5.4 Shielding Evaluation

The techniques used to perform gamma and neutron dose rate calculations for the NAC-STC in the directly loaded and canistered configurations are described below, including descriptions of the computer codes and methods that were used in the shielding analyses of the cask.

5.4.1 Computer Code Descriptions and Results

5.4.1.1 Directly Loaded Fuel Configuration

To calculate three-dimensional NAC-STC dose rates and define a minimum cool time table, a response function approach is taken to the shielding evaluation. Instead of running numerous direct-solution cases at a discrete matrix of burnups, enrichments, and cool times, three-dimensional response function cases are executed, thereby evaluating the contribution of each significant energy group in each source region. Six sets of response functions are required based on the defined source regions: fuel gamma, fuel neutron, fuel n-gamma, lower end-fitting gamma, upper plenum gamma and upper end-fitting gamma. Fuel hardware contributions to dose rates are evaluated using the fuel gamma response functions. For each source region, a subset of the 28 neutron and 22 gamma energy groups is evaluated to increase the efficiency of the analysis. Fuel gamma doses are calculated using gamma groups 7 through 16; fuel neutron and fuel n-gamma doses are calculated using neutron groups 2 through 15; and hardware sources are calculated using gamma groups 12 through 14. Neutron groups 1 and 16 through 28 contain no neutron source. The hardware source is dominated by the ^{60}Co source, which resides in groups 12 through 14. Fuel gamma groups 7 through 16 are selected based on the integrated source energy in each group (Source magnitude drops by a factor of 1,000 when moving from fuel group 7 to group 6.). The choice of energy groups evaluated is verified by running "direct" solutions using the complete spectrum and demonstrating that the total dose is reproduced within the Monte Carlo error of the analysis.

Calculational Methods

The shielding evaluation of the directly loaded configuration is performed using MCBEND. Source terms include fuel neutron, fuel gamma and gamma contributions from activated hardware. As described in Section 5.2.1.3, the evaluation includes the effect of fuel burnup peaking on fuel neutron and gamma source terms.

The MCBEND shielding model described in Section 5.3.1 is utilized with the source terms described in Section 5.2.1 to estimate the dose rate profiles at various distances from the side, top and bottom of the cask for both normal and accident conditions. The method of solution is continuous energy Monte Carlo with an adjoint diffusion solution for generating importance meshes. Radial biasing is performed within the MCBEND code to estimate dose rates on the side of the cask. Axial biasing is performed to estimates dose rates on the top and bottom of the cask.

The MCBEND code has been validated against various classical shielding problems, including fast and thermal neutron sources penetrating through single material slab geometries of iron, graphite and water. The validation suite also includes fast neutron transmission through alternating slabs of iron and water. Of particular interest is a benchmark of MCBEND to gamma and neutron dose rates outside a metal transport cask, where agreement between measurement and calculation is within 20% for the majority of dose locations.

MCBEND results are calculated using the JEF2.2 neutron cross-section library and the ANSWERS gamma library.

MCBEND Flux-to-Dose Conversion Factors

The ANSI/ANS 6.1.1-1977 flux-to-dose rate conversion factors are used in all shielding evaluations for directly loaded fuel. Tables 5.4-1 and 5.4-2 show the regrouped flux-to-dose conversion factors on the MCBEND standard 28 group neutron and 22 group gamma energy boundaries.

Loading Table for Directly Loaded Fuel

Three-dimensional radial response functions are generated for PWR fuel assemblies for both normal and accident conditions. Based on preliminary analysis, two bounding axial shift scenarios have been established: 1) maximum fuel assembly shift upward in the cask cavity without a corresponding shift in the basket and 2) no fuel assembly or basket shift. For axial biasing, the limiting shift scenario corresponds exactly to the position of the fuel assembly in the cavity, i.e., top dose rates are maximized when the fuel assembly is shifted up and bottom dose rates are maximized when the fuel assembly is as far down in the cavity as possible. For radial biasing, the two different shift scenarios are limiting for different transport conditions. The maximum fuel assembly axial shift is limiting for normal conditions because upper plenum and upper end fitting hardware move adjacent to the location in the radial shield where the radial lead shield ends. The limiting shift is downward for accident conditions due to the bottom axial lead slump, which is adjacent to the lower end fitting hardware source.

The first step in determining limiting PWR dose rates for the directly loaded cask is the generation of dose rate response functions for generation of minimum cool time tables. For each array size, at each of 7 burnups, 17 enrichments, and 18 cool time combinations, dose rate profiles are calculated for both normal and accident transport conditions. Using these dose rate profiles, the maximum radial dose rates at 2 meters from the railcar are tabulated for normal conditions.

