

Calculation Cover Sheet

Complete only applicable items.

2. Calculation Title
Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister




MOL.19990607.0075

3. Document Identifier (including Revision Number)
BBA000000-01717-0210-00051 REV 00

4. Total Pages
58

5. Total Attachments
5

6. Attachment Numbers - Number of pages in each
I-12, II-9, III-20, IV-1, V-1

	Print Name	Signature	Date
7. Originator	Lee M. Montierth		6/03/99
8. Checker	Sedat Goluoglu		6/7/99
9. Lead	J. Wesley Davis		6/7/99

10. Remarks

Revision History

11. Revision No.	12. Description of Revision
00	Initial issue

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 2 of 58

CONTENTS

	Page
1. PURPOSE.....	4
2. METHOD.....	4
3. ASSUMPTIONS.....	4
4. USE OF COMPUTER SOFTWARE AND MODELS	8
4.1 SOFTWARE APPROVED FOR QA WORK	8
4.1.1 MCNP4B2	8
4.2 SOFTWARE ROUTINES	9
4.2.1 Excel	9
5. CALCULATION	9
5.1 CALCULATION INPUTS	9
5.1.1 Description of FFTF Spent Nuclear Fuel.....	9
5.1.2 FFTF Ident-69 Pin Containers	13
5.1.3 Description of DOE SNF Canister.....	14
5.1.4 Co-disposal Waste Package	15
5.1.5 HLW Glass Pour Canisters	16
5.1.6 Description of Degraded Fuel.....	20
5.2 DESCRIPTION.....	22
5.2.1 Fuel Pin Clips/Spacers Degraded in the DFAs Surrounding the Ident-69 Container..	22
5.2.2 Partially Degraded Fuel Pin Cladding in DFAs.....	23
5.2.2.1 Partially Degraded Fuel Pin Cladding in DFAs and Ident-69 Container.....	23
5.2.3 Completely Degraded Fuel Pin Cladding in DFAs.....	23
5.2.4 Assembly Duct Fully Degraded.....	23
5.2.5 Fully Degraded Assembly Duct and Fuel Pin Cladding in DFAs with Intact Basket Assembly.....	24
5.2.6 DOE SNF Canister Basket Assembly Fully Degraded	24
5.2.7 DOE SNF Canister Basket Assembly and Assembly Duct Fully Degraded	24
5.2.8 DOE SNF Canister Basket Assembly and Fuel Pin Cladding Fully Degraded.....	25
5.2.9 DOE SNF Canister Containing Completely Degraded Fuel.....	25
5.2.9.1 DOE SNF Canister with an Intact Ident-69 Container and 5 Degraded DFAs.....	25
5.2.9.2 DOE SNF Canister Containing a Degraded Ident-69 Container and 5 Degraded DFAs.....	26
5.2.9.3 DOE SNF Canister Containing 6 Degraded DFAs.....	26
5.2.10 DOE SNF Canister Containing Degraded Fuel in the Co-disposal Waste Package..	27
5.2.10.1 DOE SNF Canister Containing Intact Ident-69 Container and 5 Degraded DFAs in the Co-disposal Waste Package	27

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 3 of 58

5.2.10.2 DOE SNF Canister Containing Degraded Ident-69 Container and 5 Degraded DFAs in the Co-disposal Waste Package.....	28
5.2.11 DOE SNF Canister Containing Degraded Fuel in the Degraded Co-disposal Waste Package	28
5.3 PLUTONIUM DECAY EFFECTS.....	28
5.4 PROCEDURE.....	28
6. RESULTS	29
6.1 RESULTS WITH PARTIALLY DEGRADED COMPONENTS IN THE DOE SNF CANISTER.....	29
6.1.1 Results for Degraded Fuel Pin Clips/Spacers Inside the DFAs	29
6.1.2 Results for Partially Degraded Fuel Pin Cladding	30
6.1.2.1 Values of k_{eff} for Partially Degraded Fuel Pin Cladding in DFAs and Ident-69 Container	31
6.1.3 Results for Degraded Fuel Pin Cladding with Dispersed Fuel Pellets.....	31
6.1.4 Results for Degraded DFA Ducts	32
6.1.5 Results for Fuel Pins with Degraded Fuel Pin Cladding in the Intact Basket Assembly	33
6.1.6 Values of k_{eff} for Degraded Basket Assembly	35
6.1.7 Results for Intact Fuel Pins in DOE SNF Canister with Degraded Basket Assembly and Assembly Ducts.....	37
6.1.8 Results for Intact Assembly Ducts with Degraded Basket Assembly and Fuel Pin Cladding	39
6.1.9 Results for the DOE SNF Canister Containing Degraded Fuel	42
6.1.9.1 Results for the DOE SNF Canister Containing an Intact Ident-69 Container and Degraded DFAs.....	42
6.1.9.2 Results for the DOE SNF Canister Containing a Degraded Ident-69 Container and Degraded DFAs.....	44
6.1.9.3 Results for the DOE SNF Canister Containing 6 Degraded DFAs.....	44
6.1.10 Results for the DOE SNF Canister Containing Completely Degraded Fuel Components in the Co-disposal Waste Package	45
6.1.10.1 Results for the DOE SNF Canister Containing an Intact Ident-69 Container and Five Degraded DFAs in the Co-disposal Waste Package (Containing Gadolinium).....	46
6.1.10.2 Results for the DOE SNF Canister Containing a Degraded Ident-69 Container and Five Degraded DFAs in the Co-disposal Waste Package (Containing Gadolinium).....	48
6.1.11 Results for the DOE SNF Canister Containing Degraded Fuel or Fuel Components with the Co-disposal Waste Package Contents Degraded.....	49
6.2 RESULTS FOR PLUTONIUM DECAY EFFECTS	51
7. REFERENCES	56
8. ATTACHMENTS	58

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 4 of 58

1. PURPOSE

The purpose of these calculations is to characterize the criticality safety concerns for the storage of Fast Flux Test Facility (FFTF) nuclear fuel in a Department of Energy spent nuclear fuel (DOE SNF) canister in a co-disposal waste package. These results will be used to support the analysis that will be done to demonstrate concept viability related to use in the Monitored Geologic Repository (MGR) environment. The calculations presented here are to be used to evaluate the criticality issues related to these degraded fuels for the post-closure time frame and provide input for canister design.

2. METHOD

The calculational method employed in this calculation is to use the MCNP Version 4B2 computer code (Ref. 7.1) to calculate the effective multiplication factor (k_{eff}) for various geometrical configurations of degraded FFTF fuel.

3. ASSUMPTIONS

- 3.1 Beginning of Life (BOL) pre-irradiation fuel compositions were used for all calculations because it is conservative to assume fresh fuel since it is more neutronically reactive than spent fuel. The dished face of the fuel pellets is neglected for treating intact fuel pellets and the fuel number density is determined by using the fuel mass and the footprint volume of the fuel. The void space in the fuel and other voids in the fuel pin are assumed to contain water since this gives more conservative results (Ref. 7.6, Table 6-13). These assumptions are used throughout Section 5 and are based on engineering judgement.
- 3.2 The uranium in the UO_2 insulators at the top and bottom of the fuel pellet stack is assumed to be composed of natural uranium rather than depleted uranium. This is based on engineering judgement and is used throughout Section 5.
- 3.3 For intact FFTF fuel pins, the spiral wire wrap around each fuel pin, the spring above the upper reflector and the tag gas capsule in each fuel pin are neglected. The basis for these assumptions is that it is conservative because these materials are made of stainless steel and will provide some small amount of neutron absorption. These assumptions are used in Section 5.1.1.
- 3.4 Variations in the cross-sectional area of the flow duct near the ends of the fuel assembly are neglected. The nominal thickness of the flow duct is used in the calculations. These assumptions are used in Section 5.1.1 and are based on engineering judgement.

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 5 of 58

- 3.5 When modelled as intact the Ident-69 pin containers are assumed to contain a most reactive configuration of FFTF fuel pins (Ref. 7.6, Table 6-15). In some cases the cladding on the fuel pins in the Ident-69 container is neglected. This is done to simulate some degree of degradation in the container and results in more conservative results. These assumptions are used in Section 5.1.2, and the basis for these assumptions is that it is conservative to assume a more reactive situation.
- 3.6 The Ident-69 pin containers contain stainless steel plates that divide the containers into several compartments and grid plates that support the fuel pins. These divider plates and grid plates were ignored in order to simplify the model. The basis for this assumption is that it is conservative to neglect these components since they will provide some small amount of neutron absorption and hence reduce k_{eff} of the system. This assumption is used in Section 5.1.2.
- 3.7 The bottom portion of the Ident-69 pin container with reduced diameter is neglected. The basis for this assumption is that it is conservative to neglect this portion of the container since it provides some small amount of neutron absorption and hence a reduction in the k_{eff} of the system. This assumption is used in Section 5.1.2.
- 3.8 The curved bottom carbon steel rupture disk, the 12.7 mm thick curved plate and the 12.7 mm flat plate at each end of the DOE canister were neglected. The ends of the canister were simplified and modeled as "squared off". This assumption is used in Section 5.1.3 and the basis is that it is conservative to neglect this portion of the canister since it provides some small amount of neutron absorption.
- 3.9 The flanged head and neck of the defense high-level waste canister are neglected and the canister is modeled as a right circular cylinder with the same top-to-bottom height as the canister. The canister is assumed to be completely filled with waste. This assumption is used in Section 5.1.4 and the basis is that it is conservative since the additional fuel will make the canister more reactive.
- 3.10 The mass density of the stainless steel is assumed to remain unchanged when doped with gadolinium. The composition of the doped stainless steel is determined by renormalizing the amount of each constituent. This assumption is used throughout Section 5 and is based on engineering judgement.
- 3.11 At least 30 cm of full density water (1.0 g/cm^3) was used in all cases to model water reflection. This is based upon a 30 cm thick water reflector being effectively equivalent to an infinite reflector (Ref. 7.3, p. 106). This assumption is used throughout Section 5.
- 3.12 For degraded mode analysis, stainless steel degrades to goethite, FeOOH , and all other constituents of the steel are neglected. The goethite is assumed to form with void

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 6 of 58

- occupying 40% or more of its volume. The void can be filled with water, fuel and/or remain void. These assumptions are used in Section 5.1.6. The bases for these assumptions are engineering judgement and because it is conservative to neglect the non-iron components of stainless steel since they provide some small amount of neutron absorption.
- 3.13 For degraded mode analysis, the fuel and UO_2 insulators remain chemically unchanged due to degradation. This assumption is used in Section 5.1.6 and is based on engineering judgement.
 - 3.14 For degraded mode analysis, materials mix together homogeneously. This assumption is used in Section 5.1.6 and is based on engineering judgement.
 - 3.15 For degraded mode analysis, the stainless steel content of a driver fuel assembly (DFA) is determined by subtracting the combined weight of the fuel, UO_2 insulators and Inconel reflectors from the total weight of the DFA. The stainless steel is assumed to be Type 316L and to be uniformly distributed over the axial length of the DFA. These assumptions are used in Section 5.1.6 and are based on engineering judgement.
 - 3.16 The divider plates of the basket assembly are assumed to have an effective width of 13 cm. For some cases the length of the basket assembly is assumed to be the same as that of the DFA assembly, 3.6576 m (12 ft), and they are axially aligned. These assumptions are used in Section 5.1.6 and are based on engineering judgement.
 - 3.17 For the degraded Ident-69 pin container, only the outer stainless steel walls of the container are used to determine the amount of goethite produced. The inner duct, divider plates, top and bottom of the container are ignored. The basis for this assumption is that it is conservative to neglect stainless steel since it provides some small amount of neutron absorption and hence a reduction in the k_{eff} of the system. This assumption is used in Section 5.1.6.
 - 3.18 For degraded fuel pins in the Ident-69 pin container, only the cladding is used to determine the amount of goethite produced. The reflectors, springs, end caps, etc. of the fuel pins are ignored. The basis of this assumption is that it is conservative to neglect the contents of these items which are mostly iron since it provides some small amount of neutron absorption and hence a reduction in the k_{eff} of the system. This assumption is used in Section 5.1.6.
 - 3.19 For loose pin configurations, i.e., cases where the fuel pin clips/spacers and assembly duct have degraded and the pins are no longer contained, the placement and stacking of the pins was chosen to give a more reactive configuration rather than a more realistic accounting for gravity. The basis of this assumption is that it is more conservative since

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 7 of 58

it gives a larger k_{eff} for the system. This assumption is used in Sections 5.2.4, 5.2.5 and 5.2.7.

- 3.20 Due to limitations in the MCNP4B2 computer code when modelling loose fuel pins it is sometimes necessary to use a symmetry boundary and represent only half the problem space. Due to the stacking of the fuel pins in the cylindrical canister, the pins are not always exactly symmetric about the plane of symmetry. Also the fuel pins are not always exactly bisected by the symmetry plane. These may result in a non-integer number of fuel pins being modelled. For these cases extra fuel pins are added to insure that at least the correct number of fuel pins is modelled. This assumption is used in Sections 5.2.5 and 5.2.7 and is based on engineering judgement and that it is conservative to model additional fuel pins.
- 3.21 When loose fuel pins surround the intact Ident-69 container, partial fuel pins, i.e., fuel pins that have been cut by the Ident-69 container when modelled in MCNP, are used but additional fuel pins are added so that the total number of fuel pins is at least equal to the correct number. This assumption is used in Section 5.2.7 and the basis is that a few extra pins placed with the same pitch would have either a negligible effect or would have a slightly conservative effect.
- 3.22 For some cases when degraded sludge material surrounds intact fuel components and some of the components are only partially submerged in the sludge, less than the exact amount of sludge (which may also contain gadolinium) is used. The remaining volume is filled with water. This assumption is based on engineering judgement (and it is conservative to neglect neutron absorbers). This assumption is used in Sections 5.2.4 – 5.2.8.
- 3.23 For cases where the basket assembly degrades but the assembly ducts remain intact, the corrosion products (which may also contain gadolinium) formed from the basket structure are assumed to remain outside the assembly ducts. Any corrosion products inside the ducts are assumed to come from the fuel pins and any void space inside the duct is filled with water. This assumption is based on engineering judgement (and it is conservative to neglect neutron absorbers). This assumption is used in Sections 5.2.6 and 5.2.8.
- 3.24 In some cases the corrosion products from the assembly ducts are neglected and the equivalent volume is replaced with water. Since these products would form around the fuel from the DFAs this would have a negligible effect on the results. This assumption is based on engineering judgement and is used in Sections 5.2.4, 5.2.5 and 5.2.7.
- 3.25 For cases where the fuel pin cladding has become completely degraded the remaining fuel pellets are assumed to maintain their axial alignment (as in the fuel pin), and the radial spacing which can be effected by the expansion of corrosion products never becomes

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 8 of 58

greater than the original spacing (pitch) of the DFA. This assumption is based on engineering judgement and is used throughout Section 5.2.

- 3.26 The values used for the densities of stainless steel Type 304L and Type 316L, 7.9 g/cm^3 and 7.9497 g/cm^3 , respectively, are slightly smaller than those used in References 7.11 (p. 2) and 7.12 (p. 2). This results in a smaller mass of stainless steel for a given volume and hence a reduced mass of neutron absorbers. The basis of this assumption is that it is conservative to neglect neutron absorbers. This assumption is used throughout Section 5.
- 3.27 After 24,100 years, more than 99% of Pu-241 and after 48,200 years, more than 99% of Pu-240 decay into Np-237 and U-236, respectively. The remaining quantities of these isotopes at these times are assumed to be zero. This assumption is based on engineering judgement and does not effect the results. This assumption is used in Section 5.3.

4. USE OF COMPUTER SOFTWARE AND MODELS

4.1 SOFTWARE APPROVED FOR QA WORK

4.1.1 MCNP4B2

MCNP4B2 computer code is used to calculate the effective neutron multiplication factor (k_{eff}) for nuclear criticality evaluations (Ref. 7.4).

- Program Name: MCNP
- Version/Revision Number: Version 4B2
- Computer Software Configuration Item (CSCI) Number: 30033 V4B2LV
- Computer Type: Hewlett Packard 9000 Workstations
- Software is installed at the Idaho National Engineering and Environment Laboratory (INEEL) on workstation "bigdog" whose INEEL property number is 336829 and Civilian Radioactive Waste Management System (CRWMS) Management and Operating (M&O) workstation "bloom" whose CRWMS M&O Tag number is 700887.

The input file used is echoed in the output file. The output files are listed in Attachment II.

- a) The MCNP4B2 computer code (Ref. 7.1) is an appropriate tool to be utilized to determine the criticality of a FFTF fuel waste package.
- b) This software has been validated over the range it was used.
- c) It was previously obtained from CRWMS M&O Software Control Management (SCM) in accordance with appropriate procedures.

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 9 of 58

4.2 SOFTWARE ROUTINES

4.2.1 Excel

- Title: Excel
- Version/Revision Number: Microsoft Excel 97

The Excel spreadsheet program was used to perform simple numeric calculations as documented in Section 5 and Attachment I (degraded_2o.xls) of this calculation file. The user-defined formulas, inputs, and results were documented in sufficient detail in Attachment I to allow an independent repetition of the various computations. This software is installed on a personal computer running Microsoft Windows 95 with CRWMS M&O Tag number 113132.

5. CALCULATION

This calculation is based in part on existing data; therefore, use of any results from this calculation for input into document supporting procurement, fabrication, or construction is required to be identified and tracked as TBV (to be verified) in accordance with appropriate procedures.

5.1 CALCULATION INPUTS

The description of the FFTF fuel is from the FFTF description document, Ref. 7.2 (pp. 1-5). All fuel related information is from this reference unless otherwise noted. Compositions for structural and other nonfuel related materials are from References 7.11 through 7.15. The material compositions that were obtained from References 7.7 and 7.11 through 7.15 are considered accepted data. These references are standard handbooks, and due to the nature of these sources, the data in it are established fact and are therefore considered accepted. The high-level waste (HLW) glass composition is from Ref. 7.9 (TBV) and the degraded composition is from Ref. 7.10 (TBV). Avogadro's number and atomic weights are from Ref. 7.5, and are considered accepted due to the nature of the references cited therein. The data from References 7.8 and 7.16 are considered qualified data. The data from References 7.2, 7.5, 7.6, 7.9 and 7.10 are considered existing data. The extra digits shown for measurements in metric units in this report are a result of converting from English units and do not represent enhanced accuracy.

5.1.1 Description of FFTF Spent Nuclear Fuel

The FFTF DFA is hexagonally shaped and contains 217 cylindrical fuel pins. A cross-sectional view of the assembly is shown in Figure 5-1. The total assembly length is 3657.6 mm. The overall height of a fuel pin is 2372.36 mm for types 3.1 and 4.1 fuels, and 2377.44 mm long for types 3.2 and 4.2 fuels. The fuel pin cladding is 0.381 mm (0.015 in.) thick stainless steel of Type 316L. The composition of Type 316L stainless steel is given in Table 5-1 (Ref. 7.11, p. 2). The inner and outer diameters of the cladding are 5.08 mm and 5.842 mm (0.230 in.),

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 10 of 58

respectively. The fueled region of each fuel pin is composed of individual fuel pellets of total length 914.4 mm (36 in.). The fuel pellet outer diameter is 4.9403 mm (0.1945 in.). The ends of the fuel pellets are dished inwardly. The fuel region is centered at 1663.7 mm (65.5 in.) from the bottom of the assembly. Each fuel pin is helically wrapped with a 1.4224 mm (0.056 in.) diameter Type 316L stainless steel wire to provide lateral spacing along its length.

The fuel pins that compose the fuel assembly are arranged in a triangular pitch and are contained within a hexagonal flow duct. The fuel pin pitch is 7.2644 mm (0.286 in.). The fuel density is reported as 90.4% of theoretical density. This corresponds to a fuel meat density of 10.02 g/cm³, or to a theoretical density, ρ_{th} , of 11.084 g/cm³. The fuel is a composition of mixed plutonium and uranium oxide (MOX), PuO_{1.96} and UO_{1.96}. On each end of the fuel region are depleted or natural uranium UO₂ fuel insulator pellets each 20.32 mm (0.8 in.) long. The uranium insulator density is 10.42 ± 0.22 g/cm³. On the outer ends of the uranium insulators are 14.478 cm long Inconel 600 reflectors. The composition of Inconel 600 is given in Table 5-2 (Ref. 7.13, p. 9). The reflector diameter is 4.8133 mm (0.1895 in.). Above the top reflector is a 125.5 mm long region containing a 0.8052 mm diameter Type 302 stainless steel spring. The maximum stainless steel spring volume is 2.7264 cm³. An 862.1 mm long stainless steel (Type 316L) plenum is above the spring, and its outer diameter is 4.9022 mm with a 0.1397 mm wall thickness. The plenum contains a small tag gas capsule that is used to locate leaking fuel pins.

Table 5-1. Chemical Composition of Type 316L Stainless Steel

Element	Weight Percent Range	Value Used
Carbon	0.03 (max)	0.03
Manganese	2.00 (max)	2.00
Phosphorus	0.045 (max)	0.045
Sulfur	0.03 (max)	0.03
Silicon	0.75 (max)	0.75
Chromium	16.00 – 18.00	17.00
Nickel	10.00 – 14.00	12.00
Molybdenum	2.00 – 3.00	2.50
Nitrogen	0.10 (max)	0.10
Iron	Balance	65.545
Density = 7.98 g/cm ³		

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 11 of 58

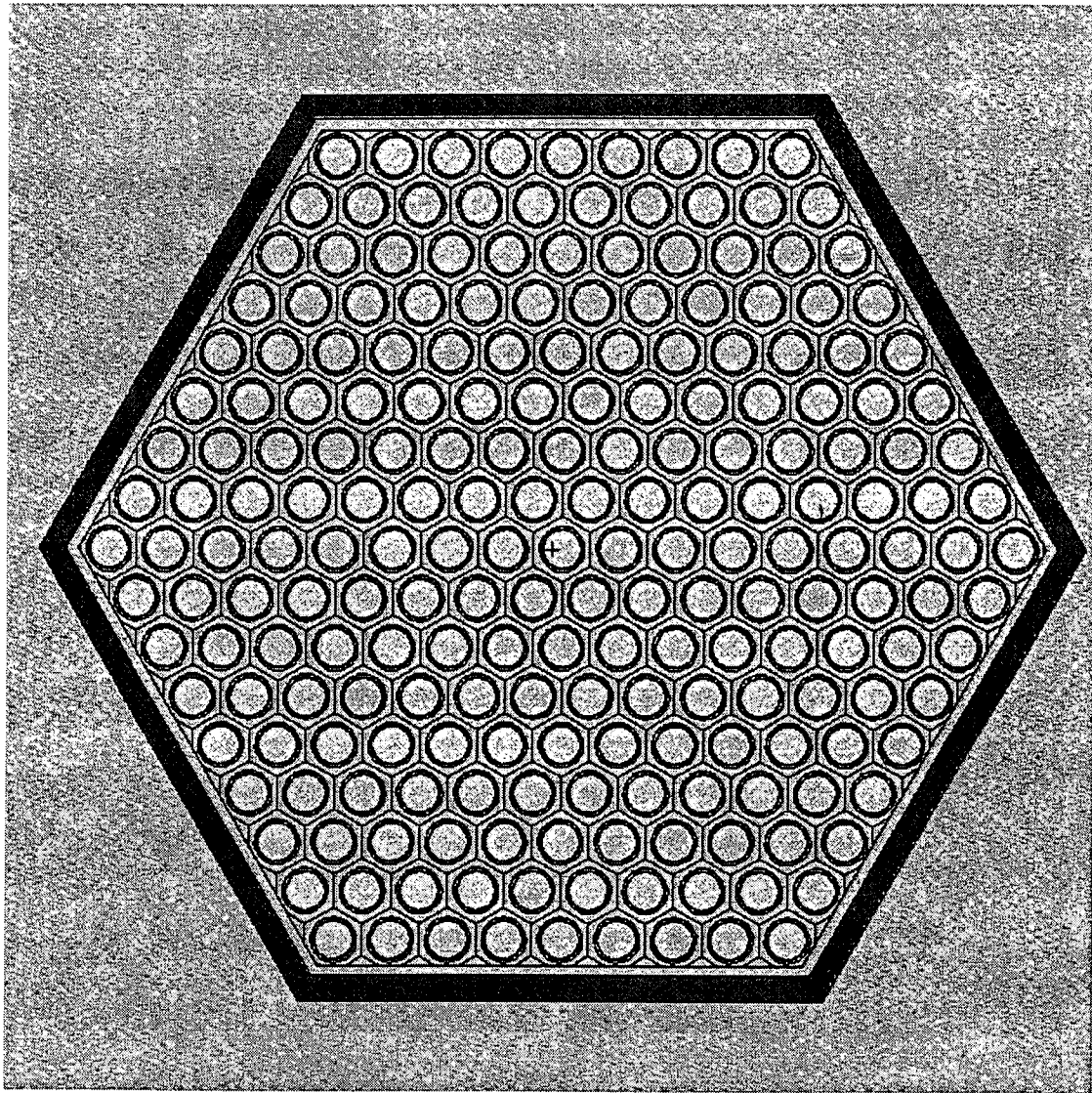


Figure 5-1. Cross-Sectional View of FFTF Assembly

Table 5-2. Chemical Composition of Inconel Alloy 600

Element	Weight Percent Range	Value Used
Nickel	72.00 (min)	74.335
Chromium	14.0 – 17.0	15.5
Iron	6.0 – 10.0	8.0
Carbon	0.15 (max)	0.15
Manganese	1.0 (max)	1.0

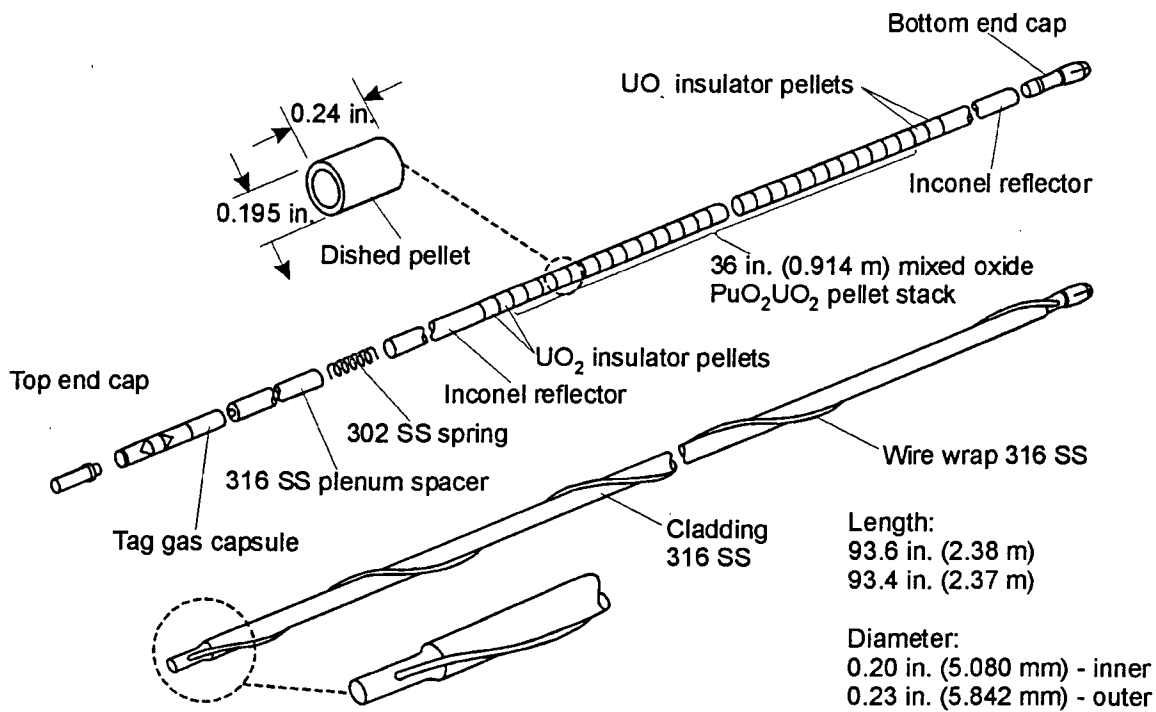
Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 12 of 58

Element	Weight Percent Range	Value Used
Sulfur	0.015 (max)	0.015
Silicon	0.5 (max)	0.5
Copper	0.5 (max)	0.5
Density = 8.47 g/cm ³		

The fuel pin end caps are made of Type 316L stainless steel and have a 5.842 mm diameter. The end cap lengths are 104.6 mm and 35.6 mm for the upper and lower end caps, respectively. The bottom end cap length is 40.6 mm for types 3.2 and 4.2 fuels. A simplified axial view of a fuel pin is shown in Figure 5-2. The fuel composition and isotopic fractions for all four types of fuels are shown in Table 5-3. Using the masses in this table, the chemical formulas for the fuel components and the footprint volume for the fuel the fuel bulk density, ρ_b , is 9.877 g/cm³.



C98 0662 2

Figure 5-2. Standard Driver Fuel Assembly Fuel Pin

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 13 of 58

Table 5-3. Uranium and Plutonium Content of a Fresh DFA (TBV)

		Driver Fuel Type			
		3.1	3.2	4.1	4.2
Plutonium	Enrichment %Pu/(Pu+U)	27.37	22.43	29.28	25.14
	Assembly content, kg	9.071	7.421	9.722	8.333
	Fuel pin content, g	41.8	34.2	44.8	38.4
	Isotopic fraction				
	Pu-239	0.8696	0.8696	0.8711	0.8711
	Pu-240	0.1173	0.1173	0.1163	0.1163
	Pu-241	0.0104	0.0104	0.0102	0.0102
Uranium	Enrichment %U/(Pu+U)	72.63	77.57	70.72	74.86
	Assembly content, kg	24.070	25.666	23.481	24.813
	Fuel pin content, g	110.9	118.3	108.2	114.3
	Isotopic fraction				
		U-235	0.007	0.007	0.002
	U-238	0.993	0.993	0.998	0.998

Note: Each assembly holds nominally 1.5 kg of uranium in insulator pellets.

The driver fuel assembly consists of a hexagonal duct that surrounds the fuel pins, discriminator, inlet nozzle, neutron shield and flow orifice region, load pads and handling socket. The duct is Type 316L stainless steel with a nominal wall thickness of 3.048 mm (0.12 in.). The duct outer dimension is 116.205 mm across the hexagonal flats, and 131.064 mm across opposing hexagonal (rounded) points. The maximum width of the assembly occurs at the load points and is 138.1125 mm across opposite hexagonal points. The DFA height is 3657.6 mm and its weight is 172.819 kg (381 lb).

5.1.2 FFTF Ident-69 Pin Containers

Loose fuel pins from disassembled DFAs are stored in containers called Ident-69 pin containers, or simply Ident-69 containers (Ref. 7.2, p. 5). These containers are 3657.6 mm (144 in.) long and are made of 5 in. Type 304L stainless steel pipe. The composition of Type 304L stainless steel is given in Table 5-4 (Ref. 7.12, p. 2). The actual dimensions of the container are 5.345 in. and 5.563 in. for the inner and outer diameters, respectively. The 5 in. pipe transitions to 2.5 in. pipe (actual dimension is 2.875 in., or 73.02 mm) at 431.8 mm (17 in.) from the bottom. The fuel pins are supported on a grid plate drilled with 1.5875 mm (1/16 in.) holes. This container can hold up to 217 fuel pins. The central compartment of the container has an inner and outer radius of 20.701 mm (0.815 in.) and 22.225 mm (0.875 in.), respectively.

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 14 of 58

Table 5-4. Chemical Composition of Type 304L Stainless Steel

Element	Weight Percent Range	Value Used
Carbon	0.03 (max)	0.03
Manganese	2.00 (max)	2.00
Phosphorus	0.045 (max)	0.045
Sulfur	0.03 (max)	0.03
Silicon	0.75 (max)	0.75
Chromium	18.00 – 20.00	19.00
Nickel	8.00 – 12.00	10.00
Nitrogen	0.10	0.10
Iron	Balance	68.045
Density = 7.94 g/cm ³		

5.1.3 Description of DOE SNF Canister

The description of the DOE SNF Canister is from Ref. 7.8 (Table 3.1 and Appendix A). (Note that REV 00 was used since most of the cases in this report were completed prior to the release of REV 01, and since the minor changes to the canister design have a totally negligible effect on criticality.) The canister is a right circular cylinder of stainless steel (Type 316L). The outside diameter of the canister is 457.2 mm (18 in.) with a wall thickness of 9.525 mm (0.375 in.). (This canister is also referred to as the 18 in. canister.) The nominal internal length of the canister is 4145 mm (163 in.) and the nominal overall length is 4569 mm (179.87 in.). There is a curved bottom carbon steel rupture disk, which varies in thickness from 15.24 mm to 50.8 mm at the top and bottom boundaries of the canister. There is also a 12.7 mm thick curved plate and a 12.7 mm flat plate at each canister end. The plan view of the canister is shown in Figure 5-3. The canister may also contain a stainless steel (Type 316L) basket that is used to hold the fuel components (see Attachment IV for a detailed sketch). The basket serves as a criticality control material and a guide for assemblies during loading. The canister basket positions are to be designed such that the center position can hold either a DFA or an Ident-69 pin container, while the outer positions are designed to hold DFAs. Figure 5-4 shows the cross-sectional view of a DOE SNF canister with a basket assembly containing an Ident-69 pin container surrounded by 5 FFTF assemblies.

