}}{\rho_{hhlw}}\left(\frac{2\left(B_{nat\ at\ wt}\right)}{2\left(B_{nat\ at\ wt}\right) + 3\left(^{16}O_{at\ wt}\right)}\right)\left(\frac{^{10}B_{at\ prop}\ ^{10}B_{at\ wt}}{B_{nat\ at\ wt}}\right)$$

$$^{11}B_{wt\ frac} = \frac{C_{B_2O_3}}{\rho_{hhlw}}\left(\frac{2\left(B_{nat\ at\ wt}\right)}{2\left(B_{nat\ at\ wt}\right) + 3\left(^{16}O_{at\ wt}\right)}\right)\left(\frac{^{11}B_{at\ prop}\ ^{11}B_{at\ wt}}{B_{nat\ at\ wt}}\right)$$

$$Si_{nat_{wt\ frac}} = \frac{C_{SiO_2}}{\rho_{hhlw}}\left(\frac{Si_{nat_{at\ wt}}}{Si_{nat_{at\ wt}} + 2\left(^{16}O_{at\ wt}\right)}\right)$$

$$^{1}H_{wt\ frac} = \frac{C_{H_2O}}{\rho_{hhlw}}\left(\frac{2\left(^{1}H_{at\ wt}\right)}{2\left(^{1}H_{at\ wt}\right) + ^{16}O_{at\ wt}}\right)$$

$$^{16}O_{at\ wt} = \frac{C_{PuO_2}}{\rho_{hhlw}}\left(\frac{2\left(^{16}O_{at\ wt}\right)}{^{239}Pu_{at\ wt} + 2\left(^{16}O_{at\ wt}\right)}\right) + \frac{C_{B_2O_3}}{\rho_{hhlw}}\left(\frac{3\left(^{16}O_{at\ wt}\right)}{2\left(B_{nat\ at\ wt}\right) + 3\left(^{16}O_{at\ wt}\right)}\right)$$
$$+ \frac{C_{SiO_2}}{\rho_{hhlw}}\left(\frac{2\left(^{16}O_{at\ wt}\right)}{Si_{nat_{at\ wt}} + 2\left(^{16}O_{at\ wt}\right)}\right) + \frac{C_{H_2O}}{\rho_{hhlw}}\left(\frac{^{16}O_{at\ wt}}{2\left(^{1}H_{at\ wt}\right) + ^{16}O_{at\ wt}}\right)$$

$$\rho_{hhlw} = C_{PuO_2} + C_{B_2O_3} + C_{SiO_2} + C_{H_2O}$$

where,

$^{239}Pu_{wt\ frac}$	=	the weight fraction of ^{239}Pu in the hypothetical HLW glass material.
$^{10}B_{wt\ frac}$	=	the weight fraction of ^{10}B in the hypothetical HLW glass material.
$^{11}B_{wt\ frac}$	=	the weight fraction of ^{11}B in the hypothetical HLW glass material.
$Si_{nat\ wt\ frac}$	=	the weight fraction of Si in the hypothetical HLW glass material.

${}^{1}H_{wt\,frac}$	=	the weight fraction of ${}^{1}H$ in the hypothetical HLW glass material.
${}^{16}O_{wt\,frac}$	=	the weight fraction of ${}^{16}O$ in the hypothetical HLW glass material.
C_{PuO2}	=	the concentration of PuO_2 in the hypothetical HLW glass material as defined by the PuO_2 parameter value selected. Refer to Table 6-4 for a list of the parameter values examined in the MCNP calculations.
C_{B2O3}	=	the concentration of B_2O_3 in the hypothetical HLW glass material as defined by the B_2O_3 parameter value selected. Refer to Table 6-4 for a list of the parameter values examined in the MCNP calculations.
C_{SiO2}	=	the concentration of SiO_2 in the hypothetical HLW glass material as defined by the SiO_2 parameter value selected. Refer to Table 6-4 for a list of the parameter values examined in the MCNP calculations.
C_{H2O}	=	the concentration of H_2O in the hypothetical HLW glass material as defined by the H_2O parameter value selected. Refer to Table 6-4 for a list of the parameter values examined in the MCNP calculations.
${}^{239}Pu_{at\,wt}$	=	the atomic weight of ${}^{239}Pu$ (239.052157), as defined in Ref. 2.2.5, pg. 70.
${}^{10}B_{at\,wt}$	=	the atomic weight of ${}^{10}B$ (10.0129370), as defined in Ref. 2.2.5, pg. 40.
${}^{11}B_{at\,wt}$	=	the atomic weight of ${}^{11}B$ (11.0093055), as defined in Ref. 2.2.5, pg. 40.
${}^{1}H_{at\,wt}$	=	the atomic weight of ${}^{1}H$ (1.00794), as defined in Ref. 2.2.5, pg. 40.
${}^{16}O_{at\,wt}$	=	the atomic weight of ${}^{16}O$ (15.9994), as defined in Ref. 2.2.5, pg. 41.
$Si_{nat\,at\,wt}$	=	the atomic weight of Si_{nat} (28.0855), as defined in Ref. 2.2.5, pg. 42.
$B_{nat\,at\,wt}$	=	the atomic weight of $B_{nat} = \left({}^{10}B_{at\,prop}\,{}^{10}B_{at\,wt}\right)+\left({}^{11}B_{at\,prop}\,{}^{11}B_{at\,wt}\right)$
${}^{10}B_{at\,prop}$	=	the atom fraction of ${}^{10}B$ in natural Boron (B_{nat}) (0.199), as defined in Ref. 2.2.5, pg. 40.
${}^{11}B_{at\,prop}$	=	the atom fraction of ${}^{11}B$ in natural Boron (B_{nat}) (0.801), as defined in Ref. 2.2.5, pg. 40.
ρ_{hhlw}	=	the density of the hypothetical HLW glass material.

6.2.2 HLW Glass Canister / DOE SNF Canister Interaction Calculations

The criticality calculations performed and recorded in this document concern HLW glass but also include DOE SNF canisters for the purpose of performing interaction studies with HLW glass canisters.

6.2.2.1 Geometry Representation

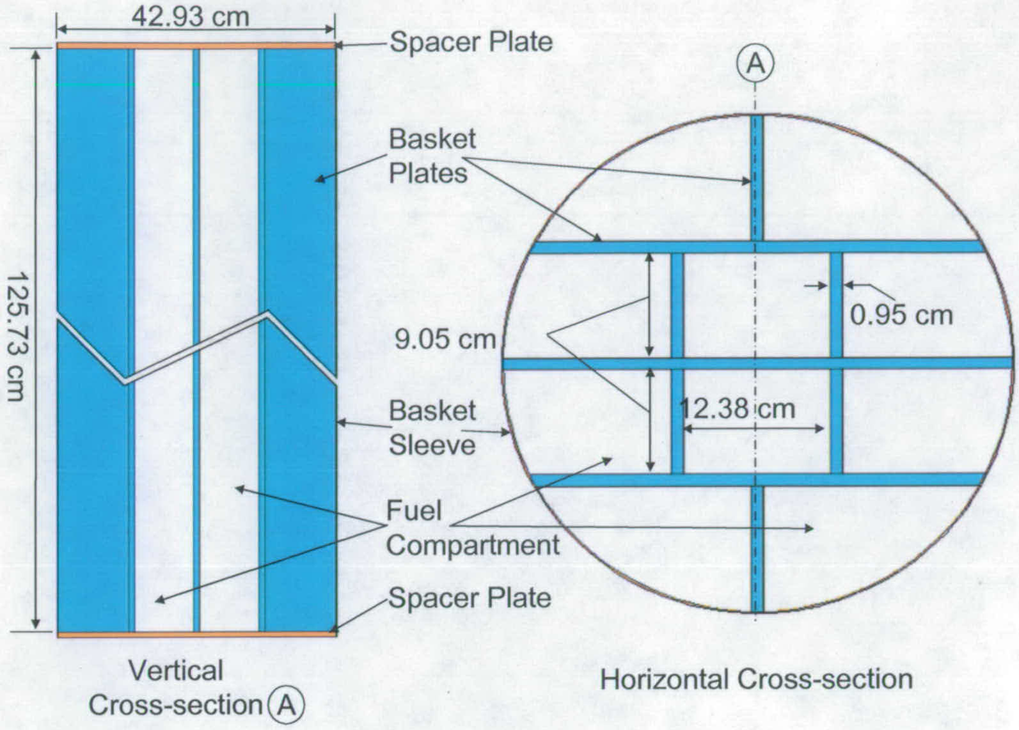
The MCNP HLW glass / DOE SNF canister interaction models consist of a centralized DOE SNF canister surrounded by a close fitting 61 cm (~24") axial/radial reflector with the same composition and density as HLW glass (Table 6-1).