Minimum cool times are calculated to ensure that a decay heat limit of 850 W/assembly is not exceeded and that the dose rate at 2 meters from the railcar does not exceed 9.5 mrem/hr. The 9.5 mrem/hr analysis limit was chosen to provide margin against the 10 mrem/hr regulatory limit. Cool times needed to reach these limits are calculated using linear interpolation on the entire array of maximum dose rates. The linear interpolation is valid because of the exponential decrease in source term and, thus, dose rate as a function of time. The interpolated cool time is rounded up to the next integer year. A sample minimum cool time generation for the 14×14 reference assembly at 40,000 MWD/MTU is shown in Table 5.4-3. Repeating this analysis for all fuel types and burnups results in the complete loading table shown in Table 5.4-5. Based on the loading table, maximum radial dose rates for each fuel type are shown in Table 5.4-4.

The minimum cool times are used to calculate maximum accident condition dose rates at 1 meter from the cask. The 1000 mrem/hr limit is not exceeded at any of the calculated minimum cool times.

Based on the radial dose rate results for normal and accident conditions and their application to the minimum cool time table, the 14×14 reference assembly provides maximum dose rates. Thus, top axial and bottom axial response functions have been executed for this assembly only. This ensures that the maximum axial dose rates for the directly loaded system are captured, and that variations in burnup, enrichment and minimum cool time are thoroughly examined.

A summary of the limiting source terms for each transport condition and detector biasing is given below. All limiting source terms are taken from the 14×14 reference fuel assembly.

Detector Biasing	Normal Conditions Burnup – Enrichment – Cool Time [MWD/MTU – wt % ^{235}U – Years]	Accident Conditions Burnup – Enrichment – Cool Time [MWD/MTU – wt % ^{235}U – Years]
Radial	40,000 – 2.3 – 10	60,000 – 3.5 – 22
Top Axial	30,000 – 2.3 – 6	45,000 – 2.3 – 14
Bottom Axial	40,000 – 2.3 – 10	60,000 – 3.7 – 20

Three-Dimensional Dose Rates for Directly Loaded Fuel

Further detail on the three-dimensional dose rates are presented in Figures 5.4-1 through 5.4-6 for the limiting 14×14 reference assembly. Maximum dose rates are tabulated in Tables 5.4-6 and 5.4-7.

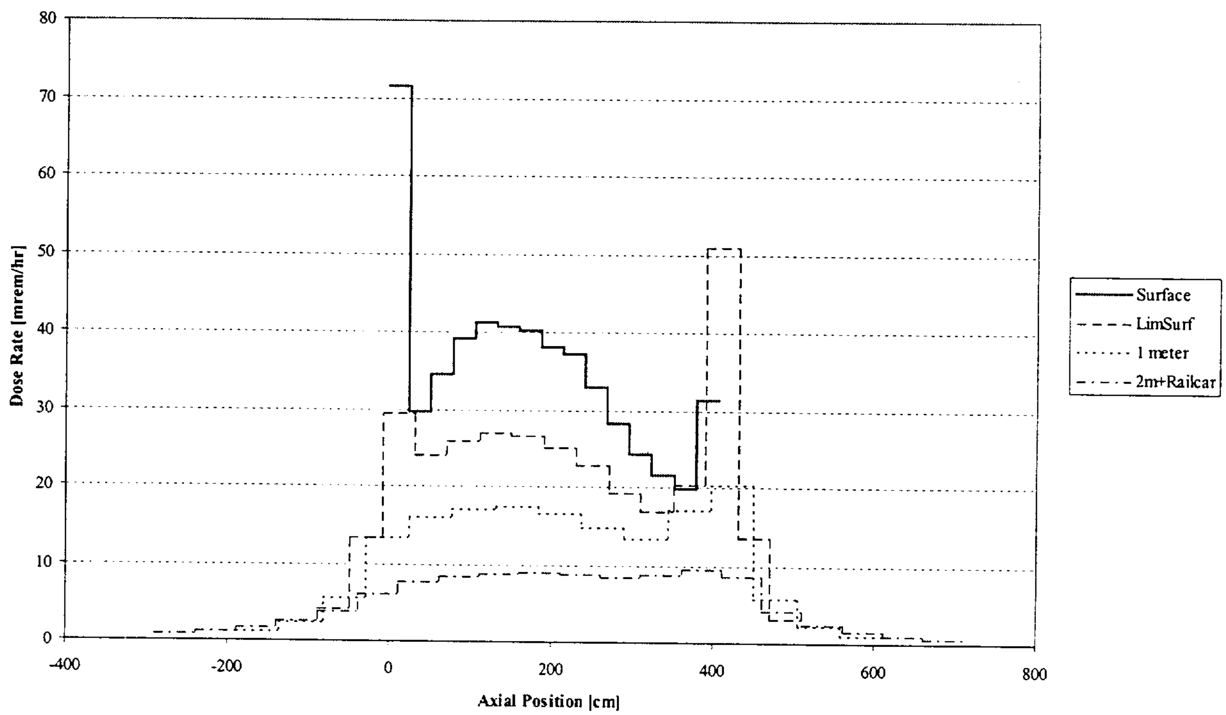
The maximum normal conditions surface dose rate is 366 mrem/hr at an axial elevation between the radial neutron shield and the upper impact limiter. At 1 meter from the surface of the neutron shield shell, the maximum dose rate is 20.3 mrem/hr. This dose rate defines the transport index. The maximum normal conditions dose rate at 2 meters from the cask railcar is 9.5 mrem/hr and occurs at an axial elevation adjacent to the upper plenum and upper end-fitting elevations. The maximum accident conditions dose rate at 1 meter from the cask is 770 mrem/hr and occurs at the cask midplane. The top and bottom axial dose rates are small when compared to the radial dose rate for the same transport conditions.