The basket assembly consists of a cylindrical center tube and 5 divider plates extending radially from the center tube to the DOE SNF canister inner wall. The center tube is stainless steel (Type 316L) with 153.0 mm inside diameter and 10 mm wall thickness. The divider plates are also stainless steel (Type 316L) with a 10 mm wall thickness. The basket height is 4125 mm.

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 15 of 58

5.1.4 Co-disposal Waste Package

The co-disposal waste package (a detailed sketch is shown in Attachment V) contains 5 HLW canisters surrounding a DOE SNF canister. The waste package barrier materials are typical of those used for commercial SNF waste packages. The inner barrier is composed of a 20 mm thickness of ASTM (American Society for Testing and Materials) B 575 (Alloy 22) and serves as a corrosion resistant material. The composition of ASTM B 575 is given in Table 5-5 (Ref. 7.14, p. 2). The outer barrier is composed of a 100 mm thickness of carbon steel (ASTM A 516 Grade 70) and serves as a corrosion allowance material. The composition of ASTM A 516 Grade 70 is given in Table 5-6 (Ref. 7.15, p. 2). The outside diameter of the waste package is 2120 mm and inside cavity length is 4617 mm. The inner barrier lids are 25 mm thick and the outer barrier lids are 110 mm thick. There is a 30 mm closure lid gap between the upper inner and outer barrier lids. There is a 225 mm long skirt at each end of the co-disposal waste package.

The DOE SNF canister is placed in a 31.75 mm thick carbon steel (ASTM A 516 Grade 70) support tube with a 565 mm nominal outer diameter. The support tube is connected to the inside wall of the co-disposal waste package by web-like carbon steel (ASTM A 516 Grade 70) plates that form emplacement positions for the HLW glass pour canisters equally spaced about the center support tube. This arrangement is shown in Figure 5-5. The support tube and plates are 4597 mm long.

Table 5-5. Chemical Composition of ASTM B 575

Element	Weight Percent Range	Value Used
Carbon	0.015 (max)	0.01
Manganese	0.50 (max)	0.50
Silicon	0.08 (max)	0.08
Chromium	20.00 – 22.5	22.0
Molybdenum	12.5 – 14.5	13.0
Cobalt	2.50 (max)	2.06
Tungsten	2.5 – 3.5	3.0
Vanadium	0.35 (max)	0.35
Iron	2.0 – 6.0	3.0
Phosphorus	0.02 (max)	0
Sulfur	0.02 (max)	0
Nickel	Remainder	56.0
Density = 8.69 g/cm ³		

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 16 of 58

Table 5-6. Chemical Composition of ASTM A 516 Grade 70

Element	Weight Percent Range	Value Used
Carbon	0.30 (max)	0.30
Manganese	0.85 – 1.20	1.025
Phosphorus	0.035 (max)	0.035
Sulfur	0.035 (max)	0.035
Silicon	0.15 – 0.40	0.275
Iron	Balance	98.33
Density = 7.832 g/cm ³		

5.1.5 HLW Glass Pour Canisters

The Hanford fifteen foot HLW canister (Ref. 7.16, pp. 1-2) is a cylindrical stainless steel (Type 304L) shell with an outer diameter of approximately 610 mm (24.00 in.), a wall thickness of 10.5 mm, and a nominal length of 4572 mm. The loaded canister weight is 4200 kg and HLW glass occupies 87% of the volume. The composition of the intact HLW glass is given in Table 5-7 (Ref. 7.9, Attachment 5, p. 3) and the non-actinide composition of the degraded HLW glass is given in Table 5-8 (Ref. 7.10, Tables 5-11 and 5-12). The nominal dimensions of the canister are used for the calculations.

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 17 of 58

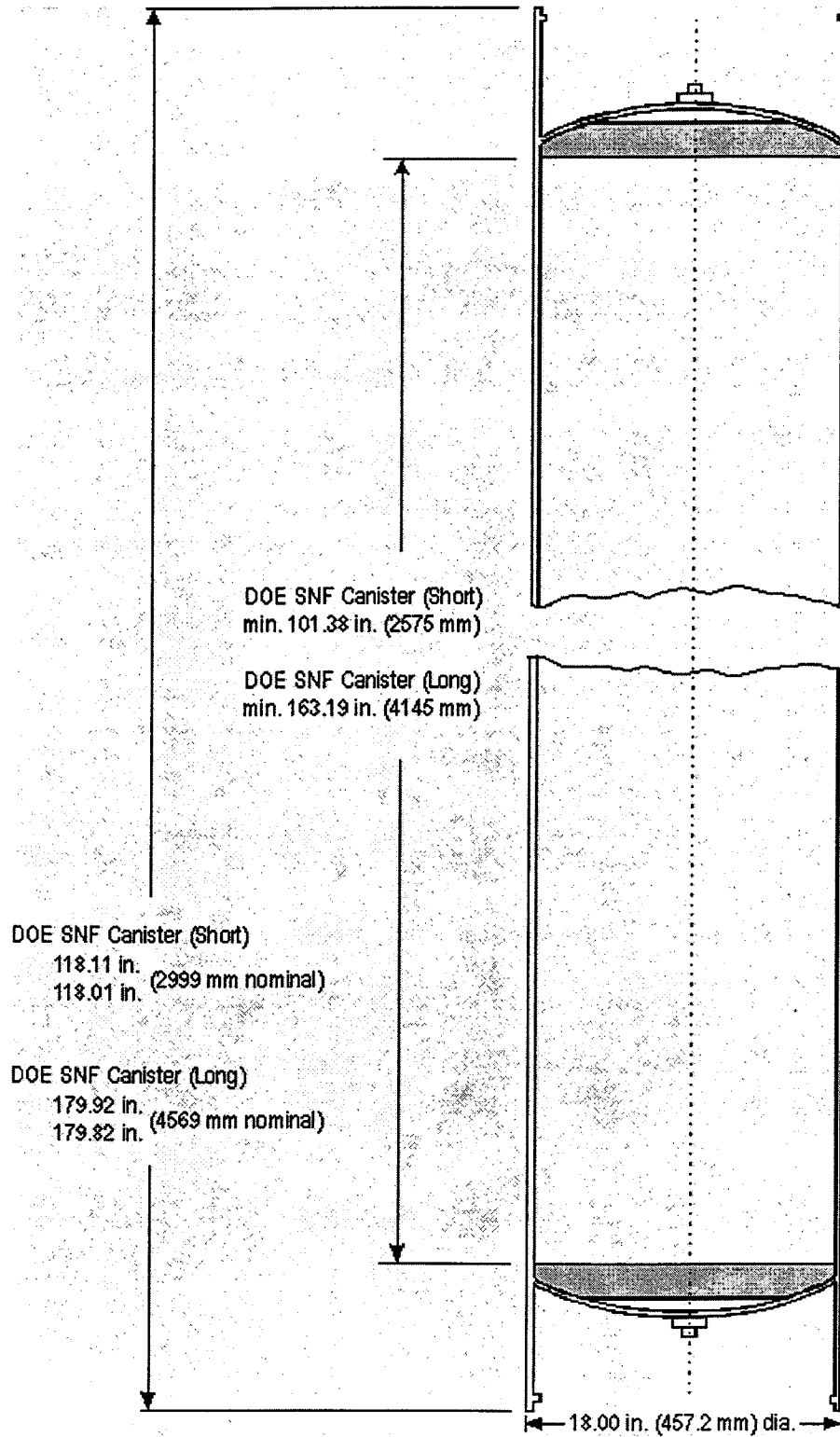
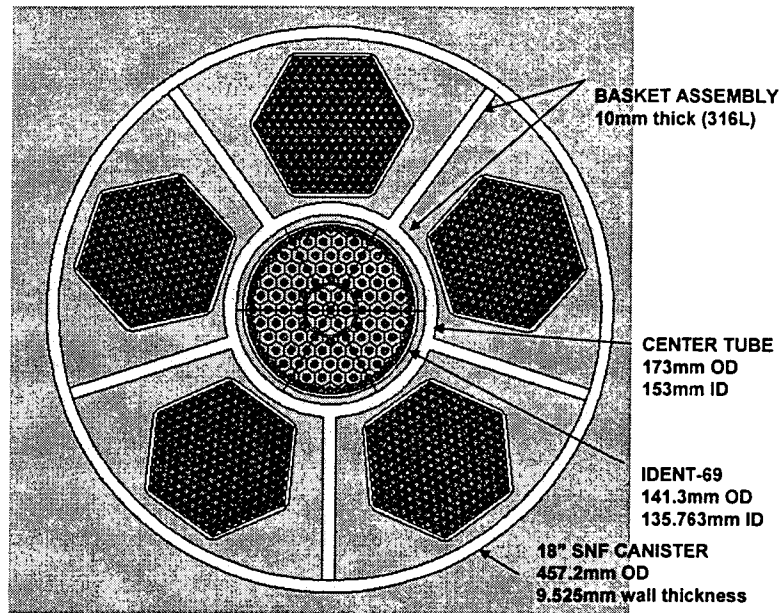


Figure 5-3. Plan View of the Proposed 18 in. DOE SNF Canister

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 18 of 58



FFTF DOE SNF CANISTER

(OD is outer diameter and ID is inner diameter)

Figure 5-4. Cross-Sectional View of the FFTF DOE SNF Canister

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 19 of 58

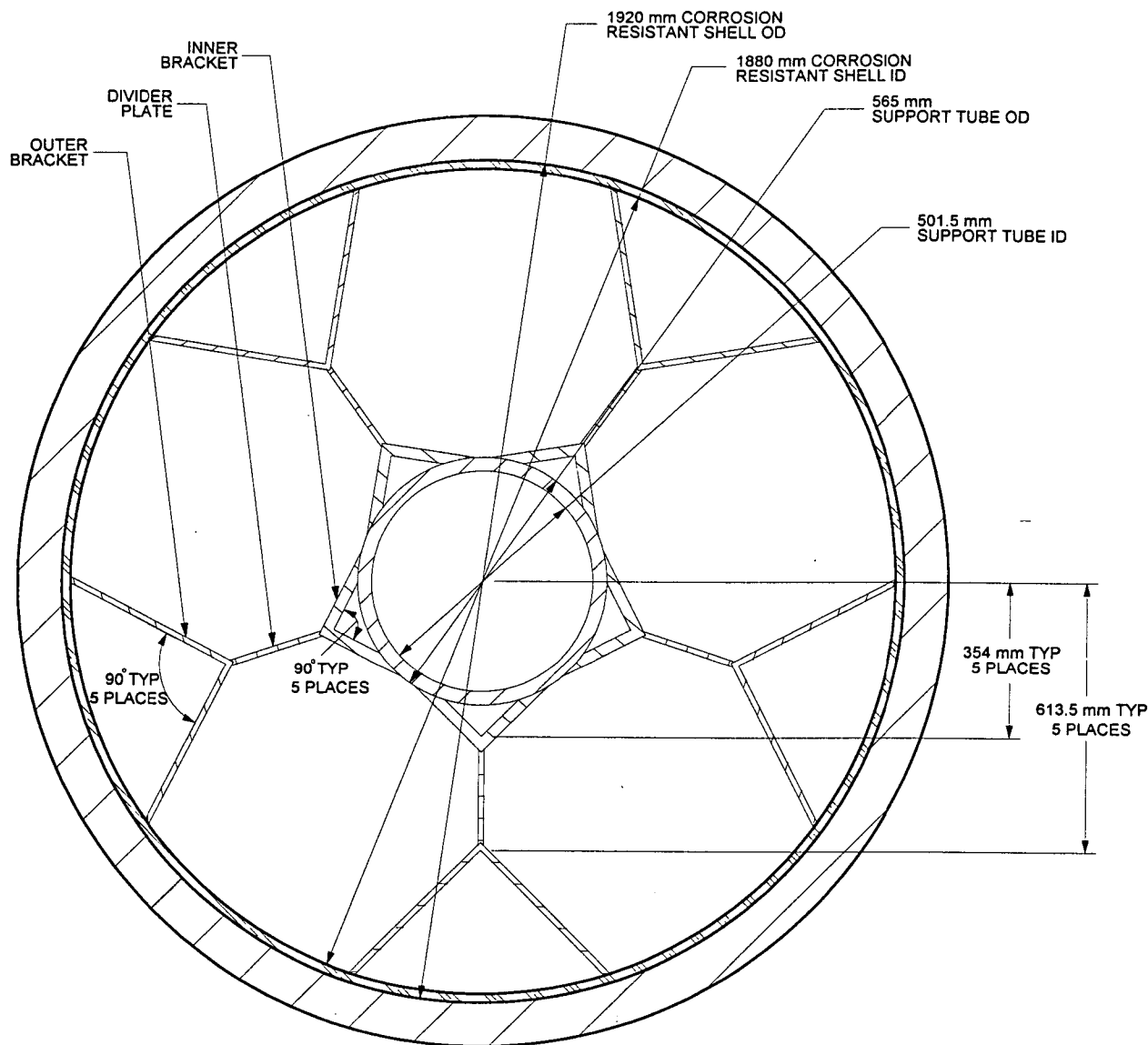


Figure 5-5. 5-Defense High-Level Waste (DHLW)/DOE Spent Fuel-Long Co-disposal Waste Package

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 20 of 58

Table 5-7. Chemical Composition of Intact HLW Glass (TBV)

Element/Isotope	Weight Percent	Element/Isotope	Weight Percent
Lithium-6	0.1080	Lithium-7	1.332
Boron-10	0.6234	Boron-11	2.509
Oxygen	44.102	Fluorine	0.03108
Sodium	8.233	Magnesium	0.8046
Aluminum	2.057	Silicon	21.967
Sulfur	0.1263	Potassium	2.916
Calcium	0.6458	Titanium	0.5823
Manganese	1.520	Iron	7.211
Nickel	0.717	Phosphorous	0.01372
Chromium	0.08055	Copper	0.1489
Silver	0.04906	Barium	0.08083
Lead	0.05948	Chlorine	0.1131
Thorium-232	0.1811	Samarium	0.0004411
Uranium-233	9.727E-09	Uranium-234	0.0003261
Uranium-236	0.001036	Neptunium-237	0.0007509
Uranium-235	0.01734	Uranium-238	3.674
Plutonium-238	0.005153	Plutonium-239	0.01234
Plutonium-240	0.002265	Plutonium-241	0.0009631
Plutonium-242	0.0001906		
Density at 25 °C = 2.85 g/cm ³			

Table 5-8. Non-Actinide Chemical Composition of Degraded HLW Glass at 3765 years (TBV)

Mineral	Mineral Formulae	Mass, kg	Volume, liters
Goethite	FeOOH	7517.8	1761.55
Smectite	[(Ca,Mg) _{0.165} (K,Na) _{0.33}]Fe ₂ Al _{0.33} Si _{3.67} H ₂ O ₁₂	13297.6	4134.53
Pyrolusite	MnO ₂	531.1	104.96
NiFe ₂ O ₄	NiFe ₂ O ₄	1090.9	207.23
Rutile	TiO ₂	140.0	32.99
Diaspore	AlOOH	41.8	12.38
Total Minerals		22619.2	6253.6
Average Density = 3.617 kg/L			

5.1.6 Description of Degraded Fuel

Most of the degraded fuel analysis assumes that only the contents of the DOE SNF canister have become degraded while the remainder of the waste package remains intact. Scenarios are

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 21 of 58

presented where the components in the canister are assumed to be intact, partially degraded and/or completely degraded. For most cases the Ident-69 container is treated as intact but the cladding on the fuel pins in the container is neglected. Some cases treat the basket assembly as being completely degraded whereas others treat it as intact. When degraded, the fuel is assumed to be chemically unchanged, while the iron content of the stainless steel is assumed to decompose into goethite, FeOOH, with a density of 4.28 g/cm³ (Ref. 7.7, p. 3.35). The other constituents of the stainless steel are neglected. The fuel, goethite and water, if present, are assumed to form a homogeneous mixture with the goethite occupying at most 60% of the volume of the mixture. Thus, when fully degraded the fuel components will degrade to goethite and fuel, and the basket assembly will degrade only to goethite.

The mass of stainless steel in a DFA is determined by subtracting the sum of the masses of the fuel, UO₂ insulators and Inconel reflectors from the total mass of the assembly. The mass of stainless steel is then assumed to be uniformly distributed over the length of the assembly. The mass of stainless steel in the basket assembly is determined directly from its volume and density, though the width of the separator plates is taken to be 13 cm which is about 0.26 cm shorter than the distance between the center tube and the inside surface of the DOE canister. The stainless steel content of the fuel pins in the Ident-69 container is determined entirely from the clad, while for the Ident-69 container it is determined solely from the outer wall. Any other stainless steel content is neglected. The stainless steel and iron content of the items in the DOE canister are given in Table 5-9 on a per unit length basis (see Attachment I).

Table 5-9. Stainless Steel, Iron and Fuel Content of Items in DOE Canister

	DFA	Basket Assembly	Fuel Pins	Ident-69 container
Mass of stainless steel, kg/m	33.8654	92.3818	0.0520	9.5189
Mass of iron, kg/m	22.1971	60.5517	0.0341	6.4771
Mass of goethite, kg/m	35.3124	96.3291	0.05420	10.3042
Volume of goethite, cm ³ /m	8.2506x10 ³	2.2507x10 ⁴	12.6597	2.4075x10 ³
Volume of fuel and insulator, cm ³	3.9726x10 ³	0	18.3070	0

The mass and volume of goethite as well as the volume of the fuel and UO₂ insulators are also given in Table 5-9. This information is used to determine the material compositions for when these components become degraded.

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 22 of 58

5.2 DESCRIPTION

The models used in this calculation assume that the FFTF fuel pins, assemblies and Ident-69 container are intact and/or partially or completely degraded. For intact cases, the fuel number density is determined by using the fuel masses, given in Table 5-3, and the footprint volume of the fuel. Number densities and volumes are calculated by an Excel spreadsheet that is listed in Attachment I. Using this volume, which is greater than the actual volume of the fuel, results in a slightly smaller density than that given in Section 5.1.1. The Ident-69 pin containers contain intact fuel pins and do not contain pulverized fuel. In some cases the fuel pin cladding in the Ident-69 pin container is neglected to simulate some degree of degradation. The bottom portion of the Ident-69 container with the reduced diameter is neglected. In cases where an Ident-69 container is surrounded by DFAs, the fueled portions of the pins inside the Ident-69 container are assumed to be axially aligned with the fueled portions of the DFAs. Unless otherwise noted, the DOE SNF canister is modelled containing an intact Ident-69 container in the center position of the basket assembly surrounded by 5 DFAs in the basket assembly's outer positions (see Figure 5-4). The basket assembly is assumed to be doped with gadolinium. The vacant spaces in the DOE canister are assumed to be fully flooded with water. The DOE canister is inside the co-disposal waste package, which also contains 5 HLW canisters. The contents of the co-disposal waste package are assumed to be intact unless otherwise noted.

Since the cases presented here model water and goethite slurries which in many cases also contain fuel, it is important to determine the sensitivity of the results to a $S(\alpha, \beta)$ treatment of the hydrogen cross-sections in the fuel slurry. The $S(\alpha, \beta)$ treatment is necessary to account for the effect of molecular vibrations of bound hydrogen atoms in water molecules on neutrons as they approach thermal energies. Since only part of the hydrogen in the fuel slurry is bound as water, using a $S(\alpha, \beta)$ treatment for water is not exactly correct. Typically not using the $S(\alpha, \beta)$ treatment is conservative for a water fuel mixture as long as it does not contain a strong thermal neutron poison (such as gadolinium). Thus it is necessary to determine the most conservative modelling method for treating slurries, even if it may be overly conservative.

Typically the amount of gadolinium in the basket assembly is increased until the value of k_{eff} is reduced to 0.93 or smaller. If the addition of gadolinium does not sufficiently decrease k_{eff} then either fuel components are removed or other strategies and/or restrictions are investigated. One method of accomplishing this is by removing the ring of fuel pins around the inside circumference of the Ident-69 container. The Ident-69 container becomes less reactive and is referred to as being "less reactive". Removing these pins does not reduce the conservatism of the calculations since this configuration is overly conservative because the pins would not maintain this configuration when positioned horizontally in the container.

5.2.1 Fuel Pin Clips/Spacers Degraded in the DFAs Surrounding the Ident-69 Container

The fuel pin clip/spacers holding the pins in the DFAs are assumed to have degraded. All other components in the DOE canister are modelled as being fully intact. The spacing between fuel

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 23 of 58

pins is varied from the initial pitch of the fuel pins until the fuel pins are touching. The fuel pins remain in a hexagonal array, and due to the influence of gravity the array is no longer centered in the assembly duct.

5.2.2 Partially Degraded Fuel Pin Cladding in DFAs

The fuel pin cladding for the fuel pins in the DFAs is modelled as being partially to completely degraded and the fuel pin clips are completely degraded. The amount of remaining clad is varied and the degraded cladding forms goethite that surrounds the fuel pins. For the case of completely degraded cladding the fuel pellets are assumed to remain touching and axially aligned. The pins also remain in a hexagonal array. The water volume fraction in the goethite is varied. This sludge maintains a separation between fuel pins, but in no case does the separation increase more than the original pin separation of the DFA. The fuel pin cladding in the Ident-69 container is completely neglected for all cases except one to simulate the effects of degradation in the container. All other components in the DOE canister are modelled as being fully intact.

5.2.2.1 Partially Degraded Fuel Pin Cladding in DFAs and Ident-69 Container

This case is similar to Section 5.2.2 except the degraded portion of the cladding is neglected and the fuel pins maintain their original separation. Also, the same amount of degradation is assumed for the fuel pins in the Ident-69 container and the degraded portion is neglected.

5.2.3 Completely Degraded Fuel Pin Cladding in DFAs

The fuel pin cladding and pin clips/spacers are completely degraded and the fuel pellets remain intact. The goethite sludge with variable water volume fraction separates the pellets in both the axial and radial directions. The amount of water in the sludge determines the separation, but in no case does the radial separation exceed the original pin separation of the DFA. The pellets retain their axial alignment. The fuel pin cladding in the Ident-69 container is neglected. Cases are also presented where the fuel in the DFAs and the Ident-69 container is displaced in the axial direction. A case is also presented where every other column of fuel pellets in the DFAs is displaced in the axial direction so that the centers of the pellets in one column align with the tops of the pellets in the adjacent columns. All other components in the DOE canister are modelled as being fully intact.

5.2.4 Assembly Duct Fully Degraded

The assembly duct surrounding each DFA and the fuel pin clips/spacers are fully degraded. The corrosion products from the degraded ducts are neglected. All other components in the DOE canister are modelled as being fully intact. The fuel pins from the DFAs are scattered in each compartment of the basket assembly and are stacked touching one another in an irregular array. If the fuel pins are touching their nearest neighbors, different portions of the array are in a triangular, square or somewhere between a triangular and square lattice. Also, a case with a

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 24 of 58

random positioning of fuel pins is investigated to account for pins falling into the canister. The two limiting cases for the orientation of the DOE canister are with a basket assembly divider plate at the 12 and 6 o'clock positions (see Figure 5-4 which shows the divider plate at the 6 o'clock position). A more reactive case of interest is also modelled with a symmetry boundary condition. This is done since cases in Sections 5.2.5 and 5.2.7 are modelled with a symmetry boundary condition due to limitations in the MCNP code. These cases do not have exact symmetry due to the irregular spacing of the fuel pins. The fuel pin cladding in the Ident-69 container is neglected for all cases but one.

5.2.5 Fully Degraded Assembly Duct and Fuel Pin Cladding in DFAs with Intact Basket Assembly

The assembly duct, fuel pin cladding and fuel pin clips/spacers are fully degraded but the basket assembly remains intact. This leaves individual fuel pellets that are axially aligned in each of the positions of the basket assembly. The corrosion products from the fuel pin cladding with varying volume fractions of water maintain separation between the fuel pellets in both the radial and axial directions. The radial separation is never assumed to be greater than the original pin separation in the intact DFAs. The corrosion products from the assembly ducts are neglected. The DOE canister is oriented in the same direction as the worst case found in Section 5.2.4. All other components in the DOE canister are modelled as being fully intact.

5.2.6 DOE SNF Canister Basket Assembly Fully Degraded

The DOE SNF canister basket assembly becomes fully degraded and the Ident-69 container or center DFA and the surrounding DFAs fall to the bottom of the canister. The goethite sludge with varying volume fractions of water surrounds these fuel components. The spacing between the Ident-69 container or center DFA and the surrounding DFAs is also varied. All other components in the DOE canister are modelled as being fully intact.

If the gadolinium poison is ineffective in sufficiently reducing k_{eff} then additional strategies will be investigated. These include the following changes to the Ident-69 container: assuming a less reactive fuel pin configuration inside the container; gadolinium doping in the duct of the container; assuming a gadolinium doped basket assembly is used in the container; the container is filled with iron shot containing gadolinium; and gadolinium is homogeneously distributed in the water inside the container. Also derating the fuel loading of the canister by reducing the number of DFAs is investigated.

5.2.7 DOE SNF Canister Basket Assembly and Assembly Duct Fully Degraded

The DOE SNF canister basket assembly, the assembly ducts and the fuel pin clips/spacers are fully degraded and intact fuel pins and intact Ident-69 container or pins from the center DFA fall to the bottom of the canister. The fuel pins are touching one another and surround the Ident-69 container, if present. The goethite sludge formed from the corrosion products of the basket

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 25 of 58

assembly and assembly ducts surrounds the pins and Ident-69 container. The position of the Ident-69 container relative to the closest edge of the DOE canister is varied. All other components in the DOE canister are modelled as being fully intact. A few cases are presented with clad fuel pins in the Ident-69 container.

5.2.8 DOE SNF Canister Basket Assembly and Fuel Pin Cladding Fully Degraded

The DOE SNF canister basket assembly, fuel pin cladding and fuel pin clips/spacers are fully degraded. The fuel pellets remain in the assembly ducts and together with the Ident-69 container or center DFA fall to the bottom of the canister. The goethite sludge from the fuel cladding remains around the fuel pins and separates the fuel pellets in the radial and axial directions. The goethite sludge formed from the basket assembly surrounds the Ident-69 container and the ducts containing the fuel pellets. The worst cases from Sections 5.2.3 and 5.2.6 are used as starting points for this case. Also as in Section 5.2.6, if the gadolinium is ineffective in reducing k_{eff} then additional strategies are investigated, including a less reactive Ident-69 container and decreasing the number of DFAs in the canister. All other components in the DOE canister are modelled as being fully intact.

5.2.9 DOE SNF Canister Containing Completely Degraded Fuel

For all cases the contents of the DOE SNF canister are assumed to have settled on the bottom of the canister which is horizontally positioned. The canister is assumed intact for all cases. The axial loading of iron is preserved in all cases, and the fuel is assumed to have either settled in its initial 0.9144 m (3 ft) or to be uniformly distributed over some greater length up to a maximum of 3.6576 m (12 ft) which is the length of the assembly. The goethite is assumed to occupy at most 60% of the volume of the homogeneous mixture of materials. In the fueled portion of the mixture, water and fuel occupy the void in the goethite, while in the non-fueled region it is occupied by water. For most cases the unoccupied region of the canister is filled with water. The DOE canister is fully reflected by water when not modelled in the co-disposal container. The basket assembly is assumed to be 3.6576 m (12 ft) long.

5.2.9.1 DOE SNF Canister with an Intact Ident-69 Container and 5 Degraded DFAs

The composition of the degraded DFAs is determined from Table 5-9 for different lengths of the fueled region. The remaining length of the DFA is composed of goethite and water. The Ident-69 container is positioned radially, axially and in angle so that the fueled region of the fuel pins in the Ident-69 container is centered in the degraded fuel mixture. The various volumes and volume fractions of water for this case are shown in Table 5-10 (see Attachment I) where the goethite was chosen to be 0.6. The volume listed in the table for the Ident-69 container corresponds to the container's volume that is surrounded by the degraded fuel mixture.

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 26 of 58

Table 5-10. Information for an Intact Ident-69 Container Surrounded by 5 Degraded DFAs

Length of Degraded Fuel Region, m	Volume of Fuel and Goethite in Degraded Fuel Region, cm ³	Total Volume of Degraded Fuel Region, cm ³	Volume Fraction of Water in Degraded Fuel Region	Total Volume of Degraded Fuel and Ident-69 Container, cm ³
0.9144	7.8165x10 ⁴	9.7170x10 ⁴	0.19558	1.1151x10 ⁵
1.5240	1.1703x10 ⁵	1.6195x10 ⁵	0.27735	1.8585x10 ⁵
2.1336	1.5590x10 ⁵	2.2673x10 ⁵	0.31239	2.6019x10 ⁵
3.0480	2.1420x10 ⁵	3.2390x10 ⁵	0.33867	3.7169x10 ⁵
3.6576	2.5307x10 ⁵	3.8868x10 ⁵	0.34890	4.4603x10 ⁵

Additional cases are presented that contain gadolinium, vary the volume fraction of water in the degraded fuel region and vary the density of water in the DOE canister. For these cases, gadolinium is added to the goethite along the length of the degraded region and water is replaced by void in the degraded fuel region.

5.2.9.2 DOE SNF Canister Containing a Degraded Ident-69 Container and 5 Degraded DFAs

The composition of the degraded fuel region is determined from Table 5-9. Since the Ident-69 container is capable of holding 217 pins, volume information for the goethite, fuel and water in the degraded fuel slurry, for a full container, an empty container and a half-filled container is tabulated in Table 5-11 (see Attachment I). These results are for a degraded fuel region 0.9144 m (3 ft) in length, and the goethite volume fraction is 0.6. The fueled portion of the pins in the Ident-69 container and the DFAs are assumed to be aligned so that all the fuel coalesces when degraded. Results for various amounts of gadolinium are also presented.

Table 5-11. Volume Information for a Degraded Ident-69 Container and 5 Degraded DFAs in a 0.9144 m (3 ft) Fuel Region

Number of Fuel Pins Initially in Ident-69 Container	Volume of Goethite in Degraded Fuel Region, cm ³	Total Volume of Degraded Fuel Region, cm ³	Volume of Fuel in Degraded Fuel Region, cm ³	Volume Fraction of Water in Degraded Fuel Region
0	6.0503x10 ⁴	1.0084x10 ⁵	1.9863x10 ⁴	0.20302
109	6.1765x10 ⁴	1.0294x10 ⁵	2.1859x10 ⁴	0.18766
217	6.3015x10 ⁴	1.0503x10 ⁵	2.3836x10 ⁴	0.17305

5.2.9.3 DOE SNF Canister Containing 6 Degraded DFAs

The composition of the degraded DFAs is determined from Table 5-9 for different fueled region lengths. The remaining length of the assembly is composed of goethite and water. Volume

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 27 of 58

information for the goethite, fuel and water content of the fuel slurry that is used in the calculations is presented in Table 5-12 for a 0.6 goethite volume fraction and for different degraded fuel region lengths (see Attachment I). Additional results are presented for gadolinium and for different volume fractions of goethite.

Table 5-12. Information for 6 Degraded DFAs

Length of Degraded Fuel Region, m	Volume of Fuel and Goethite in Degraded Fuel Region, cm ³	Total Volume of Degraded Fuel Region, cm ³	Volume Fraction of Water in Degraded Fuel Region
0.9144	8.9682x10 ⁴	1.0974x10 ⁵	0.18280
1.5240	1.3358x10 ⁵	1.8291x10 ⁵	0.26968
2.1336	1.7748x10 ⁵	2.5607x10 ⁵	0.30692
3.0480	2.4332x10 ⁵	3.6581x10 ⁵	0.33484
3.6576	2.8722x10 ⁵	4.3897x10 ⁵	0.34570

5.2.10 DOE SNF Canister Containing Degraded Fuel in the Co-disposal Waste Package

The DOE canisters are now positioned in the co-disposal waste package to determine k_{eff} for the waste package. The DOE canister is positioned either in the center of the co-disposal waste package or just slightly offset from the center so as to account for the canister's displacement due to gravity. For most cases vacancies in the co-disposal waste package are treated as voids. The co-disposal waste package is fully reflected by water for all cases.

5.2.10.1 DOE SNF Canister Containing Intact Ident-69 Container and 5 Degraded DFAs in the Co-disposal Waste Package

This set of cases examines the effect of water content in the SNF canister and the fuel sludge. The most reactive case determined from Section 5.2.9.1 for an intact Ident-69 container with 5 degraded DFAs is used for these cases. To account for gravity, the HLW canister is slightly displaced from the center of the co-disposal waste package. Three cases are shown where the Ident-69 container is centered, sunk to the bottom and at the top just covered by the degraded fuel. The goethite volume fraction is varied for the most reactive Ident-69 container orientation which in turn varies the water volume fraction.

The effect of varying water density in the DOE canister is investigated. For these cases the goethite volume fraction is taken to be 0.6, the Ident-69 container contains full density water and the density of the water in the rest of the DOE canister is varied. The vacant spaces outside the canister but inside the co-disposal waste package are treated as voids. Similarly, the effect of varying the water content in the degraded fuel mixture is also investigated. For these cases the fraction of the minimum water content in the fuel sludge (the goethite volume fraction is 0.6) is varied from 0, i.e., no water content, to 1, or the minimum amount assumed which corresponds

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 28 of 58

to a 0.1956 volume fraction. The water volume fraction in the goethite adjacent to the fuel is similarly varied. For these cases the water is replaced with void so that the slurry volumes remain unchanged. The rest of the canister is filled with full density water. Vacant spaces in the co-disposal waste package are treated as voids.

