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Calculation Cover Sheet

Complete only applicable items.

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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 intact fuels for the pre-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 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 and the fuel number density is determined by using the fuel mass and the footprint volume of the fuel. 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 The FFTF fuel assemblies and fuel pins are assumed to be intact. 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.

3.5 Ident-69 pin containers are used to store individual (derodded) fuel pins. Since the exact contents of these containers cannot be readily verified, these containers are assumed to contain a most reactive configuration of FFTF fuel pins for the intact fuel cases. These assumptions are used in Section 5.1.2, and the basis for these assumptions is that it is conservative to assume a most reactive container.

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" in all cases where the canister was used. 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 is 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.

4. USE OF COMPUTER SOFTWARE

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

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

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 the Civilian Radioactive Waste Management System (CRWMS) Management and Operating (M&O) Software Control Management (SCM) in accordance with appropriate procedures.

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 of this calculation file. The user-defined formulas, inputs, and results were documented in sufficient detail in Section 5 and Attachment I to allow an independent repetition of the various computations.

5. CALCULATION

5.1 CALCULATION INPUTS

The description of the FFTF fuel is from the FFTF description document, Ref. 7.2. All fuel and canister related information is from this reference unless otherwise noted. Compositions for structural and other nonfuel related materials are from Ref. 7.5. The high level waste (HLW) glass composition is from Ref. 7.8 (TBV – to be verified). 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 standard driver fuel assembly (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 inner and outer diameters of the cladding are 5.08 mm and 5.842 mm (0.230 in.), 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/cm^3, or to a theoretical density, ρ_{th}, of 11.084 g/cm^3. 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 UO_2 fuel insulator pellets each 20.32 mm (0.8 in.) long. The uranium insulator density is 10.42 ± 0.22 g/cm^3. On the outer ends of the uranium insulators are 14.478 cm long Inconel 600 reflectors. 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 cm^3. 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. 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 Fig. 5-2. The fuel composition and isotopic fractions for all four types of fuels are shown in Table 5-1. 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/cm^3.

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 cans. These containers are 3657.6 mm (144 in.) long and are made of 5 in. Type 304L stainless steel. 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.

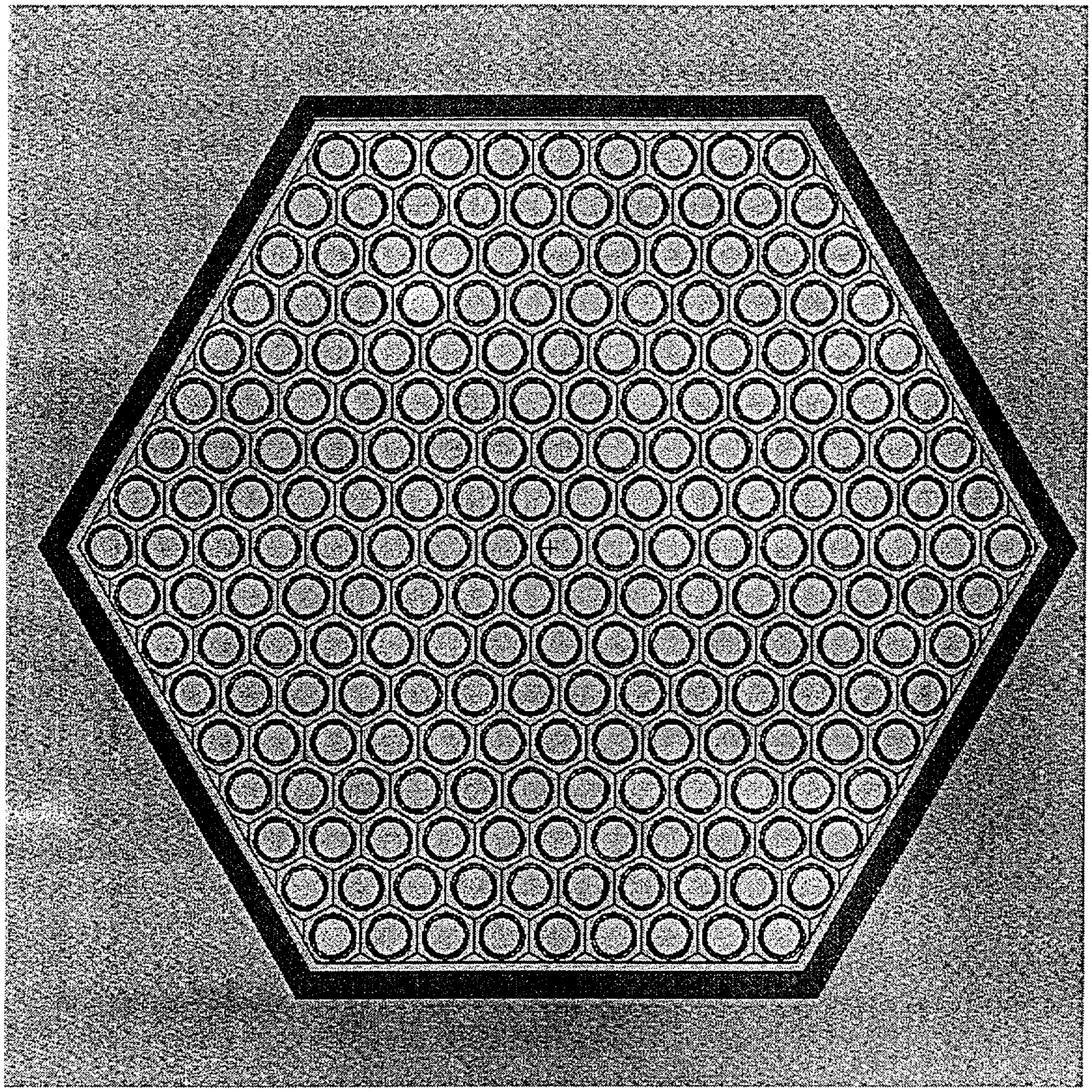

Figure 5-1. Cross-Sectional View of FFTF Assembly

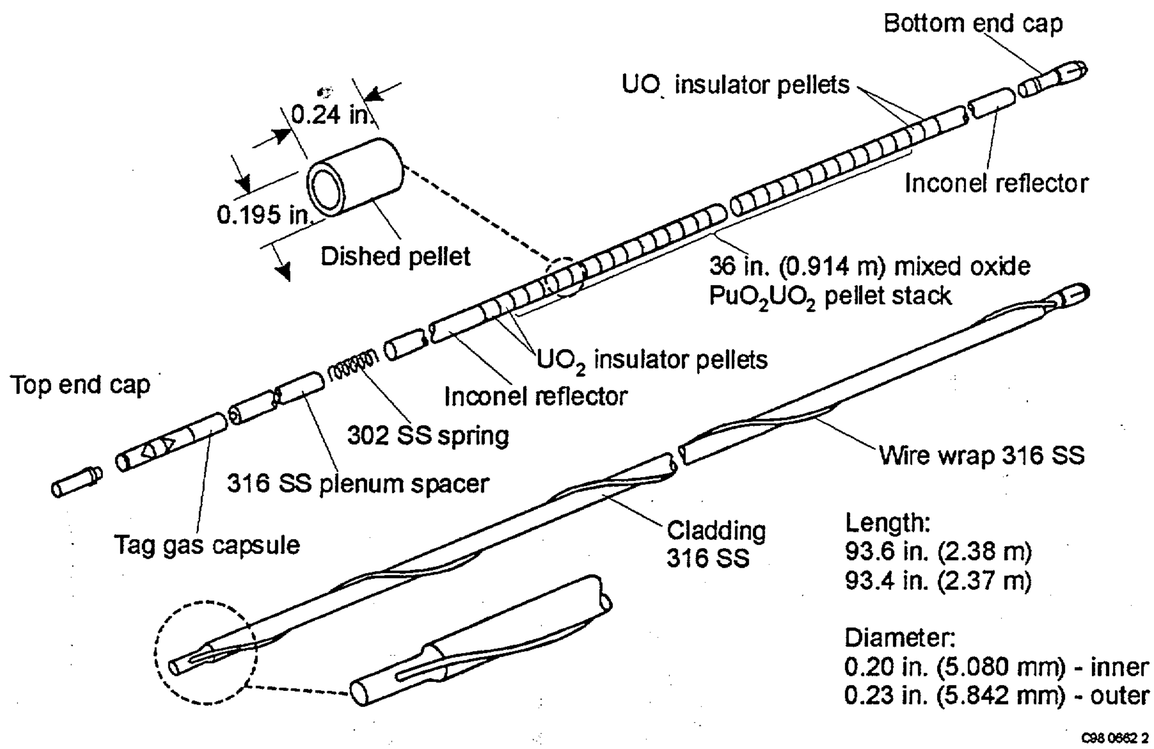

Figure 5-2. Standard Driver Fuel Assembly Fuel Pin

Table 5-1. Uranium and Plutonium Content of a Fresh DFA

			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	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.

5.1.3 Description of DOE SNF Canister

The description of the DOE SNF Canister is from Ref. 7.7 (Table 3.1 and Appendix A). 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 3. The canister may also contain a stainless steel (Type 316L) basket that is used to hold the fuel components. 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 canisters 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.