Dose rate variations from heat fins in the neutron shield are examined explicitly using azimuthal detectors that span the entire length of the neutron shield. As shown in Figure 5.4-4, peaks in the neutron dose rate correspond to dips in the gamma dose rate, and vice versa. Thus, the neutron dose rate increase resulting from the ducting is offset by the reduction of the gamma dose rate resulting from the additional shielding provided by the fins.

5.4.1.2 Canistered Yankee Class Fuel and GTCC Waste

Shielding evaluations of canistered Yankee Class fuel and GTCC waste are performed with SCALE 4.3 for the PC (ORNL, 1995). In particular, SCALE 4.3 shielding analysis sequence SAS2H (Herman, 1995) is used to generate source terms for the design basis fuel and GTCC waste hardware and SAS1 (Knight, 1995) is used to perform one-dimensional radial and axial shielding analysis. Transverse leakage is accounted for by the use of radial and axial bucklings. The 27 group neutron, 18 group gamma, coupled cross section library (27N-18COUPLE) based on ENDF/B-IV (Jordan, 1995) is used in all shielding evaluations. Fuel source terms include fuel neutron, fuel gamma, and activated hardware gamma. GTCC waste hardware source terms are based on core baffle activated hardware characterization from dose rate measurements and baffle material chemical assay. Dose rate evaluations include the effect of fuel burnup peaking on fuel neutron and gamma source terms.

Figure 5.4-1 Radial Dose Rate Profiles for Directly Loaded Fuel in Normal Conditions of Transport



Note: The dose rate at the surface of the cask between the neutron shield and the upper impact limiter is 366.3 (0.2%) mrem/hr.

Figure 5.4-2 Radial Dose Rate Profile by Source Type at 2 meters from the Railcar for Directly Loaded Fuel in Normal Conditions of Transport