5.2.10.2 DOE SNF Canister Containing Degraded Ident-69 Container and 5 Degraded DFAs in the Co-disposal Waste Package

The effect of a placing the DOE canister filled with a fully degraded Ident-69 container and degraded DFAs in a co-disposal waste package is determined. The Ident-69 container is assumed to have been either empty, half full or completely filled with fuel pins (217 pins). The portion of the DOE canister not filled with degraded materials is filled with full density water. Vacancies in the co-disposal waste package are treated as voids.

5.2.11 DOE SNF Canister Containing Degraded Fuel in the Degraded Co-disposal Waste Package

The contents of the co-disposal waste package are assumed to be degraded and the DOE SNF canister is positioned among these degradation products. The degraded contents of the waste package form a clay-like material. The contents of the canister are taken from some of the worst cases described in Sections 5.2.1 – 5.2.10. The composition of the co-disposal waste package is taken from Ref. 7.10 (Tables 5-12 and 5-13). The minimum distance between the outer edge of the canister and the co-disposal waste package is varied.

5.3 PLUTONIUM DECAY EFFECTS

Due to the long time periods considered in degraded calculations the decay of plutonium isotopes must be considered. Pu-239 decays to U-235 with a half-life of 24,100 years (Ref. 17, pp. 46, 47). Pu-240 decays to U-236 with a half-life of 6,560 years. Pu-241 decays to Np-237 through a beta decay followed by an alpha decay with total half-life of 447.1 years. Selected cases from the scenarios described in previous sections are modified to account for the decay effects. The results of these calculations are given in Section 6.2. Selected cases from the intact scenarios described in Ref. 6 are also modified to account for the decay effects.

5.4 PROCEDURE

The MCNP code tracks neutrons through the geometry and materials specified in the input and statistically determines the multiplication factor, k_{eff} , of neutrons from one generation to the next. For the results to be valid, k_{eff} must be converged which requires that there be an adequate sourcing of neutrons and a sufficient number of generations and particles per generation. The MCNP code provides diagnostics to show convergence that must be verified by the user.

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 29 of 58

The number densities of the FFTF fuel and structural materials are calculated using Excel spreadsheets and are given in Attachment I.

6. RESULTS

These results are based in part on existing data; therefore, use of any results from this calculation for input into document supporting procurement, fabrication, or construction is required to be identified and tracked as TBV in accordance with appropriate procedures.

The gadolinium content of the basket assembly is given on a per unit mass basis as a weight percent. Since the cases for the completely degraded fuel components assume a basket length of 3.6576 m (12 ft), the mass of gadolinium given for these cases is based on this length rather than the actual length of 4.125 m. This gives a mass that is 88.67% smaller than the actual mass that would be in the canister. The gadolinium mass reported in the tables is based on the actual length of the basket assembly, 4.125 m, unless otherwise noted.

The ratio of the number of hydrogen atoms to the number of fissile atoms, H/X, and the average energy of neutrons causing fission (AENCF) are given in Attachment III for all cases listed in Section 6. For homogeneous fuel slurries, the H/X ratio is simply the ratio of the number density for hydrogen divided by the sum of the number densities for the fissile isotopes, whereas for heterogeneous fuels the number densities are volume averaged over the lattice cell. For most cases the lattice cell is hexagonal, but for the case of loose fuel pins different parts of the array of pins are in a square, hexagonal or irregular (somewhere between square and hexagonal) lattice cell. For this latter case, the average of the H/X ratio for the square and hexagonal lattice cell is reported. The AENCF is the neutron energy per source particle lost to fission divided by the weight per source neutron lost to fission from the "problem summary section" of a MCNP output.

6.1 RESULTS WITH PARTIALLY DEGRADED COMPONENTS IN THE DOE SNF CANISTER

6.1.1 Results for Degraded Fuel Pin Clips/Spacers Inside the DFAs

Values of k_{eff} for the case of degraded fuel pin clips/spacers in the DFAs are shown in Table 6-1. In all cases the pitch, or center-to-center spacing between fuel pins, is uniform within the DFAs. The pitch in Table 6-1 is expressed as a fraction of the difference between the original fuel pin pitch and the minimum pitch. This fraction is referred to in the tables as the "pitch fraction" and is simply $(p - p_{\text{min}})/(p_{\text{org}} - p_{\text{min}})$ where p is the pitch, p_{org} is the original pitch of the intact DFA, 0.72644 cm, and p_{min} is the minimum pitch which occurs when the pins are touching and is simply the pin diameter, 0.5842 cm. The fuel pins are essentially touching for the smallest value of the pitch fraction listed in the table. The gadolinium content is listed in the table as a weight percent of the basket assembly and as the total weight of gadolinium in the canister. The fuel pin cladding in the Ident-69 container is included. These cases are described in Section 5.2.1.

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Table 6-1. Results for Degraded Fuel Pin Clips/Spacers

Pitch Fraction	Gd Content	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
0	0.5% (1.905 kg)	0.8005 ± 0.0011	0.8027	gcombd_gd_.5_p_.00.o
0.25	0.5% (1.905 kg)	0.8149 ± 0.0010	0.8169	gcombd_gd_.5_p_.25.o
0.50	0.5% (1.905 kg)	0.8333 ± 0.0010	0.8352	gcombd_gd_.5_p_.50.o
0.75	0.5% (1.905 kg)	0.8528 ± 0.0010	0.8549	gcombd_gd_.5_p_.75.o
1.0	0.5% (1.905 kg)	0.8724 ± 0.0011	0.8745	gcombd_gd_.5_p_1.0.o
1.0	0.1% (0.3811 kg)	0.8929 ± 0.0011	0.8950	gcombd_gd_.1_p_1.0.o
1.0	0	0.9301 ± 0.0010	0.9320	gcombd_gd_.0_p_1.0.o

6.1.2 Results for Partially Degraded Fuel Pin Cladding

Results are given in Table 6-2 for the case of partially degraded fuel pin cladding and fuel pin clips/spacers in the DFAs. This case is described in Section 5.2.2. Varying fractions of the fuel pin cladding thickness are assumed to remain and the goethite sludge surrounds the fuel pins. This causes the fuel pins to remain radially separated. The volume fraction of water in the sludge determines the separation between the fuel pins. The maximum volume fractions of water listed in the table for each amount of remaining cladding correspond to the original pin separation in the DFAs. The gadolinium content in the basket assembly is 0.1% or 0.3811 kg in the entire basket assembly. The fuel pin cladding in the Ident-69 container is neglected for all cases except the next to the last case listed in the table. The last case uses the S(α,β) for the goethite sludge

Table 6-2. Partially Degraded Fuel Pin Cladding

Fraction of Cladding Thickness Remaining	Volume Fraction of Water in Goethite	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
0.50	0.40	0.8620 ± 0.0011	0.8641	hxgcomb_gd_.1_cl_.50_wat_.4.o
0.50	0.71	0.9129 ± 0.0010	0.9148	hxgcomb_gd_.1_cl_.50_wat_.706.o
0.25	0.40	0.8779 ± 0.0010	0.8800	hxgcomb_gd_.1_cl_.25_wat_.4.o
0.25	0.60	0.9145 ± 0.0010	0.9166	hxgcomb_gd_.1_cl_.25_wat_.60.o
0	0.40	0.8895 ± 0.0011	0.8918	hxgcomb_gd_.1_cl_.00_wat_.4a.o
0	0.52	0.9157 ± 0.0010	0.9178	hxgcomb_gd_.1_cl_.00_wat_.52a.o
^A 0	0.52	0.9017 ± 0.0011	0.9038	hxgcomb_gd_.1_cl_.00_wat_.52a+c.o
^B 0	0.52	0.9093 ± 0.0011	0.9115	hxgcomb_gd_.1_cl_.00_wat_.52aS.o

^APrevious case but pins clad in Ident-69 container.

^BS(α,β) treatment in goethite sludge.

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 31 of 58

6.1.2.1 Values of k_{eff} for Partially Degraded Fuel Pin Cladding in DFAs and Ident-69 Container

Results for fuel pins with degraded cladding are given in Table 6-3 for the case where the degraded portion of the cladding is neglected. This is similar to the results in Section 6.1.2 but neglects the degraded cladding in both the DFAs and Ident-69 container. This case is described in Section 5.2.2.1. The gadolinium content in the basket assembly is 0.5% or 1.905 kg in the entire basket assembly unless otherwise specified. The last 5 cases in Table 6-3 show the effect of gravity, i.e., pins have fallen or settled in the DFAs, is slight whereas the effect is slightly greater if the DOE SNF canister is rotated by 180°.

Table 6-3. k_{eff} for the Case of Cladding Degradation in the DFAs and the Ident-69 Container

Fraction of Cladding Thickness Remaining	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
0.50	—	0.8970 ± 0.0010	0.8990	gcomb_gd_5_cl_50.o
0.25	—	0.9042 ± 0.0011	0.9065	gcomb_gd_5_cl_25.o
0	—	0.9177 ± 0.0011	0.9199	gcomb_gd_5_cl_00.o
0	Pins fallen in DFA duct	0.9128 ± 0.0011	0.9150	gcomb_gd_5_cl_00a.o
0	Canister rotated 180°	0.9206 ± 0.0011	0.9227	gcomb_gd_5_cl_00_rot.o
0	Canister rotated 180°, less reactive Ident-69, 2% Gd	0.8594 ± 0.0011	0.8617	i6030t.o
0	Canister rotated 180°, 6 DFAs, 2% Gd	0.8368 ± 0.0010	0.8388	d6030t.o
0	Canister rotated 180° and pins fallen in DFA duct	0.9147 ± 0.0011	0.9168	gcomb_gd_5_cl_00_rot_a.o

6.1.3 Results for Degraded Fuel Pin Cladding with Dispersed Fuel Pellets

Results are given in Table 6-4 for fuel pellets dispersed in the goethite sludge as described in Section 5.2.3. In this case the fuel cladding is completely degraded and the fuel pellets are dispersed in the goethite sludge. The maximum radial separation is taken to be the same as the fuel pin spacing of an intact DFA and results in the table are expressed in terms of the pitch fraction as described in Section 6.1.1, but in this case the minimum pitch, p_{min} , is the fuel pellet diameter, 0.49403 cm. The water volume fraction in the sludge is varied so as to give differing

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 32 of 58

pellet separations. The axial separation between individual fuel pellets and the water volume fraction in the sludge are listed in the table. The last and next to last cases in the table are for the fuel in the DFAs and in the Ident-69 container displaced in the axial direction by 10 cm and 20 cm, respectively. The fuel pin cladding is neglected in the Ident-69 container unless noted otherwise. The gadolinium content in the basket assembly is 0.1% or 0.3811 kg in the entire basket assembly for all cases except one as indicated.

Table 6-4. Results for Fuel Pellets Dispersed in Goethite Sludge

Pitch Fraction	Axial Separation, cm; Water Volume; Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
0.5	0.2; 46%	0.8508 ± 0.0011	0.8530	hx_pmd_gd_1_wat_46_dl_1.o
0.5	0.6; 72%	0.8569 ± 0.0011	0.8591	hx_pmd_gd_1_wat_72_dl_3.o
0.5	1.0; 81%	0.8578 ± 0.0011	0.8599	hx_pmd_gd_1_wat_81_dl_5.o
0.5	1.4; 85%	0.8536 ± 0.0011	0.8558	hx_pmd_gd_1_wat_85_dl_7.o
1.0	0; 52%	0.9169 ± 0.0011	0.9191	hx_pmx_gd_1_wat_52_dl_0.o
1.0	0.2; 70%	0.9224 ± 0.0011	0.9246	hx_pmx_gd_1_wat_70_dl_1.o
1.0	0.6; 82%	0.9309 ± 0.0011	0.9332	hx_pmx_gd_1_wat_82_dl_3.o
1.0	1.0; 88%	0.9325 ± 0.0011	0.9347	hx_pmx_gd_1_wat_88_dl_5.o
⁺ 1.0	1.0; 88%	0.9340 ± 0.0012	0.9363	hx_pmx_gd_1_wat_88_dl_5_z.o
⁺ 1.0	1.0; 88%; cladding in Ident-69 container	0.9205 ± 0.0011	0.9227	hx_pmx_gd_1_88zC.o
⁺ 1.0	1.0; 88%; cladding in less reactive Ident-69 container, 2% Gd	0.8414 ± 0.0011	0.8436	i604lr0t.o
⁺ 1.0	1.0; 88%; 0.2% Gd (0.762 kg)	0.9255 ± 0.0011	0.9277	hx_pmx_gd_2_wat_88_dl_5_z.o
1.0	1.4; 90%	0.9261 ± 0.0011	0.9282	hx_pmx_gd_1_wat_90_dl_7.o
1.0	1.6; 91%	0.9184 ± 0.0011	0.9205	hx_pmx_gd_1_wat_91_dl_8.o
^A 1.0	1.6; 91%	0.9194 ± 0.0011	0.9217	hx_pmx_gd_1_wat_91_dl_8a.o
^B 1.0	1.6; 91%	0.9180 ± 0.0011	0.9201	hx_pmx_gd_1_wat_91_dl_8b.o

⁺Every other column of fuel pellets in the DFAs is displaced in the axial direction so that the centers of the pellets in one column align with the tops of the pellets in the adjacent column.

^AFuel in DFAs displaced 10 cm in axial direction relative to fuel in Ident-69 container.

^BFuel in DFAs displaced 20 cm in axial direction relative to fuel in Ident-69 container.

6.1.4 Results for Degraded DFA Ducts

Results are given in Table 6-5 for loose pins settled in each position of the basket assembly due to the degradation of the assembly ducts and fuel pin clips/spacers as described in Section 5.2.4.

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 33 of 58

The gadolinium content in the basket assembly is 0.1% or 0.3811 kg for the entire basket assembly except for the last case that contains no gadolinium. Cases are given in the table where the orientation of the DOE SNF canister is such that a basket assembly divider plate is at the 12 o'clock position and rotated 180° so that the plate is at the 6 o'clock position. These orientations are listed in the table as either "12" or "6". The placement of pins in the canister is irregular with some pins being in a somewhat triangular array, some approximately in a square array and others being somewhere between a triangular and square array. A case is also given with the pins placed in random locations so as to account for the pins haven fallen from a DFA. Another case is given where a symmetry boundary condition is used which allows only half of the geometry (and pins) to be represented. This is useful to avoid limitations in the computer code for modelling cases in Sections 6.1.5 and 6.1.7. Due to the irregular spacing of the pins, there is not exact symmetry, but the results in Table 6-5 show agreement within 1σ. The fuel pin cladding is neglected in the Ident-69 container for all cases except one as noted.

Table 6-5. Results for Loose Pins in the Basket Assembly Positions

Orientation	Comment	$k_{\text{eff}} \pm \sigma$	$k_{\text{eff}} + 2\sigma$	File Name
12	Random placement of pins	0.8554 ± 0.0011	0.8576	lvb_co2.o
6	Irregular pitch	0.8535 ± 0.0010	0.8556	mine_co1.o
12	Irregular pitch	0.8839 ± 0.0011	0.8861	mine_co2.o
12	Previous case but symmetry boundary conditions	0.8830 ± 0.0010	0.8850	mine_co2_h.o
12	Irregular pitch and pin cladding in Ident-69 container	0.8678 ± 0.0011	0.8700	mine_co2+c.o
12	Irregular pitch and no Gd	0.9334 ± 0.0010	0.9353	mine_co2_nogd.o

6.1.5 Results for Fuel Pins with Degraded Fuel Pin Cladding in the Intact Basket Assembly

Results for DFAs with degraded fuel pin cladding, fuel pin clips/spacers and assembly ducts are presented in Table 6-6. These cases are described in Section 5.2.5. In this case individual fuel pellets are in each of the positions of the intact basket assembly. The corrosion products from the ducts would be expected to surround the fuel pellets but are neglected for these cases. The degradation products from the cladding surround the fuel pellets, which are assumed to be axially aligned, and separate the pellets in the radial direction depending on the volume fraction of water in the sludge. In no case is this separation greater than that of the fuel pins in the intact DFA. The pitch fraction is described in Section 6.1.1, but the minimum pitch, p_{min} , is the fuel pellet diameter, 0.49403 cm. The fuel pins in the Ident-69 container are cladded. The gadolinium content in the basket assembly is listed in the table. The DOE canister is oriented at the 12 o'clock position as was found to be most reactive in Section 6.1.4.

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF

Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 34 of 58

Table 6-6. Results for Fuel Pellets in the Intact Basket Assembly Positions

Pitch Fraction	Axial Separation, cm; Water Volume	Gd Content (mass, kg)	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
0.5	2.0; 88%	1.0% (3.811)	0.8206 ± 0.0012	0.8229	sc5_md_gd_1_.12_dl_1.+c.o
0.5	1.4; 84%	1.0% (3.811)	0.8369 ± 0.0011	0.8391	sc5_md_gd_1_.16_dl_7+c.o
0.5	1.0; 78%	1.0% (3.811)	0.8445 ± 0.0012	0.8469	sc5_md_gd_1_.22_dl_5+c.o
0.5	0.6; 67%	1.0% (3.811)	0.8435 ± 0.0011	0.8456	sc5_md_gd_1_.33_dl_3+c.o
0.5	0.2; 36%	1.0% (3.811)	0.8382 ± 0.0010	0.8402	sc5_md_gd_1_.64_dl_1+c.o
1.0	2.0; 92%	1.0% (3.811)	0.9047 ± 0.0011	0.9068	sc5_mx_gd_1_.08_dl_1.+c.o
1.0	1.4; 89%	1.0% (3.811)	0.9262 ± 0.0011	0.9285	sc5_mx_gd_1_.11_dl_7+c.o
1.0	1.0; 86%	1.0% (3.811)	0.9381 ± 0.0011	0.9404	sc5_mx_gd_1_.14_dl_5+c.o
1.0	0.6; 80%	1.0% (3.811)	0.9429 ± 0.0012	0.9453	sc5_mx_gd_1_.20_dl_3+c.o
1.0	0.2; 65%	1.0% (3.811)	0.9311 ± 0.0010	0.9332	sc5_mx_gd_1_.35_dl_1+c.o
1.0	0.; 43%	1.0% (3.811)	0.9258 ± 0.0010	0.9278	sc5_mx_gd_1_.57_dl_0+c.o
1.0	1.0; 86%	0.1% (0.3811)	0.9694 ± 0.0011	0.9716	sc5_mx_gd_1_.14_dl_5+c.o
1.0	1.0; 86%	0.5% (1.905)	0.9462 ± 0.0011	0.9484	sc5_mx_gd_5_.14_dl_5+c.o
+1.0	0.6; 80%	1.0% (3.811)	0.9014 ± 0.0011	0.9037	sc5_mx_gd_1_.20nor.o
1.0	0.6; 80%	2.0% (7.622)	0.9327 ± 0.0011	0.9348	sc5_mx_gd_2_.20_dl_3+c.o
1.0	0.6; 80%	3.0% (11.43)	0.9241 ± 0.0011	0.9263	sc5_mx_gd_3_.20_dl_3+c.o

+Less reactive Ident-69 container

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 35 of 58

6.1.6 Values of k_{eff} for Degraded Basket Assembly

Results are presented in Table 6-7 for cases where the basket assembly is fully degraded but all other fuel components are intact. In these cases the DFAs and Ident-69 container or the center DFA have fallen to the bottom of the SNF canister. The degradation products with varying water volume fractions have settled around the fuel components. The first 8 cases in the table are for the case of 6 DFAs in the SNF canister, i.e., the Ident-69 container has been replaced with a DFA. The remainder is for an Ident-69 container surrounded by DFAs. The water volume fractions in the goethite and gadolinium content are listed in the table. The gadolinium content is for the basket assembly unless otherwise noted. The fuel pin cladding is included inside the Ident-69 container for all cases. The water volume is 40% of the goethite sludge surrounding the DFAs and Ident-69 container for all cases unless otherwise noted. These cases are described in Section 5.2.6.

The first two cases for an Ident-69 container surrounded by DFAs show that the gadolinium poison is not very effective in reducing k_{eff} . The fuel configuration used in these cases is referred to as the base case in the table. The next 4 cases are for a less reactive Ident-69 container that neglects the ring of fuel pins around the inside of the outer edge of the Ident-69 container which acts as a reflector (Ref. 7.6, Table 6-9). Removing these pins does not reduce the conservatism of the calculations since the reflector ring configuration is not realistic for a horizontally positioned Ident-69 container. The next few cases are with the more reactive Ident-69 container but with either the inside duct or the inside duct and an assumed basket structure doped with gadolinium. The next cases assume the void spaces in the Ident-69 container contain a homogeneous mixture of iron shot mixed with water, goethite, or water with gadolinium. The cases with iron shot have 58.82% of the volume occupied with iron. Finally, the last cases in the table are for the base case but with either one or two DFAs removed from the SNF canister and some have a less reactive Ident-69 container.

Table 6-7. Results for Degraded Basket Assembly with Varying Amounts of Gadolinium and other Modifications

Gd Content	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
0	6 DFAs just touching	0.9631 ± 0.0009	0.9650	dfa6_gd_0._go_.6b.o
1.0% (3.811 kg)	6 DFAs just touching	0.9244 ± 0.0010	0.9265	dfa6_gd_1._go_.6b.o
2.0% (7.622 kg)	6 DFAs just touching	0.9186 ± 0.0010	0.9205	dfa6_gd_2._go_.6b.o
2.0% (7.622 kg)	6 DFAs just touching, 50% water volume	0.9121 ± 0.0009	0.9140	dfa6_gd_2._go_.5b.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 36 of 58

Gd Content	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
2.0% (7.622 kg)	6 DFAs just touching, 60% water volume	0.9044 ± 0.0010	0.9065	dfa6_gd_2._go_.4b.o
5.0% (19.05 kg)	6 DFAs closely spaced	0.8738 ± 0.0010	0.8757	dfa6_gd_5._go_.6a.o
5.0% (19.05 kg)	6 DFAs closely spaced, no $S(\alpha,\beta)$ treatment	0.8721 ± 0.0011	0.8742	dfa6_gd_5._go_.6a-S.o
5.0% (19.05 kg)	6 DFAs just touching	0.9119 ± 0.0010	0.9139	dfa6_gd_5._go_.6b.o
5.0% (19.05 kg)	*Ident-69 container	0.9571 ± 0.0010	0.9590	sc6_gd_5._go_.6.o
6.0% (22.86 kg)	*Ident-69 container	0.9550 ± 0.0011	0.9571	sc6_gd_6._go_.6.o
2.0% (7.622 kg)	Less reactive Ident-69 container	0.9355 ± 0.0010	0.9376	sc6_gd_2._go_.6_nor.o
3.0% (11.43 kg)	Less reactive Ident-69 container	0.9296 ± 0.0010	0.9316	sc6_gd_3._go_.6_nor.o
4.0% (15.24 kg)	Less reactive Ident-69 container	0.9252 ± 0.0010	0.9272	sc6_gd_4._go_.6_nor.o
6.0% (22.86 kg)	Less reactive Ident-69 container	0.9185 ± 0.0011	0.9207	sc6_gd_6._go_.6_nor.o
5.0 kg	Gd in duct of Ident-69 container	0.9690 ± 0.0010	0.9710	sc6_gd_5kgin_go_.6.o
1.5 kg	Gd in duct and basket of Ident-69 container	0.9525 ± 0.0011	0.9546	sc6_gd_1.5kgin_go_.6.o
5.0 kg	Gd in duct and basket of Ident-69 container	0.9386 ± 0.0010	0.9406	sc6_gd_5kgin_go_.6all.o
0 kg	Fe shot and water in Ident-69 container	0.9281 ± 0.0010	0.9300	sc6_gd_1kghom_fe.o
1.0 kg	Fe shot, Gd, and water in Ident-69 container	0.8907 ± 0.0010	0.8927	sc6_gd_0kghom_fe.o
1.0 kg	Full density goethite & Gd in Ident-69 container	0.8900 ± 0.0010	0.8921	sc6_gd_1kghom_go.o
0	Full density goethite in Ident-69 container	0.9422 ± 0.0009	0.9441	sc6_gd_0kghom_go.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 37 of 58

Gd Content	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
1.0 kg	Water and Gd in Ident-69 container	0.8670 ± 0.0009	0.8689	sc6_gd_1kghom_go_.6.o
1.0% (3.811 kg)	Base case but 1 DFA removed	0.9503 ± 0.0011	0.9525	sc6_gd_1._go_.6_-1.o
5.0% (19.05 kg)	Base case but 1 DFA removed	0.9341 ± 0.0010	0.9362	sc6_gd_5._go_.6_-1.o
2.0% (7.622 kg)	Base case but less reactive Ident-69 container and 1 DFA removed	0.9090 ± 0.0011	0.9111	sc6_gd_2._go_.6_nor-1.o
1.0% (3.811 kg)	Base case but less reactive Ident-69 container and 1 DFA removed	0.9170 ± 0.0010	0.9190	sc6_gd_1._go_.6_nor-1.o
0	Base case but 2 DFAs removed	0.9493 ± 0.0011	0.9514	sc6_gd_0._go_.6_-2.o
0.1% (0.3811 kg)	Base case but less reactive Ident-69 container and 2 DFAs removed	0.8948 ± 0.0010	0.8969	sc6_gd_.1_go_.6_nor-2.o
1.0% (3.811 kg)	Base case but 2 DFAs removed	0.8967 ± 0.0012	0.8990	sc6_gd_1._go_.6_-2.o

*Base case for fuel configuration

6.1.7 Results for Intact Fuel Pins in DOE SNF Canister with Degraded Basket Assembly and Assembly Ducts

Results for intact fuel pins with degraded basket assembly, assembly ducts and fuel pin clips/spacers are shown in Table 6-8. If present, the Ident-69 container is surrounded by fuel pins and the minimum distance between the outer edge of the Ident-69 container and the DOE SNF canister is varied as described in Section 5.2.7. This distance is also listed in the table. The first three results in the table are for 6 DFAs, in which case only fuel pins are in the DOE SNF canister. The first two cases differ in that the pins are shifted by the radius of a fuel pin and the symmetry of the arrays of pins is slightly different, i.e., in one case the line of symmetry would pass through the center of a fuel pin whereas in the other it would pass between two touching fuel pins. The next case is for an Ident-69 container surrounded by fuel pins and the canister contains only water. The water volume in the goethite slurry is 40% unless otherwise noted, and the amount of gadolinium is also given in the table. Since these cases assume a 3.6576 m (12 ft) basket assembly, the gadolinium masses are based on this length. Four cases with clad fuel

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 38 of 58

pins in the Ident-69 container are presented in the table. The last 3 cases are the base case but with 1 and 2 DFAs removed from the canister.

Table 6-8. Intact Fuel Pins with Degraded Basket Assembly and Assembly Ducts

Gd Content (mass, kg)	Comment; distance, cm	$k_{eff} \pm \sigma$	$\cdot k_{eff} + 2\sigma$	File Name
2.0% (6.758)	6 DFAs	0.8129 ± 0.0009	0.8147	dfa_.6_gd_2.0a.o
2.0% (6.758)	6 DFAs, previous case but fuel pins slightly shifted	0.8156 ± 0.0009	0.8174	dfa_.6_gd_2.0b.o
0	6 DFAs, same as previous	0.8607 ± 0.0010	0.8626	dfa_.6_gd_0.0b.o
0	Ident-69 container & water only in DOE canister; 1.67	1.0193 ± 0.0010	1.0214	sc7_h_basa.o
1.0% (3.379)	Ident-69 container; 1.67	0.9738 ± 0.0012	0.9761	sc7_h_basa_.6_gd_1.0.o
1.0% (3.379)	Less reactive Ident-69 container; 3.34	0.9495 ± 0.0010	0.9516	sc7_h_basc_.6_gd_1.0_nor.o
2.0% (6.758)	Ident-69 container; 0.	0.9674 ± 0.0010	0.9695	sc7_h_basb_.6_gd_2.0.o
2.0% (6.758)	Ident-69 container; 1.67	0.9698 ± 0.0010	0.9717	sc7_h_basa_.6_gd_2.0.o
2.0% (6.758)	Ident-69 container; 3.34	0.9694 ± 0.0010	0.9714	sc7_h_basc_.6_gd_2.0.o
2.0% (6.758)	Ident-69 container; 4.84	0.9629 ± 0.0010	0.9650	sc7_h_basd_.6_gd_2.0.o
2.0% (6.758)	Ident-69 container; 6.84	0.9518 ± 0.0010	0.9538	sc7_h_base_.6_gd_2.0.o
2.0% (6.758)	Less reactive Ident-69 container; 3.34	0.9381 ± 0.0010	0.9401	sc7_h_basc_.6_gd_2.0_nor.o
2.0% (6.758)	Cladding in Ident-69 container, 60% water volume; 3.34	0.9457 ± 0.0010	0.9477	sc7_h_basc_.4_gd_2.0+c.o
2.0% (6.758)	Cladding in Ident-69 container, 50% water volume; 3.34	0.9446 ± 0.0011	0.9468	sc7_h_basc_.5_gd_2.0+c.o
2.0% (6.758)	Cladding in Ident-69 container; 3.34	0.9471 ± 0.0010	0.9490	sc7_h_basc_.6_gd_2.0+c.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 39 of 58

Gd Content (mass, kg)	Comment; distance, cm	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
2.0% (6.758)	Cladding in less reactive Ident-69 container; 3.34	0.9237 ± 0.0010	0.9257	sc7_h_basc_.6_gd_2.0_nor+c.o
2.0% (6.758)	Base case but 1 DFA removed; 3.34	0.9393 ± 0.0011	0.9414	sc7_h_basc_.6_gd_2.0-1.o
2.0% (6.758)	Base case but 1 DFA removed and cladding in less reactive Ident-69 container; 3.34	0.8940 ± 0.0010	0.8960	sc7_h_basc_.6_gd_2.0-1nrC.o
2.0% (6.758)	Base case but 2 DFAs removed; 3.34	0.9018 ± 0.0010	0.9037	sc7_h_basc_.6_gd_2.0-2.o

*Base case

6.1.8 Results for Intact Assembly Ducts with Degraded Basket Assembly and Fuel Pin Cladding

In these cases the basket assembly, fuel pin cladding and fuel pin clips/spacers are degraded and fuel pellets are inside the intact assembly ducts which have fallen to the bottom of the DOE SNF canister as described in Section 5.2.8. The corrosion products produced by the fuel cladding surround the pellets that are, in general, separated in both the axial and radial directions. The pellets are assumed to remain axially aligned and are radially positioned in a hexagonal array. The worst cases for radial and axial pellet spacing and DFA spacing are taken from Section 6.1.3 and 6.1.6, respectively, and are used as the starting point for these cases. Results for DFAs only in the SNF canister are shown in Table 6-9, which gives the pitch fraction which is a measure of the fraction between minimum and original pitch of the DFA (see Section 6.1.1), the axial separation between pellets and the water volume fraction in the goethite formed from the degraded basket assembly. A few less reactive cases are also listed with no axially separation between pellets and maximum pitch, and with a pitch midway between minimum and original pitch (pitch fraction = 0.5) and optimal axial spacing. The last 5 cases have either 1 or 2 DFAs removed from the canister. The amount of gadolinium in the sludge formed from the degraded basket assembly is listed in the table. A $S(\alpha,\beta)$ treatment is used for the goethite sludge except as indicated.

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 40 of 58

Table 6-9. Pellets in Intact Assembly Ducts Surrounded by Degraded Basket Assembly for DFAs in DOE SNF Canister

Gd Content (mass, kg)	Pitch Fraction; Axial Separation, cm; Water Volume; Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
2% (7.622)	1.0; 0 cm; 52%	0.9257 ± 0.0009	0.9275	df8_px_gd_2_.48_dl_.0.o
2% (7.622)	1.0; 0.2 cm; 70%	0.9465 ± 0.0011	0.9486	df8_px_gd_2_.30_dl_.1.o
2% (7.622)	1.0; 1.0 cm; 88%	1.0105 ± 0.0011	1.0128	df8_px_gd_2_.12_dl_.5.o
5% (19.05)	1.0; 1.0 cm; 88%	1.0033 ± 0.0011	1.0055	df8_px_gd_5_.12_dl_.5.o
2% (7.622)	0.5; 1.0 cm; 81%	0.9204 ± 0.0011	0.9226	df8_pd_gd_2_.19_dl_.5.o
2% (7.622)	0.5; 1.0 cm; 81%; no S(α,β) treatment	0.9379 ± 0.0012	0.9403	df8_pd_gd_2_.19_dl_.5-S.o
4% (15.24)	0.5; 1.0 cm; 81%; no S(α,β) treatment	0.9321 ± 0.0011	0.9343	df8_pd_gd_4_.19_dl_.5S.o
5% (19.05)	0.5; 1.0 cm; 81%	0.9124 ± 0.0012	0.9147	df8_pd_gd_5_.19_dl_.5.o
2% (7.622)	1.0; 1.0 cm; 88%; 1 less DFA	0.9676 ± 0.0011	0.9698	df8_px_gd_2_.12_dl_.5-1.o
2% (7.622)	1.0; 1.0 cm; 88%; no S(α,β) treatment and 1 less DFA	0.9784 ± 0.0012	0.9807	df8_px_gd_2_.12_dl_.5-1S.o
5% (19.05)	1.0; 1.0 cm; 88%; no S(α,β) treatment and 1 less DFA	0.9718 ± 0.0012	0.9741	df8_px_gd_5_.12_dl_.5-1S.o
2% (7.622)	1.0; 1.0 cm; 88%; 2 less DFAs	0.9168 ± 0.0011	0.9190	df8_px_gd_2_.12_dl_.5-2.o
2% (7.622)	1.0; 1.0 cm; 88%; no S(α,β) treatment and 2 less DFAs	0.9277 ± 0.0011	0.9300	df8_px_gd_2_.12_dl_.5-2S.o

Similar results but for an Ident-69 container surrounded by DFAs are given in Table 6-10. The fuel pin cladding in the Ident-69 container is neglected for most cases as listed in the table. The less reactive Ident-69 container with cladded fuel pins in the Ident-69 container is also listed. The last 7 cases have either one or two less DFAs in the SNF canister. A S(α,β) treatment is used for the goethite sludge except as indicated.