Design information related to the seven representative DOE SNF canisters modeled for interaction studies with HLW glass canisters is based soley on information contained in a companion document, *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1, Section 6.1.3), as outlined in Section 6.1. The representation of the seven DOE SNF canisters considered in the MCNP HLW glass / DOE SNF canister interaction calculations is presented in the MCNP model cross-section plots included in the following sub-sections.

It is noted that the MCNP models examined are unaltered MCNP models from *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1 Attachment 3, *MCNP inputs.zip*), except that the DOE SNF canister reflector thickness and material have been adjusted to provide 61 cm of close fitting axial/radial reflection with the desired HLW glass compositon/density. No other modifications are applied to the MCNP models. Explicit details of the geometry and actual material properties of the MCNP models examined are therefore unaltered.

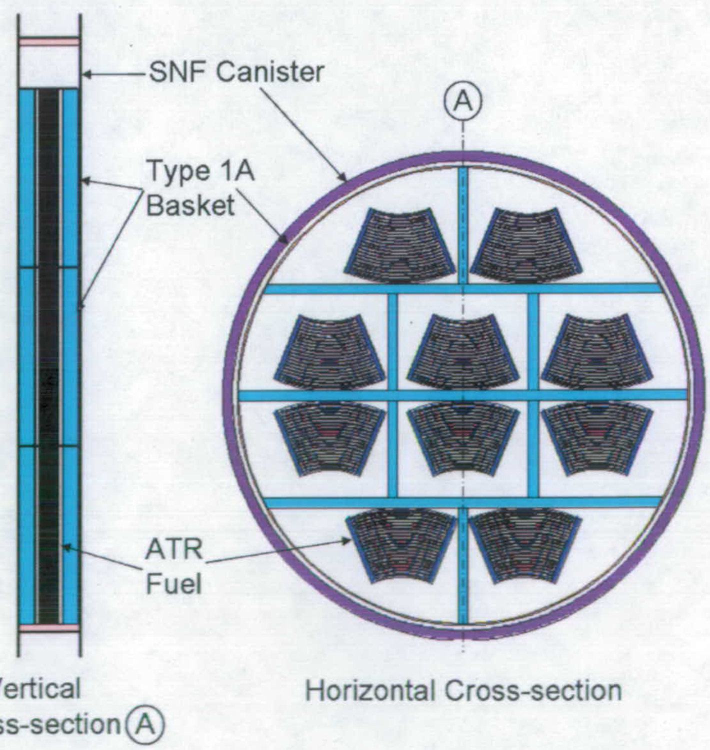
6.2.2.1.1 ATR DOE SNF Canister

The MCNP models created and used for the HLW glass / ATR DOE SNF canister interaction calculations are based on the *atr_single_can_norm_dry_96_in* MCNP model from *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1 Attachment 3, *MCNP inputs.zip*). Cross-section views of the ATR MCNP model are provided in Figure 6-1 and Figure 6-2.



Source: Ref. 2.2.1, Figure 6-6

Figure 6-1: Cross-sections of the Type 1A ATR Fuel Basket MCNP Model (Fuel elements not shown for clarity)

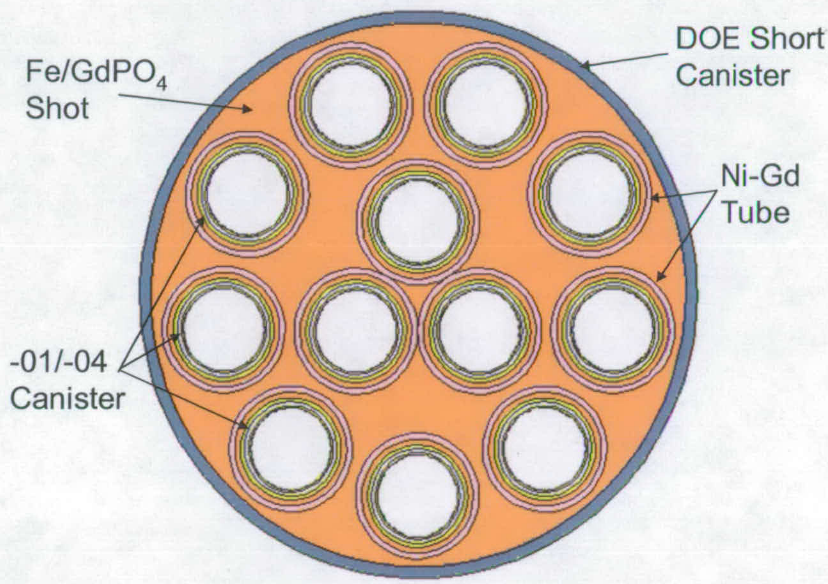


Source: Ref. 2.2.1, Figure 6-7

Figure 6-2: Cross-sections of MCNP Model of ATR Fuel loaded in DOE SNF Long Canister

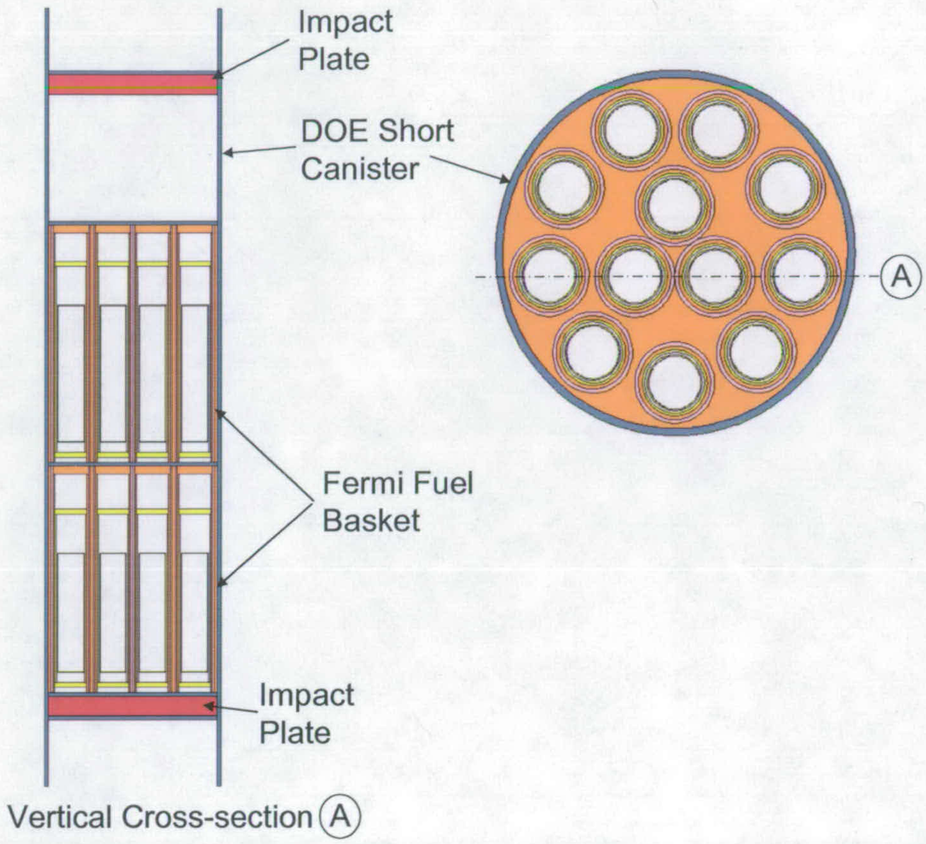
6.2.2.1.2 EF DOE SNF Canister

The MCNP models created and used for the HLW glass / EF DOE SNF canister interaction calculations are based on the *fermi_single_can_norm_dry_96_in* MCNP model from *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1 Attachment 3, *MCNP inputs.zip*). Cross-section views of the MCNP model representation of the EF DOE SNF canister are provided in Figure 6-3 and Figure 6-4.