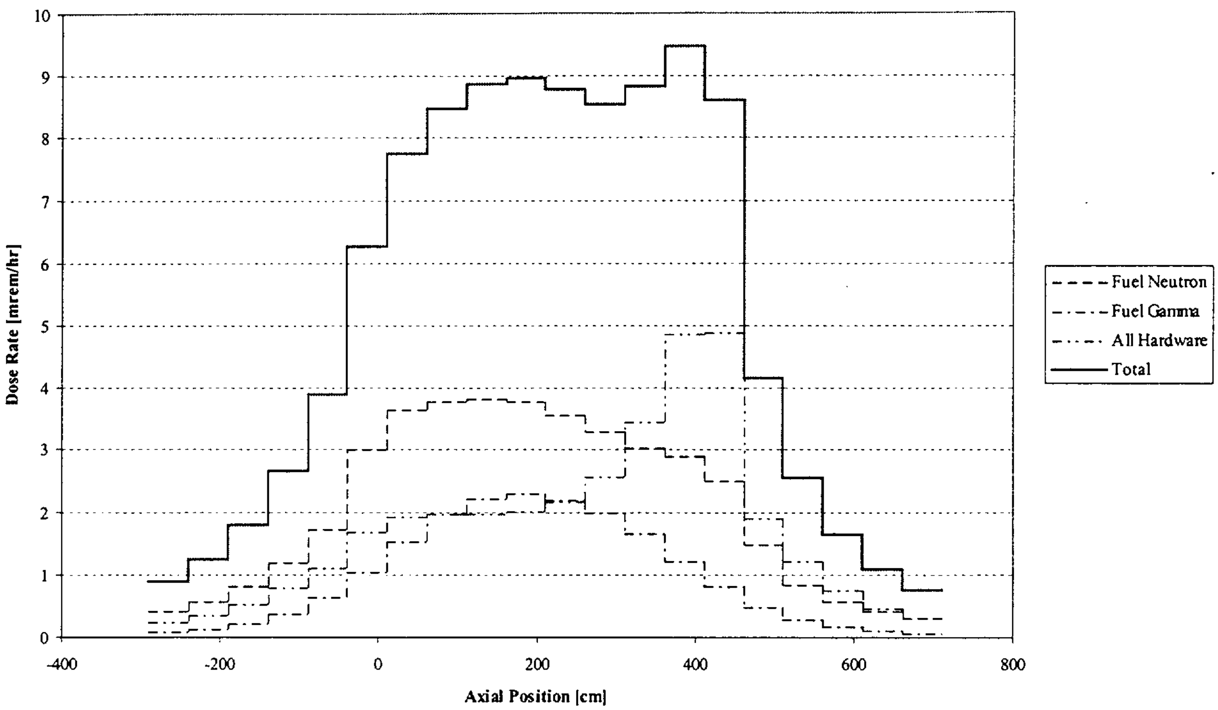


Figure 5.4-3 Azimuthal Radial Surface Dose Rate Profile by Source Type at Rotation Trunnion Elevation for Directly Loaded Fuel in Normal Conditions of Transport

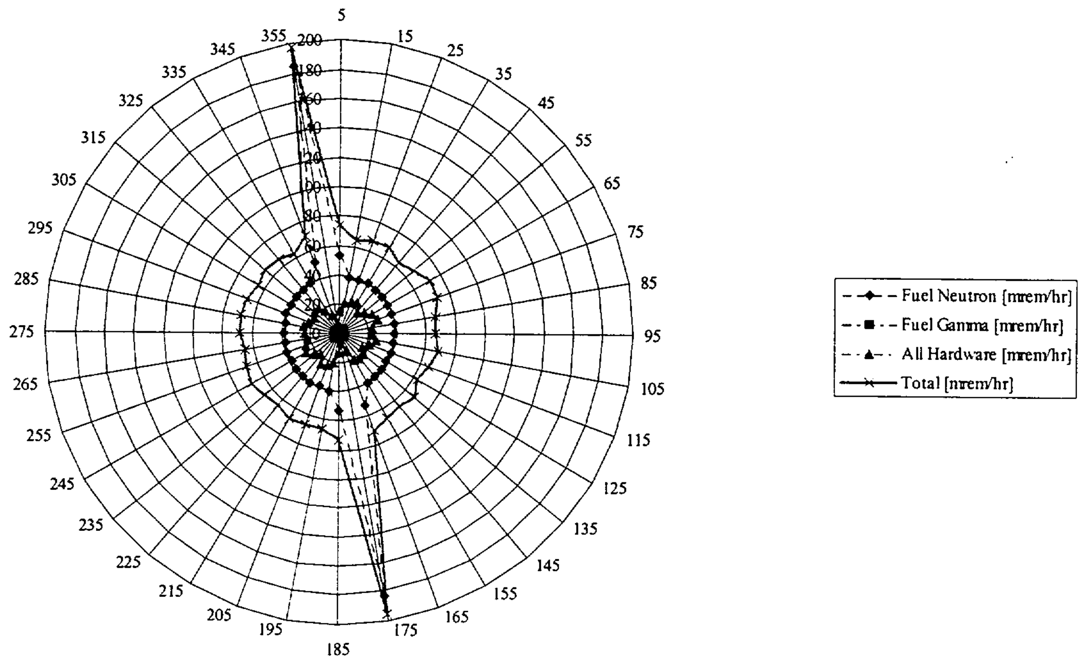


Figure 5.4-4 Azimuthal Radial Surface Dose Rate Profile by Source Type over Heat Fin Axial Extent for Directly Loaded Fuel in Normal Conditions of Transport