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 41 of 58

Table 6-10. Pellets in Intact Assembly Ducts Surrounded by Degraded Basket Assembly For Ident-69 Container Surrounded by DFAs

Gd Content (mass, kg)	Pitch Fraction; Axial Separation, cm; Water Volume; Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
2% (7.622)	1.0; 0 cm; 52%	0.9855 ± 0.0012	0.9878	sc8_px_gd_2_.48_dl_.0.o
2% (7.622)	1.0; 1.0 cm; 88%	1.0030 ± 0.0011	1.0051	sc8_px_gd_2_.12_dl_.5.o
6% (22.86)	1.0; 0 cm; 52%	0.9680 ± 0.0010	0.9701	sc8_px_gd_6_.48_dl_.0.o
6% (22.86)	1.0; 1.0 cm; 88%	0.9832 ± 0.0012	0.9855	sc8_px_gd_6_.12_dl_.5.o
6% (22.86)	1.0; 1.0 cm; 88%; cladding in Ident-69 container	0.9711 ± 0.0011	0.9733	sc8_px_gd_6_.12_dl_.5+c.o
6% (22.86)	1.0; 1.0 cm; 88%; cladding in less reactive Ident-69 container	0.9347 ± 0.0011	0.9370	sc8_px_gd_6_.12_dl_.5+cnr.o
6% (22.86)	0.5; 1.0 cm; 19%	0.8848 ± 0.0011	0.8871	sc8_pd_gd_6_.81_dl_.5.o
2% (7.622)	0.5; 1.0 cm; 19%	0.9062 ± 0.0011	0.9084	sc8_pd_gd_2_.81_dl_.5.o
6% (22.86)	1.0; 1.0 cm; 88%; 1 less DFA	0.9618 ± 0.0011	0.9640	sc8_px_gd_6_.12_dl_.5-1.o
2% (7.622)	1.0; 1.0 cm; 88%; cladding in less reactive Ident-69 container and 1 less DFA	0.9301 ± 0.0011	0.9322	sc8_px_gd_2_.dl_.5+cnr-1.o
2% (7.622)	1.0; 1.0 cm; 88%; cladding in less reactive Ident-69 container, 1 less DFA and no $S(\alpha,\beta)$ treatment	0.9374 ± 0.0011	0.9396	sc8_px_gd_2_.dl_.5+cnr-1S.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 42 of 58

Gd Content (mass, kg)	Pitch Fraction; Axial Separation, cm; Water Volume; Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
3.5% (13.34)	1.0; 1.0 cm; 88%; cladding in less reactive Ident-69 container, 1 less DFA and no S(α,β) treatment	0.9256 ± 0.0012	0.9279	sc8_px_gd_3.5_dl_.5+cnr-1S.o
6% (22.86)	1.0; 1.0 cm; 88%; 2 less DFAs	0.9140 ± 0.0012	0.9164	sc8_px_gd_6_.12_dl_.5-2.o
2% (7.622)	1.0; 1.0 cm; 88%; 2 less DFAs	0.9281 ± 0.0011	0.9304	sc8_px_gd_2_.12_dl_.5-2.o
2% (7.622)	1.0; 1.0 cm; 88%; cladding in less reactive Ident-69 container, 2 less DFAs and no S(α,β) treatment	0.8865 ± 0.0011	0.8887	sc8_px_gd_2_.12_dl_.5-2+cnrS.o

6.1.9 Results for the DOE SNF Canister Containing Degraded Fuel

All the DFAs and the basket assembly in the DOE SNF canister are assumed to have become fully degraded. The Ident-69 container is treated as being either intact or degraded. The iron content of any degraded material containing steel is oxidized to goethite while all other constituents of the steel are assumed to have formed soluble compounds and are no longer present in the canister. The chemical composition of the fuel remains unchanged. The fuel, water and goethite mix uniformly to form a homogeneous slurry. The maximum volume of goethite in the slurry is assumed to be 60%. Since the fuel occupies 0.9144 m (3 ft) of the 3.6576 m (12 ft) DFA, the fuel containing slurry is assumed to range in length from 0.9144 m (3 ft) to 3.6576 m (12 ft). For each length of fuel slurry, the fuel is assumed to have mixed with goethite formed from an equal length of assembly, basket material and, if applicable, Ident-69 container material. For fuel lengths less than 3.6576 m (12 ft), the remaining portion of the assembly is modelled as water saturated goethite. The basket assembly is assumed to be 3.6576 m (12 ft) long. The rest of the canister is assumed filled with water.

6.1.9.1 Results for the DOE SNF Canister Containing an Intact Ident-69 Container and Degraded DFAs

Results for an intact Ident-69 container surrounded by the fuel slurry from 5 degraded DFAs and the basket assembly in the DOE SNF canister are shown in Table 6-11. These cases are

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 43 of 58

described in Section 5.2.9.1. The Ident-69 container is positioned such that the fuel inside it is centered in the fuel slurry. The fuel pin cladding is included in the Ident-69 container. The remainder of the canister is flooded with water. These results are for a 60% goethite volume in the slurry and for various lengths of fuel slurry. For these results, as the length increases the height decreases so as to maintain a constant volume of fuel slurry. The canister is fully reflected by water, i.e., the co-disposal waste package is neglected. The basket assembly is assumed to have contained varying amounts of gadolinium. The mass of gadolinium is based on a 3.6576 m (12 ft) long basket assembly. Since the basket assembly is fully degraded the gadolinium is assumed to be homogeneously mixed throughout the goethite.

Table 6-11. Intact Ident-69 Container and 5 DFAs Fully Degraded in DOE SNF Canister

Length of Fuel Slurry, m	Gd Content (mass, kg); Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
0.9144	0.	1.0508 ± 0.0011	1.0530	ident_3_60.o
0.9144	2% (6.76)	0.9554 ± 0.0010	0.9573	ident_3_60_gd_2.o
0.9144	2% (6.76); less reactive Ident-69 container	0.9334 ± 0.0010	0.9353	ident_3_60_gd_2nor.o
0.9144	2% (6.76); less reactive Ident-69 container, 1 less DFA and S(α,β) treatment	0.9041 ± 0.0010	0.9061	id_3_60_gd_2.nrS-1.o
0.9144	2.5% (8.45); less reactive Ident-69 container and S(α,β) treatment	0.9269 ± 0.0010	0.9288	ident_3_60_gd_2.5norS.o
0.9144	5% (16.9)	0.9155 ± 0.0010	0.9174	ident_3_60_gd_5.o
0.9144	5% (16.9); S(α,β) treatment	0.9222 ± 0.0010	0.9242	ident_3_60_gd_5S.o
1.5240	0	1.0620 ± 0.0011	1.0642	ident_5_60.o
1.5240	2% (6.76)	0.9022 ± 0.0010	0.9042	ident_5_60_gd_2.o
1.5240	5% (16.9)	0.8602 ± 0.0010	0.8623	ident_5_60_gd_5.o
2.1336	0	1.0711 ± 0.0011	1.0733	ident_7_60.o
2.1336	2% (6.76)	0.8671 ± 0.0009	0.8690	ident_7_60_gd_2.o
2.1336	5% (16.9)	0.8199 ± 0.0010	0.8219	ident_7_60_gd_5.o
3.0480	0	1.0739 ± 0.0011	1.0760	ident_10_60.o
3.0480	2% (6.76)	0.8267 ± 0.0009	0.8285	ident_10_60_gd_2.o
3.0480	5% (16.9)	0.7847 ± 0.0010	0.7867	ident_10_60_gd_5.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 44 of 58

3.6576	0	1.0712 ± 0.0011	1.0733	ident_12_60.o
3.6576	2% (6.76)	0.8068 ± 0.0009	0.8086	ident_12_60_gd_2.o
3.6576	5% (16.9)	0.7683 ± 0.0009	0.7702	ident_12_60_gd_5.o

6.1.9.2 Results for the DOE SNF Canister Containing a Degraded Ident-69 Container and Degraded DFAs

Results for the DOE SNF canister containing a fully degraded Ident-69 container and 5 DFAs are presented in Table 6-12 for different initial numbers of fuel pins in the Ident-69 container as described in Section 5.2.9.2. The Ident-69 container is designed to hold a maximum of 217 fuel pins (Ref. 7.2, p. 5). These results are presented for different contents of gadolinium in the basket assembly. The mass of gadolinium is based on a 3.6576 m (12 ft) long basket assembly. In all cases the fuel slurry is assumed to be 0.9144 m (3 ft) long and contain a 60% goethite volume. The DOE canister is completely reflected by water.

Table 6-12. Fully Degraded Ident-69 Container and 5 Fully Degraded DFAs in DOE SNF Canister with a 0.9144 m (3 ft) Fuel Slurry Region

Number of Pins Initially Contained in Ident-69 Container	Gd Content (mass, kg)	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
0	0	0.9630 ± 0.0011	0.9652	homall_3_60_0.o
109	0	0.9678 ± 0.0011	0.9699	homall_3_60_109.o
217	0	0.9667 ± 0.0010	0.9686	homall_3_60_217.o
217	0.5% (1.69)	0.9124 ± 0.0011	0.9145	homall_3_60_217_gd_5.o
*217	0.5% (1.69)	0.9086 ± 0.0010	0.9107	homall_3_60_217_gd_5S.o
0	2% (6.76)	0.8073 ± 0.0010	0.8092	homall_3_60_0_gd_2.o
109	2% (6.76)	0.8251 ± 0.0010	0.8270	homall_3_60_109_gd_2.o
217	2% (6.76)	0.8423 ± 0.0009	0.8441	homall_3_60_217_gd_2.o

*With S(α,β) treatment of goethite slurries.

6.1.9.3 Results for the DOE SNF Canister Containing 6 Degraded DFAs

Results for 6 fully degraded DFAs are given in Table 6-13 for different amounts of gadolinium in the basket assembly and for different lengths of fuel slurry. These cases are described in Section 5.2.9.3. The portion of the DOE canister not filled with fuel slurry or goethite is filled with water. The goethite volume in the slurry is 60% unless otherwise noted. Results are also presented for a hydrogen S(α,β) treatment with and without gadolinium. These show that for the case with gadolinium a higher value of k_{eff} is obtained with the S(α,β) treatment. The last two cases are for different volume fractions of goethite in the fuel slurry. The smaller fraction

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 45 of 58

corresponds to the fuel slurry just filling the canister in the radial direction. The canister is fully reflected by water. The mass of gadolinium is based on a 3.6576 m (12 ft) long basket assembly.

Table 6-13. Six Fully Degraded DFAs in DOE SNF Canister

Length of Fuel Slurry, m	Gd Content (mass, kg); Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
0.9144	0	0.9757 ± 0.0010	0.9778	6DFAs_60_3.o
1.5240	0	1.0074 ± 0.0011	1.0096	6DFAs_60_5.o
2.1336	0	1.0253 ± 0.0012	1.0278	6DFAs_60_7.o
3.0480	0	1.0400 ± 0.0011	1.0422	6DFAs_60_10.o
3.6576	0	1.0384 ± 0.0016	1.0415	6DFAs_60_12.o
0.9144	0; S(α,β) treatment	0.9624 ± 0.0010	0.9645	6DFAs_60_3_Sab.o
0.9144	2% (6.76)	0.8469 ± 0.0009	0.8486	6DFAs_60_3_gd_2.o
1.5240	2% (6.76)	0.7677 ± 0.0009	0.7694	6DFAs_60_5_gd_2.o
2.1336	2% (6.76)	0.7020 ± 0.0009	0.7037	6DFAs_60_7_gd_2.o
3.0480	2% (6.76)	0.6202 ± 0.0008	0.6218	6DFAs_60_10_gd_2.o
3.6576	2% (6.76)	0.5743 ± 0.0014	0.5771	6DFAs_60_12_gd_2.o
0.9144	2% (6.76); S(α,β) treatment	0.8525 ± 0.0009	0.8544	6DFAs_60_3_gd_2_Sab.o
0.9144	2% (6.76); 55% goethite in slurry	0.8585 ± 0.0009	0.8603	6DFAs_55_3_gd_2.o
0.9144	2% (6.76); 47.76% goethite in slurry	0.8769 ± 0.0009	0.8786	6DFAs_fl_3_gd_2.o
0.9144	1.25% (4.22); 47.76% goethite in slurry	0.9116 ± 0.0009	0.9134	6DFAs_fl_3_gd_1.25.o
0.9144	1.25% (4.22); 47.76% goethite in slurry and S(α,β) treatment	0.9197 ± 0.0010	0.9216	6DFAs_fl_3_gd_1.25S.o

6.1.10 Results for the DOE SNF Canister Containing Completely Degraded Fuel Components in the Co-disposal Waste Package

The most reactive cases found for the DOE canister containing degraded fuel are used to determine k_{eff} in the co-disposal waste package. For all cases the co-disposal waste package is assumed fully reflected by water.

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 46 of 58

6.1.10.1 Results for the DOE SNF Canister Containing an Intact Ident-69 Container and Five Degraded DFAs in the Co-disposal Waste Package (Containing Gadolinium)

The results from Tables 6-11, 6-12 and 6-13 show that for the cases with completely degraded fuel and a given amount of gadolinium the most reactive cases are for the intact Ident-69 container. If the basket assembly contains gadolinium then the shorter fuel slurries are more reactive, whereas if the basket assembly contains no gadolinium the longer slurries are more reactive. The cases in Table 6-14 are for a DOE canister containing an intact Ident-69 container and degraded fuel from the DFAs in the co-disposal waste package. These cases are described in Section 5.2.10.1. For most cases the fuel in the Ident-69 container is centered in the fuel slurry, which is 0.9144 m (3 ft) long, and exactly overlaps the fuel slurry in the axial direction. The cladding is included on the fuel pins in the Ident-69 container. The vacant spaces in the co-disposal waste package are treated as voids for all cases except one where it is assumed to contain full density water. Due to gravity, the DOE canister rests 2 cm from the center of the co-disposal waste package on the support tube of the co-disposal waste package. A range of values of goethite volume fractions from 0.746 to 0.472 is given in the table. The larger values of volume fraction are greater than the assumed maximum of 0.6 and show the sensitivity of the results to this value, whereas the smallest value corresponds to a sludge volume that radially fills the DOE canister for the length of the fuel slurry. The co-disposal waste package is fully reflected by water. All results are for 6% or 20.3 kg gadolinium in the basket assembly unless otherwise noted (recall that the basket assembly is assumed to have a length of 12 ft and the mass of gadolinium is based on this length).

Table 6-14. Intact Ident-69 Container and 5 Fully Degraded DFAs in a 0.9144 m (3 ft) Fuel Slurry in DOE SNF Canister in the Co-disposal Waste Package

Comment; Goethite Volume Fraction	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
5% Gd (16.9 kg) with Ident-69 container centered in fuel sludge; 0.6	0.9314 ± 0.0009	0.9332	coidt_grav_gd_5_1.o
Ident-69 container centered in fuel sludge; 0.6	0.9245 ± 0.0009	0.9263	coidt_grav_gd_6_1.o
Ident-69 container at bottom of fuel sludge; 0.6	0.9032 ± 0.0009	0.9051	coidt_grav_gd_6_2.o
Ident-69 container just submerged in fuel sludge; 0.6	0.8901 ± 0.0010	0.8920	coidt_grav_gd_6_3.o
Ident-69 container centered; 0.746	0.9256 ± 0.0009	0.9275	coidt_grv_74.6_gd_6.0.o
Ident-69 container centered; 0.65	0.9263 ± 0.0010	0.9284	coidt_grv_65_gd_6.0.o
Ident-69 container centered; 0.50	0.9154 ± 0.0009	0.9172	coidt_grv_50_gd_6.0.o
Ident-69 container centered; 0.47	0.9161 ± 0.0009	0.9180	coidt_grv_fl_gd_6.0.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 47 of 58

Comment; Goethite Volume Fraction	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
Ident-69 container centered, co-disposal flooded; 0.6	0.9153 ± 0.0010	0.9174	coidt_grav_gd_6_1ff.o
Ident-69 container centered in fuel sludge and S(α,β) treatment; 0.6	0.9307 ± 0.0009	0.9325	coidt_grav_gd_6_1_S.o
4% Gd (13.52 kg) with less reactive Ident-69 container centered in fuel sludge and S(α,β) treatment; 0.6	0.9204 ± 0.0009	0.9223	coidt_grav_gd_4_1_Snr.o
4% Gd (13.52 kg) with less reactive Ident-69 container centered in fuel sludge; 0.6	0.9157 ± 0.0010	0.9176	coidt_grav_gd_4_1_nr.o
2% Gd (6.76 kg) with less reactive Ident-69 container centered in fuel sludge, 1 less DFA and S(α,β) treatment; 0.6	0.9243 ± 0.0010	0.9263	cdt_grv_gd_2_1_Snr-1.o

The effect of water in the unoccupied space in the DOE canister for the second case in Table 6-14 for 6% gadolinium is determined and the results are shown in Table 6-15. For these cases the density of water is varied from 0, i.e., no water, to 1 which is full density water. The length of the degraded fuel region is 0.9144 m (3 ft) and the degraded fuel slurry and goethite contain the minimum amount of water that has been assumed (for 60% goethite). The Ident-69 container is fully flooded with water. The total mass of gadolinium in the canister is 20.3 kg, based on a 3.6576 m (12 ft) long basket assembly.

Table 6-15. Intact Ident-69 Container and 5 Fully Degraded DFAs in a 0.9144 m (3 ft) Fuel Slurry in DOE SNF Canister with Variable Water Density and 6% Gadolinium in the Basket Assembly in the Co-disposal Waste Package

Fraction of Full Water Density in DOE Canister	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
0	0.9267 ± 0.0008	0.9283	coidt_grav_gd_6_1_0.o
0.2	0.9273 ± 0.0010	0.9293	coidt_grav_gd_6_1_2.o
0.4	0.9276 ± 0.0010	0.9295	coidt_grav_gd_6_1_4.o
0.6	0.9256 ± 0.0010	0.9275	coidt_grav_gd_6_1_6.o
0.8	0.9254 ± 0.0010	0.9273	coidt_grav_gd_6_1_8.o
1.0	0.9245 ± 0.0009	0.9263	coidt_grav_gd_6_1.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 48 of 58

The effect of water content in the degraded fuel sludge and in the goethite adjacent to the fuel is determined by again considering the second case from Table 6-14 for 6% gadolinium and varying the amount of water in the degraded fuel mixture and in the adjacent goethite mixture. The range of values is from 0, no water, to 1 or the minimum water volume fraction that has been assumed, which is 0.1956 for the degraded fuel sludge. The remaining volume fraction within the fuel is treated as void. These results are shown in Table 6-16. For these cases the unoccupied space in the DOE canister is filled with full density water. The mass of gadolinium in the canister is 20.3 kg, based on a 3.6576 m (12 ft) long basket assembly.

Table 6-16. Intact Ident-69 Container and 5 Fully Degraded DFAs in a 0.9144 m (3 ft) Fuel Slurry with Variable Water Density in DOE SNF Canister and 6% Gadolinium in the Basket Assembly in the Co-disposal Waste Package

Fraction of Minimum Water Volume in Degraded Fuel	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
0	0.9050 ± 0.0009	0.9068	coidt_grav_gd_6_1_h.0.o
0.2	0.9111 ± 0.0009	0.9129	coidt_grav_gd_6_1_h.2.o
0.4	0.9159 ± 0.0010	0.9178	coidt_grav_gd_6_1_h.4.o
0.6	0.9181 ± 0.0009	0.9200	coidt_grav_gd_6_1_h.6.o
0.8	0.9220 ± 0.0009	0.9238	coidt_grav_gd_6_1_h.8.o
1.0	0.9245 ± 0.0009	0.9263	coidt_grav_gd_6_1.o

6.1.10.2 Results for the DOE SNF Canister Containing a Degraded Ident-69 Container and Five Degraded DFAs in the Co-disposal Waste Package (Containing Gadolinium)

Results for a fully degraded Ident-69 container which contained various numbers of fuel pins and 5 degraded DFAs are presented in Table 6-17. These results are for a 0.9144 m (3 ft) fuel slurry and a basket assembly that contained 2% gadolinium (6.76 kg) and are described in Section 5.2.10.2. The mass of gadolinium is based on a 3.6576 m (12 ft) long basket assembly. The space not occupied by fuel slurry or goethite in the DOE canister is filled with water. The goethite volume in the fuel sludge is varied from 60% to a minimum of 45.71% corresponding to a volume that radially fills the DOE canister for a 0.9144 m (3 ft) length. Vacant space in the co-disposal waste package is treated as void for all cases except the last in the table. A case is also presented with the $S(\alpha, \beta)$ treatment for the degraded fuel sludge. The co-disposal waste package is fully reflected by water.

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 49 of 58

Table 6-17. Degraded Ident-69 Container and 5 Fully Degraded DFAs in a 0.9144 m (3 ft) Fuel Slurry in DOE SNF Canister with 2% Gadolinium in the Basket Assembly in the Co-disposal Waste Package

Number of Pins Initially Contained in Ident-69 Container	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
109	60% goethite	0.8485 ± 0.0008	0.8502	cohomal_grav1_109.o
217	60% goethite	0.8642 ± 0.0009	0.8659	cohomal_grav1.o
217	55% goethite	0.8786 ± 0.0009	0.8804	cohomal_grav1_55.o
217	45.71% goethite	0.9031 ± 0.0010	0.9051	cohomal_grav1_fl.o
217	45.71% goethite; S(α,β) treatment	0.9181 ± 0.0010	0.9200	cohomal_grav1_fl_S.o
217	45.71% goethite; flooded co-disposal	0.8876 ± 0.0009	0.8895	cohomal_grav1_fl_ff.o

6.1.11 Results for the DOE SNF Canister Containing Degraded Fuel or Fuel Components with the Co-disposal Waste Package Contents Degraded

The contents of the co-disposal waste package are now assumed to be completely degraded as described in Section 5.2.11. The contents of the DOE SNF canister are taken to be same as the most reactive cases in Sections 5.2.8 and 5.2.10.1, for the partially degraded and completely degraded cases, respectively. The position of the DOE canister in the clay and the water content of the clay are varied. The results for 5 completely degraded DFAs surrounding an intact Ident-69 container are given in Table 6-18. The second case in Table 6-14 is used as a starting point for these cases, but the fuel pins are cladded in the Ident-69 container. The volume fractions of clay and water are varied and the values for the water volume are listed in the table. For the first case, the water volume in the clay is chosen so that the co-disposal waste package is completely filled with clay and water. The last several cases in the table have no water mixed in with the clay and the remaining portion of the co-disposal waste package is filled with water. The gadolinium content of the basket assembly is 6% unless noted otherwise. The mass of gadolinium is based on a 3.6576 m (12 ft) basket assembly.

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 50 of 58

Table 6-18. Results for the Case of the Degraded Contents of the Co-disposal Waste Package Containing a Most Reactive DOE SNF Canister with Degraded Fuel

Volume of Water in Clay	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
47.8%	Canister at bottom of co-disposal package	0.9203 ± 0.0009	0.9221	geot_gd_6_fl_a.o
40%	Canister at bottom	0.9205 ± 0.0010	0.9225	geot_gd_6a.o
40%	Canister at bottom and S(α,β) treatment in slurry	0.9256 ± 0.0010	0.9276	geot_gd_6aS.o
40%	Canister between center and bottom	0.9163 ± 0.0010	0.9182	geot_gd_6b.o
40%	Canister in center	0.9146 ± 0.0010	0.9165	geot_gd_6c.o
30%	Canister at bottom	0.9230 ± 0.0009	0.9249	geot_gd_6_7a.o
0	Canister at bottom	0.9244 ± 0.0010	0.9265	geot_gd_6_1.a.o
0	Canister at bottom and S(α,β) treatment in slurry	0.9325 ± 0.0010	0.9346	geot_gd_6_1.aS.o
0	Canister at bottom, S(α,β) treatment in slurry, less reactive Ident-69 container and 4% Gd (13.5 kg)	0.9226 ± 0.0010	0.9246	geot_gd_4_1.anr.o
0	Canister at bottom, S(α,β) treatment in slurry, less reactive Ident-69 container, 1 less DFA and 2% Gd (6.76 kg)	0.9288 ± 0.0010	0.9307	gt_gd_2_1.anrS-1.o
0	Canister at bottom, S(α,β) treatment in slurry, less reactive Ident-69 container, 1 less DFA and 2.25% Gd (7.60 kg)	0.9223 ± 0.0009	0.9242	gt_gd_2q_1.anrS-1.o
0	Canister at bottom, S(α,β) treatment in slurry, less reactive Ident-69 container, 2 less DFAs and 1.0% Gd (3.38 kg)	0.9249 ± 0.0010	0.9269	gt_gd_1_1.anrS-2.o

Similar results but for intact fuel components are given in Table 6-19. In this case the basket assembly and fuel pin cladding has degraded but the other components in the SNF canister are intact. All cases except the last case are taken from the last few cases in Table 6-10 and have

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

only 2 DFAs removed from the SNF canister unless noted otherwise. The last case in this table is taken from the last case in Table 6-9 and has only 4 DFAs in the SNF canister. The gadolinium content in the basket assembly was 6% unless otherwise noted. The fuel pin cladding in the Ident-69 container is neglected except as stated otherwise.

Table 6-19. Results for the Case of the Degraded Contents of the Co-disposal Waste Package Containing a Most Reactive DOE SNF Canister with Intact Fuel

Volume of Water in Clay	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
47.8%	Canister at bottom of co-disposal package	0.9083 ± 0.0012	0.9107	gx_6_.5-2 fla.o
40%	Canister at bottom	0.9066 ± 0.0011	0.9088	gx_6_.5-2a_6a.o
40%	Canister between center and bottom	0.9001 ± 0.0010	0.9021	gx_6_.5-2a_6b.o
40%	Canister in center	0.8979 ± 0.0011	0.9002	gx_6_.5-2a_6c.o
30%	Canister at bottom	0.9111 ± 0.0012	0.9134	gx_6_.5-2a_7a.o
0	Canister at bottom	0.9158 ± 0.0011	0.9180	gx_6_.5-2a_1.a.o
0	Canister at bottom, cladded pins in less reactive Ident-69 container and 2% Gd (7.62 kg)	0.8820 ± 0.0011	0.8842	gx_2_.5-2a_1.acnr.o
0	Canister at bottom, cladded pins in less reactive Ident-69 container, 1 DFA removed and 2% Gd (7.62 kg)	0.9363 ± 0.0011	0.9386	gx_2_.5-1a_1.acnr.o
0	Canister at bottom, cladded pins in less reactive Ident-69 container, 1 DFA removed and 4% Gd (15.2 kg)	0.9247 ± 0.0011	0.9270	gx_4_.5-1a_1.acnr.o
0	4 DFAs (only) in canister at bottom and 2% Gd (7.62 kg)	0.9265 ± 0.0011	0.9287	dx_2_1.a.o

6.2 RESULTS FOR PLUTONIUM DECAY EFFECTS

The results from the cases used to calculate the decay effects from the plutonium isotopes are given in Table 6-20. Decay times are given in terms of the half-life of Pu-239 ($T_{1/2 \text{ Pu-239}}$). At two half-lives of Pu-239, practically all Pu-241 decays to Np-237 and more than 99% of the Pu-240 decays to U-236 (see Attachment I). The cases at time zero are the selected original cases from corresponding tables from previous sections as indicated in Table 6-20. Also, the plutonium

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF

Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 52 of 58

decay effect results for selected intact cases from Ref. 6 are given in Table 6-21. Again, the cases at time zero are the selected original cases. In Tables 6-20 and 6-21, the time “final” refers to the time at which all plutonium isotopes have decayed (e.g., at ten half-lives of Pu-239, more than 99.9% of Pu-239 decays to U-235 and all other plutonium isotopes are essentially zero).

Table 6-20. Results for Plutonium Decay Effects

Time (years)	File Name	k_{eff}	σ	$k_{eff} + 2\sigma$	AENCF (MeV)	Gd Contents (% , kg)	H/X
0	hxgcomb_gd_1_cl_00_wat_52a.o (Table 6-2)	0.9157	0.0010	0.9178	0.2611	0.1, 0.3811	13.09
24100	i6021t.O	0.9472	0.0011	0.9494	0.2027	0.1, 0.3811	13.09
48200	i6022t.O	0.9571	0.0011	0.9592	0.1822	0.1, 0.3811	13.09
48200	602g2.O	0.9200	0.0011	0.9222	0.1906	2, 7.62	13.09
final	i602nt.O	0.9468	0.0012	0.9491	0.1601	0.1, 0.3811	13.09
0	i6030t.o (Table 6-3)	0.8594	0.0011	0.8617	0.2654	2, 7.62	17.47
24100	i6031t.o	0.8868	0.0011	0.8891	0.2111	2, 7.62	17.47
48200	i6032t.o	0.8953	0.0012	0.8977	0.1864	2, 7.62	17.47
final	i6033t.o	0.8876	0.0011	0.8898	0.1664	2, 7.62	17.47
0	d6030t.o (Table 6-3)	0.8368	0.0010	0.8388	0.3329	2, 7.62	17.47
24100	d6031t.o	0.8649	0.0010	0.8669	0.2636	2, 7.62	17.47
48200	d6032t.o	0.8790	0.0010	0.8810	0.2342	2, 7.62	17.47
final	d6033t.o	0.8767	0.0011	0.8789	0.2055	2, 7.62	17.47
0	i604lr0t.o (Table 6-4)	0.8414	0.0011	0.8436	0.1328	2, 7.62	58.81
24100	i604lr1t.o	0.8709	0.0011	0.8732	0.1056	2, 7.62	59.49
48200	i604lr2t.o	0.8746	0.0010	0.8767	0.0943	2, 7.62	59.49
final	i604lr3t.o	0.8632	0.0011	0.8655	0.0834	2, 7.62	59.49
0	mine_co2.o (Table 6-5)	0.8839	0.0011	0.8861	0.3005	0.1, 0.3811	5.03
24100	i65a1t.O	0.9045	0.0011	0.9067	0.2390	0.1, 0.3811	5.03
48200	i65a2t.O	0.9146	0.0010	0.9167	0.2114	0.1, 0.3811	5.03
final	i65ant.O	0.8980	0.0011	0.9002	0.1876	0.1, 0.3811	5.03
0	mine_co2_nogd.o (Table 6-5)	0.9334	0.0010	0.9353	0.2852	0, 0	5.03
24100	i65b1t.O	0.9552	0.0011	0.9574	0.2242	0, 0	5.03
48200	i65b2t.O	0.9636	0.0010	0.9657	0.1986	0, 0	5.03
final	i65bnt.O	0.9554	0.0010	0.9574	0.1772	0, 0	5.03
0	i6060t.o (Table 6-6, same as sc5_mx_gd_1_20nor.o except 2% Gd)	0.8931	0.0011	0.8953	0.1489	2, 7.62	39.94
24100	i6061t.o	0.9238	0.0010	0.9259	0.1189	2, 7.62	39.94
48200	i6062t.o	0.9319	0.0011	0.9341	0.1058	2, 7.62	39.94
48200	i6062xt.o	0.9272	0.0012	0.9295	0.1057	3.0, 11.43	39.94

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF

Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 53 of 58

Time (years)	File Name	k_{eff}	σ	$k_{eff} + 2\sigma$	AENCF (MeV)	Gd Contents (% , kg)	H/X
48200	i6062xl.o (one less DFA)	0.8818	0.0013	0.8843	0.1078	2, 7.62	39.94
final	i606nt.o	0.9222	0.0011	0.9245	0.0923	2, 7.62	39.94
0	sc6_gd_5._go_.6.o (Table 6-7)	0.9571	0.0010	0.9590	0.3057	5, 19	13.48
48200	t7.7.O	0.9949	0.0011	0.9971	0.2138	5, 19	13.48
final	t6-7al.O	0.9776	0.0012	0.9799	0.1909	5, 19	13.48
0	sc6_gd_2._go_.6_nor.o (Table 6-7)	0.9355	0.0011	0.9376	0.2975	2, 7.622	13.48
48200	nor.7.O	0.9718	0.0012	0.9741	0.2110	2, 7.622	13.48
final	norall.O	0.9527	0.0011	0.9550	0.1877	2, 7.622	13.48
0	sc6_gd_2._go_.6_nor-1.o (Table 6-7)	0.9090	0.0011	0.9111	0.2893	2, 7.622	13.48
48200	DFA.7.O	0.9423	0.0010	0.9443	0.2059	2, 7.622	13.48
final	DFAall.O	0.9277	0.0011	0.9298	0.1837	2, 7.622	13.48
0	sc7_h_basc_6_gd_2.0-1nrC.o (Table6-8)	0.8940	0.0010	0.8960	0.3653	2, 6.758	3.98
48200	sc_1.7.O	0.9046	0.0010	0.9067	0.2600	2, 6.758	3.98
final	sc_1al.O	0.8850	0.0011	0.8871	0.2324	2, 6.758	3.98
0	sc7_h_basc_6_gd_2.0_nor+c.o (Table6-8)	0.9237	0.0010	0.9257	0.3936	2, 6.758	3.98
48200	sc7.7.O	0.9331	0.0010	0.9350	0.2793	2, 6.758	3.98
48200	sc7g25.O	0.9296	0.0011	0.9317	0.2807	2.5, 8.45	3.98
48200	sc7g30.O	0.9240	0.0010	0.9260	0.2813	3, 10.14	3.98
final	sc7all.O	0.9089	0.0010	0.9109	0.2515	2, 6.758	3.98
0	ident_3_60_gd_2.o (Table6-11)	0.9554	0.0010	0.9573	0.2215	2, 6.758	27.19
48200	t11.7.O	0.9693	0.0011	0.9714	0.1612	2, 6.758	27.19
final	t11all.O	0.9084	0.0009	0.9103	0.1500	2, 6.758	27.19
0	ident_3_60_gd_2nor.o (Table6-11)	0.9334	0.0010	0.9353	0.2073	2, 6.758	27.19
48200	nor1.7.O	0.9314	0.0010	0.9333	0.1519	2, 6.758	27.19
48200	n17g25.o	0.9190	0.0010	0.9209	0.1556	2.5, 8.45	27.19
48200	n17g30.o	0.9076	0.0009	0.9096	0.1570	3, 10.13	27.19
48200	n17g35.o	0.8983	0.0009	0.9001	0.1591	3.5, 11.826	27.19
final	nor1al.O	0.8655	0.0009	0.8673	0.1417	2, 6.758	27.19
0	id_3_60_gd_2.nrS-1.o (Table6-11)	0.9041	0.0010	0.9061	0.1911	2, 6.758	30.67
24100	id_1t.O	0.9204	0.0010	0.9223	0.1532	2, 6.758	30.67
48200	DFA1.7.O	0.9078	0.0010	0.9098	0.1398	2, 6.758	30.67
final	DFA1al.O	0.8358	0.0009	0.8376	0.1302	2, 6.758	30.67
0	homall_3_60_109.o (Table6-12)	0.9678	0.0011	0.9699	0.2286	0, 0	25.72
24100	i12alt.O	0.9825	0.0011	0.9847	0.1666	0, 0	25.72