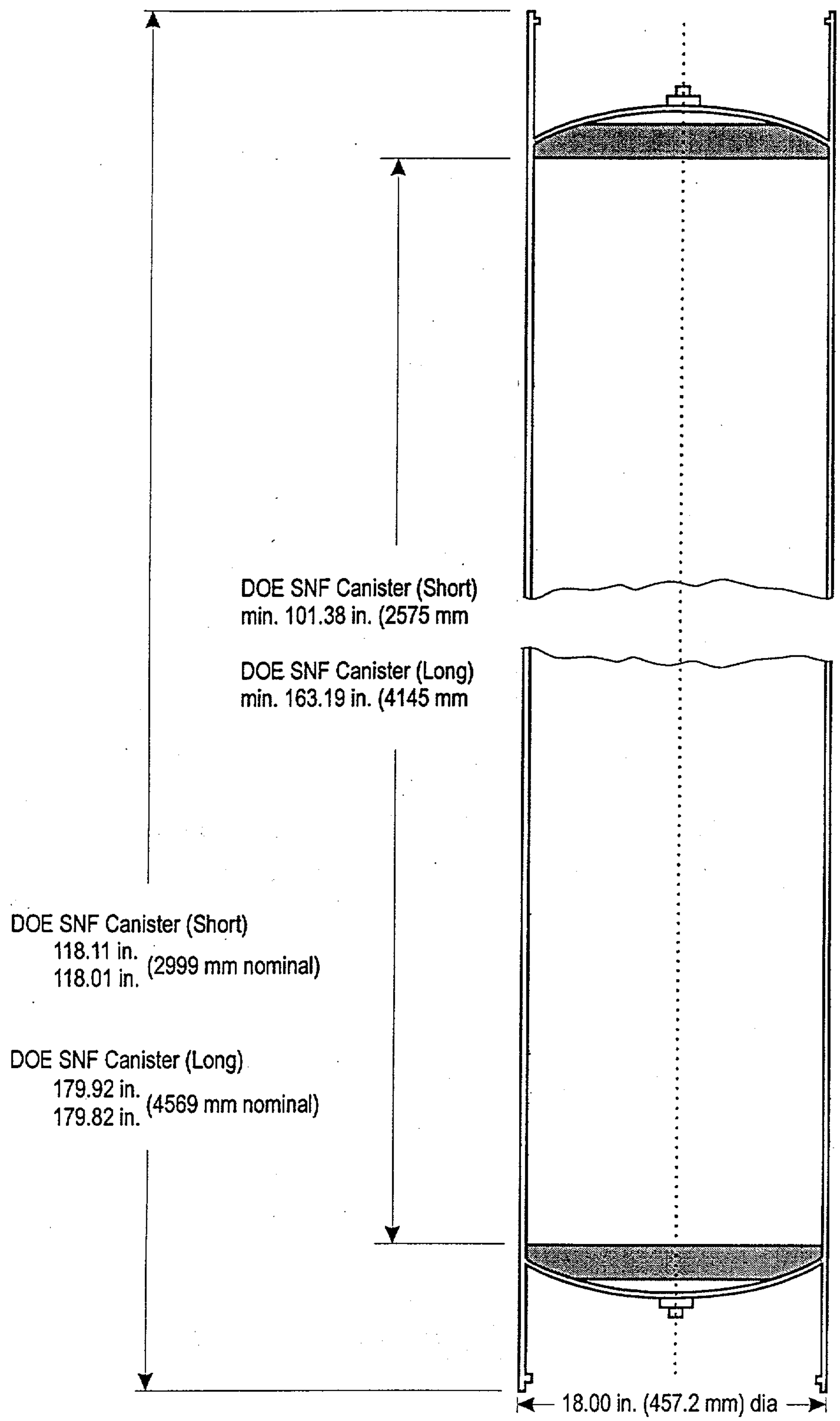

Figure 5-3. Plan View of the Proposed 18 in. DOE SNF Canister

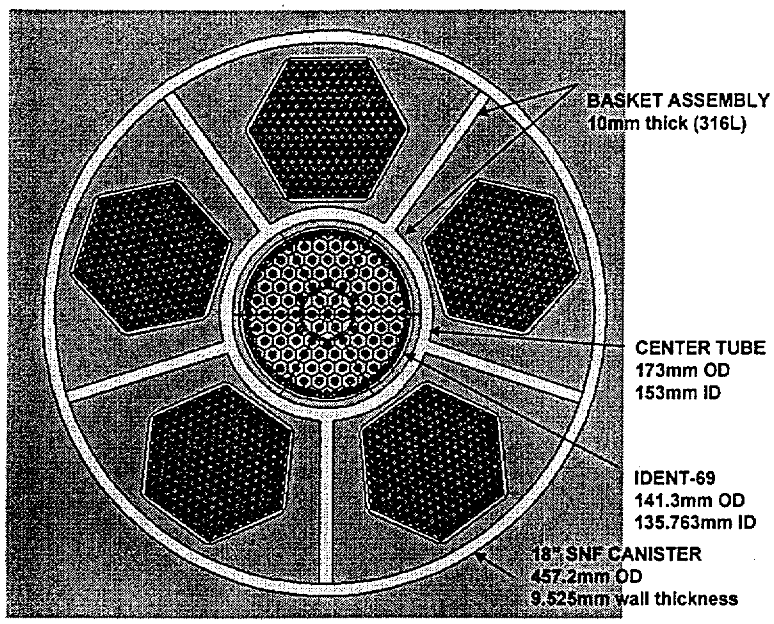

Figure 5-4. Cross-Sectional View of the FFTF DOE SNF Canister

5.1.4 Co-disposal Waste Package

The co-disposal waste package 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 Alloy 22 and serves as a corrosion resistant material. The outer barrier is composed of a 100 mm thickness of carbon steel and serves as a corrosion allowance material. 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.

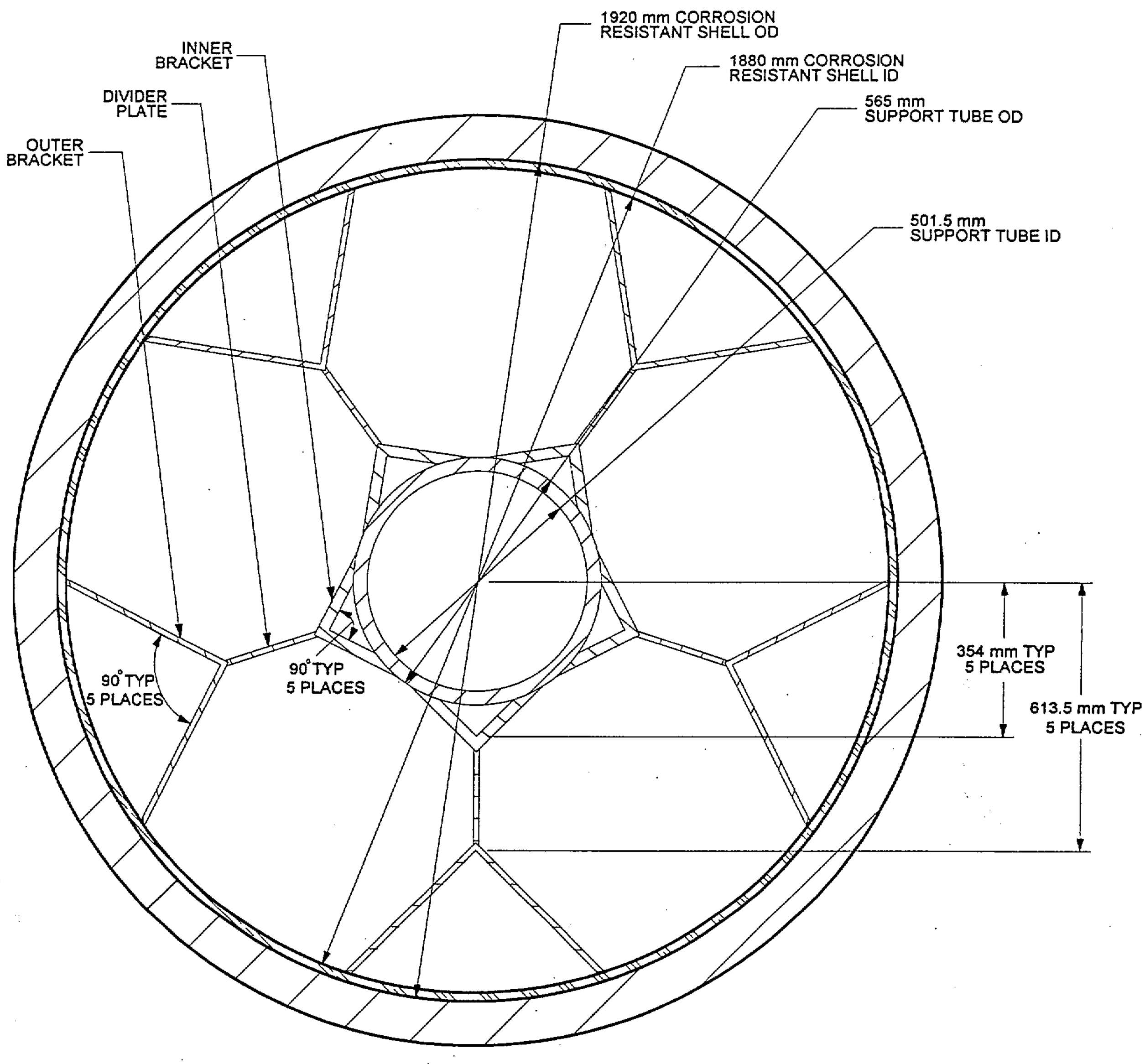

Figure 5-5. 5-HLW/DOE Spent Fuel-Long Co-disposal Waste Package

5.1.5 HLW Glass Pour Canisters

The Hanford fifteen foot High Level Waste canister 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 total canister weight is 4200 kg and HLW glass occupies 87% of the volume. The nominal dimensions of the canister are used for the calculations.

5.2 DESCRIPTION

The models used in this calculation assume that the FFTF fuel pins and assemblies are intact for all cases. The fuel number density is determined by using the fuel masses, given in Table 5-1, and the footprint volume of the fuel. Number densities and volumes are calculated by an Excel spreadsheet which 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 fuel containers contain intact fuel pins and do not contain pulverized fuel. 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.

5.2.1 Spacing Study for Minimum Critical Number of Type 4.1 DFAs

A spacing study for the minimum critical number of DFAs is determined for fully water reflected assemblies. A number of DFAs are placed in a hexagonal lattice and the lattice pitch is varied until the most reactive configuration is found. The type 4.1 fuel is considered to be a bounding case since it contains the largest amount of ^{239}Pu of the four driver type fuels. The optimal spacing, i.e., the spacing between assemblies that gives the most reactive configuration, is also determined.

5.2.1.1 Comparison of Type 4.1 DFAs with Type 3.2 DFAs

The least highly loaded fuel type in terms of ^{239}Pu content is the type 3.2 DFA. Here values of pitch near the optimal spacing for the minimum critical number of DFAs in a hexagonal array, as found from Section 5.2.1, are varied for type 3.2 fuels to show that the type 3.2 DFA is less reactive than the type 4.1 DFA.

5.2.1.2 k_{eff} for Less than Minimum Critical Number of Type 4.1 DFAs at Near Optimal Spacing

The number of type 4.1 DFAs is varied from 1 to the minimum critical number and k_{eff} for each is determined. The DFAs are kept in a hexagonal array with the optimal spacing, as found from Section 5.2.1, used for each configuration. Since the optimal spacing increases as the number of fuel items decreases, this spacing may not be optimal for less than a critical number of DFAs.

5.2.2 Type 4.1 DFAs in DOE SNF Canister without Basket Assembly

The type 4.1 DFAs are modeled in the DOE SNF canister without the basket assembly and their values of k_{eff} are determined. The number of DFAs is varied from 1 to the minimum critical number found in Section 5.2.1. The DFAs are positioned in hexagonal and square lattices and the pitch of the lattices is varied to find the most reactive configuration for each number of elements. Another case is presented where 5 DFAs are equally spaced in distance and angle about a central DFA that is located at the center of the canister. In this case, the outer DFAs are touching the center DFA.

5.2.2.1 Type 4.1 DFAs in DOE SNF Canister with Stainless Steel Basket Assembly

The type 4.1 DFAs are modeled in the DOE SNF canister with the stainless steel basket assembly and their values of k_{eff} are determined. The number of DFAs is varied from 4 to 6 (the maximum number that will fit with the basket assembly in place). The DFAs are positioned with an assembly in the center position and either 3, 4 or 5 in the outer positions. The spacing of the outer DFAs is varied as much as possible in order to find the most reactive configuration for each number of elements. The smallest value of spacing is for the outer DFAs to be just touching the center tube of the basket assembly. The spacing from the center DFA to each outer DFA and the angular separation of the outer DFAs are the same for all cases.

5.2.2.2 Type 4.1 DFAs in DOE SNF Canister with Gadolinium Doped Stainless Steel Basket Assembly

The type 4.1 DFAs are modeled in the DOE SNF canister with the gadolinium doped stainless steel basket assembly and k_{eff} is as was done in Section 5.2.2.1. The spacing of the DFAs is varied to find the most reactive configuration.