Source: Ref. 2.2.1, Figure 6-11

Figure 6-3: Horizontal Cross-section of the EF Storage Basket in a DOE Short Canister as Modeled in MCNP

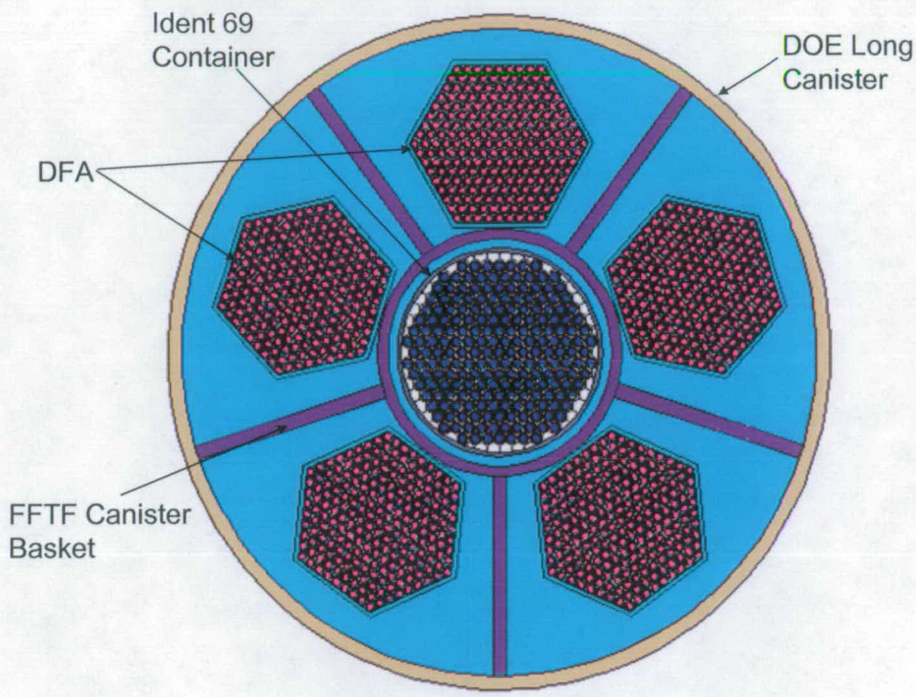


Source: Ref. 2.2.1, Figure 6-12

Figure 6-4: Vertical Cross-section of EF Fuel Baskets in a DOE Canister as Modeled in MCNP

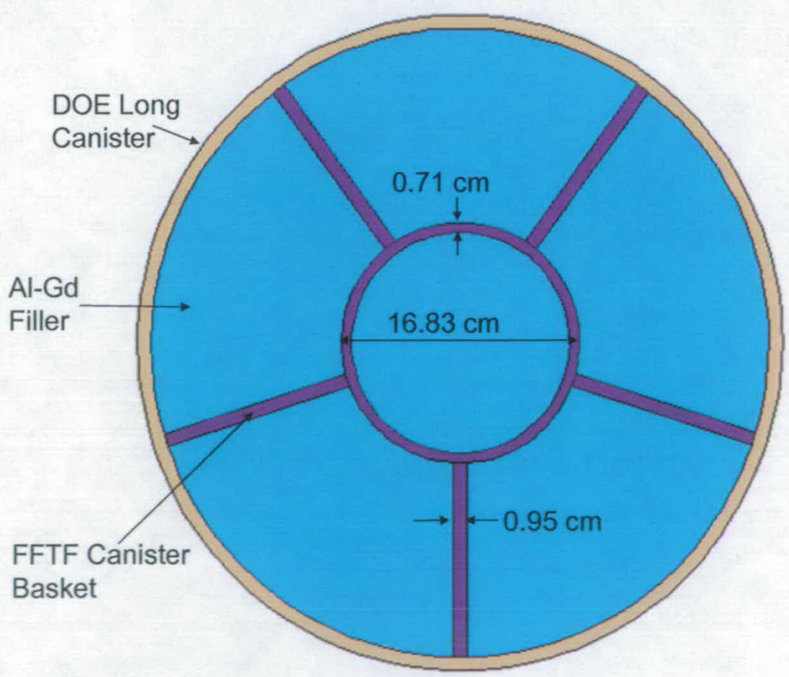
6.2.2.1.3 FFTF DOE SNF Canister

The MCNP models created and used for the HLW glass / FFTF DOE SNF canister interaction calculations are based on the *fftf_single_can_norm_dry_96_in* MCNP model from *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1 Attachment 3, *MCNP inputs.zip*). Cross-section views of the MCNP model representation of the FFTF DOE SNF canister are provided in Figure 6-5, Figure 6-6 and Figure 6-7.



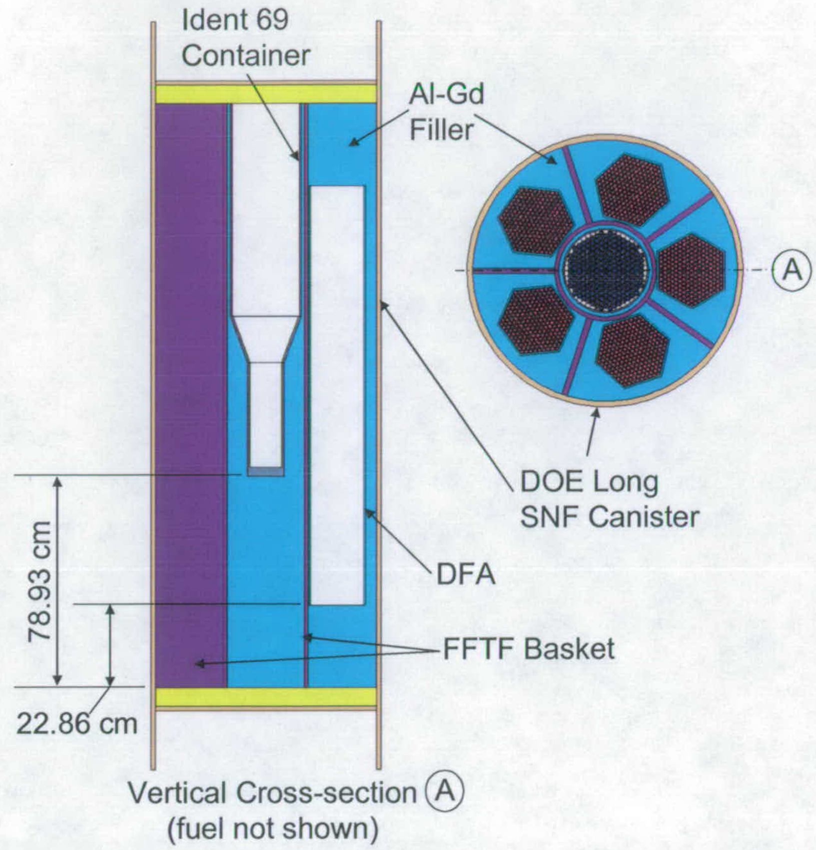
Source: Ref. 2.2.1, Figure 6-20

Figure 6-5. Representation of FFTF Fuel Units Emplaced in DOE SNF Canister Based on MCNP Model



Source: Ref. 2.2.1, Figure 6-21

Figure 6-6: Horizontal Cross-section of FFTF Canister Basket Model (Fuel not shown for Clarity)