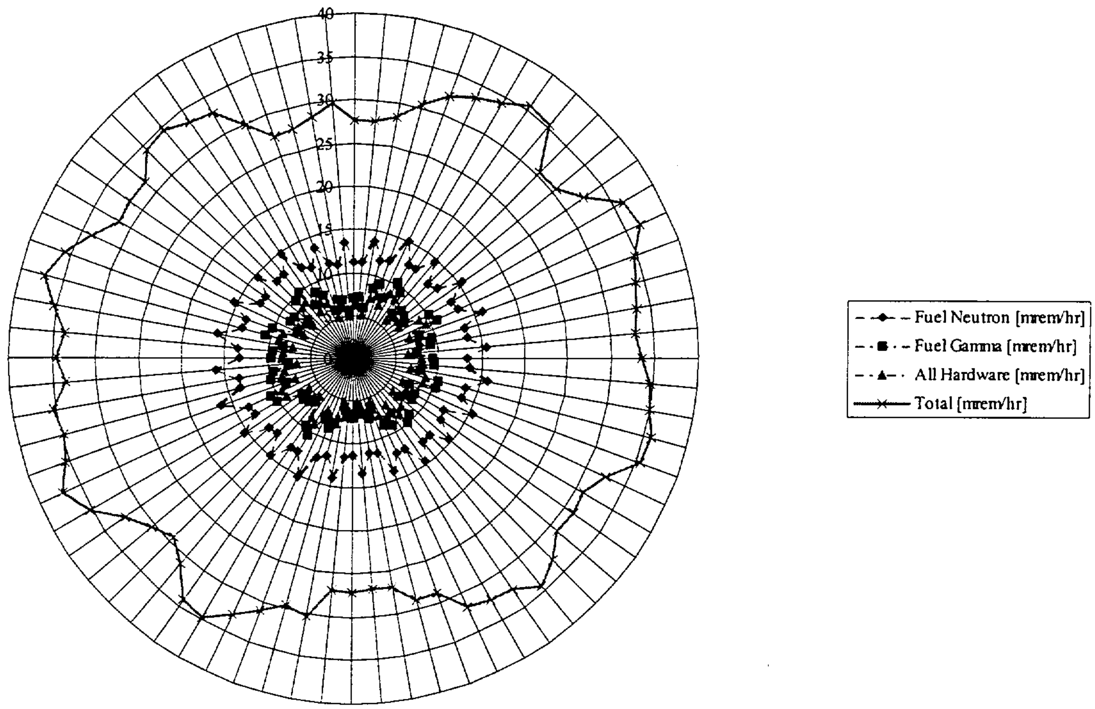


Figure 5.4-5 Radial Dose Rate Profile by Source Type at 1 meter for Directly Loaded Fuel in the Accident Condition

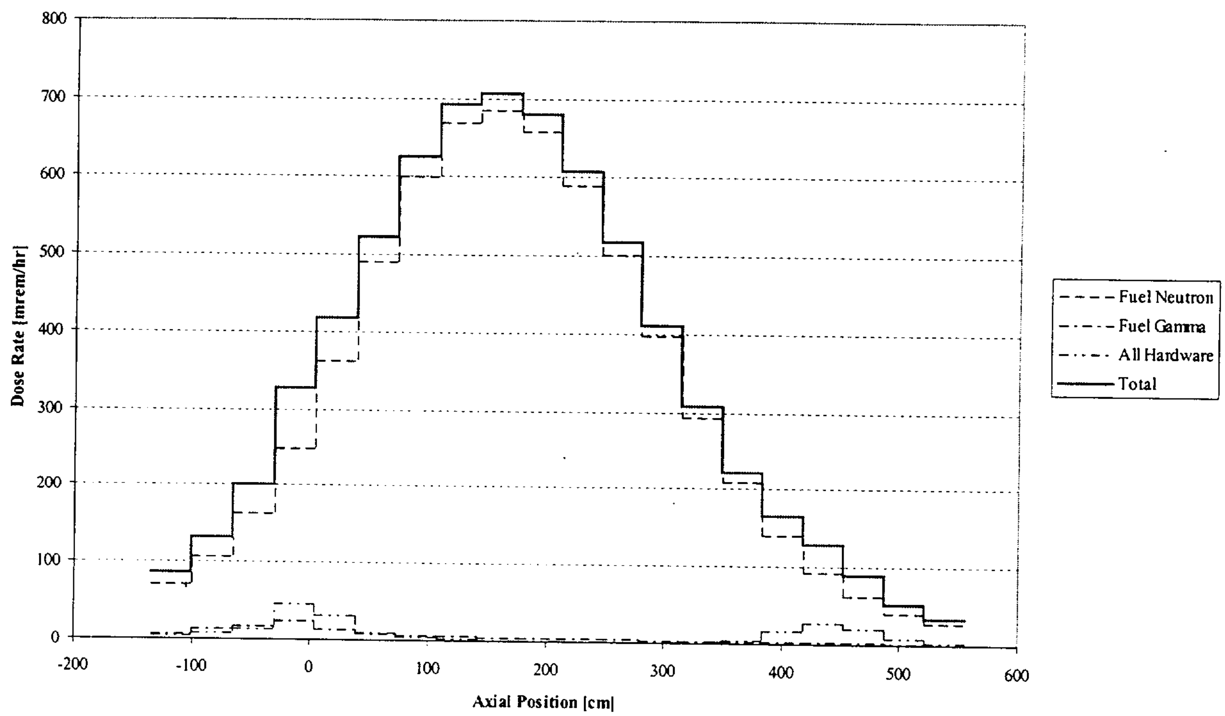


Figure 5.4-6 Azimuthal Radial Dose Rate Profile at 1 meter for Directly Loaded Fuel in the Accident Condition