5.2.3 Minimum Critical Number of Type 4.1 Fuel Pins

The minimum critical number of fuel pins is determined for water reflection. A number of pins are placed in a hexagonal lattice and the lattice pitch is varied until the most reactive configuration is found. The type 4.1 fuel is considered to be a bounding case since it contains the largest amount of ^{239}Pu of the four driver type fuels. The optimal spacing, i.e., the spacing between fuel pins that gives the most reactive configuration, is also determined. Determining the minimum critical number of fuel pins and the corresponding optimal pitch is useful in determining the most reactive possible loading for the Ident-69 containers. A uniform pitch is used for each case.

5.2.3.1 Less than Minimum Critical Number of Type 4.1 Fuel Pins

The values of k_{eff} for a number of fuel pins less than the minimum critical number are determined with full water reflection. For each number of pins, the pins are placed in a hexagonal lattice and the lattice pitch is varied until the most reactive configuration is found. The optimal spacing is determined for each number of fuel pins. The pitch is uniform for each case.

5.2.3.2 Type 4.1 Fuel Pin Spacing in Ident-69 Can

Different numbers and hence different spacings of fuel pins are modeled in the Ident-69 can. The container is assumed filled with water and has full water reflection. In order to simplify the spacing of fuel pins, the container internals, i.e., the inner duct and dividers, are neglected. Both square and hexagonal arrays are considered. Also to keep the pitch constant for all fuel pins, partial fuel pins are included. These result from part of the fuel pin being positioned at radii greater than the inside radius of the can's outer wall and the pins are cut exactly by the outer wall.

Next, the inner duct is included in the model while the stainless steel dividers are neglected. This allows for a simpler yet more conservative model. The pins are assumed to be in a hexagonal lattice for most cases and the pitch (and number of pins) is varied and is kept as uniform as possible although the pitch inside the duct compartment may be slightly different than that outside the compartment. Once an optimal pitch is determined, then additional fuel pins are placed in lattice spaces around the perimeter of the container to act like a uranium reflector and just outside and/or inside the inner compartment as space allows. Partial pins are not allowed for these latter cases.

5.2.3.3 Type 4.1 Fuel Pin Spacing in Ident-69 Can in DOE SNF Canister with 5 DFAs without Basket Assembly

The most reactive configuration of fuel pins in the Ident-69 container found in Section 5.2.3.2 is placed in a DOE SNF canister that also contains 5 DFAs. The container is positioned in the center of the canister and is surrounded with 5 assemblies. The fuel items form either a hexagonal array or are equally spaced in distance and angle about the can. The container and canister are assumed to be filled with water and have full water reflection.

5.2.3.4 DOE SNF Canister with Ident-69 Can and 5 DFAs with Basket Assembly

The most reactive model found in Section 5.2.3.2 is used as the starting point and the spacing and number of pins is varied slightly to determine the most reactive configuration for the Ident-69 canister surrounded by the DFAs and basket assembly. In some cases the pitch inside and outside the inner duct compartment of the Ident-69 container are different. The Ident-69 container is positioned in the center position and 5 DFAs are placed in each of the outer compartments of the basket assembly. The container and canister are filled with water and are reflected by water.

5.2.3.5 DOE SNF Canister with Ident-69 Can and 5 DFAs with Basket Assembly Doped with Gadolinium

The Ident-69 container and 5 DFAs configuration is modeled with a 10 mm thick gadolinium doped stainless steel basket assembly. The pitch is varied for both hexagonal and square arrays. In some cases additional pins are added to the regular arrays as space allows. This is done as was described in Section 5.2.3.2. The container and canister are filled with water and have full water reflection.

5.2.4 DOE SNF Canister in Co-disposal Waste Package

The DOE SNF canister is modeled in the co-disposal waste package containing either 6 DFAs or 5 DFAs and an Ident-69 can. The canister is assumed to be fully flooded for all cases. The DOE canister always occupies the center position of the web-like basket structure in the co-disposal waste package. The canister is either centered or slightly displaced in the co-disposal waste package. In general the empty space outside the DOE canister is modeled as a void, although in some cases the effect of water in this space is investigated. The co-disposal waste package is assumed fully reflected by water for all cases.

5.2.4.1 DOE SNF Canister Containing 6 DFAs in Co-disposal Waste Package

The DOE canister is filled with 6 DFAs in the basket assembly but the basket contains no gadolinium. The center-to-center distance between the center DFA and the outer DFAs is varied. The position of the DOE canister is varied from the center of the co-disposal waste package to being 2 cm offset from the center. This is done to account for the effect of gravity on the horizontally positioned waste package. For the most reactive case, flooding in the inner support tube of the co-disposal waste package basket, flooding outside the inner support tube around the defense HLW canisters and total flooding of the co-disposal waste package are investigated. The effects of using the actual fuel density along with the footprint volume, water saturated fuel and water saturated fuel along with void spaces in the fuel pins filled with water are investigated for the most reactive configuration. The void fraction, F_{vd}, of the fuel is easily shown to be related to the fuel bulk and theoretical densities by the expression, $F_{vd} = 1\text{-}\rho_b/\rho_{th}$, which when evaluated gives a value of 10.89%, or simply 11%. This void fraction accounts for the void inside the fuel as well as the voids between fuel pellets due to their dished ends. If the fuel pins become fully saturated with water this volume can be filled.

5.2.4.2 DOE SNF Canister Containing an Ident-69 Can and 5 DFAs in Co-disposal Waste Package without Gadolinium

The DOE canister is filled with an Ident-69 container and 5 DFAs in the inner and outer positions, respectively, of the basket assembly. The basket contains no gadolinium. The center-to-center distance between the Ident-69 container and the outer DFAs is varied. The position of the DOE canister relative to the center of the co-disposal waste package is varied by 2 cm. For the most reactive case, flooding in the inner support tube of the co-disposal basket, flooding outside the inner support tube around the defense HLW canister, and total flooding of the co-disposal waste package are investigated. The effects of using the actual fuel density along with the footprint volume, water-saturated fuel, and water-saturated fuel along with void spaces in the fuel pins filled with water are investigated for the most reactive configuration. Another case is considered where the fuel inside the fuel pins is assumed saturated with water and swells filling the gap between the fuel and the cladding.

5.2.4.3 DOE SNF Canister Containing an Ident-69 Can and 5 DFAs in Co-disposal Waste Package with Gadolinium

The basket assembly in the DOE canister is now modeled to contain gadolinium. Varying amounts of gadolinium are assumed to be uniformly distributed along the axial length of the basket assembly. Cases are evaluated for gadolinium homogeneously distributed throughout the basket assembly, homogeneously distributed only in the inner tube of the basket assembly, coated along the inside surface of the inner tube and coated along the outer surface of the inner tube. Three cases are given that show the effect of the DFAs, HLW canisters and the Ident-69 canister being displaced by gravity rather than in their most reactive configuration.

The effect of varying water density inside the co-disposal waste package is investigated. For these cases the entire contents of the DOE canister is assumed flooded with full density water and the density of water in the co-disposal waste package is varied from 0 (no water) to 1 (full density). Also, the effect of varying water density inside the Ident-69 container is investigated. For these cases the rest of the DOE canister is assumed flooded with full density water, and the water density is varied inside the Ident-69 can. Outside the DOE canister, empty spaces in the co-disposal waste package are treated as voids for all cases except for one case where the space is flooded with full density water. Finally, the effect of varying water density inside the DOE canister but outside the Ident-69 container is determined. For these cases, the Ident-69 container is filled with full density water, the vacant space inside the co-disposal waste package is void except for one case where it is filled with full density water and the water density in the rest of the DOE canister is varied.

5.3 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.

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

6. RESULTS

Existing data were used in the development of the results presented in this section. Therefore, the use of any data from this calculation for input into documents supporting procurement, fabrication, or construction is required to be identified and tracked as TBV in accordance with appropriate procedures.

6.1 RESULTS WITH TYPE 4.1 DFAS

6.1.1 Results from Spacing Study for Minimum Critical Number of Type 4.1 DFAs

The most reactive configuration for a hexagonal array of 7 type 4.1 DFAs is determined by varying the spacing between assemblies as described in Section 5.2.1. In all cases the pitch, or center-to-center spacing between adjacent DFAs, is uniform for the entire array. Values of k_{eff} for different values of pitch are shown in Table 6-1. The assemblies are essentially touching for the smallest value of pitch, 11.621 cm, listed in the table. Values of the pitch from about 12.6205 to 13.8205 cm give the largest values of k_{eff} that are critical. These values correspond to a spacing between DFAs of 1 to 2.2 cm.

Table 6-1. Spacing Study for 7 Type 4.1 DFAs

Pitch, cm	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
11.6210	0.9687 ± 0.0010	0.9707	7assem_a.o
11.8205	0.9737 ± 0.0010	0.9756	7assem_b.o
12.0205	0.9798 ± 0.0010	0.9819	7assem_c.o
12.2205	0.9845 ± 0.0010	0.9865	7assem_d.o
12.6205	0.9974 ± 0.0010	0.9994	7assem_f.o
13.0205	1.0003 ± 0.0010	1.0022	7assem_h.o
13.2205	0.9992 ± 0.0010	1.0012	7assem_i.o
13.4205	1.0021 ± 0.0010	1.0040	7assem_j.o
13.8205	0.9982 ± 0.0010	1.0002	7assem_l.o
14.2205	0.9866 ± 0.0010	0.9887	7assem_n.o
14.6205	0.9768 ± 0.0009	0.9785	7assem_p.o
15.0205	0.9631 ± 0.0010	0.9650	7assem_r.o

6.1.2 Results for the Comparison of Type 4.1 DFAs with Type 3.2 DFAs

Results are given in Table 6-2 for 7 type 3.2 DFAs similar to those for type 4.1 DFAs. Only cases near the optimal value of the pitch are investigated as described in Section 5.2.1.1. The DFAs are in a hexagonal array.

Table 6-2. Spacing Study for 7 Type 3.2 DFAs

Pitch, cm	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
13.0205	0.9601 ± 0.0010	0.9621	7assem_3.2_h.o
13.2205	0.9609 ± 0.0009	0.9627	7assem_3.2_i.o
13.4205	0.9634 ± 0.0009	0.9652	7assem_3.2_j.o
13.8205	0.9624 ± 0.0010	0.9643	7assem_3.2_l.o
14.2205	0.9545 ± 0.0010	0.9564	7assem_3.2_n.o

6.1.3 Values of k_{eff} for Less than Minimum Critical Number of Type 4.1 DFAs at Near Optimal Spacing

Results for various numbers of type 4.1 DFAs are given in Table 6-3. In each case the pitch of the hexagonal array of DFAs is 13.2205 cm which was found in Section 6.1.1 to be near the center of the range of values for the most reactive configuration for a critical number of DFAs. Typically the optimal spacing increases as the number of elements in an array decreases. Therefore the results given in Table 6-3 for less than a critical number of DFAs may not always be at the optimal spacing as described in Section 5.2.1.2.