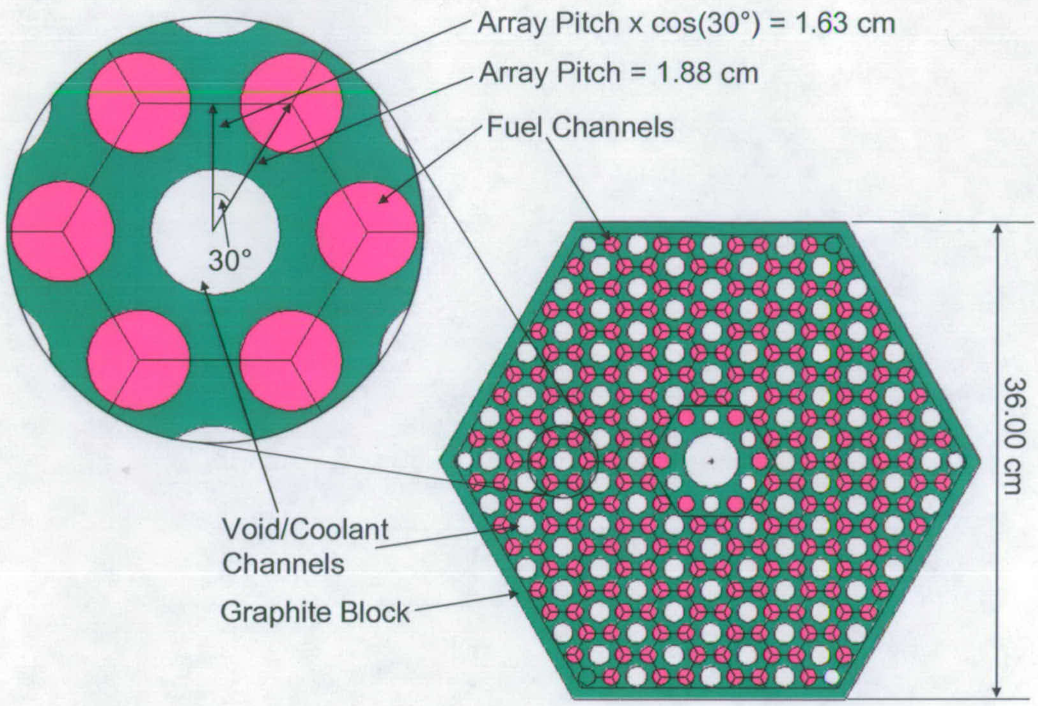


Source: Ref. 2.2.1, Figure 6-22

Figure 6-7: Vertical Cross-section of FFTF Basket in a DOE Long SNF Canister

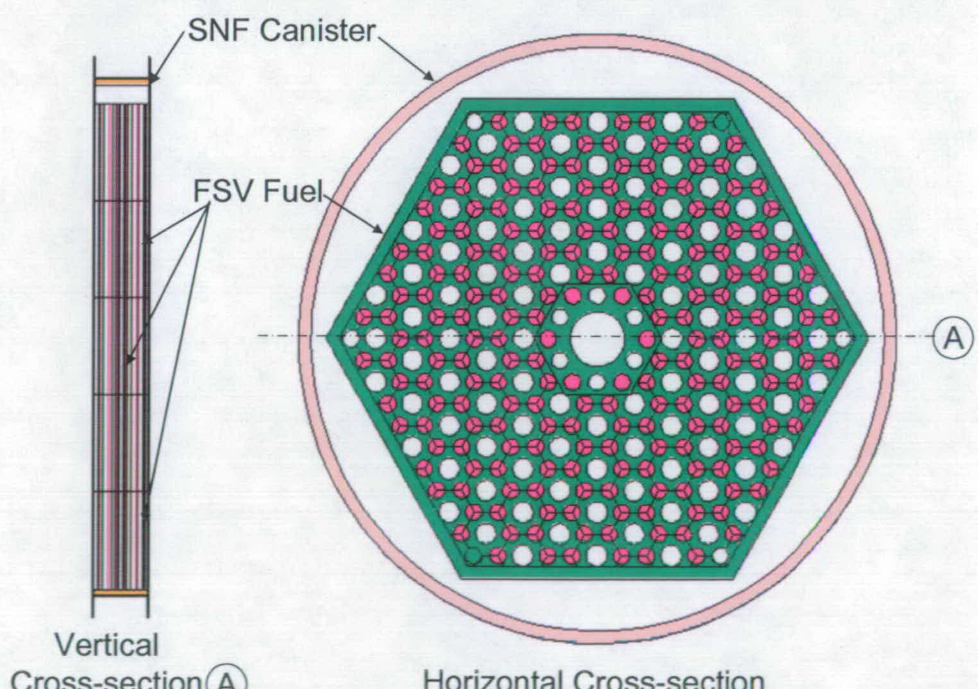
6.2.2.1.4 FSV DOE SNF Canister

The MCNP models created and used for the HLW glass / FSV DOE SNF canister interaction calculations are based on the *fsv_single_can_norm_dry_96_in* MCNP model from *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1 Attachment 3, *MCNP inputs.zip*). Cross-section views of the MCNP model representation of the FSV DOE SNF canister are provided in Figure 6-8 and Figure 6-9.



Source: Ref. 2.2.1, Figure 6-24

Figure 6-8: Horizontal Cross-section of FSV Fuel Element MCNP Model

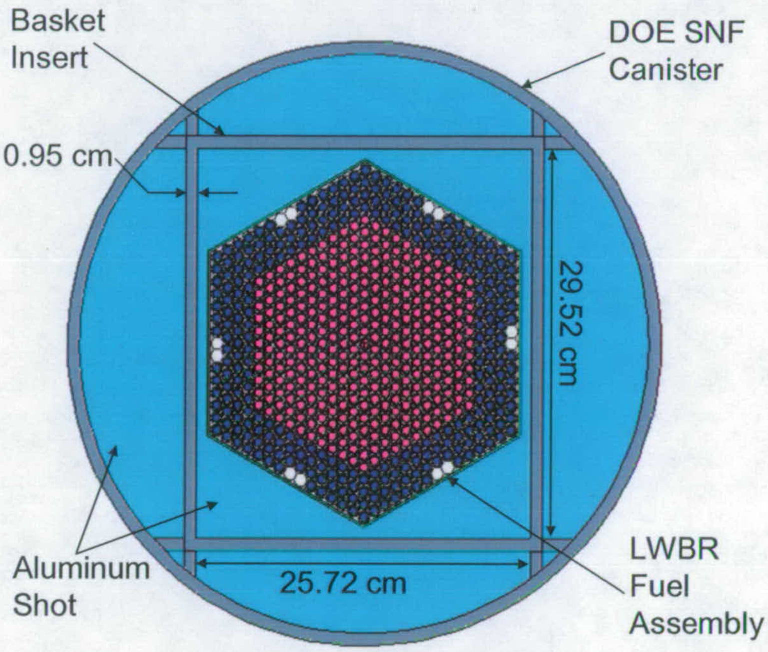


Source: Ref. 2.2.1, Figure 6-25

Figure 6-9: Cross-sections of the FSV Fuel in the DOE SNF Long Canister MCNP Model

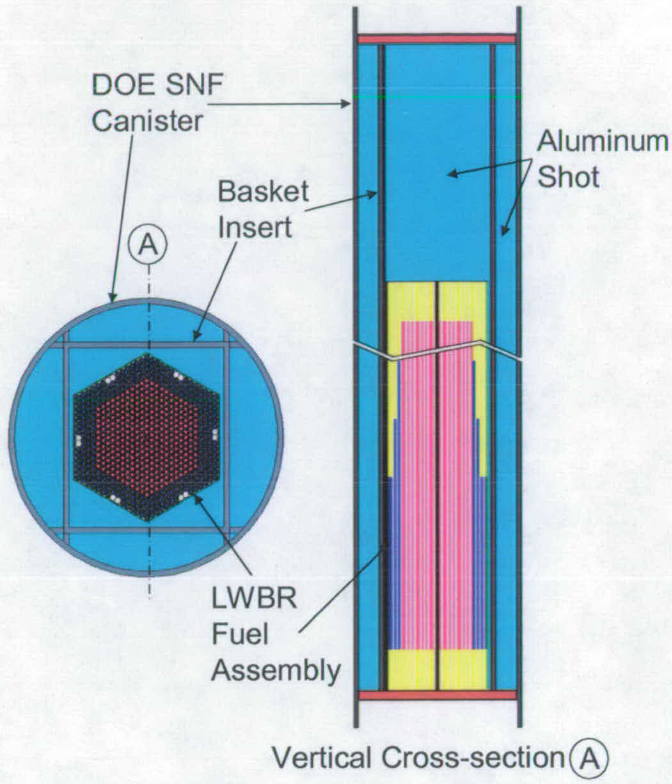
6.2.2.1.5 SLWBR DOE SNF Canister

The MCNP models created and used for the HLW glass / SLWBR DOE SNF canister interaction calculations are based on the *slwbr_single_can_norm_dry_96_in* MCNP model from *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1 Attachment 3, *MCNP inputs.zip*). Cross-section views of the MCNP model representation of the SLWBR DOE SNF canister are provided in Figure 6-10 and Figure 6-11.