Waste Package Operations

Calculation

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF

Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 54 of 58

Time (years)	File Name	k_{eff}	σ	$k_{eff} + 2\sigma$	AENCF (MeV)	Gd Contents (% , kg)	H/X
48200	i12a2t.O	1.0596	0.0011	1.0617	0.1547	0, 0	25.72
final	i12ant.O	1.0580	0.0011	1.0602	0.1350	0, 0	25.72
0	homall_3_60_109_gd_2.o (Table 6-12)	0.8251	0.0010	0.8270	0.2769	2, 6.76	25.72
24100	i12b1t.O	0.8330	0.0010	0.8349	0.2250	2, 6.76	25.72
48200	i12b2t.O	0.8148	0.0008	0.8165	0.2075	2, 6.76	25.72
final	i12bnt.O	0.7229	0.0007	0.7243	0.2040	2, 6.76	25.72
0	6DFAs_60_10.o (Table 6-13)	1.0400	0.0011	1.0422	0.0650	0, 0	111.37
24100	i13a1t.O	1.1185	0.0010	1.1206	0.0500	0, 0	111.37
48200	i13a2t.O	1.1207	0.0010	1.1228	0.0444	0, 0	111.37
final	i13ant.O	1.0899	0.0010	1.0920	0.0399	0, 0	111.37
0	6DFAs_60_3_gd_2_Sab.o (Table 6-13)	0.8525	0.0009	0.8544	0.2781	2, 6.76	24.88
24100	i13b1t.O	0.5556	0.0007	0.5569	0.2199	2, 6.76	24.88
48200	i13b2t.O	0.4995	0.0006	0.5006	0.2270	2, 6.76	24.88
final	i13bnt.O	0.3776	0.0004	0.3784	0.2633	2, 6.76	24.88
0	cdt_grv_gd_2_1_Snr-1.o (Table 6-14)	0.9243	0.0010	0.9263	0.1888	2, 6.76	30.67
24100	i6141t.O	0.9412	0.0010	0.9433	0.1539	2, 6.76	30.67
48200	i6142t.O	0.9276	0.0009	0.9294	0.1395	2, 6.76	30.67
final	i614nt.O	0.8517	0.0009	0.8535	0.1308	2, 6.76	30.67
0	geot_gd_6_1.aS.o (Table 6-18)	0.9325	0.0010	0.9346	0.2280	6, 20.28	27.19
24100	i18a1t.O	0.9489	0.0010	0.9510	0.1851	6, 20.28	27.19
48200	i18a2t.O	0.9396	0.0009	0.9415	0.1684	6, 20.28	27.19
final	i18ant.O	0.8703	0.0009	0.8722	0.1587	6, 20.28	27.19
0	gt_gd_2q_1.anrS-1.o (Table 6-18)	0.9223	0.0009	0.9242	0.1876	2.25, 7.60	30.67
24100	i18b1t.O	0.9384	0.0009	0.9402	0.1521	2.25, 7.60	30.67
48200	i18b2t.O	0.9242	0.0010	0.9263	0.1402	2.25, 7.60	30.67
final	i18bnt.O	0.8464	0.0010	0.8483	0.1312	2.25, 7.60	30.67
0	i18bq0t.o (Table 6-18, same as above except Gd content)	0.9118	0.0010	0.9137	0.1933	2.75, 9.29	30.67
24100	i18bq1t.o	0.9250	0.0010	0.9269	0.1548	2.75, 9.29	31.02
48200	i18bq2t.o	0.9074	0.0009	0.9092	0.1418	2.75, 9.29	31.02
final	i18bq3t.o	0.8323	0.0009	0.8340	0.1339	2.75, 9.29	31.02
0	i18dp0t.o (Table 6-18, same as gt_gd_1_1.anrS-2.o except Gd content)	0.9051	0.0010	0.9071	0.1669	1.5, 5.07	36.46
24100	i18dp1t.o	0.9168	0.0009	0.9185	0.1347	1.5, 5.07	36.88
48200	i18dp2t.o	0.8988	0.0009	0.9006	0.1245	1.5, 5.07	36.88

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF

Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 55 of 58

Time (years)	File Name	k_{eff}	σ	$k_{eff} + 2\sigma$	AENCF (MeV)	Gd Contents (% , kg)	H/X
final	i18dp3t.o	0.8278	0.0009	0.8296	0.1163	1.5, 5.07	36.88
0	gx_2_5-1a_1.acnr.o (Table 6-19)	0.9363	0.0011	0.9386	0.1346	2, 7.62	42.22
24100	i6191t.O	0.9675	0.0011	0.9697	0.1070	2, 7.62	42.22
48200	i6192t.O	0.9770	0.0011	0.9793	0.0952	2, 7.62	42.22
final	i619nt.O	0.9588	0.0012	0.9612	0.0838	2, 7.62	42.22

Table 6-21. Results for Plutonium Decay Effects for Selected Intact Cases

Decay Time (years)	File Name	k_{eff}	σ	$k_{eff} + 2\sigma$	AENCF (MeV)	Gd Content (mass)
0	comb01+5b_ss_1.0++_gd.o	0.8577	0.0011	0.8599	0.2875	5% (19 kg)
24100	i612-1to	0.8779	0.0011	0.8801	0.2285	5% (19 kg)
48200	i612-2to	0.8838	0.0011	0.8860	0.2040	5% (19 kg)
final	i612-nto	0.8714	0.0010	0.8734	0.1815	5% (19 kg)
0	comb01+5b_ss_gd1.0_sqb.o	0.8271	0.0010	0.8291	0.2927	5% (19 kg)
24100	i612-1xo	0.8508	0.0011	0.8529	0.2293	5% (19 kg)
48200	i612-2xo	0.8533	0.0011	0.8555	0.2084	5% (19 kg)
final	i612-nxo	0.8468	0.0010	0.8488	0.1817	5% (19 kg)
0	6packd0_ss_10_w_1a.o	0.8763	0.0011	0.8785	0.3264	0
24100	i613-1to	0.8998	0.0010	0.9019	0.2588	0
48200	i613-2to	0.9060	0.0010	0.9081	0.2310	0
final	i613-nto	0.9014	0.0010	0.9035	0.2042	0
0	comb01+5b_ss_10a_w_1a_c.o	0.9538	0.0010	0.9558	0.2628	0
24100	i614-1to	0.9858	0.0011	0.9880	0.2076	0
48200	i614-2to	0.9988	0.0011	1.0010	0.1837	0
final	i614-nto	0.9912	0.0011	0.9934	0.1614	0
0	comb01+5b_ss_10a_w_1a_gd_5_1.6.o	0.9167	0.0010	0.9188	0.2629	0.5% (1.93 kg)
24100	i615-1to	0.9414	0.0011	0.9437	0.2078	0.5% (1.93 kg)
48200	i615-2to	0.9528	0.0011	0.9550	0.1864	0.5% (1.93 kg)
final	i615-nto	0.9372	0.0012	0.9395	0.1654	0.5% (1.93 kg)
0	comb01+5b_ss_10a_w_1a_gd_2_1.6.o	0.8990	0.0011	0.9012	0.2681	2% (7.7 kg)
48200	i615-gd2.o	0.9328	0.0011	0.9349	0.1905	2% (7.7 kg)
48200	i615-gd2nr.o (less reactive)	0.8794	0.0011	0.8816	0.1927	2% (7.7 kg)

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 56 of 58

7. REFERENCES

- 7.1 Los Alamos National Laboratory (LANL) 1997. *MCNP- A General Monte Carlo N-Particle Transport Code, Version 4B – UC 705 and UC 700*. LA-12625-M, Version 4B. Los Alamos, New Mexico: LANL. ACC: MOL.19980624.0328.
- 7.2 Idaho National Engineering and Environmental Laboratory (INEEL) 1998. *FFTF (MOX) Fuel Characteristics for Disposal Criticality Analysis*. DOE/SNF/REP-032. Idaho Falls, Idaho: Lockheed Martin Idaho Technologies Company INEEL. TIC: 241492.
- 7.3 LANL 1987. *Critical Dimensions of Systems Containing ²³⁵U, ²³⁹Pu and ²³³U, 1986 Revision*. LA-10860-MS. Los Alamos, New Mexico: LANL. TIC: 209447.
- 7.4 Civilian Radioactive Waste Management System (CRWMS) Management and Operating (M&O) Contractor 1998. *Software Qualification Report for MCNP Version 4B2, A General Monte Carlo N-Particle Transport Code*. Computer Software Configuration Item (CSCI): 30033 V4B2LV. Document Identifier Number: 30033-2003 REV 01. Las Vegas, Nevada: M&O. ACC: MOL.19980622.0637.
- 7.5 CRWMS M&O 1996. *Material Compositions and Number Densities for Neutronics Calculations*. BBA000000-01717-0200-00002 REV 00. Las Vegas, Nevada: M&O. ACC: MOL.19960624.0023.
- 7.6 CRWMS M&O 1999. *Fast Flux Test Facility (FFTF) Reactor Fuel Criticality Calculations*. BBA000000-01717-0210-00016 REV 00. Las Vegas, Nevada: M&O. ACC: MOL.19990426.0142.
- 7.7 Dean, John A., Ed. 1992. *Lange's Handbook of Chemistry*, Fourteenth Edition. New York, New York: McGraw-Hill, Inc. TIC: 240690.
- 7.8 DOE National Spent Nuclear Fuel Program 1998. *Preliminary Design Specification for Department of Energy Standardized Spent Nuclear Fuel Canisters, Volume I – Design Specification*. DOE/SNF/REP-011, Revision 0. Idaho Falls, Idaho: INEEL, Lockheed Martin Idaho Technologies Company. TIC: 239252
- 7.9 CRWMS M&O 1998. *Dose Calculations for the Co-Disposal WP of HLW Canisters and the Fast Flux Test Facility (FFTF) Fuel*. BBA000000-01717-0210-00019 REV 00. Las Vegas, Nevada: M&O. ACC: MOL.19990129.0075.

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 57 of 58

- 7.10 CRWMS M&O 1998. *EQ6 Calculations for Chemical Degradation of Fast Flux Test Facility (FFTF) Waste Packages*. BBA000000-01717-0210-00028 REV 00. Las Vegas, Nevada: M&O. ACC: MOL.19981229.0081.
- 7.11 American Society for Testing and Materials (ASTM) 1991. *Standard Specification for Stainless and Heat-Resisting Steel Bars and Shapes*. ASTM A 276-91a. Philadelphia, Pennsylvania: ASTM. TIC: 240022.
- 7.12 ASTM 1995. *Standard Specification for Heat-Resisting Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels*. ASTM A 240/A 240M-94b. Philadelphia, Pennsylvania: ASTM. TIC: 240020.
- 7.13 Inco Alloys International 1988. *Product Handbook*. IAI-38. Huntington, West Virginia: Inco Alloys International, Inc. TIC: 239397.
- 7.14 ASTM 1997. *Standard Specification for Low-Carbon Nickel-Molybdenum-Chromium, Low-Carbon Nickel-Chromium-Molybdenum, Low-Carbon Nickel-Chromium-Molybdenum-Copper and Low-Carbon Nickel-Chromium-Molybdenum-Tungsten Alloy Plate, Sheet, and Strip*. ASTM B 575-97. Philadelphia, Pennsylvania: ASTM. TIC: 241816.
- 7.15 ASTM 1990. *Standard Specification for Pressure Vessel Plates, Carbon Steel for Moderate- and Lower-Temperature Service*. ASTM A 516/A 516M-90. Philadelphia, Pennsylvania: ASTM. TIC: 240032.
- 7.16 CRWMS M&O 1997. *Incorporating Hanford 15 Foot (4.5 meter) Canister into Civilian Radioactive Waste Management System (CRMWS) Baseline*. 97-WDD-053. Richland, Washington: DOE Richland Operations Office. ACC: HQP.19970609.0014.
- 7.17 General Electric Company 1989. *Nuclides and Isotopes Fourteenth Edition: Chart of the Nuclides*. San Jose, California: General Electric Company. TIC: 201637.
- 7.18 CRWMS M&O 1999. *Electronic Attachments for BBA000000-01717-0210-00051 REV 00, Attachment II, CD-ROM*. Las Vegas, Nevada: M&O. ACC: MOL.19990604.0147.

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page 58 of 58

8. ATTACHMENTS

Attachment I: EXCEL spreadsheets (12 pages).

Attachment II: Electronic attachments for MCNP outputs are provided on CD-ROM and listed in Table II-1 (9 pages). The CD-ROM that contains the output files is moved to Ref. 18.

Attachment III: Tables repeating all results plus H/X ratios and average energy of neutrons causing fission (20 pages).

Attachment IV. Sketch of FFTF DOE SNF Basket Assembly, Sketch Number SK-0109 REV 00 (1 page).

Attachment V. Sketch of 5-DHLW/DOE Spent Fuel-Long Disposal Container, Sketch Number SK-0070 REV 02 (1 page).

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T				
1	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T				
2	2	Avogadro's number from Ref. 7.5, BBA000000-01717-0200-00002 REV00:					0.602252	Note: all (unless otherwise noted) molecular weights are from Ref. 7.5, BBA000000-01717-0200-00002 REV00					FFTF fuel information is from Ref. 7.2											
3	3	Diameter of fuel pellet and insulator pellet, cm =					0.49403						DOE SNF Canister information from Ref. 7.8											
4	4	Footprint length of fuel pellets in fuel pins, cm =					91.44	NOTE: abbreviations																
5	5	Volume of fuel in fuel pin= $\pi \cdot \text{diameter}^2 \cdot \text{length} / 4$, cm^3 =					17.52801529	MW is molecular weight					vf is volume fraction											
6	6						(This is footprint volume.)	# density is number density																
7	7	Length of natural Uranium insulator, cm =					2.032	#den is number density																
8	8	Number of fuel pins in an assembly:					217	wt. fraction is weight fraction																
9	9	Number of natural U insulators in a fuel pin:					2	atomic abund. is atomic abundance																
10	10	Volume of insulators= $\pi \cdot \text{diameter}^2 \cdot \text{length} \cdot (\# \text{ of insulators}) / 4$, cm^3 =					169.0479697	Avog.# is Avogadro's number																
11	11						(Total volume of insulators in an assembly.)	# is number																
12	12	$1 / \text{MW} = \text{sum}(\text{wt. fraction}_i / \text{MW}_i)$										$1 / \text{MW} = \text{sum}(\text{wt. fraction}_i / \text{MW}_i)$												
13	13	atomic Abundances										atomic Abundances												
14	14	(wt. fraction) for Pu										(wt. fraction) for U												
15	15	MW	Type 3.2	Type 4.1	Type 3.2	Type 4.1	Element	MW	Type 3.2	Type 4.1	Type 3.2	Type 4.1												
16	16	Pu-239	239.052146	0.8723	0.8735	0.003648995	0.003654014	U-235	235.043915	0.007	0.002	2.97817E-05	8.50905E-06											
17	17	Pu-240	240.053882	0.1173	0.1163	0.00048864	0.000484475	U-238	238.05077	0.993	0.998	0.004171379	0.004192383											
18	18	Pu-241	241.056737	0.0104	0.0102	4.31434E-05	4.23137E-05	O	15.994915															
19	19	O	15.994915																					
20	20	239.1904974					MW Pu	239.189913	239.1885163	MW U					238.0294547	238.0446795								
21	21	MW PuO_1.96					270.5399464	270.5385497	MW UO_1.96					269.3794881	269.3947129									
22	22																							
23	23	$N_i = \text{Mass}_i \cdot \text{Avog.} \# / (\text{MW}_i \cdot \text{Volume})$																						
24	24	Type 3.2					Type 4.1	Type 3.2	Type 4.1	Type 3.2					Type 4.1	Type 3.2	Type 4.1							
25	25	mass of Pu in fuel pin, g:					34.2	44.8	mass of U in fuel pin, g:					118.3	108.2									
26	26	masses					masses	# density	# density	masses					masses	# density	# density							
27	27	Pu-239	29.83266	39.1328	4.2879E-03	5.6246E-03	U-235	0.8281	0.2164	1.2105E-04	3.1634E-05													
28	28	Pu-240	4.01166	5.21024	5.7420E-04	7.4575E-04	U-238	117.4719	107.9836	1.6955E-02	1.5586E-02													
29	29	Pu-241	0.35568	0.45696	5.0697E-05	6.5134E-05	O	15.58088244	14.24973505	3.3470E-02	3.0610E-02													
30	30	O	4.482509855	5.871860063	9.6291E-03	1.2614E-02	Total O (MOX)	Saturated MOX fuel @11% H2O																
31	31																							
32	32											Total O (MOX and H2O)					4.6777E-02	4.6902E-02						
33	33											Total H					7.3565E-03	7.3565E-03						
34	34																							
35	35																							
36	36	$N_i = \text{Mass}_i \cdot \text{Avog.} \# / (\text{MW}_i \cdot \text{Volume})$										Following determines the mass/pin of insulator												
37	37	Following is for the Nat. U insulators; (U-234 assumed to be U-235)										#den UO2:					2.2451E-02	mass UO_2 insulators/pin, g=	7.841438017					
38	38	Nuclide					atomic abund.	MW	#den U-235:					1.6288E-04	Nuclide	mass/pin, g								
39	39	atomic abundances from					U-235	0.007255	235.043915	1.705243603	#den U-238:					2.2288E-02	U	6.912442396						
40	40	Nuclides and Isotopes,					U-238	0.992745	238.05077	236.3237117	#den O:					4.4901E-02	U-235	0.049520858						
41	41	Fifteenth Edition Chart of					O	15.994915	Saturated Insulator @11% H2O					U-238					6.862921538					
42	42	the Nuclides					Total MW of natural U=	238.0289553	Total O #den:					4.8580E-02	O	0.928995621								
43	43						Total MW of UO_2=	270.0187853	Total H #den:					7.3565E-03		7.841438017								
44	44	Total mass of natural U insulators in an assembly:					1500	Total mass UO_2 insulators in assembly=	1701.59205															
45	45																							
46	46	$N_i = (\text{mass density}) \cdot \text{wt. fraction}_i \cdot \text{Avog.} \# / \text{MW}_i$																						
47	47	Following is for water:					density=	1																
48	48	Full density water, 1 g/cm ³																						
49	49	MW	# density																					
50	50	H:	1.00782519	6.6878E-02																				
51	51	O:	15.994915	3.3439E-02																				
52	52	total MW:					18.01056538																	
53	53	Saturated MOX Fuel @11% H2O Type 4.1 Fuel																						
54	54	$N_i = 0.11 \cdot N_i$ (water)																						
55	55	O:	3.6783E-03																					
56	56	H:	7.3565E-03																					
57	57																							
58	58	$N_i = (\text{mass density}) \cdot \text{wt. fraction}_i \cdot \text{Avog.} \# / \text{MW}_i$										$N_i = (\text{mass density}) \cdot \text{wt. fraction}_i \cdot \text{Avog.} \# / \text{MW}_i$												
59	59	The following is for Type 304L SS, density=					7.9	The following is for the Inconel Alloy 600, density, g/cm ³ =					8.47											
60	60	From Ref. 7.12										From Ref. 7.13												
61	61	Element	MW	wt fraction	# density	Element					MW	wt fraction	# density											
62	62	C	12.01115	0.0003	1.1883E-04	Ni	58.71	0.74335	6.4587E-02															
63	63	N	14.00307439	0.001	3.3977E-04	Cr	51.996	0.155	1.5206E-02															
64	64	Si	28.086	0.0075	1.2705E-03	Fe	55.847	0.08	7.3072E-03															
65	65	P	30.9737647	0.00045	6.9123E-05	C	12.01115	0.0015	6.3704E-04															
66	66	S	31.9720737	0.0003	4.4643E-05	Mn	54.9380503	0.01	9.2851E-04															
67	67	Cr	51.996	0.19	1.7386E-02	S	31.9720737	0.00015	2.3932E-05															
68	68	Mn	54.9380503	0.02	1.7321E-03	Si	28.086	0.005	9.0812E-04															
69	69	Fe	55.847	0.68045	5.7970E-02	Ni	58.71	0.1	8.1039E-03															
70	70	Ni	58.71	0.1	8.1039E-03	Sum =					1	Sum =					1							
71	71																							
72	72																							
73	73																							
74	74	weights of components in an assembly from Ref. 7.2										Note the volume and mass of the Inconel reflectors (2 reflectors/pin) are determined (reflectors are right circular cylinders) volume= $\pi \cdot \text{radius}^2 \cdot \text{length}$ and mass=volume*density												
75	75	kg					kg	kg	kg	radius, cm =	0.240665	length, cm =	14.478											

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T														
226	226	0.5	0.610235	0.5	1.0	0.218061007	0.781938993	6.3266E-03	3.8800E-02	5.8621E-02	1.037476E-01	36.55																						
227	227	0.5	0.610235	0.3	0.6	0.325737126	0.674262874	9.4506E-03	4.1448E-02	5.4544E-02	1.054419E-01	23.58																						
228	228	0.5	0.610235	0.1	0.2	0.643480885	0.356519115	1.8669E-02	4.9260E-02	4.2512E-02	1.104416E-01	10.46																						
229	229	1	0.72644	1.0	2.0	0.079994568	0.920005432	2.3209E-03	3.5406E-02	6.3849E-02	1.015752E-01	104.02																						
230	230	1	0.72644	0.7	1.4	0.107775878	0.892224122	3.1269E-03	3.6089E-02	6.2797E-02	1.020123E-01	76.57																						
231	231	1	0.72644	0.5	1.0	0.140246733	0.859753267	4.0690E-03	3.6887E-02	6.1567E-02	1.025232E-01	58.27																						
232	232	1	0.72644	0.3	0.6	0.200719873	0.799280127	5.8235E-03	3.8374E-02	5.9277E-02	1.034748E-01	39.94																						
233	233	1	0.72644	0.1	0.2	0.352877503	0.647122497	1.0238E-02	4.2115E-02	5.3516E-02	1.058690E-01	21.55																						
234	234	1	0.72644	0	0.0	0.568268026	0.431731974	1.6487E-02	4.7411E-02	4.5360E-02	1.092582E-01	12.26																						
235	235																																	
236	236	For Table 6-7																																
237	237	For this case need the DFAs and Ident-69 container are surrounded by the goethite sludge from the basket assembly which will submerge the Ident-69 container and DFAs																																
238	238	Need the volume of the Ident-69 container and the DFAs. The volume of the Ident-69 container is simply, $\pi r_o^2 L_{idt}$, and																																
239	239	the volume of the DFA is $1.5 L_{dfa} p_{dfa}^2 \tan(30)$, where r_o is the outer radius of the Ident-69 container, L_{idt} is its height,																																
240	240	L_{dfa} is the height of the DFA and p_{dfa} is distance across the outside flats of the DFA.																																
241	241	L_{idt} , cm=	365.76	L_{dfa} , cm=	365.76	p_{dfa} , cm=	11.6205																											
242	242	Volume Ident-69 container, cm ³ =	57355.04743																															
243	243	Volume of DFA, cm ³ =	42773.66566																															
244	244	It is also necessary to determine the volume of the components and void space inside the Ident-69.																																
245	245	The Ident-69 contains a duct and as modelled 115 fuel pins.																																
246	246	The fuel pin length is L_{pin} and the duct inner and outer radii are r_{di} and r_{do} .																																
247	247	L_{pin} , cm=	237.24	r_{di} , cm=	2.0701	r_{do} , cm=	2.2225																											
248	248	Volume Ident-69 duct, cm ³ =	751.7119766	[$\pi L_{idt}(r_{do}^2 - r_{di}^2)$]																														
249	249	Volume fuel pin, cm ³ =	63.59176836	[$\pi L_{pin} r_{pin}^2$]																														
250	250	Volume all fuel pins, cm ³ =	7313.053361																															
251	251	Volume inside Ident-69 (excluding duct and fuel pins), cm ³ =	52947.92468																															
252	252	Void space inside Ident-69, cm ³ =	44883.15934																															
253	253	A basket assembly insert is investigated for the Ident-69 container. This insert is made of 0.1524 cm thick SS-304L and has 4 compartments.																																
254	254	It connects from the outer surface of the duct to the inner surface of the Ident-69 container, and the total volume of the plates composing the basket is:																																
255	255	Volume Ident-69 basket, cm ³ =	1017.990635																															
256	256	Now, Table 6-7: vol goethite+water is the volume of the goethite and water sludge; sub DFA and sub Ident are the number of DFAs and Ident-69 containers submerged in the sludge;																																
257	257	total volume is the total volume of sludge and submerged DFAs and Ident-69; this volume fits in the horizontal DOE canister at a height h;																																
258	258	this height and volume are related by $Volume = R_{inz}^2 * L_{hz} * (\theta - 0.5 * \sin(2 * \theta))$ and $h = R_{inz} * \cos(\theta)$, where																																
259	259	R_{inz} , cm=	21.9075	L_{hz} , cm=	412.5	(this is the length of the DOE SNF basket assembly);																												
260	260	d Vol is used by Excel to solve this relationship and should ideally be near zero; wt. % Gd is the weight % of gadolinium that was in the basket assembly;																																
261	261	The mass of Gd is determined as a % of the basket insert, kg/%=																																
262	262	MW Gd=	157.25	For the fuel pins in the DFA:				3.810750989	# den of Gd=	mass*Avog. #/(volume*Atomic weight)																								
263	263	vf goethite		vf water		vol goethite+water		sub DFA		sub Ident		total volume		theta0		height, cm		wt % Gd		mass Gd (kg)		# den Fe		#den O		#den H		#den Gd		total # den		d Vol		H/X (unit cell)
264	264	0.6	0.4	154734.2938		5	0	368602.6221	1.717377343	3.19974	0	0	1.7408E-02	4.8191E-02	4.4159E-02	0	1.09757E-01	2.1304E-08	13.48															
265	265	0.6	0.4	154734.2938		5	0	368602.6221	1.717377343	3.19974	1	3.810750989	1.7408E-02	4.8191E-02	4.4159E-02	9.4322E-05	1.09852E-01	2.1304E-08	13.48															
266	266	0.6	0.4	154734.2938		5	0	368602.6221	1.717377343	3.19974	2	7.621501978	1.7408E-02	4.8191E-02	4.4159E-02	1.8864E-04	1.09946E-01	2.1304E-08	13.48															
267	267	0.5	0.5	185681.1525		6	0	442323.1465	1.915895903	7.41110	2	7.621501978	1.4506E-02	4.5732E-02	4.7945E-02	1.5720E-04	1.08341E-01	-3.59316E-07	13.48															
268	268	0.4	0.6	232101.4406		6	0	488743.4346	2.056101759	10.21938	2	7.621501978	1.1605E-02	4.3274E-02	5.1732E-02	1.2576E-04	1.06736E-01	-2.71131E-07	13.48															
269	269	0.6	0.4	154734.2938		5	0	368602.6221	1.717377343	3.19974	5	19.05375495	1.7408E-02	4.8191E-02	4.4159E-02	4.7161E-04	1.10229E-01	2.1304E-08	13.48															
270	270	0.6	0.4	154734.2938		5	0	368602.6221	1.717377343	3.19974	5	19.05375495	1.7408E-02	4.8191E-02	4.4159E-02	4.7161E-04	1.10229E-01	2.1304E-08	13.48															
271	271	0.6	0.4	154734.2938		4	1	383184.0038	1.755235645	4.01773	5	19.05375495	1.7408E-02	4.8191E-02	4.4159E-02	4.7161E-04	1.10229E-01	0	13.48															
272	272	0.6	0.4	154734.2938		4	1	383184.0038	1.755235645	4.01773	6	22.86450594	1.7408E-02	4.8191E-02	4.4159E-02	5.6593E-04	1.10323E-01	0	13.48															
273	273	0.6	0.4	154734.2938		4	1	383184.0038	1.755235645	4.01773	2	7.621501978	1.7408E-02	4.8191E-02	4.4159E-02	1.8864E-04	1.09946E-01	0	13.48															
274	274	0.6	0.4	154734.2938		4	1	383184.0038	1.755235645	4.01773	3	11.43225297	1.7408E-02	4.8191E-02	4.4159E-02	2.8297E-04	1.10040E-01	0	13.48															
275	275	0.6	0.4	154734.2938		4	1	383184.0038	1.755235645	4.01773	4	15.24300396	1.7408E-02	4.8191E-02	4.4159E-02	3.7729E-04	1.10135E-01	0	13.48															
276	276	0.6	0.4	154734.2938		4	1	383184.0038	1.755235645	4.01773	6	22.86450594	1.7408E-02	4.8191E-02	4.4159E-02	5.6593E-04	1.10323E-01	0	13.48															
277	277	0.6	0.4	154734.2938		4	1	383184.0038	1.755235645	4.01773	0	0	1.7408E-02	4.8191E-02	4.4159E-02	0.0	1.09757E-01	0	13.48															
278	278	0.6	0.4	154734.2938		4	1	383184.0038	1.755235645	4.01773	0	0	1.7408E-02	4.8191E-02	4.4159E-02	0.0	1.09757E-01	0	13.48															
279	279	0.6	0.4	154734.2938		4	1	383184.0038	1.755235645	4.01773	0	0	1.7408E-02	4.8191E-02	4.4159E-02	0.0	1.09757E-01	0	13.48															
280	280	0.6	0.4	154734.2938		4	1	383184.0038	1.755235645	4.01773	0	0	1.7408E-02	4.8191E-02	4.4159E-02	0.0	1.09757E-01	0	13.48															
281	281	0.6	0.4	154734.2938		4	1	383184.0038	1.755235645	4.01773	0	0	1.7408E-02	4.8191E-02	4.4159E-02	0.0	1.09757E-01	0	13.48															
282	282	0.6	0.4	154734.2938		4	1	383184.0038	1.755235645	4.01773	0	0	1.7408E-02	4.8191E-02	4.4159E-02	0.0	1.09757E-01	0	13.48															
283	283	0.6	0.4	154734.2938		4	1	383184.0038	1.755235645	4.01773	0	0	1.7408E-02	4.8191E-02	4.4159E-02	0.0	1.09757E-01	0	13.48															
284	284	0.6	0.4	154734.2938		4	1	383184.0038	1.755235645	4.01773	0	0	1.7408E-02	4.8191E-02	4.4159E-02	0.0	1.09757E-01	0	13.48															
285	285	0.6	0.4	154734.2938		3.5	0.8	350326.1615	1.6705032	2.18071	1	3.810750989	1.7408E-02	4.8191E-02	4.4159E-02	9.4322E-05	1.09852E-01	0	13.48															
286	286	0.6	0.4	154734.2938		3.5	0.8	350326.1615	1.6705032	2.18071	5	19.05375495	1.7408E-02	4.8191E-02	4.4159E-02	4.7161E-04	1.10229E-01	0	13.48															
287	287	0.6	0.4	154734.2938		3.5	0.8	350326.1615	1.6705032	2.18071	2	7.621501978	1.7408E-02	4.8191E-02	4.4159E-02	1.8864E-04	1.09946E-01	0	13.48															
288	288	0.6	0.4	154734.2938		3	0.75	326071.5763	1.608935138	0.83532	0	0	1.7408E-02	4.8191E-02	4.4159E-02	0.0	1.09757E-01	0	13.48															
289	289	0.6	0.4	154734.2938		3	0.75	326071.5763	1.608935138	0.83532	0.1	0.381075099	1.7408E-02	4.8191E-02	4.4159E-02	9.4322E-06	1.09767E-01	0	13.48															
290	290	0.6	0.4	154734.2938		3	0.75	326071.5763	1.608935138	0.83532	1	3.810750989	1.7408E-02	4.8191E-02	4.4159E-02	9.4322E-05	1.09852E-01																	