Table 6-3. k_{eff} for Various Numbers of Type 4.1 DFAs

Number of DFAs	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
1	0.5692 ± 0.0009	0.5710	1assem_i.o
2	0.6945 ± 0.0010	0.6965	2assem_i.o
3	0.8055 ± 0.0010	0.8074	3assem_i.o
4	0.8713 ± 0.0010	0.8734	4assem_i.o
5	0.9153 ±.0 0011	0.9174	5assem_i.o
6	0.9528 ± 0.0010	0.9547	6assem_i.o
7	0.9992 ± 0.0010	1.0012	7assem_i.o

6.2 RESULTS FOR TYPE 4.1 DFAS IN DOE SNF CANISTER WITHOUT BASKET ASSEMBLY

Results are given in Table 6-4 for various numbers of type 4.1 DFAs in the DOE SNF canister without the stainless steel basket assembly. Hexagonal and square arrays and a variety of spacings are used to produce these results as described in Section 5.2.2.

Table 6-4. Results for Various Numbers of Type 4.1 DFAs in DOE SNF Canister without a Basket Assembly

Number of DFAs	Pitch, cm - Array	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
1	--	0.5656 ± 0.0009	0.5674	1packd0.o
3	16.8300 - hex.	0.7864 ± 0.0010	0.7883	3packd0.o
4	13.2205 - hex.	0.8721 ± 0.0010	0.8741	4pack_i.o
4	14.0000 - hex.	0.8659 ± 0.0010	0.8679	4packd0.o
5	13.2205 - hex.	0.9127 ± 0.0009	0.9146	5pack_i.o
5	13.8000 - sq.	0.8577 ± 0.0010	0.8596	5packd0.o
5	13.2000 - sq.	0.8717 ± 0.0010	0.8736	5packd0a.o
6	13.2205 - hex.	0.9508 ± 0.0011	0.9529	6pack_i.o
6	*	0.9492 ± 0.0010	0.9512	6packd0.o

Number of DFAs	Pitch, cm - Array	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
7	13.2205 - hex.	0.9981 ± 0.0009	1.0000	7pack_i.o
7	13.8000 - hex.	0.9920 ± 0.0010	0.9940	7packd0.o

* 5 DFAs equally spaced about center DFA, center-to-center distance from outer DFAs to center DFA is 13.2 cm

6.2.1 Results for Type 4.1 DFAs in DOE SNF Canister with Stainless Steel Basket Assembly

Results similar to those in Table 6-4 are given in Table 6-5 for type 4.1 DFAs in the DOE SNF canister, but in this case with the stainless steel basket assembly. In each case the center position of the basket is occupied and the DFAs are positioned so as to find the most reactive configuration as described in Section 5.2.2.1. The distance listed in the table is the center-to-center distance between the outer DFAs and the center DFA.

Table 6-5. Results for Various Numbers of Type 4.1 DFAs in DOE SNF Canister with Basket Assembly

Number of DFAs	Distance between Inner and Outer DFAs, cm	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
4	14.461	0.7606 ± 0.0010	0.7625	4packd0_ss_10.o
5	14.461	0.7945 ± 0.0010	0.7965	5packd0_ss_10.o
6	14.461	0.8407 ± 0.0010	0.8427	6packd0_ss_10.o
6	15.0	0.8194 ± 0.0010	0.8214	6packd0_ss_10.a.o

6.2.2 Results for Type 4.1 DFAs in DOE SNF Canister with Gadolinium Doped Stainless Steel Basket Assembly

Results for the same configurations as used in Section 6.2.1 but with a gadolinium doped basket assembly are presented in Table 6-6. These cases are described in Section 5.2.2.2. The basket assembly contains 5% gadolinium (19.26 kg), which is assumed homogeneously distributed throughout the metal composing the basket.

Table 6-6. Results for Various Numbers of Type 4.1 DFAs in DOE SNF Canister with Gadolinium Doped Basket Assembly

Number of DFAs	Distance between Inner and Outer DFAs, cm	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
5	14.461	0.7196 ± 0.0010	0.7216	5packd0_ss_10_gd.o
6	14.461	0.7596 ± 0.0010	0.7615	6packd0_ss_10_gd.o
6	15.000	0.7431 ± 0.0010	0.7450	6packd0_ss_10.a_gd.o

6.3 RESULTS FOR TYPE 4.1 Fuel Pins

Results are now presented for Type 4.1 fuel pins in spaced in water, for Type 4.1 fuel pins in the Ident-69 container, and for the Ident-69 container in the DOE SNF canister surrounded by 5 DFAs.

6.3.1 Values of k_{eff} for Various Numbers and Spacings of Type 4.1 Fuel Pins

As described in Secs. 5.2.3 and 5.2.3.1 the values of k_{eff} for loose FFTF type 4.1 fuel pins in a hexagonal array with uniform pitch are determined next. Results are presented in Table 6-7 for various numbers of pins at a variety of spacings. The results show that 133 (or just less) number of fuel pins constitute a minimum critical number of fuel pins. The optimal spacing between pins is about 2.25 cm.

Table 6-7. Spacing Study and Minimum Critical Number of Type 4.1 Fuel Pins

Number of fuel pins	Pitch, cm	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
91	2.16	0.9011 ± 0.0011	0.9033	pins091_2.159.o
91	2.25	0.9071 ± 0.0011	0.9093	pins091_2.25.o
91	2.50	0.9101 ± 0.0011	0.9123	pins091_2.50.o
91	2.75	0.8969 ± 0.0010	0.8989	pins091_2.75.o
91	3.00	0.8756 ± 0.0010	0.8776	pins091_3.00.o
127	2.05	0.9792 ± 0.0010	0.9813	pins127_2.050.o
127	2.16	0.9849 ± 0.0010	0.9869	pins127_2.159.o
127	2.25	0.9873 ± 0.0012	0.9896	pins127_2.25.o
127	2.50	0.9847 ± 0.0011	0.9869	pins127_2.50.o
133	2.0	0.9880 ± 0.0011	0.9901	pins133_2.00.o
133	2.25	0.9985 ± 0.0010	1.0005	pins133_2.25.o
133	2.50	0.9935 ± 0.0010	0.9955	pins133_2.50.o
169	2.25	1.0538 ± 0.0010	1.0558	pins169_2.25.o

6.3.2 Results for Type 4.1 Fuel Pin Spacing in Ident-69 Can

Next results for hexagonal and square arrays in Ident-69 containers with different spacings between fuel pins is shown in Table 6-8. The pins are placed in the array with uniform spacing filling the entire Ident-69 container and neglect the presence of the inner duct of the Ident-69 container as described in Section 5.2.3.2. Any portion of the outermost ring of fuel pins that do not exactly fit in the container are assumed to be cut so that they exactly fit along the inside surface of the can. This, in general, results in the container containing a noninteger number of fuel pins. The container is assumed to be fully flooded and is positioned in the center of the 18 in. canister.

Table 6-8. Type 4.1 Fuel Pins Spacing Study in Ident-69 Can

Pitch, cm - Array	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
0.590 - hex.	0.6245 ± 0.0009	0.6262	cs-1_F.o
0.72644 - hex.	0.6509 ± 0.0009	0.6528	cs0_F.o
0.8 - hex.	0.6642 ± 0.0010	0.6661	cs0.8_F.o
0.9 - hex.	0.6805 ± 0.0010	0.6825	cs0.9_F.o
1.0 - hex.	0.6908 ± 0.0011	0.6930	cs1.0.o
1.1 - hex.	0.7136 ± 0.0010	0.7156	cs1.1.o
1.1 - sq.	0.7124 ± 0.0011	0.7146	cs1.10.new.sq.o
1.20 - hex.	0.7153 ± 0.0007	0.7167	cs1.20.o
1.25 - hex.	0.7209 ± 0.0007	0.7222	cs1.25.o
1.25 - sq.	0.7150 ± 0.0010	0.7171	cs1.25.new.sq.o
1.29 - hex.	0.7188 ± 0.0007	0.7201	cs1.29.o
1.33 - hex.	0.7035 ± 0.0007	0.7048	cs1.33.o
1.35 - hex.	0.7002 ± 0.0006	0.7014	cs1.35.o
1.40 - sq.	0.6825 ± 0.0011	0.6847	cs1.40.new.sq.o
1.5 - hex.	0.7175 ± 0.0007	0.7188	cs1.5.o
1.55 - hex.	0.6992 ± 0.0010	0.7012	cs1.55.o
1.60 - hex.	0.6846 ± 0.0011	0.6867	cs1.6.o
1.70 - hex.	0.6849 ± 0.0010	0.6868	cs1.7.o
2.0 - hex.	0.6219 ± 0.0010	0.6240	cs2.0.o

Next the inside duct is included for the hexagonal array with a pitch of 1.25 cm and the results are shown as the first entry in Table 6-9. Partial fuel pins are included in some of these cases as listed in the table though they are not included in the count of "whole fuel pins". Results from several other cases are presented where additional fuel pins are placed just inside and/or outside the inside duct of the container and a square array with a pitch of 1.25 cm is used. For the final 6 cases presented in this table the location of the outermost row of fuel is adjusted so as to eliminate partial fuel pins. The pitch for the portion of the array outside the inner duct is also slightly increased to 1.26 cm to better position the fuel pins. Results for cases where different permutations of adding pins just inside and/or outside the duct and around the outer edge of the array are also shown in the table. The most reactive case in the table has 60 pins around the outer edge of the container plus 6 pins placed just outside the inside duct. This case has a total of 145 fuel pins (7 pins inside the duct) and has a $k_{eff} + 2\sigma$ of 0.7329.

Table 6-9. Fuel Pin Arrangement Study in Ident-69 Can

Pitch Inside/Outside Duct, cm - Array # of whole fuel pins	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
1.25 / 1.25 - hex. 91	Partial pins	0.7097 ± 0.0010	0.7117	cs1.25.new.0.o
1.25 / 1.25 - hex. 97	Partial pins; 6 pins added just inside duct	0.7078 ± 0.0011	0.7100	cs1.25.new.in.o

Pitch Inside/Outside Duct, cm - Array # of whole fuel pins	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
1.25 / 1.25 - hex. 97	Partial pins; 6 pins added just outside duct	0.7099 ± 0.0011	0.7120	cs1.25.new.out.o
1.25 / 1.25 - hex. 103	Partial pins; 6 pins added just inside and 6 added just outside duct	0.7036 ± 0.0010	0.7055	cs1.25.new.both.o
1.25 / 1.258 - sq. 89	Partial pins	0.7039 ± 0.0011	0.7061	cs1.25.new.0a.o
1.25 / 1.26 - hex. 121	36 total pins around outer edge of can; 6 pins added just outside duct	0.7171 ± 0.0011	0.7192	cs1.25.new.outa.o
1.25 / 1.26 - hex. 115	36 total pins around outer edge of can; no additional pins added either outside or inside duct	0.7196 ± 0.0010	0.7215	cs1.25.new.outb.o
1.25 / 1.26 - hex. 121	36 total pins around outer edge of can; 6 additional pins added just inside duct	0.7168 ± 0.0011	0.7189	cs1.25.new.outc.o
1.25 / 1.26 - hex. 127	36 total pins around outer edge of can; 6 additional pins added just outside duct and 6 added just inside duct	0.7128 ± 0.0010	0.7149	cs1.25.new.outd.o
1.25 / 1.26 - hex. 145	60 total pins around outer edge of can; 6 pins added just outside duct	0.7299 ± 0.0011	0.7321	cs1.25.new.outap.o
1.25 / 1.26 - hex. 181	60 total pins around outer edge of container plus vacant spaces filled next to outer edge; 6 pins added just outside duct	0.7194 ± 0.0010	0.7213	cs1.25.new.outapp.o

6.3.3 Results for Type 4.1 Fuel Pin Spacing in Ident-69 Can in DOE SNF Canister with 5 DFAs

The most reactive configuration inside the Ident-69 can, containing 145 pins with a $k_{eff} + 2\sigma$ of 0.7329, is now modeled surrounded by 5 DFAs in the DOE SNF canister. The first set of results, shown in Table 6-10, neglects the basket assembly and the Ident-69 container occupies the center position of either a hexagonal array or is surrounded by the DFAs with an equal distance from the center of the Ident-69 container as described in Section 5.2.3.3. In this latter configuration the centers of the assemblies lie on a circle whose origin is coincident with the center of the

Ident-69 can, with radius equal to the center-to-center distance given in the table. The DFAs are equally spaced in angle about the center of the Ident-69 container at 72° increments.