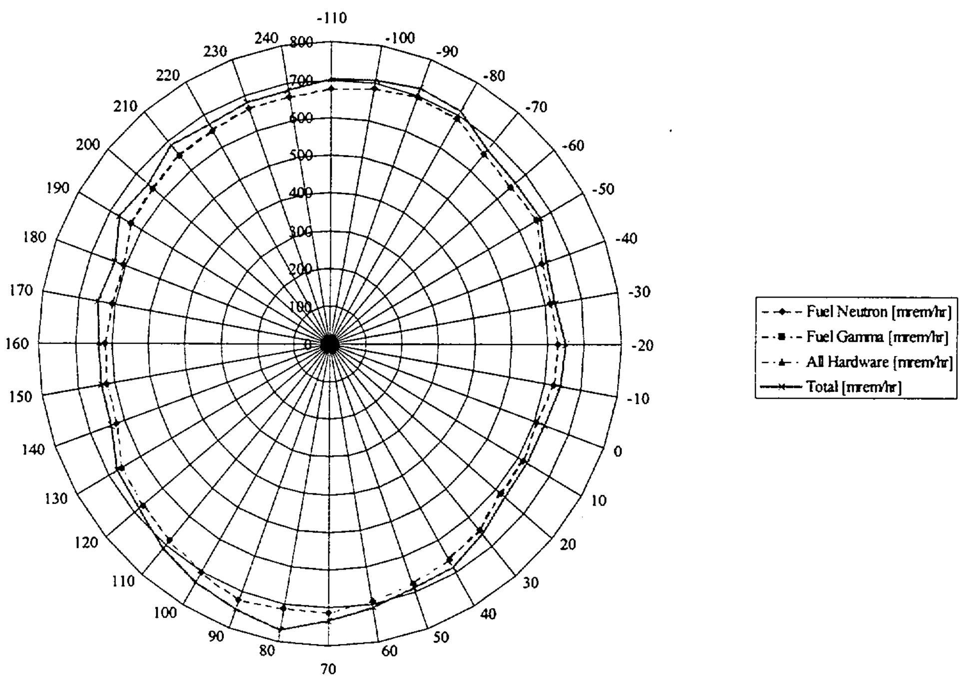


Table 5.4-1 MCBEND Neutron Flux-to-Dose Conversion Factors

Group	Upper E [MeV]	Lower E [MeV]	Response [(mrem/hr)/(n/cm^2/sec)]
1	1.46E+01	1.36E+01	2.0533E-01
2	1.36E+01	1.25E+01	1.8999E-01
3	1.25E+01	1.13E+01	1.7250E-01
4	1.13E+01	1.00E+01	1.5399E-01
5	1.00E+01	8.25E+00	1.4700E-01
6	8.25E+00	7.00E+00	1.4700E-01
7	7.00E+00	6.07E+00	1.4929E-01
8	6.07E+00	4.72E+00	1.5348E-01
9	4.72E+00	3.68E+00	1.4580E-01
10	3.68E+00	2.87E+00	1.3478E-01
11	2.87E+00	1.74E+00	1.2657E-01
12	1.74E+00	6.40E-01	1.2570E-01
13	6.40E-01	3.90E-01	8.8205E-02
14	3.90E-01	1.10E-01	4.6004E-02
15	1.10E-01	6.74E-02	1.8108E-02
16	6.74E-02	2.48E-02	1.0774E-02
17	2.48E-02	9.12E-03	4.9057E-03
18	9.12E-03	2.95E-03	3.6168E-03
19	2.95E-03	9.61E-04	3.7152E-03
20	9.61E-04	3.54E-04	3.8611E-03
21	3.54E-04	1.66E-04	4.0252E-03
22	1.66E-04	4.81E-05	4.1919E-03
23	4.81E-05	1.60E-05	4.3795E-03
24	1.60E-05	4.00E-06	4.5200E-03
25	4.00E-06	1.50E-06	4.4895E-03
26	1.50E-06	5.50E-07	4.3924E-03
27	5.50E-07	7.09E-08	3.9685E-03
28	7.09E-08	0.00E+00	2.3759E-03

Table 5.4-2 MCBEND Gamma Flux-to-Dose Conversion Factors

Group	Upper E [MeV]	Lower E [MeV]	Response [(mrem/hr)/(γ/cm²/sec)]
1	1.40E+01	1.20E+01	1.1728E-02
2	1.20E+01	1.00E+01	1.0225E-02
3	1.00E+01	8.00E+00	8.7164E-03
4	8.00E+00	6.50E+00	7.4457E-03
5	6.50E+00	5.00E+00	6.3551E-03
6	5.00E+00	4.00E+00	5.3991E-03
7	4.00E+00	3.00E+00	4.5984E-03
8	3.00E+00	2.50E+00	3.9449E-03
9	2.50E+00	2.00E+00	3.4485E-03
10	2.00E+00	1.66E+00	2.9982E-03
11	1.66E+00	1.44E+00	2.6706E-03
12	1.44E+00	1.22E+00	2.3929E-03
13	1.22E+00	1.00E+00	2.1055E-03
14	1.00E+00	8.00E-01	1.8164E-03
15	8.00E-01	6.00E-01	1.5143E-03
16	6.00E-01	4.00E-01	1.1686E-03
17	4.00E-01	3.00E-01	8.6947E-04
18	3.00E-01	2.00E-01	6.2398E-04
19	2.00E-01	1.00E-01	3.8050E-04
20	1.00E-01	5.00E-02	2.7163E-04
21	5.00E-02	2.00E-02	5.8620E-04
22	2.00E-02	1.00E-02	2.3540E-03