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
376	376	4.00	1.00	383184.0038	1.755235645	4.01773	6	22.86450594	1.7408E-02	4.8191E-02	4.4159E-02	5.6593E-04	1.10323E-01	0						
377	377	4.00	1.00	383184.0038	1.755235645	4.01773	2	7.621501978	1.7408E-02	4.8191E-02	4.4159E-02	1.8864E-04	1.09946E-01	0						
378	378	3.50	0.80	350326.1615	1.6705032	2.18071	6	22.86450594	1.7408E-02	4.8191E-02	4.4159E-02	5.6593E-04	1.10323E-01	0						
379	379	3.50	0.80	350326.1615	1.6705032	2.18071	2	7.621501978	1.7408E-02	4.8191E-02	4.4159E-02	1.8864E-04	1.09946E-01	0						
380	380	3.50	0.80	350326.1615	1.6705032	2.18071	3.5	13.33762846	1.7408E-02	4.8191E-02	4.4159E-02	3.3013E-04	1.10088E-01	0						
381	381	3.50	0.80	350326.1615	1.6705032	2.18071	4	15.24300396	1.7408E-02	4.8191E-02	4.4159E-02	3.7729E-04	1.10135E-01	0						
382	382	3.00	0.75	326071.5763	1.608935138	0.83532	6	22.86450594	1.7408E-02	4.8191E-02	4.4159E-02	5.6593E-04	1.10323E-01	0						
383	383	3.00	0.75	326071.5763	1.608935138	0.83532	2	7.621501978	1.7408E-02	4.8191E-02	4.4159E-02	1.8864E-04	1.09946E-01	0						
384	384																			
385	385	The following are used for Table 6-10 for the goethite from the degraded cladding that surrounds the fuel pins.																		
386	386																			
387	387	define $f_p = (p - p_{minimum}) / (p_{original} - p_{minimum})$																		
388	388	f_p	p	dl	separation	F_g	vf of water	# den Fe	# den O	# den H	total # density	H/X (unit cell)								
389	389	1.00	0.72644	0.0	0.0	0.477139409	0.522860591	1.3843E-02	4.5170E-02	4.8811E-02	1.078243E-01	13.09								
390	390	1.00	0.72644	0.5	1.0	0.124723877	0.875276123	3.6186E-03	3.6505E-02	6.2155E-02	1.022790E-01	58.81								
391	391	1.00	0.72644	0.0	0.0	0.477139409	0.522860591	1.3843E-02	4.5170E-02	4.8811E-02	1.078243E-01	13.09								
392	392	1.00	0.72644	0.5	1.0	0.124723877	0.875276123	3.6186E-03	3.6505E-02	6.2155E-02	1.022790E-01	58.81								
393	393	1.00	0.72644	0.5	1.0	0.124723877	0.875276123	3.6186E-03	3.6505E-02	6.2155E-02	1.022790E-01	58.81								
394	394	1.00	0.72644	0.5	1.0	0.124723877	0.875276123	3.6186E-03	3.6505E-02	6.2155E-02	1.022790E-01	58.81								
395	395	0.50	0.61024	0.5	1.0	0.191857616	0.808142384	5.5663E-03	3.8156E-02	5.9613E-02	1.033353E-01	37.15								
396	396	0.50	0.61024	0.5	1.0	0.191857616	0.808142384	5.5663E-03	3.8156E-02	5.9613E-02	1.033353E-01	37.15								
397	397	1.00	0.72644	0.5	1.0	0.124723877	0.875276123	3.6186E-03	3.6505E-02	6.2155E-02	1.022790E-01	58.81								
398	398	1.00	0.72644	0.5	1.0	0.124723877	0.875276123	3.6186E-03	3.6505E-02	6.2155E-02	1.022790E-01	58.81								
399	399	1.00	0.72644	0.5	1.0	0.124723877	0.875276123	3.6186E-03	3.6505E-02	6.2155E-02	1.022790E-01	58.81								
400	400	1.00	0.72644	0.5	1.0	0.124723877	0.875276123	3.6186E-03	3.6505E-02	6.2155E-02	1.022790E-01	58.81								
401	401																			
402	402	For the remaining tables which contain completely degraded fuel, it is convenient to calculate the number density for the fuel.																		
403	403	This is done by assuming the fuel pellets and insulator pellets become homogeneously mixed together. The number density is																		
404	404	determined using the mass and volume of the fuel and insulator in a fuel pin. Volume fuel+insulator (from Table 5-9), cm ³ =																		
405	405	18.3070 The masses listed below are on a per pin basis.																		
406	406	Pu-239 Pu-240 Pu-241 U-235 U-238 O																		
407	407	mass/pin, g 39.1328 5.21024 0.45696 0.265920858 114.8465215 21.05059074																		
408	408	# den 5.3853E-03 7.1402E-04 6.2362E-05 3.7219E-05 1.5871E-02 4.3295E-02																		
409	409																			
410	410	Information used in Table 6-11, for intact Ident-69 container surrounded by degraded DFAs. # of DFAs= 5 table 6-11																		
411	411	L_sl is the length of the fuel slurry; Gd content is the Gd content in the basket assembly which is fully degraded.																		
412	412	These results use the results in Table 5-10 above (vf goethite= 0.6)																		
413	413	Number densities for mixtures of goethite and water are given in Table G+W above. Length of basket assembly assumed to be 12' rather than 412.5 cm, 12 ft, cm= 365.76																		
414	414	Total mass of Gd in assumed 12 ft basket assembly at 2% Gd, kg= 6.7579E+00 Same but for 5% Gd, kg= 1.6895E+01 Same but for 2.5% Gd, kg= 8.4474E+00																		
415	415	The degraded fuel:																		
416	416	L_sl, ft	L_sl, m	# den Fe	# den O	# den H	# den Pu-239	# den Pu-240	# den Pu-241	# den U-235	# den U-238	total # den	# den Gd	# den Gd	#den Gd	height, cm	theta0	d Vol	H/X	
417	417	3	0.9144	1.7408E-02	5.0206E-02	3.0488E-02	1.1008E-03	1.4596E-04	1.2748E-05	7.6082E-06	3.2443E-03	1.0261E-01	6.6590E-05	1.6648E-04	8.3238E-05	11.12474	2.103431129	9.4033E-07	27.19	
418	418	5	1.524	1.7408E-02	4.9400E-02	3.5956E-02	6.6051E-04	8.7574E-05	7.6487E-06	4.5649E-06	1.9466E-03	1.0547E-01	6.6590E-05	1.6648E-04		11.12474	2.103431129	-6.63567E-09	53.45	
419	419	7	2.1336	1.7408E-02	4.9054E-02	3.8300E-02	4.7179E-04	5.4634E-05	5.4634E-06	3.2606E-06	1.3904E-03	1.0670E-01	6.6590E-05	1.6648E-04		11.12474	2.103431129	-9.25502E-09	79.71	
420	420	10	3.048	1.7408E-02	4.8795E-02	4.0057E-02	3.3025E-04	4.3787E-05	3.8243E-06	2.2825E-06	9.7330E-04	1.0761E-01	6.6590E-05	1.6648E-04		11.12474	2.103431129	-1.31549E-08	119.09	
421	421	12	3.6576	1.7408E-02	4.8695E-02	4.0741E-02	2.7521E-04	3.6489E-05	3.1870E-06	1.9020E-06	8.1108E-04	1.0797E-01	6.6590E-05	1.6648E-04		11.12474	2.103431129	-1.58325E-08	145.35	
422	422	3	0.9144	1.7408E-02	5.0042E-02	3.1596E-02	1.0116E-03	1.3412E-04	1.1714E-05	6.9912E-06	2.9812E-03	1.0319E-01	7.6488E-05			7.64595	1.927311596	1.81433E-07	30.67	
423	423	(above is for 4 DFAs only)																		
424	424	Information used in Table 6-12, for degraded Ident-69 container with degraded DFAs. # of DFAs= 5 table 6-12																		
425	425	L_sl is the length of the fuel slurry; Gd content is the Gd content in the basket assembly which is fully degraded.																		
426	426	These results use the results in Table 5-11 above (vf goethite= 0.6)																		
427	427	Number densities for mixtures of goethite and water are given in Table G+W above. Length of basket assembly assumed to be 12' rather than 412.5 cm, 12 ft, cm= 365.76																		
428	428	Total mass of Gd in assumed 12 ft basket assembly at 2% Gd, kg= 6.7579E+00 Same but for 0.5% Gd, kg= 1.6895E+00																		
429	429	L_sl, ft = 3 L_sl, m = 0.9144 Note: No fuel pins is the original number of fuel pins in the Ident-69 container																		
430	430																			
431	431	No fuel pins	# den Fe	# den O	# den H	# den Pu-239	# den Pu-240	# den Pu-241	# den U-235	# den U-238	total # den	# den Gd	# den Gd	height, cm	theta0	d Vol	H/X			
432	432	0	1.7408E-02	5.0133E-02	3.0985E-02	1.0608E-03	1.4065E-04	1.2284E-05	7.3313E-06	3.1263E-03	1.0287E-01	6.4167E-05			8.15554	1.95225146	1.69413E-07	28.68		
433	433	109	1.7408E-02	5.0284E-02	2.9958E-02	1.1435E-03	1.5161E-04	1.3242E-05	7.9030E-06	3.3701E-03	1.0234E-01	6.2856E-05			8.72436	1.980389777	-6.95436E-08	25.72		
434	434	217	1.7408E-02	5.0428E-02	2.8981E-02	1.2222E-03	1.6205E-04	1.4153E-05	8.4469E-06	3.6020E-03	1.0183E-01	6.1609E-05	1.5402E-05		9.29496	2.008965193	-9.32923E-08	23.28		
435	435																			
436	436																			
437	437																			
438	438	Information used in Table 6-13, for degraded DFAs. # of DFAs= 6 table 6-13																		
439	439	L_sl is the length of the fuel slurry; Gd content is the Gd content in the basket assembly which is fully degraded.																		
440	440	These results use the results in Table 5-10 above (vf goethite= 0.6)																		
441	441	Number densities for mixtures of goethite and water are given in Table G+W above. Length of basket assembly assumed to be 12' rather than 412.5 cm, 12 ft, cm= 365.76																		
442	442	Total mass of Gd in assumed 12 ft basket assembly at 2% Gd, kg= 6.7579E+00 Same but for 1.25% Gd, kg= 4.2237E+00																		
443	443																			
444	444	L_sl, ft	L_sl, m	# den Fe	# den O	# den H	# den Pu-239	# den Pu-240	# den Pu-241	# den U-235	# den U-238	total # den	# den Gd	# den Gd	height, cm	theta0	d Vol	H/X		
445	445	3	0.9144	1.7408E-02	5.0332E-02	2.9633E-02	1.1697E-03	1.5508E-04	1.3545E-05	8.0838E-06	3.4471E-03	1.0217E-01	5.8961E-05	3.6850E-05	10.61733	2.076751773	5.00586E-09	24.88		
446	446	5	1.524	1.7408E-02	4.9475E-02	3.5443E-02	7.0179E-04	9.3049E-05	8.1268E-06	4.8503E-06	2.0683E-03	1.0520E-01	5.8961E-05		10.61733	2.076751773	8.26549E-09	49.59		
447	447	7	2.1336	1.7408E-02	4.9108E-02	3.7934E-02	5.0128E-04	6.6463E-05	5.8049E-06	3.4645E-06	1.4773E-03	1.0650E-01	5.8961E-05		10.61733	2.076751773	1.1496E-08	74.30		
448	448	10	3.048	1.7408E-02	4.8833E-02	3.9801E-02	3.5090E-04	4.6524E-05	4.0634E-06	2.4251E-06	1.0341E-03	1.0748E-01	5.8961E-05		10.61733	2.076751773	1.64728E-08	111.37		
449	449	12	3.6576	1.7408E-02	4.8726E-02	4.0527E-02	2.9241E-04	3.8770E-05	3.3862E-06	2.0209E-06	8.6178E-04	1.0786E-01	5.8961E-05		10.61733	2.076751773	1.99652E-08	136.08		
450	450	Following is for file 6DFAs_55_3_gd_2 and has a vf of goethite= 0.55																		

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
676	676	the clay # dens are																		
677	677	Element	# den	isotope	# den															
678	678	Fe	8.8518E-03	Th-232	7.9747E-06	The information, number densities, H/X, etc. for the DOE SNF canister and contents are found as the second entry in Table 6-14 above.														
679	679	O	4.5766E-02	U-233	4.2649E-13															
680	680	H	3.5105E-02	U-234	1.4237E-08															
681	681	Mg	2.8252E-04	U-236	4.4846E-08	Fissile for this case: U-233, U-235, Pu-239 and Pu-241														
682	682	Ni	2.6894E-04	U-235	7.5380E-07	H/X= 26553.26														
683	683	Ti	1.0126E-04	U-238	1.5770E-04															
684	684	Al	6.0532E-04	Np-237	3.2367E-08															
685	685	Ca	2.8252E-04	Pu-238	2.2118E-07															
686	686	Mn	3.5303E-04	Pu-239	5.2745E-07															
687	687	K	5.6505E-04	Pu-240	9.6408E-08															
688	688	Na	5.6505E-04	Pu-241	4.0823E-08															
689	689	Si	6.2840E-03	Pu-242	8.0456E-09															
690	690																			
691	691	filenames: geot_gd_6_7a.o contains an intact Ident-69+5 degraded DFAs																		
692	692		volume of clay	volume of clay	height of clay															
693	693	vf water	vf clay	and water, cm^3	water+canister	muck, cm	theta0	d Vol												
694	694	0.3	0.7	8933771.429	9587418.908	39.41677	2.003500576	0												
695	695	the clay # dens are																		
696	696	Element	# den	isotope	# den															
697	697	Fe	1.0327E-02	Th-232	9.3038E-06	The information, number densities, H/X, etc. for the DOE SNF canister and contents are found as the second entry in Table 6-14 above.														
698	698	O	4.7821E-02	U-233	4.9757E-13															
699	699	H	2.9810E-02	U-234	1.6610E-08															
700	700	Mg	3.2961E-04	U-236	5.2320E-08	Fissile for this case: U-233, U-235, Pu-239 and Pu-241														
701	701	Ni	3.1376E-04	U-235	8.7943E-07	H/X= 19326.76														
702	702	Ti	1.1814E-04	U-238	1.8398E-04															
703	703	Al	7.0620E-04	Np-237	3.7761E-08															
704	704	Ca	3.2961E-04	Pu-238	2.5805E-07															
705	705	Mn	4.1187E-04	Pu-239	6.1535E-07															
706	706	K	6.5922E-04	Pu-240	1.1248E-07															
707	707	Na	6.5922E-04	Pu-241	4.7627E-08															
708	708	Si	7.3314E-03	Pu-242	9.3865E-09															
709	709																			
710	710	filenames: geot_gd_6_1a.o contains an intact Ident-69+5 degraded DFAs																		
711	711		volume of clay	volume of clay	height of clay															
712	712	vf water	vf clay	and water, cm^3	water+canister	muck, cm	theta0	d Vol												
713	713	0	1	6253640	6907287.48	6.91027	1.644376206	0												
714	714	the clay # dens are																		
715	715	Element	# den	isotope	# den															
716	716	Fe	1.4753E-02	Th-232	1.3291E-05	The information, number densities, H/X, etc. for the DOE SNF canister and contents are found as the second entry in Table 6-14 above.														
717	717	O	5.3985E-02	U-233	7.1081E-13															
718	718	H	1.3924E-02	U-234	2.3728E-08															
719	719	Mg	4.7087E-04	U-236	7.4743E-08	Fissile for this case: U-233, U-235, Pu-239 and Pu-241														
720	720	Ni	4.4823E-04	U-235	1.2563E-06	H/X= 6319.04														
721	721	Ti	1.6876E-04	U-238	2.6283E-04															
722	722	Al	1.0089E-03	Np-237	5.3945E-08															
723	723	Ca	4.7087E-04	Pu-238	3.6864E-07	The remaining cases with 4% Gd, with 1 DFA removed														
724	724	Mn	5.8839E-04	Pu-239	8.7908E-07	with 2% and 2.25% Gd and with 2 DFAs removed and 1.5% Gd														
725	725	K	9.4175E-04	Pu-240	1.6068E-07	are listed in Table 6-14 above.														
726	726	Na	9.4175E-04	Pu-241	6.8039E-08															
727	727	Si	1.0473E-02	Pu-242	1.3409E-08															
728	728																			
729	729																			
730	730	Information for Table 6-19																		
731	731	The information, number densities, H/X, etc. for the DOE SNF canister and contents for all but the last case are taken from																		
732	732	the last few cases in Table 6-10 above. The last case is taken from the last case in Table 6-9.																		
733	733	The information for the clay-water slurry is the same (the same order) as that for Table 6-18.																		
734	734																			
735	735																			
736	736	The H/X ratio of the number of hydrogen atoms to that of fissile atoms:																		
737	737	For homogeneous fuel it is simply the ratio of the hydrogen # density to that of the sum of the fissile nuclides # density.																		
738	738	For heterogeneous fuel it is calculated on a unit cell basis, i.e., given the volume/unit length																		
739	739	of fuel and volume/unit length of hydrogen containing material, V_f and V_H, H/X is																		
740	740																			
741	741	$H/X = \text{Sum}(V_H \cdot \# \text{den})_{i,j} / \text{Sum}(V_f \cdot \# \text{den})_{k,l}$																		
742	742																			
743	743	where $(V_H \cdot \# \text{den})_{i,j}$ is the product of the volume/(unit length) times the # density of hydrogen for the																		
744	744	j-th material in the i-th region, and $(V_f \cdot \# \text{den})_{k,l}$ is the product of the volume/(unit length) times																		
745	745	the # density of the l-th fissile nuclide in the k-th region of the cell. For all cases considered here the																		
746	746	volume/(unit length) is simply the cross-sectional area. The following isotopes are considered fissile:																		
747	747	Pu-239, Pu-241 and U-235 unless noted otherwise.																		
748	748																			
749	749	Volume/(unit length) for shapes in unit cell:																		
750	750	Hexagonal (unit cell) = $1.5 \cdot (\text{pitch})^2 \cdot \tan(30)$; cylinder (unit cell) = $\pi \cdot (\text{radius})^2$																		

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Attachment II

Table II-1. MCNP Outputs used in Engineering Calculations and Stored in Electronic Format (CD-ROM)

Bytes Used	Date Last Accessed	Output File Name	Table Used
3,464,875	04/19/1999	gcombd_gd_0_p_1.0.o	Table 6-1
3,465,579	04/19/1999	gcombd_gd_1_p_1.0.o	Table 6-1
3,466,522	04/19/1999	gcombd_gd_5_p_00.o	Table 6-1
3,466,118	04/19/1999	gcombd_gd_5_p_25.o	Table 6-1
3,465,591	04/19/1999	gcombd_gd_5_p_50.o	Table 6-1
3,465,591	04/19/1999	gcombd_gd_5_p_75.o	Table 6-1
3,465,586	04/19/1999	gcombd_gd_5_p_1.0.o	Table 6-1
3,591,514	04/19/1999	hxgcomb_gd_1_cl_00_wat_4a.o	Table 6-2
3,591,443	04/19/1999	hxgcomb_gd_1_cl_00_wat_52a+c.o	Table 6-2
3,591,513	04/19/1999	hxgcomb_gd_1_cl_00_wat_52a.o	Table 6-2
3,591,875	04/19/1999	hxgcomb_gd_1_cl_00_wat_52aS.o	Table 6-2
3,702,142	04/19/1999	hxgcomb_gd_1_cl_25_wat_4.o	Table 6-2
3,701,781	04/19/1999	hxgcomb_gd_1_cl_25_wat_60.o	Table 6-2
3,702,108	04/19/1999	hxgcomb_gd_1_cl_50_wat_4.o	Table 6-2
3,701,783	04/19/1999	hxgcomb_gd_1_cl_50_wat_706.o	Table 6-2
2,383,198	05/25/1999	d6030t.o	Table 6-3
3,218,537	04/19/1999	gcomb_gd_5_cl_00.o	Table 6-3
3,461,170	04/19/1999	gcomb_gd_5_cl_00a.o	Table 6-3
3,224,449	04/19/1999	gcomb_gd_5_cl_00_rot.o	Table 6-3
3,470,783	04/19/1999	gcomb_gd_5_cl_00_rot_a.o	Table 6-3
3,218,775	04/19/1999	gcomb_gd_5_cl_25.o	Table 6-3
3,219,089	04/19/1999	gcomb_gd_5_cl_50.o	Table 6-3
3,168,581	05/25/1999	i6030t.o	Table 6-3
404,374	04/19/1999	hx_pmd_gd_1_wat_46_dl_1.o	Table 6-4
404,159	04/19/1999	hx_pmd_gd_1_wat_72_dl_3.o	Table 6-4
404,159	04/19/1999	hx_pmd_gd_1_wat_81_dl_5.o	Table 6-4
404,159	04/19/1999	hx_pmd_gd_1_wat_85_dl_7.o	Table 6-4
405,687	05/01/1999	hx_pmx_gd_1_88zC.o	Table 6-4
3,340,994	04/19/1999	hx_pmx_gd_1_wat_52_dl_0.o	Table 6-4
404,473	04/19/1999	hx_pmx_gd_1_wat_70_dl_1.o	Table 6-4
404,062	04/19/1999	hx_pmx_gd_1_wat_82_dl_3.o	Table 6-4
404,161	04/19/1999	hx_pmx_gd_1_wat_88_dl_5.o	Table 6-4
405,484	04/19/1999	hx_pmx_gd_1_wat_88_dl_5_z.o	Table 6-4

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page II-2

Bytes Used	Date Last Accessed	Output File Name	Table Used
404,159	04/19/1999	hx_pmx_gd_1_wat_90_dl_7.o	Table 6-4
404,393	04/19/1999	hx_pmx_gd_1_wat_91_dl_8.o	Table 6-4
572,874	04/19/1999	hx_pmx_gd_1_wat_91_dl_8a.o	Table 6-4
643,751	04/19/1999	hx_pmx_gd_1_wat_91_dl_8b.o	Table 6-4
405,796	05/01/1999	hx_pmx_gd_2_wat_88_dl_5_z.o	Table 6-4
409,258	05/25/1999	i604lr0t.o	Table 6-4
7,462,267	04/19/1999	lvb_co2.o	Table 6-5
7,461,075	04/19/1999	mine_co1.o	Table 6-5
7,460,567	04/19/1999	mine_co2+c.o	Table 6-5
7,460,947	04/19/1999	mine_co2.o	Table 6-5
4,633,396	04/19/1999	mine_co2_h.o	Table 6-5
7,460,551	04/19/1999	mine_co2_nogd.o	Table 6-5
589,685	04/19/1999	sc5_md_gd_1_12_dl_1+c.o	Table 6-6
589,565	04/19/1999	sc5_md_gd_1_16_dl_7+c.o	Table 6-6
589,239	04/19/1999	sc5_md_gd_1_22_dl_5+c.o	Table 6-6
589,142	04/19/1999	sc5_md_gd_1_33_dl_3+c.o	Table 6-6
589,863	04/19/1999	sc5_md_gd_1_64_dl_1+c.o	Table 6-6
587,539	04/19/1999	sc5_mx_gd_1_14_dl_5+c.o	Table 6-6
587,735	04/19/1999	sc5_mx_gd_5_14_dl_5+c.o	Table 6-6
588,179	04/19/1999	sc5_mx_gd_1_08_dl_1+c.o	Table 6-6
587,736	04/19/1999	sc5_mx_gd_1_11_dl_7+c.o	Table 6-6
587,736	04/19/1999	sc5_mx_gd_1_14_dl_5+c.o	Table 6-6
580,823	05/01/1999	sc5_mx_gd_1_20nor.o	Table 6-6
587,736	04/19/1999	sc5_mx_gd_1_20_dl_3+c.o	Table 6-6
587,639	04/19/1999	sc5_mx_gd_1_35_dl_1+c.o	Table 6-6
587,486	04/19/1999	sc5_mx_gd_1_57_dl_0+c.o	Table 6-6
584,516	05/01/1999	sc5_mx_gd_2_20_dl_3+c.o	Table 6-6
583,891	05/02/1999	sc5_mx_gd_3_20_dl_3+c.o	Table 6-6
2,273,461	04/19/1999	dfa6_gd_0_go_6b.o	Table 6-7
2,273,295	04/19/1999	dfa6_gd_1_go_6b.o	Table 6-7
2,271,759	04/19/1999	dfa6_gd_2_go_4b.o	Table 6-7
2,272,260	04/19/1999	dfa6_gd_2_go_5b.o	Table 6-7
2,273,392	04/19/1999	dfa6_gd_2_go_6b.o	Table 6-7
2,272,333	04/19/1999	dfa6_gd_5_go_6a-S.o	Table 6-7
2,274,472	04/19/1999	dfa6_gd_5_go_6a.o	Table 6-7
2,273,295	04/19/1999	dfa6_gd_5_go_6b.o	Table 6-7
1,542,578	05/03/1999	sc6_gd_1_go_6_nor-2.o	Table 6-7
2,522,619	04/19/1999	sc6_gd_0_go_6_-2.o	Table 6-7

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Bytes Used	Date Last Accessed	Output File Name	Table Used
3,273,392	04/19/1999	sc6_gd_0kghom_fe.o	Table 6-7
3,272,448	04/19/1999	sc6_gd_0kghom_go.o	Table 6-7
3,287,427	04/19/1999	sc6_gd_1.5kgin_go_.6.o	Table 6-7
2,817,450	04/19/1999	sc6_gd_1._go_.6_-1.o	Table 6-7
2,522,769	04/19/1999	sc6_gd_1._go_.6_-2.o	Table 6-7
1,837,155	04/26/1999	sc6_gd_1._go_.6_nor-1.o	Table 6-7
3,273,039	04/19/1999	sc6_gd_1kghom_fe.o	Table 6-7
3,273,447	04/19/1999	sc6_gd_1kghom_go.o	Table 6-7
3,272,727	04/19/1999	sc6_gd_1kghom_go_.6.o	Table 6-7
1,840,386	04/19/1999	sc6_gd_2._go_.6_nor-1.o	Table 6-7
2,135,563	04/19/1999	sc6_gd_2._go_.6_nor.o	Table 6-7
2,135,565	04/19/1999	sc6_gd_3._go_.6_nor.o	Table 6-7
2,132,753	05/01/1999	sc6_gd_4._go_.6_nor.o	Table 6-7
3,109,316	04/19/1999	sc6_gd_5._go_.6.o	Table 6-7
2,814,445	04/19/1999	sc6_gd_5._go_.6_-1.o	Table 6-7
3,111,009	04/19/1999	sc6_gd_5kgin_go_.6.o	Table 6-7
3,283,996	04/19/1999	sc6_gd_5kgin_go_.6all.o	Table 6-7
3,109,316	04/19/1999	sc6_gd_6._go_.6.o	Table 6-7
2,132,853	04/19/1999	sc6_gd_6._go_.6_nor.o	Table 6-7
4,668,734	04/27/1999	dfa_.6_gd_0.0b.o	Table 6-8
4,613,658	04/19/1999	dfa_.6_gd_2.0a.o	Table 6-8
4,676,670	04/19/1999	dfa_.6_gd_2.0b.o	Table 6-8
3,961,936	04/19/1999	sc7_h_basa.o	Table 6-8
4,121,109	04/19/1999	sc7_h_basa_.6_gd_1.0.o	Table 6-8
3,990,480	04/19/1999	sc7_h_basa_.6_gd_2.0.o	Table 6-8
3,962,954	04/19/1999	sc7_h_basb_.6_gd_2.0.o	Table 6-8
15,275,062	04/19/1999	sc7_h_basc_.4_gd_2.0+c.o	Table 6-8
3,942,104	04/19/1999	sc7_h_basc_.5_gd_2.0+c.o	Table 6-8
14,262,901	04/19/1999	sc7_h_basc_.6_gd_1.0_nor.o	Table 6-8
3,984,078	04/19/1999	sc7_h_basc_.6_gd_2.0+c.o	Table 6-8
3,253,373	04/19/1999	sc7_h_basc_.6_gd_2.0-1.o	Table 6-8
3,253,745	05/01/1999	sc7_h_basc_.6_gd_2.0-1nrC.o	Table 6-8
2,543,147	04/19/1999	sc7_h_basc_.6_gd_2.0-2.o	Table 6-8
3,942,199	04/19/1999	sc7_h_basc_.6_gd_2.0.o	Table 6-8
3,930,527	04/27/1999	sc7_h_basc_.6_gd_2.0_nor+c.o	Table 6-8
3,947,286	04/19/1999	sc7_h_basc_.6_gd_2.0_nor.o	Table 6-8
3,957,565	04/19/1999	sc7_h_basd_.6_gd_2.0.o	Table 6-8
3,964,266	04/19/1999	sc7_h_base_.6_gd_2.0.o	Table 6-8

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page II-4

Bytes Used	Date Last Accessed	Output File Name	Table Used
391,320	04/19/1999	df8_pd_gd_2_.19_dl_.5-S.o	Table 6-9
392,967	04/19/1999	df8_pd_gd_2_.19_dl_.5.o	Table 6-9
392,782	05/01/1999	df8_pd_gd_4_.19_dl_.5S.o	Table 6-9
393,090	04/19/1999	df8_pd_gd_5_.19_dl_.5.o	Table 6-9
392,348	04/19/1999	df8_px_gd_2_.12_dl_.5-1.o	Table 6-9
390,463	04/26/1999	df8_px_gd_2_.12_dl_.5-1S.o	Table 6-9
391,667	04/19/1999	df8_px_gd_2_.12_dl_.5-2.o	Table 6-9
389,683	04/26/1999	df8_px_gd_2_.12_dl_.5-2S.o	Table 6-9
393,189	04/19/1999	df8_px_gd_2_.12_dl_.5.o	Table 6-9
394,074	04/19/1999	df8_px_gd_2_.30_dl_.1.o	Table 6-9
392,415	04/19/1999	df8_px_gd_2_.48_dl_.0.o	Table 6-9
390,364	04/26/1999	df8_px_gd_5_.12_dl_.5-1S.o	Table 6-9
393,270	04/19/1999	df8_px_gd_5_.12_dl_.5.o	Table 6-9
405,715	04/19/1999	sc8_pd_gd_2_.81_dl_.5.o	Table 6-10
405,618	04/19/1999	sc8_pd_gd_6_.81_dl_.5.o	Table 6-10
398,313	04/28/1999	sc8_px_gd_2_.12_dl_.5-2+cnrS.o	Table 6-10
404,645	04/19/1999	sc8_px_gd_2_.12_dl_.5-2.o	Table 6-10
406,345	04/19/1999	sc8_px_gd_2_.12_dl_.5.o	Table 6-10
405,074	04/19/1999	sc8_px_gd_2_.48_dl_.0.o	Table 6-10
401,168	04/19/1999	sc8_px_gd_2_.dl_.5+cnr-1.o	Table 6-10
398,561	04/26/1999	sc8_px_gd_2_.dl_.5+cnr-1S.o	Table 6-10
398,872	04/29/1999	sc8_px_gd_3.5_dl_.5+cnr-1S.o	Table 6-10
406,137	04/19/1999	sc8_px_gd_6_.12_dl_.5+c.o	Table 6-10
402,050	04/19/1999	sc8_px_gd_6_.12_dl_.5+cnr.o	Table 6-10
405,538	04/19/1999	sc8_px_gd_6_.12_dl_.5-1.o	Table 6-10
404,349	04/19/1999	sc8_px_gd_6_.12_dl_.5-2.o	Table 6-10
405,707	04/19/1999	sc8_px_gd_6_.12_dl_.5.o	Table 6-10
405,180	04/19/1999	sc8_px_gd_6_.48_dl_.0.o	Table 6-10
1,573,079	04/19/1999	ident_10_60.o	Table 6-11
1,574,283	04/19/1999	ident_10_60_gd_2.o	Table 6-11
1,574,382	04/19/1999	ident_10_60_gd_5.o	Table 6-11
1,574,497	04/19/1999	ident_12_60.o	Table 6-11
1,574,277	04/19/1999	ident_12_60_gd_2.o	Table 6-11
1,574,909	04/19/1999	ident_12_60_gd_5.o	Table 6-11
1,574,276	04/19/1999	ident_3_60.o	Table 6-11
1,487,926	04/29/1999	ident_3_60_gd_2.5norS.o	Table 6-11
1,574,281	04/19/1999	ident_3_60_gd_2.o	Table 6-11
1,487,748	04/28/1999	ident_3_60_gd_2nor.o	Table 6-11