Table 6-10. Ident-69 Can Spaced Among 5 DFAs without Basket Assembly

Pitch Inside/Outside Duct of Ident-69 Can, cm	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
1.25 / 1.26	Ident-69 container centered in DFAs in hex. array with pitch = 13.22 cm	1.0007 ± 0.0011	1.0029	combo1+5a.o
1.25 / 1.26	Ident-69 equally centered between DFAs; distance from center-center = 12.88 cm	1.0009 ± 0.0010	1.0029	combo1+5b.o
1.25 / 1.26	Ident-69 equally centered between DFAs; distance from center-center = 13.40 cm	1.0018 ± 0.0011	1.0040	combo1+5c.o
1.25 / 1.26	Ident-69 equally centered between DFAs; distance from center-center = 13.90 cm	0.9995 ± 0.0010	1.0015	combo1+5d.o

Similar results but with the basket assembly included are presented in Table 6-11. These cases are described in Section 5.2.3.4. For these cases the center-to-center distance between the Ident-69 container and the DFAs is 14.461 cm which corresponds to the assemblies just touching the outer center tube of the basket assembly. Since additional fuel is being placed around the Ident-69 can, the spacing of the fuel pins inside the container needs to be varied to determine if a significantly more reactive configuration can be found. Results in the table are for the pitch inside and outside the internal duct ranging from 1.02 to 1.60 cm and 1.10 to 1.60 cm, respectively. This ranges from 169 pins for the tighter arrays to 115 pins for the larger spacing. The results show that k_{eff} is essentially constant for values of the pitch ranging from 1.40 to 1.60 cm. Larger values of pitch were not investigated since as indicated in Table 6-8 they should be less reactive.

Table 6-11. Ident-69 Can Spaced Among 5 DFAs with Basket Assembly

Pitch Inside/Outside Duct of Ident-69, cm; # of pins in Ident-69 Can	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
1.02 / 1.10 169	54 total pins around outer edge of can; 6 pins added just outside duct	0.9104 ± 0.0011	0.9125	combo1+5b_ss_1.0-.o
1.25 / 1.26 145	60 total pins around outer edge of can; 6 pins added just outside duct	0.9236 ± 0.0011	0.9257	combo1+5b_ss_1.0.o
1.40 / 1.40 115	54 total pins around outer edge of can	0.9322 ± 0.0011	0.9343	combo1+5b_ss_1.0+.o
1.50 / 1.50 115	54 total pins around outer edge of can	0.9316 ± 0.0010	0.9336	combo1+5b_ss_1.0++.o
1.60 / 1.60 115	60 total pins around outer edge of can	0.9313± 0.0010	0.9334	combo1+5b_ss_1.0+++p.o

The basket assembly is now assumed to be doped with 5% gadolinium (19.26 kg) and the results are presented in Table 6-12. These cases are described in Section 5.2.3.5. The center-to-center distance between the Ident-69 container and the DFAs is 14.461 cm, which corresponds to the assemblies just touching the outer tube surface. Results are included that deal with various numbers of fuel pins in the Ident-69 container in hexagonal and square arrays. Again, as in the previous case, the most reactive configurations are for hexagonal arrays with a pitch spacing between 1.40 and 1.60 cm where k_{eff}, with a value of about 0.86, is essentially constant.

6.4 RESULTS FOR THE DOE SNF CANISTER IN THE CO-DISPOSAL WASTE PACKAGE

Results are presented for the DOE SNF canister in the co-disposal waste package as described in Section 5.2.4. The DOE SNF canister will either contain 6 DFAs or 1 Ident-69 container and 5 DFAs. The basket assembly is assumed to be present in all cases with the center positions containing either a DFA or the Ident-69 container for the 6 and 5 DFA cases, respectively. The canister is assumed to be fully flooded in all cases. The DOE canister is placed in the center position surrounded by 5 HLW glass canisters. Cases are presented where the canister is either centered in the co-disposal waste package or offset from the center to account for settling. A cases is presented where the entire co-disposal waste package is flooded. In all cases the co-disposal waste package is water reflected.

Table 6-12. Ident-69 Can Spaced Among 5 DFAs with Basket Assembly Doped with Gadolinium

Pitch Inside/Outside Duct of Ident-69 can, cm - Array type; # pins in Ident-69 Can	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
0.85 / 1.0662 - hex. 187	60 total pins around outer edge of can; 6 pins added just outside duct	0.8316 ± 0.0011	0.8338	combo1+5b_ss_gd1.0+.o
0.98 / 1.125 - hex. 163	42 total pins around outer edge of can; 6 pins added just outside duct	0.8340 ± 0.0010	0.8360	combo1+5b_ss_gd1.0+a.o
0.98 / 1.125 - hex. 175	54 total pins around outer edge of can; 6 pins added just outside duct	0.8352 ± 0.0011	0.8373	combo1+5b_ss_gd1.0+b.o
1.25 / 1.26 - hex. 145	60 total pins around outer edge of can	0.8493 ± 0.0011	0.8515	combo1+5b_ss_gd1.0.o
1.40 / 1.40 - hex. 115	54 total pins around outer edge of can	0.8556 ± 0.0010	0.8576	combo1+5b_ss_1.0+_gd.o
1.50 / 1.50 - hex. 115	54 total pins around outer edge of can	0.8577 ± 0.0011	0.8599	combo1+5b_ss_1.0++_gd.o
1.60 / 1.60 - hex. 115	60 total pins around outer edge of can	0.8549 ± 0.0010	0.8569	combo1+5b_ss_1.0+++p_gd.o
00.88 / 0.918 - sq. 153	regular array; no additional pins	0.8163 ± 0.0010	0.8183	combo1+5b_ss_gd1.0_sqd.o
1.06 / 1.0662 - sq. 109	regular array; no additional pins	0.8268 ± 0.0011	0.8289	combo1+5b_ss_gd1.0_sqc.o
1.2528 / 1.26 - sq. 89	regular array; no additional pins	0.8271 ± 0.0010	0.8291	combo1+5b_ss_gd1.0_sqb.o
1.532 / 1.52 - sq. 57	regular array; no additional pins	0.8096 ± 0.0010	0.8116	combo1+5b_ss_gd1.0_sqa.o
0.795 / 1.0662 - sq. 121	regular array; no additional pins	0.8251 ± 0.0010	0.8271	combo1+5b_ss_gd1.0_sqc1.o
0.795 / 1.0662 - sq. 133	12 added just outside duct	0.8178 ± 0.0012	0.8201	combo1+5b_ss_gd1.0_sqc2.o
0.795 / 1.0662 - sq. 157	24 added around outer edge of can; 12 added just outside duct	0.8335 ± 0.0011	0.8356	combo1+5b_ss_gd1.0_sqc3.o

Pitch Inside/Outside Duct of Ident-69 can, cm - Array type; # pins in Ident-69 Can	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
1.06 / 1.0662 - sq. 121	12 added just outside duct	0.8236 ± 0.0011	0.8258	combo1+5b_ss_gd1.0_sqc2a.o
1.06 / 1.0662 - sq. 145	24 added around outer edge of can; 12 added just outside duct	0.8395 ± 0.0010	0.8415	combo1+5b_ss_gd1.0_sqc3a.o

6.4.1 Results for the DOE SNF Canister Containing 6 DFAs in the Co-disposal Waste Package

The DOE SNF canister is now assumed to be filled with 6 DFAs and the results are presented in Table 6-13. These cases are described in Section 5.2.4.1. The center-to-center distance gives the spacing of the outer DFAs from the center DFA in the DOE SNF canister. Results are also presented where the actual density rather than the bulk density of the fuel is used. In this case the fuel footprint volume is used which gives fuel masses slightly greater than those used in Table 5-1. Also cases are given where water is assumed to have penetrated into the fuel pins of the DFAs. The void fraction inside the fuel and the space between the dished surfaces of the fuel pellets are shown in Section 5.2.4.1 to constitute 11% of the footprint volume of the fuel. A case is shown where this volume is fully saturated and another case is given where this volume and other voids inside the fuel pins are flooded. This latter case increases k_{eff} by slightly more than 1%. None of the cases in this table include gadolinium in the DOE canister basket assembly. Inclusion of gadolinium would further decrease k_{eff}.

Table 6-13. Six DFAs in DOE SNF Canister Inside Co-disposal Waste Package

Center-to-Center Distance, cm	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
14.461	18 in. canister displaced 2 cm from center of co-disposal waste package	0.8572 ± 0.0010	0.8592	6packd0_ss_10.o
14.461	18 in. canister centered in co-disposal waste package	0.8559 ± 0.0011	0.8580	6packd0_ss_10_c.o
14.75	18 in. canister displaced 2 cm from center of co-disposal waste package	0.8441 ± 0.0010	0.8460	6packd0_ss_10b.o
15.00	18 in. canister displaced 2 cm from center of co-disposal waste package	0.8355 ± 0.0010	0.8374	6packd0_ss_10c.o

Center-to-Center Distance, cm	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
15.25	18 in. canister displaced 2 cm from center of co-disposal waste package	0.8267 ± 0.0010	0.8287	6packd0_ss_10d.o
14.461	Co-disposal waste package is fully flooded	0.8484 ± 0.0009	0.8502	6packd0_ss_10_ff.o
14.461	Actual fuel density used	0.8584 ± 0.0010	0.8603	6packd0_ss_10+.o
14.461	Fuel volume and fuel 100% saturated	0.8665 ± 0.0010	0.8684	6packd0_ss_10_w_1.o
14.461	Fuel volume and fuel 100% saturated; voids inside fuel pins flooded	0.8763 ± 0.0011	0.8785	6packd0_ss_10_w_1a.o

6.4.2 Results for the DOE SNF Canister Containing an Ident-69 Can Plus 5 DFAs in the Co-disposal Waste Package (No Gadolinium)

The DOE SNF canister is now assumed to be filled with a most reactive Ident-69 container and 5 DFAs and the results are presented in Table 6-14. These cases are described in Section 5.2.4.2. None of the cases in this table include gadolinium in the basket assembly. The center-to-center distance gives the spacing of the DFAs from the Ident-69 can. Results are also presented where the actual density rather than the bulk density of the fuel is used. In this case the same fuel volume is used which gives fuel masses slightly greater than those used in Table 5-1. Also cases are given where water is assumed to have penetrated into every fuel pin. The void fraction inside the fuel and the space between the dished surfaces of the fuel pellets are shown in Section 5.2.4.1 to constitute 11% of the footprint volume of the fuel. A case is shown where this volume is fully saturated and another case is given where this volume and other voids inside the fuel pins are flooded.