Source: Ref. 2.2.1, Figure 6-32

Figure 6-10: Horizontal Cross-section of MCNP Model of the LWBR Fuel Assembly Basket Insert for a DOE SNF Canister

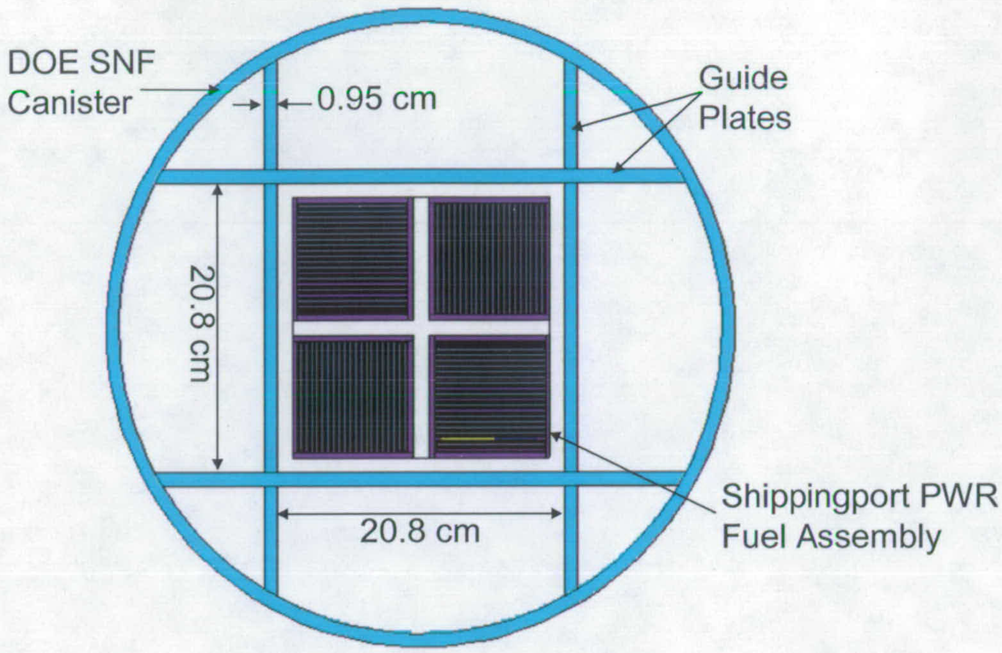


Source: Ref. 2.2.1, Figure 6-33

Figure 6-11: Vertical Cross-Section of MCNP Model of the LWBR Fuel Assembly in a DOE SNF Canister

6.2.2.1.6 SPWR DOE SNF Canister

The MCNP models created and used for the HLW glass / SPWR DOE SNF canister interaction calculations are based on the *spwr_single_can_norm_dry_96_in* MCNP model from *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1 Attachment 3, *MCNP inputs.zip*). A cross-section view of the MCNP model representation of the SPWR DOE SNF canister is provided in Figure 6-12.

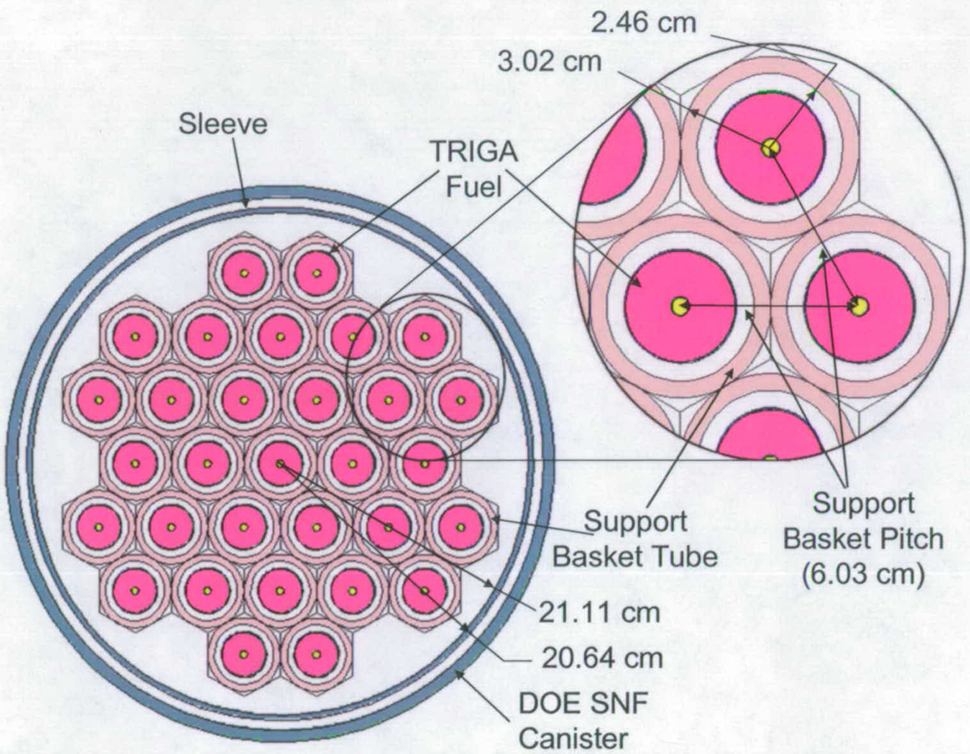


Source: Ref. 2.2.1, Figure 6-43

Figure 6-12: Cross-Sectional View of the Canister and Guide Assembly for SPWR

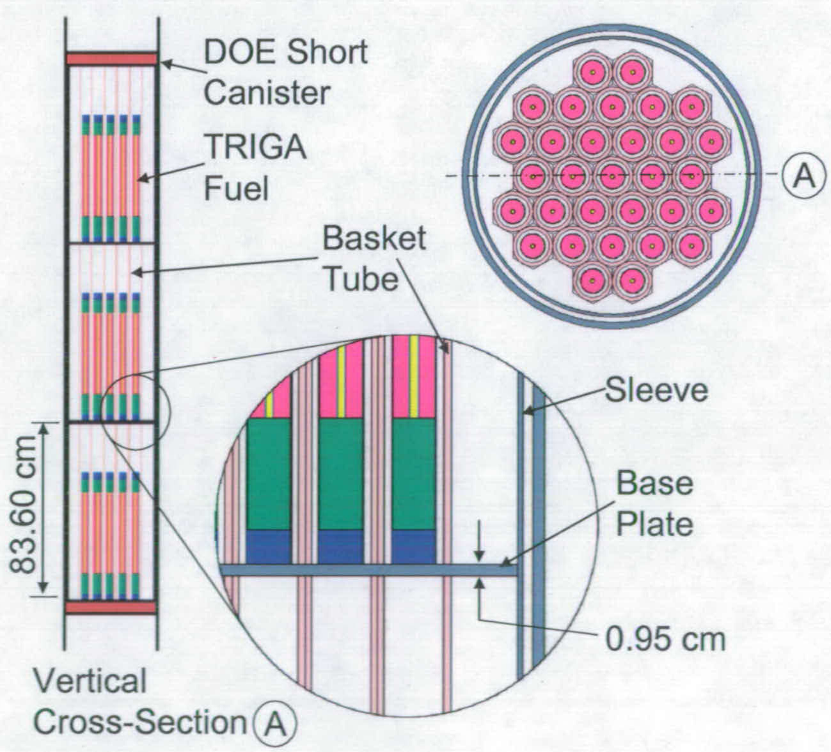
6.2.2.1.7 TRIGA DOE SNF Canister

The MCNP models created and used for the HLW glass / TRIGA DOE SNF canister interaction calculations are based on the *triga_single_can_norm_dry_96_in* MCNP model from *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1 Attachment 3, *MCNP inputs.zip*). Cross-section views of the MCNP model representation of the TRIGA DOE SNF canister are provided in Figure 6-13 and Figure 6-14.



Source: Ref. 2.2.1, Figure 6-47

Figure 6-13: Horizontal Cross-section of TRIGA Fuel Basket MCNP Model



Source: Ref. 2.2.1, Figure 6-48

Figure 6-14: Vertical Cross-section of TRIGA Fuel Baskets in a Short DOE Canister as Modeled in MCNP

6.2.2.2 Material Specification

The material specification used to represent the HLW glass reflector in the MCNP HLW glass / DOE SNF canister interaction calculations is based on the HLW glass material specifications defined in Section 6.2.1.2.1, with the exception that only dry HLW glass material compositions are examined (i.e. the water content parameter is set to zero). Omitting water content is conservative because, based on the results reported in Figure 7-1 and the conclusion drawn in Section 7 (2^{nd} paragraph), it is seen that dry HLW glass produces the highest calculated k_{inf}.

The specification of the materials used to represent the seven DOE SNF canisters examined in the MCNP HLW glass / DOE SNF canister interaction calculations is provided in the references cited in the individual subsections of Section 6.2.2.1.

7. RESULTS AND CONCLUSIONS

The results of the calculations described in Section 6 are presented in Sections 7.1 and 7.2 for the HLW glass canister calculations and the HLW glass canister / DOE SNF canister interaction calculations, respectively.