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page II-5

Bytes Used	Date Last Accessed	Output File Name	Table Used
1,574,807	04/19/1999	ident_3_60_gd_5.o	Table 6-11
1,574,777	04/28/1999	ident_3_60_gd_5S.o	Table 6-11
1,574,272	04/19/1999	ident_5_60.o	Table 6-11
1,574,090	04/19/1999	ident_5_60_gd_2.o	Table 6-11
1,574,616	04/19/1999	ident_5_60_gd_5.o	Table 6-11
1,574,182	04/19/1999	ident_7_60.o	Table 6-11
1,574,235	04/19/1999	ident_7_60_gd_2.o	Table 6-11
1,574,664	04/19/1999	ident_7_60_gd_5.o	Table 6-11
1,487,871	05/02/1999	id_3_60_gd_2.nrS-1.o	Table 6-11
364,889	04/19/1999	homall_3_60_0.o	Table 6-12
365,752	04/19/1999	homall_3_60_0_gd_2.o	Table 6-12
364,893	04/19/1999	homall_3_60_109.o	Table 6-12
365,952	04/19/1999	homall_3_60_109_gd_2.o	Table 6-12
364,796	04/19/1999	homall_3_60_217.o	Table 6-12
365,440	04/28/1999	homall_3_60_217_gd_5.o	Table 6-12
366,055	04/28/1999	homall_3_60_217_gd_5S.o	Table 6-12
365,952	04/19/1999	homall_3_60_217_gd_2.o	Table 6-12
365,434	04/19/1999	6DFAs_55_3_gd_2.o	Table 6-13
364,426	04/19/1999	6DFAs_60_10.o	Table 6-13
365,200	04/19/1999	6DFAs_60_10_gd_2.o	Table 6-13
206,763	04/19/1999	6DFAs_60_12.o	Table 6-13
209,117	04/19/1999	6DFAs_60_12_gd_2.o	Table 6-13
364,786	04/19/1999	6DFAs_60_3.o	Table 6-13
365,942	04/19/1999	6DFAs_60_3_gd_2.o	Table 6-13
366,152	04/19/1999	6DFAs_60_3_gd_2_Sab.o	Table 6-13
365,405	04/19/1999	6DFAs_60_3_Sab.o	Table 6-13
364,472	04/19/1999	6DFAs_60_5.o	Table 6-13
365,533	04/19/1999	6DFAs_60_5_gd_2.o	Table 6-13
364,876	04/19/1999	6DFAs_60_7.o	Table 6-13
365,630	04/19/1999	6DFAs_60_7_gd_2.o	Table 6-13
365,123	04/27/1999	6DFAs_fl_3_gd_1.25.o	Table 6-13
365,540	04/28/1999	6DFAs_fl_3_gd_1.25S.o	Table 6-13
365,434	04/19/1999	6DFAs_fl_3_gd_2.o	Table 6-13
1,530,784	05/02/1999	cdt_grv_gd_2_1_Snr-1.o	Table 6-14
1,530,425	04/27/1999	coidt_grav_gd_4_1_nr.o	Table 6-14
1,530,698	04/27/1999	coidt_grav_gd_4_1_Snr.o	Table 6-14
1,615,612	04/27/1999	coidt_grav_gd_5_1.o	Table 6-14
1,616,918	04/19/1999	coidt_grav_gd_6_1.o	Table 6-14

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page II-6

Bytes Used	Date Last Accessed	Output File Name	Table Used
1,616,349	04/19/1999	coidt_grav_gd_6_1ff.o	Table 6-14
1,617,436	04/19/1999	coidt_grav_gd_6_1_S.o	Table 6-14
1,617,017	04/19/1999	coidt_grav_gd_6_2.o	Table 6-14
1,656,317	04/19/1999	coidt_grav_gd_6_3.o	Table 6-14
1,617,069	04/19/1999	coidt_grv_50_gd_6.0.o	Table 6-14
1,617,021	04/19/1999	coidt_grv_65_gd_6.0.o	Table 6-14
1,616,035	04/19/1999	coidt_grv_74.6_gd_6.0.o	Table 6-14
1,656,370	04/19/1999	coidt_grv_fl_gd_6.0.o	Table 6-14
1,617,361	04/19/1999	coidt_grav_gd_6_1_.0.o	Table 6-15
1,618,590	04/19/1999	coidt_grav_gd_6_1_.2.o	Table 6-15
1,618,493	04/19/1999	coidt_grav_gd_6_1_.4.o	Table 6-15
1,618,805	04/19/1999	coidt_grav_gd_6_1_.6.o	Table 6-15
1,618,851	04/19/1999	coidt_grav_gd_6_1_.8.o	Table 6-15
1,617,865	04/19/1999	coidt_grav_gd_6_1_h.0.o	Table 6-16
1,617,964	04/19/1999	coidt_grav_gd_6_1_h.2.o	Table 6-16
1,618,390	04/19/1999	coidt_grav_gd_6_1_h.4.o	Table 6-16
1,617,865	04/19/1999	coidt_grav_gd_6_1_h.6.o	Table 6-16
1,616,101	04/19/1999	coidt_grav_gd_6_1_h.8.o	Table 6-16
449,439	04/19/1999	cohomal_gravl.o	Table 6-17
449,544	04/19/1999	cohomal_gravl_109.o	Table 6-17
449,542	04/19/1999	cohomal_gravl_55.o	Table 6-17
449,346	04/19/1999	cohomal_gravl_fl.o	Table 6-17
447,102	04/19/1999	cohomal_gravl_fl_ff.o	Table 6-17
449,963	04/19/1999	cohomal_gravl_fl_S.o	Table 6-17
1,642,575	05/01/1999	geot_gd_4_1.anr.o	Table 6-18
1,740,176	04/19/1999	geot_gd_6a.o	Table 6-18
1,740,276	04/27/1999	geot_gd_6aS.o	Table 6-18
1,779,525	04/19/1999	geot_gd_6b.o	Table 6-18
1,779,444	04/19/1999	geot_gd_6c.o	Table 6-18
1,740,182	04/19/1999	geot_gd_6_.7a.o	Table 6-18
1,740,035	04/19/1999	geot_gd_6_1.a.o	Table 6-18
1,740,331	05/01/1999	geot_gd_6_1.aS.o	Table 6-18
1,740,184	04/19/1999	geot_gd_6_fl_a.o	Table 6-18
1,668,779	05/02/1999	gt_gd_2q_1.anrS-1.o	Table 6-18
1,668,777	05/02/1999	gt_gd_2_1.anrS-1.o	Table 6-18
1,681,828	05/03/1999	gt_gd_1_1.anrS-2.o	Table 6-18
379,822	04/29/1999	dx_2_1.a.o	Table 6-19
389,293	04/29/1999	gx_2_.5-1a_1.acnr.o	Table 6-19

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Bytes Used	Date Last Accessed	Output File Name	Table Used
388,283	04/29/1999	gx_2_.5-2a_1.acnr.o	Table 6-19
389,292	05/01/1999	gx_4_.5-1a_1.acrn.o	Table 6-19
393,192	04/23/1999	gx_6_.5-2a_.7a.o	Table 6-19
393,273	04/23/1999	gx_6_.5-2a_1.a.o	Table 6-19
393,091	04/23/1999	gx_6_.5-2a_6a.o	Table 6-19
393,393	04/23/1999	gx_6_.5-2a_6b.o	Table 6-19
393,399	04/23/1999	gx_6_.5-2a_6c.o	Table 6-19
393,091	04/23/1999	gx_6_.5-2 fla.o	Table 6-19
3,627,021	05/24/1999	602g2.O	Table 6-20
2,383,351	05/24/1999	d6031t.o	Table 6-20
2,382,460	05/24/1999	d6032t.o	Table 6-20
2,383,035	05/24/1999	d6033t.o	Table 6-20
1,858,162	05/24/1999	DFA.7.O	Table 6-20
1,504,029	05/24/1999	DFA1.7.O	Table 6-20
1,502,918	05/24/1999	DFA1al.O	Table 6-20
1,857,904	05/24/1999	DFAall.O	Table 6-20
369,307	05/24/1999	i12a1t.O	Table 6-20
369,368	05/24/1999	i12a2t.O	Table 6-20
368,343	05/24/1999	i12ant.O	Table 6-20
370,380	05/24/1999	i12b1t.O	Table 6-20
370,530	05/24/1999	i12b2t.O	Table 6-20
369,407	05/24/1999	i12bnt.O	Table 6-20
369,096	05/24/1999	i13a1t.O	Table 6-20
369,220	05/24/1999	i13a2t.O	Table 6-20
367,804	05/24/1999	i13ant.O	Table 6-20
370,859	05/24/1999	i13b1t.O	Table 6-20
371,113	05/24/1999	i13b2t.O	Table 6-20
369,965	05/24/1999	i13bnt.O	Table 6-20
1,759,221	05/24/1999	i18a1t.O	Table 6-20
1,758,729	05/24/1999	i18a2t.O	Table 6-20
1,757,999	05/24/1999	i18ant.O	Table 6-20
1,686,047	05/24/1999	i18b1t.O	Table 6-20
1,685,294	05/24/1999	i18b2t.O	Table 6-20
1,684,956	05/24/1999	i18bnt.O	Table 6-20
1,684,803	05/27/1999	i18bq0t.o	Table 6-20
1,685,474	05/27/1999	i18bq1t.o	Table 6-20
1,685,872	05/27/1999	i18bq2t.o	Table 6-20
1,684,431	05/27/1999	i18bq3t.o	Table 6-20

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page II-8

Bytes Used	Date Last Accessed	Output File Name	Table Used
1,698,045	05/27/1999	i18dp0t.o	Table 6-20
1,699,023	05/27/1999	i18dp1t.o	Table 6-20
1,698,606	05/27/1999	i18dp2t.o	Table 6-20
1,697,837	05/27/1999	i18dp3t.o	Table 6-20
3,627,483	05/24/1999	i6021t.O	Table 6-20
3,629,662	05/24/1999	i6022t.O	Table 6-20
3,627,071	05/24/1999	i602nt.O	Table 6-20
2,964,052	05/24/1999	i6031t-1.o	Table 6-20
2,964,477	05/24/1999	i6031t-1a.o	Table 6-20
3,168,099	05/24/1999	i6031t.o	Table 6-20
3,165,969	05/24/1999	i6032t.o	Table 6-20
3,165,556	05/24/1999	i6033t.o	Table 6-20
409,570	05/25/1999	i604lr1t.o	Table 6-20
409,570	05/25/1999	i604lr2t.o	Table 6-20
409,475	05/25/1999	i604lr3t.o	Table 6-20
585,818	06/02/1999	i6060to	Table 6-20
586,544	06/02/1999	i6061to	Table 6-20
588,989	06/02/1999	i6062to	Table 6-20
587,054	06/02/1999	i6062xlo	Table 6-20
586,542	06/02/1999	i6062xto	Table 6-20
586,449	06/02/1999	i606nto	Table 6-20
1,548,174	05/24/1999	i6141t.O	Table 6-20
1,547,569	05/24/1999	i6142t.O	Table 6-20
1,547,019	05/24/1999	i614nt.O	Table 6-20
394,108	05/24/1999	i6191t.O	Table 6-20
395,504	05/24/1999	i6192t.O	Table 6-20
394,015	05/24/1999	i619nt.O	Table 6-20
7,529,475	05/24/1999	i65a1t.O	Table 6-20
7,533,920	05/24/1999	i65a2t.O	Table 6-20
7,528,936	05/24/1999	i65ant.O	Table 6-20
7,529,272	05/24/1999	i65b1t.O	Table 6-20
7,533,639	05/24/1999	i65b2t.O	Table 6-20
7,529,205	05/24/1999	i65bnt.O	Table 6-20
1,504,628	05/24/1999	id_1t.O	Table 6-20
1,505,184	05/24/1999	n17g25.o	Table 6-20
1,505,135	05/24/1999	n17g30.o	Table 6-20
1,504,720	05/24/1999	n17g35.o	Table 6-20
2,156,241	05/24/1999	nor.7.O	Table 6-20

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page II-9

Bytes Used	Date Last Accessed	Output File Name	Table Used
1,503,169	05/24/1999	nor1.7.O	Table 6-20
1,502,204	05/24/1999	nor1al.O	Table 6-20
2,156,082	05/24/1999	norall.O	Table 6-20
3,967,812	05/24/1999	sc7.7.O	Table 6-20
3,967,678	05/24/1999	sc7all.O	Table 6-20
3,967,615	05/24/1999	sc7g25.O	Table 6-20
3,967,794	05/24/1999	sc7g30.O	Table 6-20
3,279,533	05/24/1999	sc_1.7.O	Table 6-20
3,279,200	05/24/1999	sc_1al.O	Table 6-20
1,590,569	05/24/1999	t11.7.O	Table 6-20
1,589,361	05/24/1999	t11all.O	Table 6-20
3,141,976	05/24/1999	t6-7al.O	Table 6-20
3,142,610	05/24/1999	t7.7.O	Table 6-20
2,285,411	05/24/1999	6packd0_ss_10_w_1a.o	Table 6-21
2,892,749	05/24/1999	comb01+5b_ss_1.0+_gd.o	Table 6-21
3,247,279	05/24/1999	comb01+5b_ss_10a_w_1a_c.o	Table 6-21
3,150,102	05/24/1999	comb01+5b_ss_10a_w_1a_gd_5_1.6.o	Table 6-21
3,152,963	05/24/1999	comb01+5b_ss_10a_w_1a_gd_2_1.6.o	Table 6-21
2,096,463	05/24/1999	comb01+5b_ss_gd1.0_sqb.o	Table 6-21
2,895,790	05/24/1999	i612-1to	Table 6-21
2,096,577	05/24/1999	i612-1xo	Table 6-21
2,896,007	05/24/1999	i612-2to	Table 6-21
2,097,492	05/24/1999	i612-2xo	Table 6-21
2,895,450	05/24/1999	i612-nto	Table 6-21
2,097,854	05/24/1999	i612-nxo	Table 6-21
2,285,025	05/24/1999	i613-1to	Table 6-21
2,288,000	05/24/1999	i613-2to	Table 6-21
2,284,824	05/24/1999	i613-nto	Table 6-21
3,242,691	05/24/1999	i614-1to	Table 6-21
3,245,308	05/24/1999	i614-2to	Table 6-21
3,242,033	05/24/1999	i614-nto	Table 6-21
3,149,266	05/24/1999	i615-1to	Table 6-21
3,151,907	05/24/1999	i615-2to	Table 6-21
3,150,184	05/24/1999	i615-gd2.o	Table 6-21
3,063,064	05/24/1999	i615-gd2nr.o	Table 6-21
3,148,754	05/24/1999	i615-nto	Table 6-21

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page III-1

Attachment III

The tables and the entries in the tables in this section are in the same order as in Section 6. All results are repeated here and the H/X ratio (the ratio of the number of hydrogen atoms to fissile atoms) and the average energy of neutrons causing fission (AENCF) are given. The H/X ratios in the tables are for either the DFAs or the degraded fuel slurry. The H/X ratio for the Ident-69 container is given in an additional table at the end of this section.

Table III-1. Results for Degraded Fuel Pin Clips/Spacers

Pitch Fraction	Gd Content	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
0	0.5% (1.905 kg)	0.8005 ± 0.0011	0.8027	3.63	334.1	gcombd_gd_5_p_00.o
0.25	0.5% (1.905 kg)	0.8149 ± 0.0010	0.8169	5.90	319.6	gcombd_gd_5_p_25.o
0.50	0.5% (1.905 kg)	0.8333 ± 0.0010	0.8352	8.29	301.6	gcombd_gd_5_p_50.o
0.75	0.5% (1.905 kg)	0.8528 ± 0.0010	0.8549	10.82	285.7	gcombd_gd_5_p_75.o
1.0	0.5% (1.905 kg)	0.8724 ± 0.0011	0.8745	13.48	273.1	gcombd_gd_5_p_10.o
1.0	0.1% (0.3811 kg)	0.8929 ± 0.0011	0.8950	13.48	267.6	gcombd_gd_1_p_10.o
1.0	0	0.9301 ± 0.0010	0.9320	13.48	254.3	gcombd_gd_0_p_10.o

Table III-2. Partially Degraded Fuel Pin Cladding

Fraction of Cladding Thickness Remaining	Volume Fraction of Water in Goethite	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
0.50	0.40	0.8620 ± 0.0011	0.8641	6.35	292.2	hxgcomb_gd_1_cl_50_wat_4.o
0.50	0.71	0.9129 ± 0.0010	0.9148	13.28	259.3	hxgcomb_gd_1_cl_50_wat_706.o
0.25	0.40	0.8779 ± 0.0010	0.8800	8.44	282.2	hxgcomb_gd_1_cl_25_wat_4.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page III-2

Fraction of Cladding Thickness Remaining	Volume Fraction of Water in Goethite	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
0.25	0.60	0.9145 ± 0.0010	0.9166	13.18	257.7	hxgcomb_gd_1_cl_25_wat_60.o
0	0.40	0.8895 ± 0.0011	0.8918	9.78	276.6	hxgcomb_gd_1_cl_00_wat_4a.o
0	0.52	0.9157 ± 0.0010	0.9178	13.09	261.1	hxgcomb_gd_1_cl_00_wat_52a.o
^A 0	0.52	0.9017 ± 0.0011	0.9038	13.09	266.5 ¹	hxgcomb_gd_1_cl_00_wat_52a+c.o
^B 0	0.52	0.9093 ± 0.0011	0.9115	13.09	259.6	hxgcomb_gd_1_cl_00_wat_52aS.o

^APrevious case but pins clad in Ident-69 container.

^BS(α, β) in goethite sludge and unclad pins in Ident-69 container.

Table III-3. k_{eff} for the Case of Cladding Degradation in the DFAs and the Ident-69 Container

Fraction of Cladding Thickness Remaining	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
0.50	—	0.8970 ± 0.0010	0.8990	15.54	264.8	gcomb_gd_5_cl_50.o
0.25	—	0.9042 ± 0.0011	0.9065	16.52	262.7	gcomb_gd_5_cl_25.o
0	—	0.9177 ± 0.0011	0.9199	17.47	256.3	gcomb_gd_5_cl_00.o
0	Pins fallen in DFA duct	0.9128 ± 0.0011	0.9150	17.47	259.2	gcomb_gd_5_cl_00a.o
0	Canister rotated 180°	0.9206 ± 0.0011	0.9227	17.47	256.0	gcomb_gd_5_cl_00_rot.o
0	Canister rotated 180°, less reactive Ident-69, 2% Gd	0.8594 ± 0.0011	0.8617	17.47	265.4	i6030t.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page III-3

Fraction of Cladding Thickness Remaining	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
0	Canister rotated 180°, 6 DFAs, 2% Gd	0.8368 ± 0.0010	0.8388	17.47	332.9	d6030t.o
0	Canister rotated 180° and pins fallen in DFA duct	0.9147 ± 0.0011	0.9168	17.47	254.4	gcomb_gd_5_cl_00_rot_a.o

Table III-4. Results for Fuel Pellets Dispersed in Goethite Sludge

Pitch Fraction	Axial Separation, cm; Water Volume; Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
0.5	0.2; 46%	0.8508 ± 0.0011	0.8530	11.34	248.2	hx_pmd_gd_1_wat_46_dl_1.o
0.5	0.6; 72%	0.8569 ± 0.0011	0.8591	24.25	189.5	hx_pmd_gd_1_wat_72_dl_3.o
0.5	1.0; 81%	0.8578 ± 0.0011	0.8599	37.15	160.9	hx_pmd_gd_1_wat_81_dl_5.o
0.5	1.4; 85%	0.8536 ± 0.0011	0.8558	50.06	145.3	hx_pmd_gd_1_wat_85_dl_7.o
1.0	0; 52%	0.9169 ± 0.0011	0.9191	13.09	257.2	hx_pmx_gd_1_wat_52_dl_0.o
1.0	0.2; 70%	0.9224 ± 0.0011	0.9246	22.24	209.1	hx_pmx_gd_1_wat_70_dl_1.o
1.0	0.6; 82%	0.9309 ± 0.0011	0.9332	40.52	158.0	hx_pmx_gd_1_wat_82_dl_3.o
1.0	1.0; 88%	0.9325 ± 0.0011	0.9347	58.81	131.0	hx_pmx_gd_1_wat_88_dl_5.o
*1.0	1.0; 88%	0.9340 ± 0.0012	0.9363	58.81	130.4	hx_pmx_gd_1_wat_88_dl_5_z.o
*1.0	1.0; 88%; cladding in Ident-69 container	0.9205 ± 0.0011	0.9227	58.81	132.8	hx_pmx_gd_1_88zC.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page III-4

Pitch Fraction	Axial Separation, cm; Water Volume; Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
⁺ 1.0	1.0; 88%; cladding in less reactive Ident-69 container, 2% Gd	0.8414 ± 0.0011	0.8436	58.81	132.8	i604lr0t.o
⁺ 1.0	1.0; 88%; 0.2% Gd (0.762 kg)	0.9255 ± 0.0011	0.9277	58.81	133.8	hx_pmx_gd_.2_wat_.88_dl_.5_z.o
1.0	1.4; 90%	0.9261 ± 0.0011	0.9282	77.10	120.1	hx_pmx_gd_.1_wat_.90_dl_.7.o
1.0	1.6; 91%	0.9184 ± 0.0011	0.9205	86.24	115.0	hx_pmx_gd_.1_wat_.91_dl_.8.o
[^] 1.0	1.6; 91%	0.9194 ± 0.0011	0.9217	86.24	116.5	hx_pmx_gd_.1_wat_.91_dl_.8a.o
[^] 1.0	1.6; 91%	0.9180 ± 0.0011	0.9201	86.24	114.9	hx_pmx_gd_.1_wat_.91_dl_.8b.o

*Every other column of fuel pellets in the DFAs is displaced in the axial direction so that the centers of the pellets in one column align with the tops of the pellets in the adjacent column.

[^]Fuel in DFAs displaced 10 cm in axial direction relative to fuel in Ident-69 container.

[^]Fuel in DFAs displaced 20 cm in axial direction relative to fuel in Ident-69 container

Table III-5. Results for Loose Pins in the Basket Assembly Positions

Orientation	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	⁺ H/X	AENCF, keV	File Name
12	Random placement of pins	0.8554 ± 0.0011	0.8576	5.03	277.2	lvb_co2.o
6	Irregular pitch	0.8535 ± 0.0010	0.8556	5.03	304.8	mine_co1.o
12	Irregular pitch	0.8839 ± 0.0011	0.8861	5.03	300.5	mine_co2.o
12	Previous case but symmetry boundary conditions	0.8830 ± 0.0010	0.8850	5.03	299.1	mine_co2_h.o
12	Irregular pitch and pin cladding in Ident-69 container	0.8678 ± 0.0011	0.8700	5.03	311.0	mine_co2+c.o
12	Irregular pitch and no Gd	0.9334 ± 0.0010	0.9353	5.03	285.2	mine_co2_nogd.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page III-5

*This is the average of the hexagonal and square array values for H/X. The values for hexagonal and square arrays are 3.63 and 6.42, respectively.

Table III-6. Results for Fuel Pellets in the Intact Basket Assembly Positions

Pitch Fraction	Axial Separation, cm; Water Volume	Gd Content (mass, kg)	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
0.5	2.0; 88%	1.0% (3.811)	0.8206 ± 0.0012	0.8229	68.88	133.7	sc5_md_gd_1_.12_dl_1.+c.o
0.5	1.4; 84%	1.0% (3.811)	0.8369 ± 0.0011	0.8391	49.50	146.8	sc5_md_gd_1_.16_dl_.7+c.o
0.5	1.0; 78%	1.0% (3.811)	0.8445 ± 0.0012	0.8469	36.55	161.8	sc5_md_gd_1_.22_dl_.5+c.o
0.5	0.6; 67%	1.0% (3.811)	0.8435 ± 0.0011	0.8456	23.58	192.1	sc5_md_gd_1_.33_dl_.3+c.o
0.5	0.2; 36%	1.0% (3.811)	0.8382 ± 0.0010	0.8402	10.46	252.2	sc5_md_gd_1_.64_dl_.1+c.o
1.0	2.0; 92%	1.0% (3.811)	0.9047 ± 0.0011	0.9068	104.02	106.8	sc5_mx_gd_1_.08_dl_1.+c.o
1.0	1.4; 89%	1.0% (3.811)	0.9262 ± 0.0011	0.9285	76.57	116.8	sc5_mx_gd_1_.11_dl_.7+c.o
1.0	1.0; 86%	1.0% (3.811)	0.9381 ± 0.0011	0.9404	58.27	128.7	sc5_mx_gd_1_.14_dl_.5+c.o
1.0	0.6; 80%	1.0% (3.811)	0.9429 ± 0.0012	0.9453	39.94	152.8	sc5_mx_gd_1_.20_dl_.3+c.o
1.0	0.2; 65%	1.0% (3.811)	0.9311 ± 0.0010	0.9332	21.55	205.4	sc5_mx_gd_1_.35_dl_.1+c.o
1.0	0.; 43%	1.0% (3.811)	0.9258 ± 0.0010	0.9278	12.26	258.0	sc5_mx_gd_1_.57_dl_.0+c.o
1.0	1.0; 86%	0.1% (0.3811)	0.9694 ± 0.0011	0.9716	58.27	124.1	sc5_mx_gd_1_.14_dl_.5+c.o
1.0	1.0; 86%	0.5% (1.905)	0.9462 ± 0.0011	0.9484	58.27	129.0	sc5_mx_gd_5_.14_dl_.5+c.o
*1.0	0.6; 80%	1.0% (3.811)	0.9014 ± 0.0011	0.9037	39.94	147.2	sc5_mx_gd_1_.20nor.o
1.0	0.6; 80%	2.0% (7.622)	0.9327 ± 0.0011	0.9348	39.94	154.3	sc5_mx_gd_2_.20_dl_.3+c.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page III-6

Pitch Fraction	Axial Separation, cm; Water Volume	Gd Content (mass, kg)	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
1.0	0.6; 80%	3.0% (11.43)	0.9241 ± 0.0011	0.9263	39.94	154.0	sc5_mx_gd_3._20_dl_.3+c.o

*Less reactive Ident-69 container

Table III-7. Results for Degraded Basket Assembly with Varying Amounts of Gadolinium and other Modifications

Gd Content	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
0	6 DFAs just touching	0.9631 ± 0.0009	0.9650	13.48	372.1	dfa6_gd_0._go_.6b.o
1.0% (3.811 kg)	6 DFAs just touching	0.9244 ± 0.0010	0.9265	13.48	393.2	dfa6_gd_1._go_.6b.o
2.0% (7.622 kg)	6 DFAs just touching	0.9186 ± 0.0010	0.9205	13.48	396.6	dfa6_gd_2._go_.6b.o
2.0% (7.622 kg)	6 DFAs just touching, 50% water volume	0.9121 ± 0.0009	0.9140	13.48	404.1	dfa6_gd_2._go_.5b.o
2.0% (7.622 kg)	6 DFAs just touching, 60% water volume	0.9044 ± 0.0010	0.9065	13.48	411.1	dfa6_gd_2._go_.4b.o
5.0% (19.05 kg)	6 DFAs closely spaced	0.8738 ± 0.0010	0.8757	13.48	399.5	dfa6_gd_5._go_.6a.o
5.0% (19.05 kg)	6 DFAs just touching, no S(α,β) treatment	0.8721 ± 0.0011	0.8742	13.48	400.0	dfa6_gd_5._go_.6a-S.o
5.0% (19.05 kg)	6 DFAs just touching	0.9119 ± 0.0010	0.9139	13.48	400.3	dfa6_gd_5._go_.6b.o
5.0% (19.05 kg)	*Ident-69 container	0.9571 ± 0.0010	0.9590	13.48	305.7	sc6_gd_5._go_.6.o
6.0% (22.86 kg)	*Ident-69 container	0.9550 ± 0.0011	0.9571	13.48	306.0	sc6_gd_6._go_.6.o
2.0% (7.622 kg)	Less reactive Ident-69 container	0.9355 ± 0.0010	0.9376	13.48	297.5	sc6_gd_2._go_.6_nor.o
3.0% (11.43 kg)	Less reactive Ident-69 container	0.9296 ± 0.0010	0.9316	13.48	300.7	sc6_gd_3._go_.6_nor.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page III-7

Gd Content	Comment	$k_{\text{eff}} \pm \sigma$	$k_{\text{eff}} + 2\sigma$	H/X	AENCF, keV	File Name
4.0% (15.24 kg)	Less reactive Ident-69 container	0.9252 ± 0.0010	0.9272	13.48	302.4	sc6_gd_4._go_.6_nor.o
6.0% (22.86 kg)	Less reactive Ident-69 container	0.9185 ± 0.0011	0.9207	13.48	303.0	sc6_gd_6._go_.6_nor.o
5.0 kg	Gd in duct of Ident-69	0.9690 ± 0.0010	0.9710	120.8	303.5	sc6_gd_5kgin_go_.6.o
1.5 kg	Gd in duct and basket of Ident-69 container	0.9525 ± 0.0011	0.9546	120.8	311.9	sc6_gd_1.5kgin_go_.6.o
5.0 kg	Gd in duct and basket of Ident-69 container	0.9386 ± 0.0010	0.9406	120.8	317.5	sc6_gd_5kgin_go_.6.all.o
0 kg	Fe shot and water in Ident-69 container	0.9281 ± 0.0010	0.9300	50.90	335.7	sc6_gd_1kghom_fe.o
1.0 kg	Fe shot, Gd, and water in Ident-69 container	0.8907 ± 0.0010	0.8927	50.90	355.7	sc6_gd_0kghom_fe.o
1.0 kg	Full density goethite & Gd in Ident-69 container	0.8900 ± 0.0010	0.8921	13.48	354.0	sc6_gd_1kghom_go.o
0	Full density goethite in Ident-69 container	0.9422 ± 0.0009	0.9441	13.48	328.1	sc6_gd_0kghom_go.o
1.0 kg	Water and Gd in Ident-69 container	0.8670 ± 0.0009	0.8689	13.48	357.3	sc6_gd_1kghom_go_.6.o
1.0% (3.811 kg)	Base case but 1 DFA removed	0.9503 ± 0.0011	0.9525	13.48	289.8	sc6_gd_1._go_.6_-1.o
5.0% (19.05 kg)	Base case but 1 DFA removed	0.9341 ± 0.0010	0.9362	13.48	293.6	sc6_gd_5._go_.6_-1.o
2.0% (7.622 kg)	Base case but less reactive Ident-69 container and 1 DFA removed	0.9090 ± 0.0011	0.9111	13.48	289.3	sc6_gd_2._go_.6_nor-1.o
1.0% (3.811 kg)	Base case but less reactive Ident-69 container and 1 DFA removed	0.9170 ± 0.0010	0.9190	13.48	287.4	sc6_gd_1._go_.6_nor-1.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page III-8

Gd Content	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
0	Base case but 2 DFAs removed	0.9493 ± 0.0011	0.9514	13.48	269.1	sc6_gd_0._go_.6_-2.o
0.1% (0.3811 kg)	Base case but less reactive Ident-69 container and 2 DFAs removed	0.8948 ± 0.0010	0.8969	13.48	277.9	sc6_gd_.1_go_.6_nor-2.o
1.0% (3.811 kg)	Base case but 2 DFAs removed	0.8967 ± 0.0012	0.8990	13.48	287.5	sc6_gd_1._go_.6_-2.o

*Base case for fuel configuration

Table III-8. Intact Fuel Pins with Degraded Basket Assembly and Assembly Ducts

Gd Content (mass, kg)	Comment; distance, cm	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
2.0% (6.758)	6 DFAs	0.8129 ± 0.0009	0.8147	3.98	713.4	dfa_6_gd_2.0a.o
2.0% (6.758)	6 DFAs, previous case but fuel pins slightly shifted	0.8156 ± 0.0009	0.8174	3.98	720.5	dfa_6_gd_2.0b.o
0	6 DFAs, same as previous	0.8607 ± 0.0010	0.8626	3.98	661.2	dfa_6_gd_0.0b.o
0	Ident-69 container and water only in DOE canister; 1.67	1.0193 ± 0.0010	1.0214	5.03	365.4	sc7_h_basa.o
1.0% (3.379)	Ident-69 container; 1.67	0.9738 ± 0.0012	0.9761	3.98	392.1	sc7_h_basa_.6_gd_1.0.o
1.0% (3.379)	Less reactive Ident-69 container; 3.34	0.9495 ± 0.0010	0.9516	3.98	377.3	sc7_h_basc_.6_gd_1.0_nor.o
2.0% (6.758)	Ident-69 container; 0	0.9674 ± 0.0010	0.9695	3.98	397.1	sc7_h_basb_.6_gd_2.0.o
2.0% (6.758)	Ident-69 container; 1.67	0.9698 ± 0.0010	0.9717	3.98	392.4	sc7_h_basa_.6_gd_2.0.o
*2.0% (6.758)	Ident-69 container; 3.34	0.9694 ± 0.0010	0.9714	3.98	394.8	sc7_h_basc_.6_gd_2.0.o
2.0% (6.758)	Ident-69 container; 4.84	0.9629 ± 0.0010	0.9650	3.98	400.1	sc7_h_basd_.6_gd_2.0.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page III-9

Gd Content (mass, kg)	Comment; distance, cm	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	⁺ H/X	AENCF, keV	File Name
2.0% (6.758)	Ident-69 container; 6.84	0.9518 ± 0.0010	0.9538	3.98	407.9	sc7_h_base_.6_gd_2.0.o
2.0% (6.758)	Less reactive Ident-69 container; 3.34	0.9381 ± 0.0010	0.9401	3.98	379.6	sc7_h_basc_.6_gd_2.0_nor.o
2.0% (6.758)	Cladding in Ident-69 container, 60% water volume; 3.34	0.9457 ± 0.0010	0.9477	4.33	405.3	sc7_h_basc_.4_gd_2.0+c.o
2.0% (6.758)	Cladding in Ident-69 container, 50% water volume; 3.34	0.9446 ± 0.0011	0.9468	4.16	407.7	sc7_h_basc_.5_gd_2.0+c.o
2.0% (6.758)	Cladding in Ident-69 container; 3.34	0.9471 ± 0.0010	0.9490	3.98	408.7	sc7_h_basc_.6_gd_2.0+c.o
2.0% (6.758)	Cladding in less reactive Ident-69 container; 3.34	0.9237 ± 0.0010	0.9257	3.98	393.6	sc7_h_basc_.6_gd_2.0_nor+c.o
2.0% (6.758)	Base case but 1 DFA removed; 3.34	0.9393 ± 0.0011	0.9414	3.98	372.4	sc7_h_basc_.6_gd_2.0-1.o
2.0% (6.758)	Base case but 1 DFA removed and cladding in less reactive Ident-69 container; 3.34	0.8940 ± 0.0010	0.8960	3.98	365.3	sc7_h_basc_.6_gd_2.0-1nrC.o
2.0% (6.758)	Base case but 2 DFAs removed; 3.34	0.9018 ± 0.0010	0.9037	3.98	346.1	sc7_h_basc_.6_gd_2.0-2.o