Table 6-14. Ident-69 and 5 DFAs in DOE SNF Canister Inside Co-disposal Waste Package

Center-to-Center Distance, cm	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
14.461	18 in. canister displaced 2 cm from center of co-disposal waste package	0.9360 ± 0.0010	0.9380	combo1+5b_ss_10a.o
14.750	18 in. canister displaced 2 cm from center of co-disposal waste package	0.9290 ± 0.0010	0.9309	combo1+5b_ss_10b.o

Center-to-Center Distance, cm	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
15.000	18 in. canister displaced 2 cm from center of co-disposal waste package	0.9207 ± 0.0010	0.9227	combo1+5b_ss_10c.o
15.250	18 in. canister displaced 2 cm from center of co-disposal waste package	0.9120 ± 0.0010	0.9140.	combo1+5b_ss_10d.o
14.461	Co-disposal waste package is fully flooded	0.9275 ± 0.0010	0.9296	combo1+5b_ss_10aff.o
14.461	Actual rather than bulk fuel density used	0.9385 ± 0.0011	0.9406	combo1+5b_ss_10a+.o
14.461	Voids inside fuel pins flooded (no water absorption in fuel)	0.9424 ± 0.0010	0.9445	combo1+5b_ss_10aa.o
14.461	Fuel volume and fuel 50% saturated	0.9430 ± 0.0010	0.9449	combo1+5b_ss_10a_w_.5.o
14.461	Fuel volume and fuel 100% saturated	0.9467 ± 0.0011	0.9488	combo1+5b_ss_10a_w_1.o
14.461	Swollen fuel volume 100% saturated	0.9517 ± 0.0010	0.9537	combo1+5b_ss_10a_w_1b.o
14.461	Fuel volume and fuel 100% saturated; voids inside fuel pins flooded	0.9526 ± 0.0010	0.9546	combo1+5b_ss_10a_w_1a.o
14.461	Swollen fuel volume 100% saturated; voids inside fuel pins flooded	0.9509 ± 0.0010	0.9529	combo1+5b_ss_10a_w_1c.o
14.461	Fuel volume and fuel 100% saturated; voids inside fuel pins flooded; 18 in. canister centered in co-disposal waste package	0.9538 ± 0.0010	0.9558	combo1+5b_ss_10a_w_1a_c.o

6.4.3 Results for the DOE SNF Canister Containing an Ident-69 Can Plus 5 DFAs in the Co-disposal Waste Package (Containing Gadolinium)

Results similar to those in the previous table are given in Table 6-15 but the basket assembly in the DOE SNF canister contains gadolinium. These cases are described in Section 5.2.4.3. The gadolinium is assumed to be doped into the stainless steel structure or coated either on the inside or outside of the inner support tube.

Table 6-15. Ident-69 and 5 DFAs in DOE SNF Canister Containing Gadolinium Inside Co-disposal Waste Package

Gd Content	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
0.5% in 18 in. basket (1.93 kg)	Fuel volume and fuel 100% saturated; voids inside fuel pins flooded	0.9093 ± 0.0010	0.9113	combo1+5b_ss_10a_w_1a_gd_.5.o
0.5% in 18 in. basket (1.93 kg)	Fuel volume and fuel 100% saturated; voids inside fuel pins flooded; 1.6 cm pitch inside Ident-69 can	0.9167 ± 0.0010	0.9188	combo1+5b_ss_10a_w_1a_gd_.5_1.6.o
0.5% in 18 in. basket (1.93 kg)	Same as previous case but HLW canisters displaced by gravity	0.9151 ± 0.0010	0.9171	grav1.o
0.5% in 18 in. basket (1.93 kg)	Same as previous case but entire waste package displaced by gravity	0.8743 ± 0.0011	0.8765	grav2.o
0.5% in 18 in. basket (1.93 kg)	Same as previous case but DOE canister rotated 180° and displaced by gravity	0.8810 ± 0.0010	0.8830	grav2a.o
1.0% in 18 in. basket (3.85 kg)	Fuel volume and fuel 100% saturated; voids inside fuel pins flooded	0.9036 ± 0.0011	0.9059	combo1+5b_ss_10a_w_1a_gd_1.o
2.5% in 18 in. basket (9.63 kg)	Fuel volume and fuel 100% saturated; voids inside fuel pins flooded	0.8932 ± 0.0010	0.8952	combo1+5b_ss_10a_w_1a_gd_2.5.o
5% in 18 in. basket (19.3 kg)	18 in. canister displaced 2 cm from center of co-disposal	0.8624 ± 0.0011	0.8646	combo1+5b_ss_10a_gd.o

Gd Content	Comment	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
5% in 18 in. basket (19.3 kg)	Fuel volume and fuel 100% saturated; voids inside fuel pins flooded	0.8787 ± 0.0011	0.8809	combo1+5b_ss_10a_w_1a_gd.o
5% in inner tube of basket (8.40 kg)	Fuel volume and fuel 100% saturated; voids inside fuel pins flooded	0.8985 ± 0.0010	0.9005	combo1+5b_ss_10a_w_1a_gd_in_h.o
19.3 kg coated on inside surface of inner tube	Fuel volume and fuel 100% saturated; voids inside fuel pins flooded	0.8884 ± 0.0010	0.8904	combo1+5b_ss_10a_w_1a_gd_in_i0.o
8.40 kg coated on inside surface of inner tube	Fuel volume and fuel 100% saturated; voids inside fuel pins flooded	0.9017 ± 0.0011	0.9038	combo1+5b_ss_10a_w_1a_gd_in_i1.o
8.40 kg coated on outside surface of inner tube	Fuel volume and fuel 100% saturated; voids inside fuel pins flooded	0.9057 ± 0.0010	0.9078	combo1+5b_ss_10a_w_1a_gd_in_o1.o

The effect of varying water density in the entire co-disposal canister is investigated for the most reactive case in Table 6-15 and the results are shown in Table 6-16. For these cases the fuel pin pitch inside the Ident-69 container is 1.6 cm, the fuel in all fuel pins is completely saturated, voids in the fuel pins are filled with water, voids inside the 18 in. canister are filled with full density water, and the basket assembly contains 0.5% gadolinium (1.93 kg). The range of water densities varies from full density to zero, i.e., a void.

Table 6-16. Varying Water Density Inside Co-disposal Waste Package with a DOE SNF Canister Containing Ident-69 Can and 5 DFAs with Basket Assembly Containing 0.5% Gadolinium

Water Density in Co-disposal Waste Package, g/cm^3	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
0.	0.9167 ± 0.0010	0.9188	combo1+5b_ss_10a_w_1a_gd_.5_1.6.o
0.2	0.9139 ± 0.0011	0.9161	case_.2.o
0.4	0.9093 ± 0.0010	0.9113	case_.4.o
0.6	0.9083 ± 0.0010	0.9104	case_.6.o

Water Density in Co-disposal Waste Package, g/cm^3	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
0.8	0.9096 ± 0.0011	0.9117	case_.8.o
1.0	0.9059 ± 0.0011	0.9080	case_1.o

The results for varying water density inside the Ident-69 container for the most reactive case in Table 6-15 are shown in Table 6-17. For these cases the pitch inside the Ident-69 container is 1.6 cm, the fuel in all the fuel pins is completely saturated, voids in the fuel pins are filled with water, voids outside the Ident-69 container but inside the 18 in. canister are filled with full density water and the basket assembly contains 0.5% gadolinium (1.93 kg). The rest of the co-disposal waste package is treated as a void for all cases except one where the waste package is assumed to be flooded with full density water.

Table 6-17. Varying Water Density in an Ident-69 container Surrounded by 5 DFAs in DOE SNF Canister Containing a 0.5% Gadolinium Assembly Inside Co-disposal Waste Package

Water Density Inside Ident-69 Can, g/cm^3	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
0.	0.7690 ± 0.0010	0.7709	caseinid_.0.o
0. (outside 18 in. canister fully flooded)	0.7656 ± 0.0010	0.7676	caseinid_.0a.o
0.2	0.7835 ± 0.0011	0.7856	caseinid_.2.o
0.4	0.8066 ± 0.0010	0.8085	caseinid_.4.o
0.6	0.8379 ± 0.0010	0.8399	caseinid_.6.o
0.8	0.8749 ± 0.0011	0.8770	caseinid_.8.o
1.	0.9167 ± 0.0010	0.9188	combo1+5b_ss_10a_w_1a_gd_.5_1.6.o

The results for varying water density inside the 18 in. canister but outside the Ident-69 container for the most reactive case in Table 6-15 are shown in Table 6-18. For these cases the pitch inside the Ident-69 container is 1.6 cm, the fuel in all the fuel pins is completely saturated, voids in the fuel pins are filled with water, the Ident-69 container is filled with full density water and the basket assembly contains 0.5% gadolinium (1.93 kg). The rest of the co-disposal waste package is treated as a void for all cases except one where the container is assumed to be flooded with full density water.

Table 6-18. Varying Water Density for Ident-69 and 5 DFAs in DOE SNF Canister Containing 0.5% Gadolinium Inside Co-disposal Waste Package

Water Density Outside Ident-69 Can, g/cm^3	$k_{eff} \pm \sigma$	$k_{eff} + 2\sigma$	File Name
0.	0.7517 ± 0.0010	0.7536	caseoutid_.0.o
0. (outside 18 in. canister fully flooded)	0.7633 ± 0.0010	0.7654	caseoutid_.0a.o
0.2	0.8238 ± 0.0010	0.8258	caseoutid_.2.o
0.4	0.8612 ± 0.0010	0.8632	caseoutid_.4.o
0.6	0.8837 ± 0.0011	0.8859	caseoutid_.6.o
0.8	0.8991 ± 0.0011	0.9013	caseoutid_.8.o
1.	0.9167 ± 0.0010	0.9188	combo1+5b_ss_10a_w_1a_gd_.5_1.6.o

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. 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. 241492.

7.3 Los Alamos National Laboratory (LANL) 1987. *Critical Dimensions of Systems Containing ^{235}U, ^{239}Pu and ^{233}U, 1986 Revision.* LA-10860-MS. Los Alamos, New Mexico: LANL. 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. 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. MOL.19960624.0023.

7.6 CRWMS M&O 1999. Electronic Attachments for BBA000000-01717-0210-00016 REV 00, Attachment II, CD-ROM. Las Vegas, Nevada: M&O. MOL.19981102.0081.

7.7 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: Idaho National Engineering and Environmental Laboratory, Lockheed Martin Idaho Technologies Company. 239252

7.8 Lawrence Livermore National Laboratory (LLNL) 1991. *Preliminary Waste Form Characteristics Report.* Livermore, California: University of California, LLNL. MOL.19940726.0118.