Table 5.4-3 Minimum Cooling Time Evaluation for 14×14 Reference Fuel

Enrichment [wt % ^{235}U]	Minimum Cooling Time (Years) 40,000 MWD/MTU			Active Constraint
	Decay Heat 850 W/assy	2m+Railcar 9.5 mrem/hr	Limiting	
1.7	-	-	-	-
1.9	6.2	11.6	12	2m+Railcar
2.1	6.1	10.8	11	2m+Railcar
2.3	6.0	10.0	10	2m+Railcar
2.5	5.9	9.3	10	2m+Railcar
2.7	5.8	8.7	9	2m+Railcar
2.9	5.8	8.2	9	2m+Railcar
3.1	5.7	7.7	8	2m+Railcar
3.3	5.6	7.3	8	2m+Railcar
3.5	5.6	6.9	7	2m+Railcar
3.7	5.5	6.5	7	2m+Railcar
3.9	5.5	6.2	7	2m+Railcar
4.1	5.4	5.9	6	2m+Railcar
4.3	5.4	5.7	6	2m+Railcar
4.5	5.3	5.6	6	2m+Railcar
4.7	5.3	5.4	6	2m+Railcar
4.9	5.2	5.2	6	Decay Heat

Table 5.4-4 Radial Dose Rate Loading Table Results for Directly Loaded Fuel in Normal Conditions of Transport

Assembly	Source Term			Radial Dose Rate [mrem/hr]	
	Burnup [MWD/MTU]	Enrichment [wt % ^{235}U]	Cool Time [years]	Surface	2m+Railcar
14x14	40,000	2.3	10	366.3	9.5
15x15	40,000	2.5	9	337.8	9.4
16x16	40,000	1.7	10	319.8	9.2
17x17	40,000	2.3	9	358.9	9.2

Table 5.4-5 Loading Table for Directly Loaded PWR Fuel

Minimum Initial Enrichment wt % ^{235}U (E)	Burnup ≤30 GWD/MTU Minimum Cooling Time [years]				30< Burnup ≤35 GWD/MTU Minimum Cooling Time [years]			
	14x14	15x15	16x16	17x17	14x14	15x15	16x16	17x17
1.7 ≤ E < 1.9	8	7	6	7	10	10	7	9
1.9 ≤ E < 2.1	7	7	5	7	9	9	7	8
2.1 ≤ E < 2.3	7	7	5	6	9	8	6	8
2.3 ≤ E < 2.5	6	6	5	6	8	8	6	7
2.5 ≤ E < 2.7	6	6	5	6	8	7	6	7
2.7 ≤ E < 2.9	6	6	5	5	7	7	5	6
2.9 ≤ E < 3.1	6	5	5	5	7	7	5	6
3.1 ≤ E < 3.3	5	5	5	5	7	6	5	6
3.3 ≤ E < 3.5	5	5	5	5	6	6	5	6
3.5 ≤ E < 3.7	5	5	5	5	6	6	5	6
3.7 ≤ E < 3.9	5	5	5	5	6	6	5	6
3.9 ≤ E < 4.1	5	5	5	5	6	6	5	6
4.1 ≤ E < 4.3	5	5	5	5	5	6	5	6
4.3 ≤ E < 4.5	5	5	5	5	5	6	5	6
4.5 ≤ E < 4.7	5	5	5	5	5	6	5	6
4.7 ≤ E < 4.9	5	5	5	5	5	6	5	6
E ≥ 4.9	5	5	5	5	5	5	5	6
Minimum Initial Enrichment wt % ^{235}U (E)	35< Burnup ≤40 GWD/MTU Minimum Cooling Time [years]				40< Burnup ≤45 GWD/MTU Minimum Cooling Time [years]			
	14x14	15x15	16x16	17x17	14x14	15x15	16x16	17x17
1.7 ≤ E < 1.9	-	-	-	-	-	-	-	-
1.9 ≤ E < 2.1	12	13	9	11	-	-	-	-
2.1 ≤ E < 2.3	11	11	8	10	-	-	-	-
2.3 ≤ E < 2.5	10	10	8	9	14	15	12	14
2.5 ≤ E < 2.7	10	9	7	9	13	14	10	12
2.7 ≤ E < 2.9	9	9	7	8	12	12	9	11
2.9 ≤ E < 3.1	9	8	6	8	11	11	8	10
3.1 ≤ E < 3.3	8	8	6	7	10	10	8	9.
3.3 ≤ E < 3.5	8	7	6	7	10	10	7	9
3.5 ≤ E < 3.7	7	7	6	7	9	9	7	9
3.7 ≤ E < 3.9	7	7	6	7	9	9	7	9
3.9 ≤ E < 4.1	7	7	6	7	8	9	7	9
4.1 ≤ E < 4.3	6	7	6	7	8	8	7	9
4.3 ≤ E < 4.5	6	7	6	7	8	8	7	8
4.5 ≤ E < 4.7	6	7	6	7	7	8	7	8
4.7 ≤ E < 4.9	6	7	6	7	7	8	7	8
E ≥ 4.9	6	7	6	7	7	8	7	8