*Base case

+Average value of H/X for a hexagonal and square arrays

Table III-9. Pellets in Intact Assembly Ducts Surrounded by Degraded Basket Assembly for DFAs in DOE SNF Canister

Gd Content (mass, kg)	Pitch Fraction; Axial Separation, cm; Water Volume; Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
2% (7.622)	1.0; 0 cm; 52%	0.9257 ± 0.0009	0.9275	13.09	401.3	df8_px_gd_2_.48_dl_.0.o
2% (7.622)	1.0; 0.2 cm; 70%	0.9465 ± 0.0011	0.9486	22.24	289.0	df8_px_gd_2_.30_dl_.1.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF

Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page III-10

Gd Content (mass, kg)	Pitch Fraction; Axial Separation, cm; Water Volume; Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
2% (7.622)	1.0; 1.0 cm; 88%	1.0105 ± 0.0011	1.0128	58.81	144.8	df8_px_gd_2_.12_dl_.5.o
5% (19.05)	1.0; 1.0 cm; 88%	1.0033 ± 0.0011	1.0055	58.81	146.1	df8_px_gd_5_.12_dl_.5.o
2% (7.622)	0.5; 1.0 cm; 81%	0.9204 ± 0.0011	0.9226	37.15	179.2	df8_pd_gd_2_.19_dl_.5.o
2% (7.622)	0.5; 1.0 cm; 81%; no S(α,β) treatment	0.9379 ± 0.0012	0.9403	37.15	174.6	df8_pd_gd_2_.19_dl_.5-S.o
4% (15.24)	0.5; 1.0 cm; 81%; no S(α,β) treatment	0.9321 ± 0.0011	0.9343	37.15	177.2	df8_pd_gd_4_.19_dl_.5S.o
5% (19.05)	0.5; 1.0 cm; 81%	0.9124 ± 0.0012	0.9147	37.15	180.4	df8_pd_gd_5_.19_dl_.5.o
2% (7.622)	1.0; 1.0 cm; 88%; 1 less DFA	0.9676 ± 0.0011	0.9698	58.81	147.0	df8_px_gd_2_.12_dl_.5-1.o
2% (7.622)	1.0; 1.0 cm; 88%; no S(α,β) treatment and 1 less DFA	0.9784 ± 0.0012	0.9807	58.81	144.7	df8_px_gd_2_.12_dl_.5-1S.o
5% (19.05)	1.0; 1.0 cm; 88%; no S(α,β) treatment and 1 less DFA	0.9718 ± 0.0012	0.9741	58.81	147.2	df8_px_gd_5_.12_dl_.5-1S.o
2% (7.622)	1.0; 1.0 cm; 88%; 2 less DFAs	0.9168 ± 0.0011	0.9190	58.81	152.1	df8_px_gd_2_.12_dl_.5-2.o
2% (7.622)	1.0; 1.0 cm; 88%; no S(α,β) treatment and 2 less DFAs	0.9277 ± 0.0011	0.9300	58.81	150.8	df8_px_gd_2_.12_dl_.5-2S.o

Table III-10. Pellets in Intact Assembly Ducts Surrounded by Degraded Basket Assembly For Ident-69 Container Surrounded by DFAs

Gd Content (mass, kg)	Pitch Fraction; Axial Separation, cm; Water Volume; Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
2% (7.622)	1.0; 0 cm; 52%	0.9855 ± 0.0012	0.9878	13.09	293.3	sc8_px_gd_2_.48_dl_.0.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF

Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page III-11

Gd Content (mass, kg)	Pitch Fraction; Axial Separation, cm; Water Volume; Comment	$k_{\text{eff}} \pm \sigma$	$k_{\text{eff}} + 2\sigma$	H/X	AENCF, keV	File Name
2% (7.622)	1.0; 1.0 cm; 88%	1.0030 ± 0.0011	1.0051	58.81	142.3	sc8_px_gd_2_.12_dl_.5.o
6% (22.86)	1.0; 0 cm; 52%	0.9680 ± 0.0010	0.9701	13.09	297.9	sc8_px_gd_6_.48_dl_.0.o
6% (22.86)	1.0; 1.0 cm; 88%	0.9832 ± 0.0012	0.9855	58.81	146.3	sc8_px_gd_6_.12_dl_.5.o
6% (22.86)	1.0; 1.0 cm; 88%; cladding in Ident-69 container	0.9711 ± 0.0011	0.9733	58.81	146.9	sc8_px_gd_6_.12_dl_.5+c.o
6% (22.86)	1.0; 1.0 cm; 88%; cladding in less reactive Ident-69 container	0.9347 ± 0.0011	0.9370	58.81	137.4	sc8_px_gd_6_.12_dl_.5+cnr.o
6% (22.86)	0.5; 1.0 cm; 19%	0.8848 ± 0.0011	0.8871	37.15	168.1	sc8_pd_gd_6_.81_dl_.5.o
2% (7.622)	0.5; 1.0 cm; 19%	0.9062 ± 0.0011	0.9084	37.15	163.9	sc8_pd_gd_2_.81_dl_.5.o
6% (22.86)	1.0; 1.0 cm; 88%; 1 less DFA	0.9618 ± 0.0011	0.9640	58.81	145.2	sc8_px_gd_6_.12_dl_.5-1.o
2% (7.622)	1.0; 1.0 cm; 88%; cladding in less reactive Ident-69 container and 1 DFA removed	0.9301 ± 0.0011	0.9322	58.81	133.6	sc8_px_gd_2_.dl_.5+cnr-1.o
2% (7.622)	1.0; 1.0 cm; 88%; cladding in less reactive Ident-69 container, 1 less DFA and no S(α,β) treatment	0.9374 ± 0.0011	0.9396	58.81	135.9	sc8_px_gd_2_.dl_.5+cnr-1S.o
3.5% (13.34)	1.0; 1.0 cm; 88%; cladding in less reactive Ident-69 container, 1 less DFA and no S(α,β) treatment	0.9256 ± 0.0012	0.9279	58.81	135.6	sc8_px_gd_3.5_dl_.5+cnr-1S.o
6% (22.86)	1.0; 1.0 cm; 88%; 2 less DFAs	0.9140 ± 0.0012	0.9164	58.81	148.1	sc8_px_gd_6_.12_dl_.5-2.o
2% (7.622)	1.0; 1.0 cm; 88%; 2 less DFAs	0.9281 ± 0.0011	0.9304	58.81	144.2	sc8_px_gd_2_.12_dl_.5-2.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page III-12

Gd Content (mass, kg)	Pitch Fraction; Axial Separation, cm; Water Volume; Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
2% (7.622)	1.0; 1.0 cm; 88%; cladding in less reactive Ident-69 container, 2 less DFAs and no S(α,β) treatment	0.8865 \pm 0.0011	0.8887	58.81	140.0	sc8_px_gd_2_.12_dl_.5-2+cnrS.o

Table III-11. Intact Ident-69 Container and 5 DFAs Fully Degraded in DOE SNF Canister

Length of Fuel Slurry, m	Gd Content (mass, kg); Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
0.9144	0	1.0508 \pm 0.0011	1.0530	27.19	197.4	ident_3_60.o
0.9144	2% (6.76)	0.9554 \pm 0.0010	0.9573	27.19	221.5	ident_3_60_gd_2.o
0.9144	2% (6.76); less reactive Ident-69 container	0.9334 \pm 0.0010	0.9353	27.19	207.3	ident_3_60_gd_2nor.o
0.9144	2% (6.76); less reactive Ident-69 container, 1 less DFA and S(α,β) treatment	0.9041 \pm 0.0010	0.9061	30.67	191.1	id_3_60_gd_2.nrS-1.o
0.9144	2.5% (8.45); less reactive Ident-69 container and S(α,β) treatment	0.9269 \pm 0.0010	0.9288	27.19	208.9	ident_3_60_gd_2.5norS.o
0.9144	5% (16.9)	0.9155 \pm 0.0010	0.9174	27.19	231.4	ident_3_60_gd_5.o
0.9144	5% (16.9); S(α,β) treatment	0.9222 \pm 0.0010	0.9242	27.19	230.5	ident_3_60_gd_5S.o
1.5240	0	1.0620 \pm 0.0011	1.0642	53.45	129.1	ident_5_60.o
1.5240	2% (6.76)	0.9022 \pm 0.0010	0.9042	53.45	161.9	ident_5_60_gd_2.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page III-13

Length of Fuel Slurry, m	Gd Content (mass, kg); Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
1.5240	5% (16.9)	0.8602 ± 0.0010	0.8623	53.45	172.8	ident_5_60_gd_5.o
2.1336	0	1.0711 ± 0.0011	1.0733	79.71	98.9	ident_7_60.o
2.1336	2% (6.76)	0.8671 ± 0.0009	0.8690	79.71	138.2	ident_7_60_gd_2.o
2.1336	5% (16.9)	0.8199 ± 0.0010	0.8219	79.71	151.4	ident_7_60_gd_5.o
3.0480	0	1.0739 ± 0.0011	1.0760	119.09	79.4	ident_10_60.o
3.0480	2% (6.76)	0.8267 ± 0.0009	0.8285	119.09	126.0	ident_10_60_gd_2.o
3.0480	5% (16.9)	0.7847 ± 0.0010	0.7867	119.09	138.3	ident_10_60_gd_5.o
3.6576	0	1.0712 ± 0.0011	1.0733	145.4	72.0	ident_12_60.o
3.6576	2% (6.76)	0.8068 ± 0.0009	0.8086	145.4	123.6	ident_12_60_gd_2.o
3.6576	5% (16.9)	0.7683 ± 0.0009	0.7702	145.4	135.1	ident_12_60_gd_5.o

Table III-12. Fully Degraded Ident-69 Container and 5 Fully Degraded DFAs in DOE SNF Canister with a 0.9144 m (3 ft) Fuel Slurry Region

Number of Pins Initially Contained in Ident-69 Container	Gd Content (mass, kg)	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
0	0	0.9630 ± 0.0011	0.9652	28.68	211.6	homall_3_60_0.o
109	0	0.9678 ± 0.0011	0.9699	25.72	228.6	homall_3_60_109.o
217	0	0.9667 ± 0.0010	0.9686	23.28	246.7	homall_3_60_217.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page III-14

Number of Pins Initially Contained in Ident-69 Container	Gd Content (mass, kg)	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
217	0.5% (1.69)	0.9124 ± 0.0011	0.9145	23.28	265.7	homall_3_60_217_gd_5.o
*217	0.5% (1.69)	0.9086 ± 0.0010	0.9107	23.28	268.4	homall_3_60_217_gd_5S.o
0	2% (6.76)	0.8073 ± 0.0010	0.8092	28.68	259.0	homall_3_60_0_gd_2.o
109	2% (6.76)	0.8251 ± 0.0010	0.8270	25.72	276.9	homall_3_60_109_gd_2.o
217	2% (6.76)	0.8423 ± 0.0009	0.8441	23.28	293.2	homall_3_60_217_gd_2.o

*With S(α,β) treatment of goethite slurries.

Table III-13. Six Fully Degraded DFAs in DOE SNF Canister

Length of Fuel Slurry, m	Gd Content (mass, kg); Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
0.9144	0	0.9757 ± 0.0010	0.9778	24.88	235.5	6DFAs_60_3.o
1.5240	0	1.0074 ± 0.0011	1.0096	49.59	135.5	6DFAs_60_5.o
2.1336	0	1.0253 ± 0.0012	1.0278	74.30	94.8	6DFAs_60_7.o
3.0480	0	1.0400 ± 0.0011	1.0422	111.37	65.5	6DFAs_60_10.o
3.6576	0	1.0384 ± 0.0016	1.0415	136.08	55.4	6DFAs_60_12.o
0.9144	0; S(α,β) treatment	0.9624 ± 0.0010	0.9645	24.88	239.6	6DFAs_60_3_Sab.o
0.9144	2% (6.76)	0.8469 ± 0.0009	0.8486	24.88	278.6	6DFAs_60_3_gd_2.o
1.5240	2% (6.76)	0.7677 ± 0.0009	0.7694	49.59	183.3	6DFAs_60_5_gd_2.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page III-15

Length of Fuel Slurry, m	Gd Content (mass, kg); Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
2.1336	2% (6.76)	0.7020 ± 0.0009	0.7037	74.30	141.5	6DFAs_60_7_gd_2.o
3.0480	2% (6.76)	0.6202 ± 0.0008	0.6218	111.37	111.6	6DFAs_60_10_gd_2.o
3.6576	2% (6.76)	0.5743 ± 0.0014	0.5771	136.08	98.7	6DFAs_60_12_gd_2.o
0.9144	2% (6.76); S(α,β) treatment	0.8525 ± 0.0009	0.8544	24.88	278.1	6DFAs_60_3_gd_2_Sab.o
0.9144	2% (6.76); 55% goethite in slurry	0.8585 ± 0.0009	0.8603	29.98	251.8	6DFAs_55_3_gd_2.o
0.9144	2% (6.76); 47.76% goethite in slurry	0.8769 ± 0.0009	0.8786	39.26	215.7	6DFAs_fl_3_gd_2.o
0.9144	1.25% (4.22); 47.76% goethite in slurry	0.9116 ± 0.0009	0.9134	39.26	206.2	6DFAs_fl_3_gd_1.25.o
0.9144	1.25% (4.22); 47.76% goethite in slurry and S(α,β) treatment	0.9197 ± 0.0010	0.9216	39.26	203.9	6DFAs_fl_3_gd_1.25S.o

Table III-14. Intact Ident-69 Container and 5 Fully Degraded DFAs in a 0.9144 m (3 ft) Fuel Slurry in DOE SNF Canister in the Co-disposal Waste Package

Comment; Goethite Volume Fraction	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
5% Gd (16.9 kg) with Ident-69 container centered in fuel sludge; 0.6	0.9314 ± 0.0009	0.9332	27.19	231.3	coidt_grav_gd_5_1.o
Ident-69 container centered in fuel sludge; 0.6	0.9245 ± 0.0009	0.9263	27.19	232.4	coidt_grav_gd_6_1.o
Ident-69 container at bottom of fuel sludge; 0.6	0.9032 ± 0.0009	0.9051	27.19	230.8	coidt_grav_gd_6_2.o
Ident-69 container just submerged in fuel sludge;	0.8901 ± 0.0010	0.8920	27.19	237.4	coidt_grav_gd_6_3.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page III-16

Comment; Goethite Volume Fraction	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
0.6					
Ident-69 container centered; 0.746	0.9256 ± 0.0009	0.9275	15.53	272.4	coidt_grv_74.6_gd_6.0.o
Ident-69 container centered; 0.65	0.9263 ± 0.0010	0.9284	22.60	244.9	coidt_grv_65_gd_6.0.o
Ident-69 container centered; 0.50	0.9154 ± 0.0009	0.9172	39.12	204.4	coidt_grv_50_gd_6.0.o
Ident-69 container centered; 0.472	0.9161 ± 0.0009	0.9180	43.37	196.5	coidt_grv_fl_gd_6.0.o
Ident-69 container centered, co-disposal flooded; 0.6	0.9153 ± 0.0010	0.9174	27.19	231.2	coidt_grav_gd_6_1ff.o
Ident-69 container centered in fuel sludge and S(α,β) treatment; 0.6	0.9307 ± 0.0009	0.9325	27.19	231.3	coidt_grav_gd_6_1_S.o
4% Gd (13.52 kg) with less reactive Ident-69 container centered in fuel sludge and S(α,β) treatment; 0.6	0.9204 ± 0.0009	0.9223	27.19	213.1	coidt_grav_gd_4_1_Snr.o
4% Gd (13.52 kg) with less reactive Ident-69 container centered in fuel sludge; 0.6	0.9157 ± 0.0010	0.9176	27.19	214.4	coidt_grav_gd_4_1_nr.o
2% Gd (6.76 kg) with less reactive Ident-69 container centered in fuel sludge, 1 less DFA and S(α,β) treatment; 0.6	0.9243 ± 0.0010	0.9263	30.67	188.8	cdt_grv_gd_2_1_Snr-1.o

Table III-15. Intact Ident-69 Container and 5 Fully Degraded DFAs in a 0.9144 m (3 ft) Fuel Slurry in DOE SNF Canister with Variable Water Density and 6% Gadolinium in the Basket Assembly in the Co-disposal Waste Package

Fraction of Full Water Density in DOE Canister	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
0	0.9267 ± 0.0008	0.9283	27.19	232.6	coidt_grav_gd_6_1_0.o
0.2	0.9273 ± 0.0010	0.9293	27.19	232.2	coidt_grav_gd_6_1_2.o
0.4	0.9276 ± 0.0010	0.9295	27.19	231.3	coidt_grav_gd_6_1_4.o
0.6	0.9256 ± 0.0010	0.9275	27.19	233.5	coidt_grav_gd_6_1_6.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page III-17

0.8	0.9254 ± 0.0010	0.9273	27.19	232.6	coidt_grav_gd_6_1_8.o
1.0	0.9245 ± 0.0009	0.9263	27.19	232.4	coidt_grav_gd_6_1.o

Table III-16. Intact Ident-69 Container and 5 Fully Degraded DFAs in a 0.9144 m (3 ft) Fuel Slurry with Variable Water Density in DOE SNF Canister and 6% Gadolinium in the Basket Assembly in the Co-disposal Waste Package

Fraction of Minimum Water Volume in Degraded Fuel	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
0	0.9050 ± 0.0009	0.9068	15.53	273.1	coidt_grav_gd_6_1_h.0.o
0.2	0.9111 ± 0.0009	0.9129	17.86	263.4	coidt_grav_gd_6_1_h.2.o
0.4	0.9159 ± 0.0010	0.9178	20.19	254.5	coidt_grav_gd_6_1_h.4.o
0.6	0.9181 ± 0.0009	0.9200	22.53	246.7	coidt_grav_gd_6_1_h.6.o
0.8	0.9220 ± 0.0009	0.9238	24.86	239.0	coidt_grav_gd_6_1_h.8.o
1.0	0.9245 ± 0.0009	0.9263	27.19	232.4	coidt_grav_gd_6_1.o

Table III-17. Degraded Ident-69 Container and 5 Fully Degraded DFAs in a 0.9144 m (3 ft) Fuel Slurry in DOE SNF Canister with 2% Gadolinium in the Basket Assembly in the Co-disposal Waste Package

Number of Pins Initially Contained in Ident-69 Container	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
109	60% goethite	0.8485 ± 0.0008	0.8502	25.72	273.0	cohomal_grav1_109.o
217	60% goethite	0.8642 ± 0.0009	0.8659	23.28	289.9	cohomal_grav1.o
217	55% goethite	0.8786 ± 0.0009	0.8804	28.17	261.3	cohomal_grav1_55.o
217	45.71% goethite	0.9031 ± 0.0010	0.9051	40.08	211.1	cohomal_grav1_fl.o
217	45.71% goethite; S(α,β) treatment	0.9181 ± 0.0010	0.9200	40.08	210.5	cohomal_grav1_fl_S.o
217	45.71% goethite; flooded co-disposal	0.8876 ± 0.0009	0.8895	40.08	211.7	cohomal_grav1_fl_ff.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page III-18

Table III-18. Results for the Case of the Degraded Contents of the Co-disposal Waste Package Containing a Most Reactive DOE SNF Canister

Volume of Water in Clay	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
47.8%	Canister at bottom of co-disposal package	0.9203 ± 0.0009	0.9221	27.19	230.5	geot_gd_6_fl_a.o
40%	Canister at bottom	0.9205 ± 0.0010	0.9225	27.19	231.5	geot_gd_6a.o
40%	Canister at bottom and S(α,β) treatment in slurry	0.9256 ± 0.0010	0.9276	27.19	232.8	geot_gd_6aS.o
40%	Canister between center and bottom	0.9163 ± 0.0010	0.9182	27.19	231.5	geot_gd_6b.o
40%	Canister in center	0.9146 ± 0.0010	0.9165	27.19	232.1	geot_gd_6c.o
30%	Canister at bottom	0.9230 ± 0.0009	0.9249	27.19	230.6	geot_gd_6_7a.o
0	Canister at bottom	0.9244 ± 0.0010	0.9265	27.19	231.1	geot_gd_6_1.a.o
0	Canister at bottom and S(α,β) treatment in slurry	0.9325 ± 0.0010	0.9346	27.19	228.0	geot_gd_6_1.aS.o
0	Canister at bottom, S(α,β) treatment in slurry, less reactive Ident-69 container and 4% Gd (13.5 kg)	0.9226 ± 0.0010	0.9246	27.19	211.9	geot_gd_4_1.anr.o
0	Canister at bottom, S(α,β) treatment in slurry, less reactive Ident-69 container, 1 less DFA and 2% Gd (6.76 kg)	0.9288 ± 0.0010	0.9307	30.67	186.9	gt_gd_2_1.anrS-1.o
0	Canister at bottom, S(α,β) treatment in slurry, less reactive Ident-69 container, 1 less DFA and 2.25% Gd (7.60 kg)	0.9223 ± 0.0009	0.9242	30.67	187.6	gt_gd_2q_1.anrS-1.o
0	Canister at bottom, S(α,β) treatment in slurry, less reactive Ident-69 container, 2 less DFAs and 1.0% Gd (3.38 kg)	0.9249 ± 0.0010	0.9269	36.46	162.6	gt_gd_1_1.anrS-2.o

Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page III-19

Table III-19. Results for the Case of the Degraded Contents of the Co-disposal Waste Package Containing a Most Reactive DOE SNF Canister with Intact Fuel

Volume of Water in Clay	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	H/X	AENCF, keV	File Name
47.8%	Canister at bottom of co-disposal package	0.9083 ± 0.0012	0.9107	58.81	148.1	gx_6_.5-2 fla.o
40%	Canister at bottom	0.9066 ± 0.0011	0.9088	58.81	149.8	gx_6_.5-2a_6a.o
40%	Canister between center and bottom	0.9001 ± 0.0010	0.9021	58.81	148.9	gx_6_.5-2a_6b.o
40%	Canister in center	0.8979 ± 0.0011	0.9002	58.81	150.5	gx_6_.5-2a_6c.o
30%	Canister at bottom	0.9111 ± 0.0012	0.9134	58.81	147.5	gx_6_.5-2a_.7a.o
0	Canister at bottom	0.9158 ± 0.0011	0.9180	58.81	147.2	gx_6_.5-2a_1.a.o
0	Canister at bottom, clad pins in less reactive Ident-69 container and 2% Gd (7.62 kg)	0.8820 ± 0.0011	0.8842	58.81	138.9	gx_2_.5-2a_1.acnr.o
0	Canister at bottom, clad pins in less reactive Ident-69 container, 1 DFA removed and 2% Gd (7.62 kg)	0.9363 ± 0.0011	0.9386	58.81	134.6	gx_2_.5-1a_1.acnr.o
0	Canister at bottom, clad pins in less reactive Ident-69 container, 1 DFA removed and 4% Gd (15.2 kg)	0.9247 ± 0.0011	0.9270	58.81	136.0	gx_4_.5-1a_1.acnr.o
0	4 DFAs (only) in canister at bottom and 2% Gd (7.62 kg)	0.9265 ± 0.0011	0.9287	58.81	150.7	dx_2_1.a.o

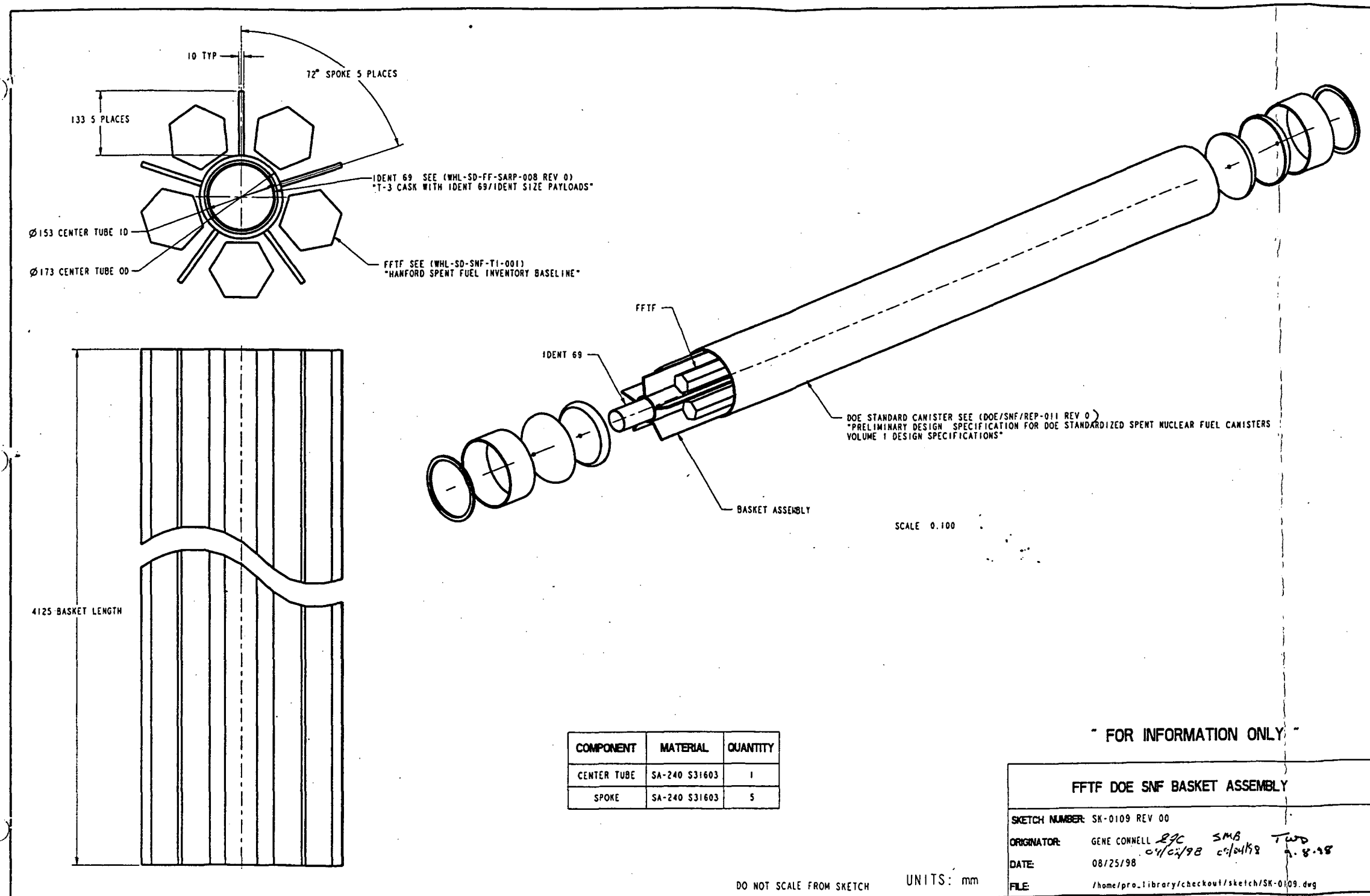
Title: Fast Flux Test Facility (FFTF) Reactor Fuel Degraded Criticality Calculations: Intact SNF Canister

Document Identifier: BBA000000-01717-0210-00051 REV 00

Page III-20

Table III-20. H/X Ratios for the Ident-69 Container

Comment	H/X
All cladded cases except those given below	120.80
All uncladded cases except those given below	126.13
Case sc6_gd_1khom_fe.o in Table 6-7	50.90
Case sc6_gd_0khom_fe.o in Table 6-7	50.90

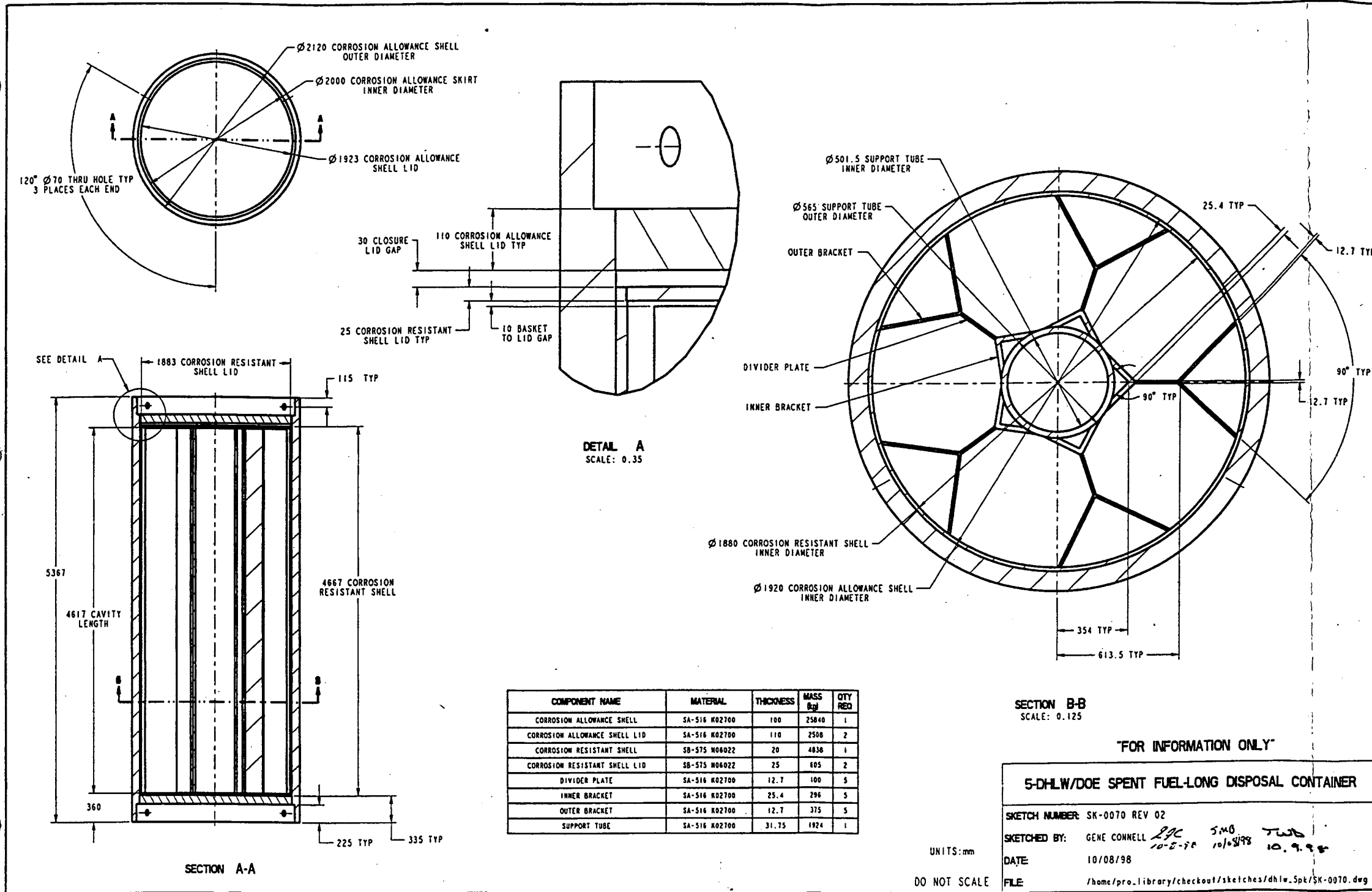


COMPONENT	MATERIAL	QUANTITY
CENTER TUBE	SA-240 S31603	1
SPOKE	SA-240 S31603	5

FOR INFORMATION ONLY

FFTF DOE SNF BASKET ASSEMBLY	
SKETCH NUMBER:	SK-0109 REV 00
ORIGINATOR:	GENE CONNELL <i>RAC</i> <i>SMB</i> <i>TWD</i>
DATE:	08/25/98 <i>04/02/98</i> <i>02/24/98</i> <i>7.8.98</i>
FILE:	/home/pro.library/checkout/sketch/SK-0109.dwg

DO NOT SCALE FROM SKETCH UNITS: mm



COMPONENT NAME	MATERIAL	THICKNESS	MASS (kg)	QTY REQ
CORROSION ALLOWANCE SHELL	SA-516 K02700	100	25040	1
CORROSION ALLOWANCE SHELL LID	SA-516 K02700	110	2508	2
CORROSION RESISTANT SHELL	SB-575 N04022	20	4836	1
CORROSION RESISTANT SHELL LID	SB-575 N04022	25	405	2
DIVIDER PLATE	SA-516 K02700	12.7	100	5
INNER BRACKET	SA-516 K02700	25.4	296	5
OUTER BRACKET	SA-516 K02700	12.7	375	5
SUPPORT TUBE	SA-516 K02700	31.75	1924	1

SECTION B-B
SCALE: 0.125

"FOR INFORMATION ONLY"

5-DHLW/DOE SPENT FUEL-LONG DISPOSAL CONTAINER

SKETCH NUMBER: SK-0070 REV 02

SKETCHED BY: GENE CONNELL *GPC* *SMG* *TWB*
10-2-98 *10/6/98* *10.9.98*

DATE: 10/08/98

FILE: /home/pro.library/checkout/sketches/dhlw_spt/SK-0070.dwg

UNITS: mm
DO NOT SCALE