8. ATTACHMENTS

Attachment I: EXCEL spreadsheets (2 pages).
Attachment II: Electronic attachments for MCNP outputs are provided on CD-ROM (Ref. 7.6) and listed in Table II-1 (5 pages).

Attachment I

	A	B	C	D	E	F	G	H	I	J	K	L
1	Avogadro's number from Ref. 7.5, BBA000000-01717-0200-00002 REV00:					0.602252					Note: all molecular weights are from Ref. 7.5, BBA000000-01717-0200-00002 REV00	
2	Diameter of fuel pellet and insulator pellet:					0.49403	cm					
3	Footprint length of fuel pellets in fuel pins:					91.44	cm				NOTE: abbreviations	
4	Volume of fuel in fuel pin=pi*diameter^2*length/4=					17.528015	cm^3 (This is footprint volume.)				MW is molecular weight	
5											# density is number density	
6	Length of natural Uranium insulator:					2.032	cm				#den is number density	
7	Number of fuel pins in an assembly:					217					wt. fraction is weight fraction	
8	Number of natural U insulators in a fuel pin:					2					atomic abund. Is atomic abundance	
9	Volume of insulators=pi*diameter^2*length*(# of insulators)/4=					169.04797	cm^3 (Total volume of insulators in an assembly.)				Avog.# is Avogadro's number	
10											# is number	
11		1 / MW=sum(wt. fraction_I / MW_I)						1 / MW=sum(wt. fraction_I / MW_I)				
12			atomic Abundances						atomic Abundances			
13			(wt. fraction) for Pu						(wt. fraction) for U			
14		MW	Type 3.2	Type 4.1	Type 3.2	Type 4.1		MW	Type 3.2	Type 4.1	Type 3.2	Type 4.1
15	Pu-239	239.05215	0.8723	0.8735	0.003649	0.003654	U-235	235.043915	0.007	0.002	2.978E-05	8.509E-06
16	Pu-240	240.05388	0.1173	0.1163	0.0004886	0.0004845	U-238	238.05077	0.993	0.998	0.0041714	0.0041924
17	Pu-241	241.05674	0.0104	0.0102	4.314E-05	4.231E-05	O	15.994915				
18	O	15.994915										
19				MW Pu	239.18991	239.18852				MW U	238.02945	238.04468
20				MW PuO_1.96	270.53995	270.53855				MW UO_1.96	269.37949	269.39471
21												
22	N_I=Mass_I*Avog.# / (MW_I *Volume)											
23			Type 3.2	Type 4.1	Type 3.2	Type 4.1			Type 3.2	Type 4.1	Type 3.2	Type 4.1
24	mass of Pu in fuel pin, g:		34.2	44.8			mass of U in fuel pin, g		118.3	108.2		
25			masses	masses	# density	# density			masses	masses	# density	# density
26		Pu-239	29.83266	39.1328	4.2879E-03	5.6246E-03		U-235	0.8281	0.2164	1.2105E-04	3.1634E-05
27		Pu-240	4.01166	5.21024	5.7420E-04	7.4575E-04		U-238	117.4719	107.9836	1.6955E-02	1.5586E-02
28		Pu-241	0.35568	0.45696	5.0697E-05	6.5134E-05		O	15.580882	14.24973505	3.3470E-02	3.0610E-02
29		O	4.4825099	5.87186006	9.6291E-03	1.2614E-02		Total O (MOX)			4.3099E-02	4.3224E-02
30										Saturated MOX fuel @11% H2O		
31								Total O (MOX and H2O)			4.6777E-02	4.6902E-02
32								Total H			7.3565E-03	7.3565E-03
33												

	A	B	C	D	E	F	G	H	I	J	K	L
34												
35	N_I=Mass_I*Avog.# / (MW_I*Volume)											
36	Following is for the Nat. U insulators; (U-234 assumed to be U-235)							#den UO2:	2.2451E-02			
37			Nuclide	atomic abund.	MW			#den U-235:	1.6288E-04			
38	atomic abundances from		U-235	0.007255	235.04392	1.7052436		#den U-238:	2.2288E-02			
39	Nuclides and Isotopes,		U-238	0.992745	238.05077	236.32371		#den O:	4.4901E-02			
40	Fifteenth Edition Chart of		O		15.994915			Saturated Insulator @11% H2O				
41	the Nuclides			Total MW of natural U		238.02896		Total O #den:	4.8580E-02			
42				Total MW of UO_2		270.01879		Total H #den:	7.3565E-03			
43	Total mass of natural U insulators in an assembly:				1500	Total mass UO_2 insulators in assembly=			1701.592			
44												
45	N_I=(mass density)*wt. fraction_I*Avog.# / MW_I											
46	Following is for water:		density=		1							
47	Full density water, 1 g/cm^3											
48		MW	# density									
49	H:	1.0078252	6.6878E-02									
50	O:	15.994915	3.3439E-02									
51	total MW:	18.010565										
52	Saturated MOX Fuel @11% H2O Type 4.1 Fuel											
53	N_I=0.11*N_I (water)											
54	O:		3.6783E-03									
55	H:		7.3565E-03									
56												
57	N_I=(mass density)*wt. fraction_I*Avog.# / MW_I						N_I=(mass density)*wt. fraction_I*Avog.# / MW_I					
58	The following is for Type 304L SS,density=					7.9	The following is for the Inconel Alloy 600,density=			8.47		
59	Density of Type 304L from Ref. 7.5, BBA000000-01717-0200-00002 Rev 00						Density of Inconel Alloy 600 from Inco Alloys International, Inc.					
60	Element	MW	wt fraction	# density			1988 Product Handbook, IAI-38.					
61	C	12.01115	0.0003	1.1883E-04			Element	MW	wt fraction	# density		
62	N	14.003074	0.001	3.3977E-04			Ni	58.71	0.74335	6.4587E-02		
63	Si	28.086	0.0075	1.2705E-03			Cr	51.996	0.155	1.5206E-02		
64	P	30.973765	0.00045	6.9123E-05			Fe	55.847	0.08	7.3072E-03		
65	S	31.972074	0.0003	4.4643E-05			C	12.01115	0.0015	6.3704E-04		
66	Cr	51.996	0.19	1.7386E-02			Mn	54.9380503	0.01	9.2851E-04		
67	Mn	54.93805	0.02	1.7321E-03			S	31.9720737	0.00015	2.3932E-05		
68	Fe	55.847	0.68045	5.7970E-02			Si	28.086	0.005	9.0812E-04		
69	Ni	58.71	0.1	8.1039E-03			Cu	63.54	0.005	4.0141E-04		
70		Sum =	1					Sum =	1			

Attachment II

Table II-1 MCNP Outputs used in Engineering Calculations and Stored in Electronic Format (CD-ROM, Ref. 7.6)

Bytes Used	Date Last Accessed	Output File Name	AENCF* (MeV)	Table Used
2,965,934	9/4/98	7assem_a.o	0.39323	table 6-1
2,965,523	9/4/98	7assem_b.o	0.38199	table 6-1
2,965,622	9/4/98	7assem_c.o	0.37448	table 6-1
2,965,213	9/4/98	7assem_d.o	0.36463	table 6-1
2,965,114	9/4/98	7assem_f.o	0.34937	table 6-1
2,965,211	9/4/98	7assem_h.o	0.33836	table 6-1
2,965,114	9/2/98	7assem_i.o	0.33236	table 6-1
2,965,114	9/4/98	7assem_j.o	0.32608	table 6-1
2,965,200	9/5/98	7assem_l.o	0.31860	table 6-1
2,964,899	9/5/98	7assem_n.o	0.31215	table 6-1
2,963,810	9/5/98	7assem_p.o	0.30711	table 6-1
2,964,899	9/5/98	7assem_r.o	0.30667	table 6-1
2,966,766	7/17/98	7assem_3.2_h.o	0.31131	table 6-2
2,966,766	7/17/98	7assem_3.2_i.o	0.30181	table 6-2
2,966,766	7/18/98	7assem_3.2_j.o	0.30036	table 6-2
2,966,766	7/18/98	7assem_3.2_l.o	0.29058	table 6-2
2,965,519	7/20/98	7assem_3.2_n.o	0.28553	table 6-2
802,495	8/31/98	1assem_i.o	0.43341	table 6-3
1,162,952	9/1/98	2assem_i.o	0.38388	table 6-3
1,523,721	9/1/98	3assem_i.o	0.35977	table 6-3
1,883,769	9/1/98	4assem_i.o	0.34886	table 6-3
2,243,985	9/1/98	5assem_i.o	0.34236	table 6-3
2,604,541	9/2/98	6assem_i.o	0.33585	table 6-3
2,965,114	11/16/98	7assem_i.o	0.33236	table 6-3
785,172	9/11/98	1packd0.o	0.43092	table 6-4
1,603,660	9/11/98	3packd0.o	0.34232	table 6-4
1,966,237	9/10/98	4pack_i.o	0.34847	table 6-4
1,985,993	9/11/98	4packd0.o	0.33666	table 6-4
2,242,315	9/10/98	5pack_i.o	0.34351	table 6-4
2,194,810	9/14/98	5packd0.o	0.33385	table 6-4
2,193,822	9/14/98	5packd0a.o	0.33998	table 6-4
2,605,394	9/14/98	6pack_i.o	0.33879	table 6-4

Bytes Used	Date Last Accessed	Output File Name	AENCF* (MeV)	Table Used
2,565,579	9/14/98	6packd0.o	0.32939	table 6-4
2,963,185	9/9/98	7pack_i.o	0.33387	table 6-4
2,964,026	9/9/98	7packd0.o	0.32257	table 6-4
1,591,350	11/10/98	4packd0_ss_10.o	0.37493	table 6-5
1,889,056	9/17/98	5packd0_ss_10.o	0.36611	table 6-5
2,183,335	9/17/98	6packd0_ss_10.a.o	0.35561	table 6-5
2,183,524	11/16/98	6packd0_ss_10.o	0.35533	table 6-5
1,890,259	9/17/98	5packd0_ss_10_gd.o	0.40716	table 6-6
2,183,914	9/18/98	6packd0_ss_10.a_gd.o	0.39366	table 6-6
2,184,125	9/18/98	6packd0_ss_10_gd.o	0.39197	table 6-6
605,222	9/9/98	pins091_2.159.o	7.123E-02	table 6-7
605,320	9/10/98	pins091_2.25.o	6.810E-02	table 6-7
605,221	9/10/98	pins091_2.50.o	6.252E-02	table 6-7
603,132	9/17/98	pins091_2.75.o	6.082E-02	table 6-7
603,116	9/17/98	pins091_3.00.o	5.860E-02	table 6-7
641,703	9/10/98	pins127_2.050.o	7.055E-02	table 6-7
641,898	9/10/98	pins127_2.159.o	6.656E-02	table 6-7
641,800	9/10/98	pins127_2.25.o	6.577E-02	table 6-7
641,796	9/9/98	pins127_2.50.o	6.021E-02	table 6-7
647,929	9/10/98	pins133_2.00.o	7.178E-02	table 6-7
647,833	9/11/98	pins133_2.25.o	6.506E-02	table 6-7
647,929	9/11/98	pins133_2.50.o	5.962E-02	table 6-7
684,313	9/11/98	pins169_2.25.o	6.318E-02	table 6-7
1,324,524	9/10/98	cs-1_F.o	0.69455	table 6-8
1,310,589	9/11/98	cs0.8_F.o	0.33943	table 6-8
1,310,587	9/11/98	cs0.9_F.o	0.26697	table 6-8
1,323,806	9/11/98	cs0_F.o	0.42068	table 6-8
794,051	9/11/98	cs1.0.o	0.21898	table 6-8
794,051	9/11/98	cs1.1.o	0.18168	table 6-8
760,806	9/10/98	cs1.10.new.sq.o	0.16232	table 6-8
795,612	9/22/98	cs1.20.o	0.15993	table 6-8
760,919	9/11/98	cs1.25.new.sq.o	0.13481	table 6-8
793,176	9/23/98	cs1.25.o	0.14745	table 6-8
794,267	9/23/98	cs1.29.o	0.13895	table 6-8
794,364	9/23/98	cs1.33.o	0.13619	table 6-8
793,176	9/21/98	cs1.35.o	0.13568	table 6-8
760,822	9/11/98	cs1.40.new.sq.o	0.12034	table 6-8