7.1 HLW GLASS CANISTER CALCULATIONS

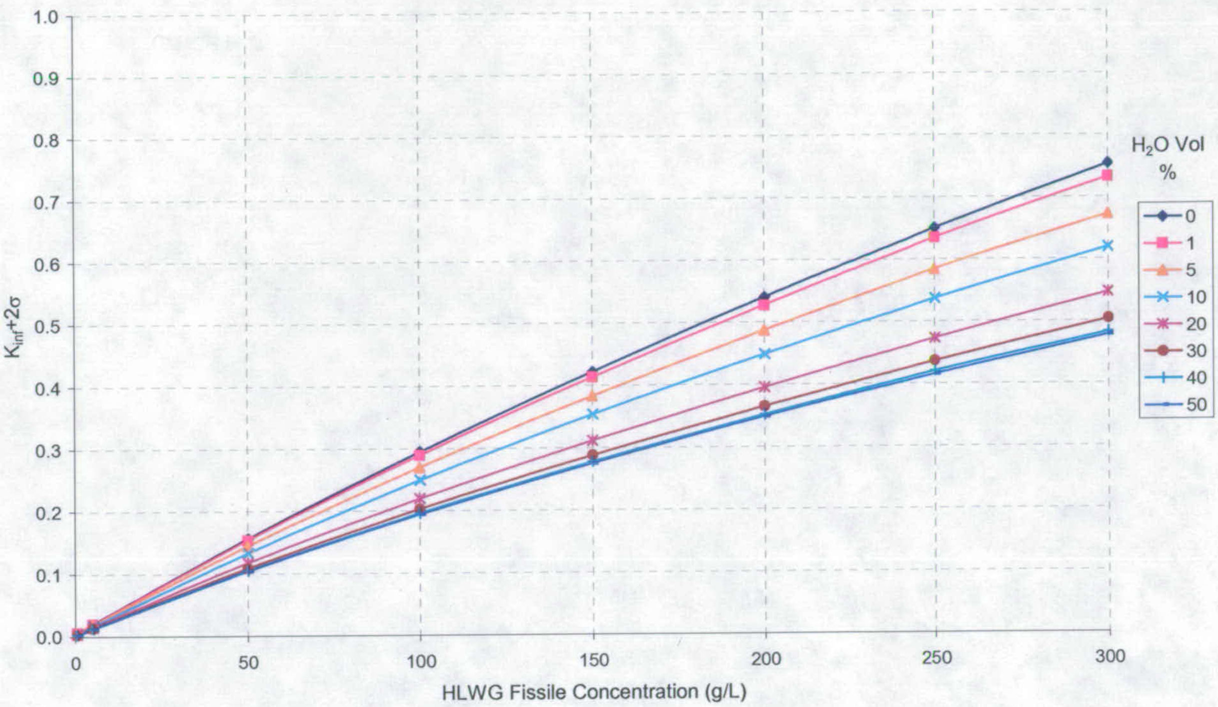
7.1.1 HLW glass

The results of the HLW glass calculations are presented in Table 7-1 and Figure 7-1, which were generated in the *HLWG MCNP Results.xls* Excel workbook in Attachment 2.

Table 7-1: k_{inf} +2σ values for an infinite sea of HLW Glass, with varying fissile concentration for a range of moisture contents

Fissile Concentration (g/L)	k_{inf} +2σ values for an infinite sea of HLW Glass for a range of moisture contents (H_2O vol. %)							
	0	1	5	10	20	30	40	50
0.5	0.00561	0.00549	0.00488	0.00427	0.00336	0.00276	0.00234	0.00202
5.0	0.01992	0.01967	0.01837	0.01678	0.01437	0.01302	0.01230	0.01195
50.0	0.15614	0.15372	0.14420	0.13308	0.11740	0.10848	0.10509	0.10377
100.0	0.29442	0.28880	0.26944	0.24873	0.21937	0.20263	0.19574	0.19399
150.0	0.42161	0.41307	0.38273	0.35310	0.31089	0.28790	0.27697	0.27462
200.0	0.54022	0.52702	0.48663	0.44819	0.39515	0.36476	0.35148	0.34858
250.0	0.65014	0.63433	0.58383	0.53693	0.47289	0.43670	0.42031	0.41542
300.0	0.75368	0.73211	0.67206	0.61843	0.54634	0.50370	0.48258	0.47764

Source: Original



Source: Original

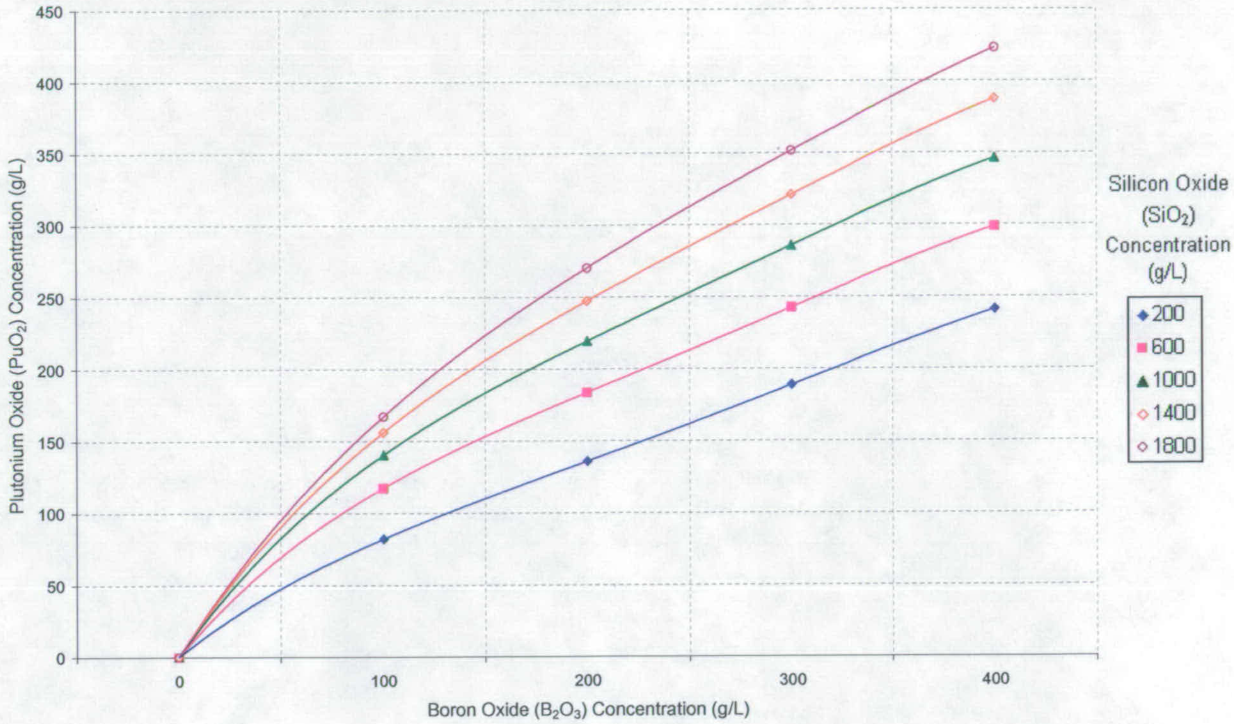
Figure 7-1: k_{inf} +2σ values for an infinite sea of HLW Glass, with varying fissile concentration and water content

Based on the results provided in Figure 7-1, it is seen that the presence of water within the HLW glass matrix results in a decrease in k_{inf}. Thus, a dry HLW glass composition produces the highest k_{inf} value. This trend is caused by the presence of boron in the HLW glass composition, whose neturon absorption effectiveness increases with decreasing neutron energy. It is also seen from the results provided in Table 7-1 and Figure 7-1 that for dry HLW glass, k_{inf} is essentially zero (< 0.01) at the nominal fissile concentration value of ~0.51g/L.

7.1.2 Hypothetical HLW glass

The results of the hypothetical HLW glass calculations are presented in Figure 7-2 and Figure 7-3, which were generated in the *HHLWG MCNP Results.xls* Excel workbook in Attachment 2.

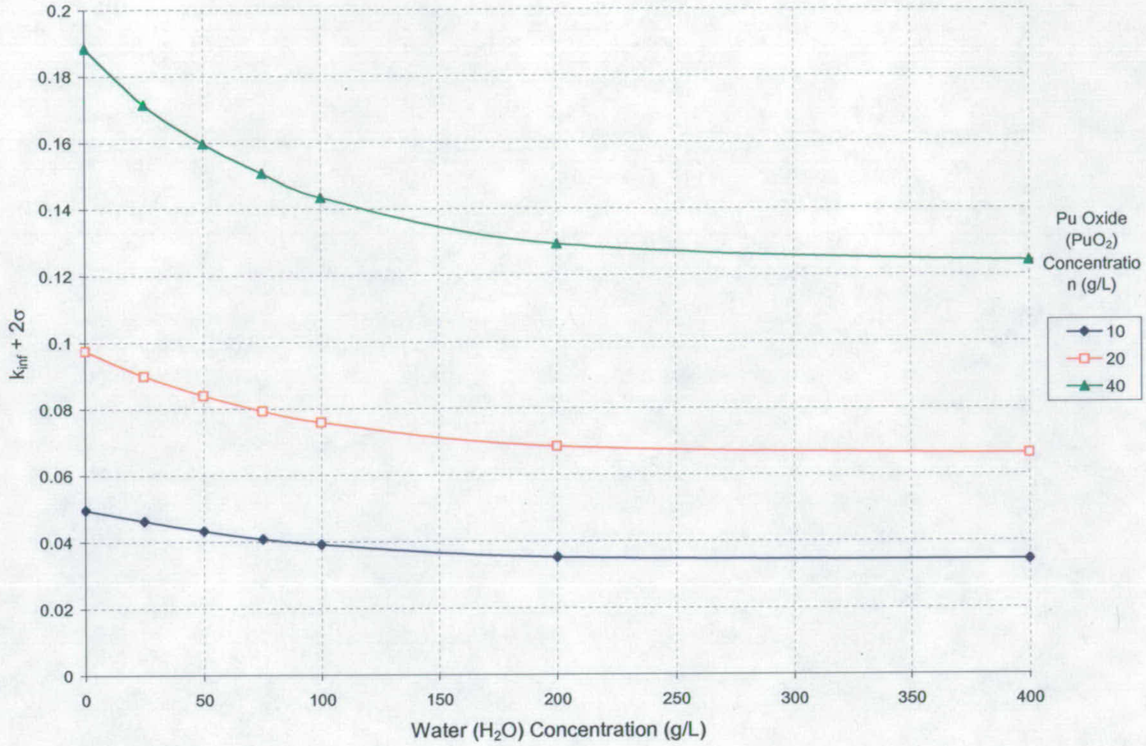
Figure 7-2 presents boundary curves for an infinite sea of hypothetical HLW glass with no water content. The curves were generated by interpolating the MCNP k_{inf} +2σ results to establish the PuO_2 concentration as a function of the B_2O_3 concentration, for each SiO_2 concentration value examined that resulted in a k_{inf}+2σ value of 0.8. The interpolation of the MCNP results was performed by fitting a series of results to a third order polynomial utilizing the LINEST spreadsheet function in Excel (Section 4.2.2). The fitting parameters may be found in the *HHLWG MCNP Results.xls* Excel workbook in Attachment 2. Refer to worksheet "Overview" in the *HHLWG MCNP Results.xls* Excel workbook in Attachment 2 for a description of the data and computations performed.



Source: Original

Figure 7-2: Domain boundaries corresponding to a k_{inf}+2σ value of 0.8 for an infinite sea of hypothetical HLW Glass with no water content

Figure 7-3 depicts the variation in k_{inf} +2σ values for HLW glass with varying fissile concentration and moderator ingress concentration values. Fissile concentration values up to almost two orders of magnitude greater than the nominal fissile concentration value of ~0.51g/L are presented. The data presented in Figure 7-3 represents fixed B_2O_3 and SiO_2 concentration values of 200 g/L and 1000 g/L, respectively. These values presented fall within the expected range of concentrations detailed in Table 6-5. Refer to the *HHLWG MCNP Results.xls* Excel workbook in Attachment 2 for additional data.



Source: Original

Figure 7-3: $k_{inf}+2\sigma$ values for an infinite sea of hypothetical HLW Glass, with varying water and PuO_2 concentration, and a fixed B_2O_3 and SiO_2 concentration of 200 g/L and 1000 g/L, respectively.

Based on the data plotted in Figure 7-3 it is seen that, for the fixed B_2O_3 and SiO_2 concentration values of 200 g/L and 1000 g/L selected, the maximum $k_{inf}+2\sigma$ value is less than 0.2 for HLW glass fissile concentration values up to almost two orders of magnitude greater than the nominal fissile concentration value of ~0.51g/L. It is also seen that the presence of water in the hypothetical HLW glass material matrix results in a decrease in k_{inf}. This reduction is caused by the presence of boron in the HLW glass composition, as previously noted.

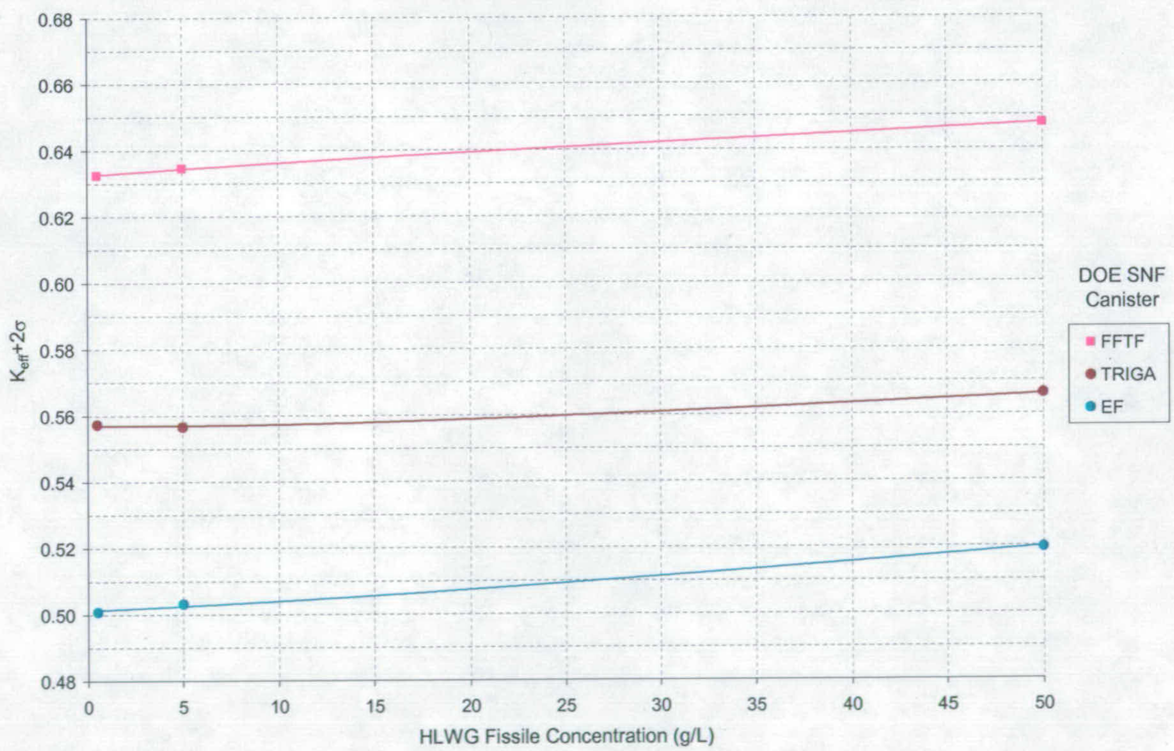
7.2 HLW GLASS CANISTER / DOE SNF CANISTER INTERACTION CALCULATIONS

The results of the HLW glass / DOE SNF canister interaction studies are presented in Table 7-2, Figure 7-4 and Figure 7-5. This data was generated in the *HLWG MCNP Results.xls* Excel workbook in Attachment 2. The results are presented as a function of the HLW glass fissile concentration and the interacting DOE SNF canister type. Figure 7-4 and Figure 7-5 present the results of the interaction studies with a HLW glass fissile concentration up to two orders of magnitude greater than the nominal fissile concentration of ~0.51 g/L.