Bytes Used	Date Last Accessed	Output File Name	AENCF* (MeV)	Table Used
794,364	9/22/98	cs1.5.o	0.11519	table 6-8
791,868	9/18/98	cs1.55.o	0.11283	table 6-8
791,672	9/18/98	cs1.6.o	0.10916	table 6-8
791,771	9/18/98	cs1.7.o	0.10380	table 6-8
793,855	9/11/98	cs2.0.o	9.437E-02	table 6-8
761,474	9/10/98	cs1.25.new.0.o	0.14476	table 6-9
610,557	9/22/98	cs1.25.new.0a.o	0.13512	table 6-9
797,174	9/11/98	cs1.25.new.both.o	0.15972	table 6-9
779,004	9/11/98	cs1.25.new.in.o	0.14985	table 6-9
780,728	9/11/98	cs1.25.new.out.o	0.14961	table 6-9
1,687,840	9/11/98	cs1.25.new.outa.o	0.15784	table 6-9
1,730,684	9/11/98	cs1.25.new.outap.o	0.17745	table 6-9
1,795,334	9/11/98	cs1.25.new.outapp.o	0.21961	table 6-9
1,677,716	9/11/98	cs1.25.new.outb.o	0.15213	table 6-9
1,688,425	9/12/98	cs1.25.new.outc.o	0.15968	table 6-9
1,698,754	9/12/98	cs1.25.new.outd.o	0.16751	table 6-9
3,385,550	9/11/98	combo1+5a.o	0.28499	table 6-10
3,027,198	9/11/98	combo1+5b.o	0.28207	table 6-10
3,027,002	9/12/98	combo1+5c.o	0.26935	table 6-10
3,020,549	9/12/98	combo1+5d.o	0.26050	table 6-10
2,867,614	9/23/98	combo1+5b_ss_1.0+++p.o	0.26357	table 6-11
2,864,713	9/23/98	combo1+5b_ss_1.0++.o	0.26482	table 6-11
2,860,443	9/11/98	combo1+5b_ss_1.0+.o	0.26395	table 6-11
3,156,999	9/12/98	combo1+5b_ss_1.0-.o	0.29299	table 6-11
3,111,924	9/11/98	combo1+5b_ss_1.0.o	0.27841	table 6-11
2,871,742	9/23/98	combo1+5b_ss_1.0+++p_gd.o	0.28950	table 6-12
2,861,353	9/23/98	combo1+5b_ss_1.0++_gd.o	0.28754	table 6-12
2,863,948	9/22/98	combo1+5b_ss_1.0+_gd.o	0.28827	table 6-12
3,487,419	9/12/98	combo1+5b_ss_gd1.0+.o	0.33127	table 6-12
3,562,246	9/12/98	combo1+5b_ss_gd1.0+a.o	0.31943	table 6-12
3,581,755	9/12/98	combo1+5b_ss_gd1.0+b.o	0.32386	table 6-12
3,113,123	9/12/98	combo1+5b_ss_gd1.0.o	0.30373	table 6-12
2,033,525	9/12/98	combo1+5b_ss_gd1.0_sqa.o	0.28607	table 6-12
2,072,789	9/12/98	combo1+5b_ss_gd1.0_sqb.o	0.29270	table 6-12
2,097,257	9/12/98	combo1+5b_ss_gd1.0_sqc.o	0.30431	table 6-12
2,849,402	9/13/98	combo1+5b_ss_gd1.0_sqc1.o	0.30798	table 6-12
2,877,151	9/13/98	combo1+5b_ss_gd1.0_sqc2.o	0.31916	table 6-12

Bytes Used	Date Last Accessed	Output File Name	AENCF* (MeV)	Table Used
2,811,994	9/13/98	combo1+5b_ss_gd1.0_sqc2a.o	0.30827	table 6-12
2,918,396	9/13/98	combo1+5b_ss_gd1.0_sqc3.o	0.31937	table 6-12
2,853,140	9/13/98	combo1+5b_ss_gd1.0_sqc3a.o	0.31074	table 6-12
2,150,737	9/13/98	combo1+5b_ss_gd1.0_sqd.o	0.32553	table 6-12
2,261,413	9/4/98	6packd0_ss_10+.o	0.35241	table 6-13
2,257,897	9/1/98	6packd0_ss_10.o	0.34726	table 6-13
2,261,652	9/4/98	6packd0_ss_10_1.o	0.35158	table 6-13
2,262,439	9/5/98	6packd0_ss_10_2.o	0.34726	table 6-13
2,257,558	9/16/98	6packd0_ss_10_c.o	0.34836	table 6-13
2,262,759	9/5/98	6packd0_ss_10_ff.o	0.35158	table 6-13
2,258,371	9/23/98	6packd0_ss_10_w_1.o	0.33445	table 6-13
2,259,699	9/24/98	6packd0_ss_10_w_1a.o	0.32644	table 6-13
2,257,732	9/4/98	6packd0_ss_10b.o	0.34836	table 6-13
2,257,684	9/4/98	6packd0_ss_10c.o	0.34605	table 6-13
2,256,496	9/4/98	6packd0_ss_10d.o	0.34866	table 6-13
3,205,906	9/3/98	combo1+5b_ss_10a+.o	0.27940	table 6-14
3,208,716	9/1/98	combo1+5b_ss_10a.o	0.27715	table 6-14
3,206,078	9/3/98	combo1+5b_ss_10a1.o	0.27704	table 6-14
3,207,083	10/13/98	combo1+5b_ss_10a2.o	0.27809	table 6-14
3,207,005	9/8/98	combo1+5b_ss_10a_w_.5.o	0.27146	table 6-14
3,206,906	9/8/98	combo1+5b_ss_10a_w_1.o	0.26592	table 6-14
3,211,141	9/9/98	combo1+5b_ss_10a_w_1a.o	0.26325	table 6-14
3,212,361	9/16/98	combo1+5b_ss_10a_w_1a_c.o	0.26280	table 6-14
3,210,558	9/10/98	combo1+5b_ss_10a_w_1b.o	0.26062	table 6-14
3,211,130	9/10/98	combo1+5b_ss_10a_w_1c.o	0.26119	table 6-14
3,210,043	9/10/98	combo1+5b_ss_10aa.o	0.27121	table 6-14
3,207,546	10/13/98	combo1+5b_ss_10aff.o	0.27694	table 6-14
3,208,714	9/4/98	combo1+5b_ss_10b.o	0.27411	table 6-14
3,208,615	9/4/98	combo1+5b_ss_10c.o	0.27293	table 6-14
3,208,615	9/5/98	combo1+5b_ss_10d.o	0.27246	table 6-14
3,210,956	9/12/98	combo1+5b_ss_10a_gd.o	0.30250	table 6-15
3,211,630	9/12/98	combo1+5b_ss_10a_w_1a_gd.o	0.28570	table 6-15
3,212,881	9/22/98	combo1+5b_ss_10a_w_1a_gd_.5.o	0.27523	table 6-15
3,116,189	10/15/98	combo1+5b_ss_10a_w_1a_gd_.5_1.6.o	0.26294	table 6-15
3,211,731	9/17/98	combo1+5b_ss_10a_w_1a_gd_1.o	0.27670	table 6-15
3,211,733	9/17/98	combo1+5b_ss_10a_w_1a_gd_2.5.o	0.28218	table 6-15
3,215,397	11/7/98	combo1+5b_ss_10a_w_1a_gd_in_h.o	0.28086	table 6-15

Bytes Used	Date Last Accessed	Output File Name	AENCF* (MeV)	Table Used
3,213,009	9/17/98	combo1+5b_ss_10a_w_1a_gd_in_i0.o	0.28577	table 6-15
3,212,796	9/17/98	combo1+5b_ss_10a_w_1a_gd_in_i1.o	0.27816	table 6-15
3,214,895	11/7/98	combo1+5b_ss_10a_w_1a_gd_in_o1.o	0.27678	table 6-15
3,141,185	10/30/98	grav1.o	0.26207	table 6-15
3,228,664	11/4/98	grav2.o	0.27260	table 6-15
3,224,365	11/5/98	grav2a.o	0.26777	table 6-15
3,119,985	10/15/98	case_.2.o	0.26339	table 6-16
3,120,082	10/16/98	case_.4.o	0.26233	table 6-16
3,120,181	10/16/98	case_.6.o	0.26455	table 6-16
3,120,082	10/16/98	case_.8.o	0.26288	table 6-16
3,120,080	10/16/98	case_1.o	0.26540	table 6-16
3,116,189	11/16/98	combo1+5b_ss_10a_w_1a_gd_.5_1.6.o	0.26294	table 6-16
3,228,385	10/15/98	caseinid_.0.o	0.36703	table 6-17
3,229,588	10/16/98	caseinid_.0a.o	0.36690	table 6-17
3,229,166	10/16/98	caseinid_.2.o	0.35390	table 6-17
3,229,164	10/16/98	caseinid_.4.o	0.33182	table 6-17
3,229,263	10/16/98	caseinid_.6.o	0.31135	table 6-17
3,228,902	10/16/98	caseinid_.8.o	0.28604	table 6-17
3,116,189	11/16/98	combo1+5b_ss_10a_w_1a_gd_.5_1.6.o	0.26294	table 6-17
3,333,119	10/16/98	caseoutid_.0.o	0.41180	table 6-18
3,332,682	10/16/98	caseoutid_.0a.o	0.40724	table 6-18
3,333,238	10/16/98	caseoutid_.2.o	0.35740	table 6-18
3,332,827	10/16/98	caseoutid_.4.o	0.32357	table 6-18
3,332,203	10/17/98	caseoutid_.6.o	0.29666	table 6-18
3,332,205	10/17/98	caseoutid_.8.o	0.27795	table 6-18
3,116,189	11/16/98	combo1+5b_ss_10a_w_1a_gd_.5_1.6.o	0.26294	table 6-18

*AENCF= Average energy of neutron causing fission. AENCF is calculated by dividing the average energy loss to fission per source particle by average weight loss to fission per source particle.