Table 7-2: $k_{eff}+2\sigma$ values for an an individual undamaged and dry DOE SNF canister with close fitting 61 cm thick axial/radial reflection by dry HLW Glass with a range of fissile concentrations

Fissile Concentration (g/L)	$k_{eff}+2\sigma$ values for individual undamaged and dry DOE SNF canisters with close fitting 61 cm thick axial/radial reflection by HLW Glass						
	ATR	FFTF	FSV	SLWBR	SPWR	TRIGA	EF
0.5	0.10446	0.63249	0.18064	0.29258	0.13786	0.55735	0.50072
5.0	0.10919	0.63473	0.18367	0.29435	0.14088	0.55661	0.50311
50.0	0.17649	0.64761	0.23521	0.31597	0.19466	0.56606	0.51943
100.0	0.27329	0.66490	0.30672	0.35675	0.28394	0.57803	0.54412
150.0	0.37067	0.68439	0.39068	0.41295	0.37657	0.59387	0.57267
200.0	0.46266	0.70599	0.47600	0.48281	0.46688	0.61634	0.61041
250.0	0.55032	0.73426	0.55731	0.55806	0.55470	0.64222	0.65341
300.0	0.63080	0.76814	0.63575	0.63357	0.63488	0.68101	0.70753

Source: Original



Source: Original

Figure 7-4: $k_{eff}+2\sigma$ values versus fissile material concentration for an individual undamaged and dry DOE SNF canister with close fitting 61 cm thick axial/radial reflection by HLW Glass (FFTF, TRIGA and EF DOE SNF canister results presented)

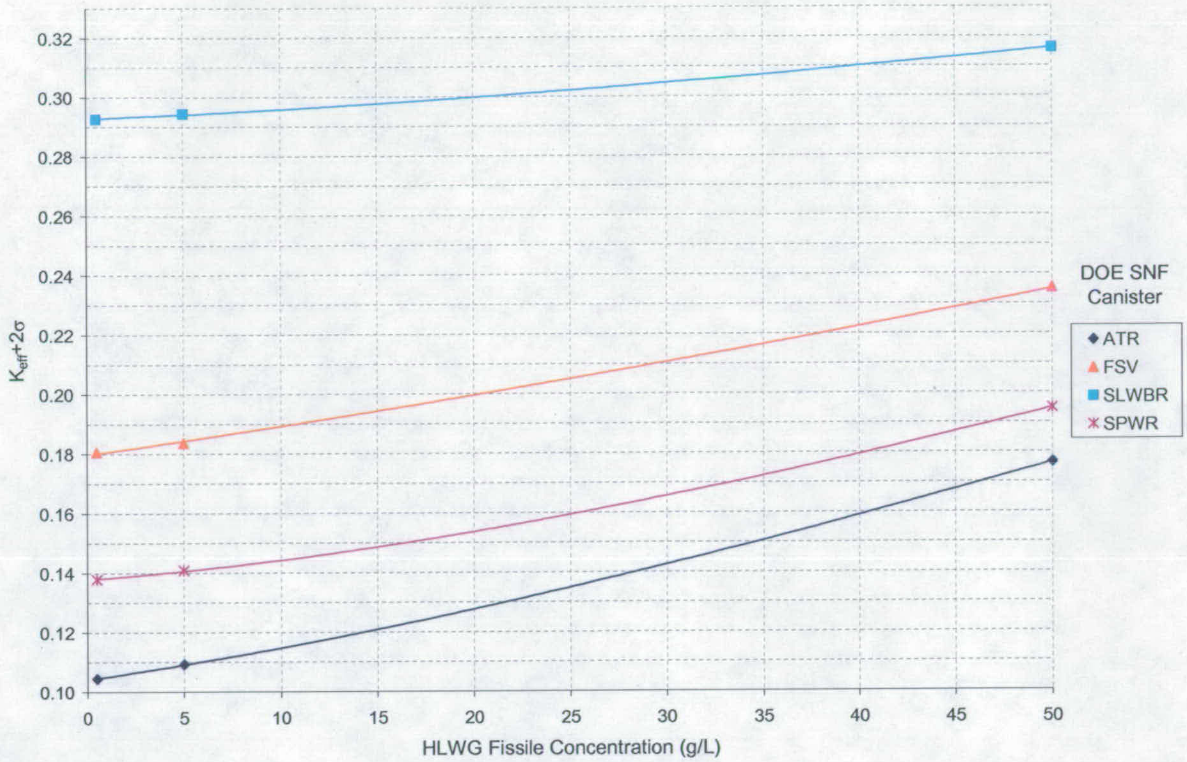


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Figure 7-5: k_{eff}+2σ values versus fissile material concentration for an individual undamaged and dry DOE SNF canister with close fitting 61 cm thick axial/radial reflection by HLW Glass (ATR, FSV, SLWBR and SPWR DOE SNF canister results presented)

As expected from the results of the single undamaged dry DOE SNF canister studies reported in Figure 7-1 of *Nuclear Criticality Calculations for Canister-Based Facilities - DOE SNF* (Reference 2.2.1), it is seen that the most onerous DOE SNF canister from an interaction standpoint, is an FFTF DOE SNF canister (refer to Figure 7-4). Based on the results provided in Figure 7-4 and Table 7-2, it is seen that a two order magnitude increase in the nominal fissile concentration value of ~0.51 g/L (i.e. an increase to ~50 g/L) only results in a +0.015 Δk_{eff} increase in k_{eff} (Figure 7-5).

7.3 IDENTIFICATION OF SSCS, SAEFTY FUNCTIONS, NUCLEAR SAFETY DESIGN BASES AND PROCEDURAL SAFETY CONTROLS

This calculation has not identified any specific Systems, Structures and Components (SSCs) or procedural safety controls that are important to safety (ITS) or the nuclear safety design bases.

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ATTACHMENT 2 ON 1CD

14. RPC Electronic Media Verification

Attachment 1: Compact Disc Listing

This attachment contains a listing and description of the files contained on the attachment CD of this document (Attachment 2). The zip archives were created using WinZip 9.0 (Section 4.2.3). The attributes of the files contained in the CD are as follows:

Filename	File Size (bytes)	File Date	File Time	Description
HLWG MCNP inputs.zip	615,000	9/15/08	17:30	WinZip file containing all MCNP input files relevant to the HLW glass calculations described in this document (including the HLW Glass Canister/DOE SNF Canister interaction calculations).
HLWG MCNP outputs.zip	10,156,000	9/15/08	17:32	WinZip file containing all MCNP output files relevant to the HLW glass calculations described in this document (including the HLW Glass Canister/DOE SNF Canister interaction calculations).
HHLWG MCNP inputs.zip	4,279,000	12/22/08	17:41	WinZip file containing all MCNP input files relevant to the hypothetical HLW glass calculations described in this document.
HHLWG MCNP outputs.zip	121,138,000	12/19/08	18:50	WinZip file containing all MCNP output files relevant to the hypothetical HLW glass calculations described in this document.
HLWG MCNP Results.xls	150,000	3/4/09	18:34	Microsoft Excel workbook containing the MCNP results (Figures 7-1, 7-5, 7-6 and Tables 7-1 and 7-2) relevant to this document.
HHLWG MCNP Results.xls	2,898,000	3/4/09	18:51	Microsoft Excel workbook containing the MCNP results (Figures 7-2 and 7-3) relevant to this document.
atr_single_can_norm_dry_96_in	25,000	7/28/07	13:45	Base case MCNP model used for representation of the ATR DOE SNF canister in the HLW glass canister – DOE SNF canister interaction calculations performed in this document. Refer to Section 6.2.2.1 for details.
fermi_single_can_norm_dry_96_in	21,000	9/4/07	12:34	Base case MCNP model used for representation of the Enrico Fermi DOE SNF canister in the HLW glass canister – DOE SNF canister interaction calculations performed in this document. Refer to Section 6.2.2.1 for details.
fftf_single_can_norm_dry_96_in	27,000	8/2/07	15:48	Base case MCNP model used for representation of the FFTF DOE SNF canister in the HLW glass canister – DOE SNF canister interaction calculations performed in this document. Refer to Section 6.2.2.1 for details.
fsv_single_can_norm_dry_96_in	17,000	7/28/07	13:50	Base case MCNP model used for representation of the FSV DOE SNF canister in the HLW glass canister – DOE SNF canister interaction calculations performed in this document. Refer to Section 6.2.2.1 for details.
slwbr_single_can_norm_dry_96_in	19,000	7/28/07	13:53	Base case MCNP model used for representation of the SLWBR DOE SNF canister in the HLW glass canister – DOE SNF canister interaction calculations performed in this document. Refer to Section 6.2.2.1 for details.

Filename	File Size (bytes)	File Date	File Time	Description
spwr_single_can_norm_dry_96_in	35,000	7/28/07	13:56	Base case MCNP model used for representation of the SPWR DOE SNF canister in the HLW glass canister – DOE SNF canister interaction calculations performed in this document. Refer to Section 6.2.2.1 for details.
triga_single_can_norm_dry_96_in	16,000	7/28/07	13:58	Base case MCNP model used for representation of the TRIGA DOE SNF canister in the HLW glass canister – DOE SNF canister interaction calculations performed in this document. Refer to Section 6.2.2.1 for details.

There are two hundred and twenty eight (228) files contained in each zip archive file *HLWG MCNP inputs.zip* and *HLWG MCNP outputs.zip*. In addtion, there are six thousand two hundred and sixty eight (6268) files contained in each zip archive file *HHLWG MCNP inputs.zip* and *HHLWG MCNP outputs.zip*. Files suffixed "_in" are input files, whereas files suffixed "_ino" denote output files.