Table 5.4-5 Loading Table for Directly Loaded PWR Fuel (Continued)

Minimum Initial Enrichment wt % ^{235}U (E)	45< Burnup ≤50 GWD/MTU Minimum Cooling Time [years]				50< Burnup ≤55 GWD/MTU Minimum Cooling Time [years]			
	14x14	15x15	16x16	17x17	14x14	15x15	16x16	17x17
1.7 ≤ E < 1.9	-	-	-	-	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-	-	-	-	-
2.7 ≤ E < 2.9	17	17	14	17	-	-	-	-
2.9 ≤ E < 3.1	15	16	13	15	-	-	-	-
3.1 ≤ E < 3.3	14	15	12	14	19	20	17	20
3.3 ≤ E < 3.5	13	14	10	12	18	19	16	18
3.5 ≤ E < 3.7	12	12	10	12	16	17	14	17
3.7 ≤ E < 3.9	11	12	9	12	15	16	13	16
3.9 ≤ E < 4.1	10	12	9	12	14	16	12	16
4.1 ≤ E < 4.3	10	11	8	11	13	16	11	16
4.3 ≤ E < 4.5	9	11	8	11	12	15	11	15
4.5 ≤ E < 4.7	9	11	8	11	12	15	11	15
4.7 ≤ E < 4.9	9	11	8	11	11	15	10	15
E ≥ 4.9	9	11	8	11	11	15	10	15

Minimum Initial Enrichment wt % ^{235}U (E)	55< Burnup ≤60 GWD/MTU Minimum Cooling Time [years]			
	14x14	15x15	16x16	17x17
1.7 ≤ E < 1.9	-	-	-	-
1.9 ≤ E < 2.1	-	-	-	-
2.1 ≤ E < 2.3	-	-	-	-
2.3 ≤ E < 2.5	-	-	-	-
2.5 ≤ E < 2.7	-	-	-	-
2.7 ≤ E < 2.9	-	-	-	-
2.9 ≤ E < 3.1	-	-	-	-
3.1 ≤ E < 3.3	-	-	-	-
3.3 ≤ E < 3.5	-	-	-	-
3.5 ≤ E < 3.7	22	23	20	23
3.7 ≤ E < 3.9	20	21	18	21
3.9 ≤ E < 4.1	19	21	17	21
4.1 ≤ E < 4.3	18	20	16	20
4.3 ≤ E < 4.5	16	20	14	20
4.5 ≤ E < 4.7	15	20	14	20
4.7 ≤ E < 4.9	15	20	14	20
E ≥ 4.9	15	19	14	20

Table 5.4-6 Detector Maximum Dose Rates for Directly Loaded Fuel in Normal Conditions of Transport

Detector	Source	Surface		2 meter	
		mrem/hr	RSD	mrem/hr	RSD
Top Axial	Fuel Neutron	0.4	0.2%	0.1	0.2%
	Fuel Gamma	0.2	0.8%	0.0	1.1%
	Fuel Hardware	0.3	1.8%	0.0	2.2%
	Fuel N-Gamma	0.1	1.3%	0.0	1.4%
	Upper Plenum	2.1	0.5%	0.4	0.5%
	Upper Nozzle	3.0	0.6%	0.6	0.6%
	Lower Nozzle	0.0	0.0%	0.0	0.0%
	Total	6.1	0.3%	1.3	0.3%
Radial	Fuel Neutron	152.2	0.3%	2.9	0.3%
	Fuel Gamma	2.2	3.8%	1.2	0.8%
	Fuel Hardware	6.1	5.7%	0.5	4.4%
	Fuel N-Gamma	1.4	4.7%	0.8	0.9%
	Upper Plenum	87.2	0.4%	1.8	0.4%
	Upper Nozzle	117.3	0.4%	2.2	0.5%
	Lower Nozzle	0.0	15.0%	0.0	0.8%
	Total	366.3	0.2%	9.5	0.3%
Bottom Axial	Fuel Neutron	4.0	0.3%	0.7	0.2%
	Fuel Gamma	0.7	1.1%	0.1	0.7%
	Fuel Hardware	2.3	0.9%	0.4	4.1%
	Fuel N-Gamma	0.4	1.3%	0.1	0.9%
	Upper Plenum	0.0	0.0%	0.0	0.0%
	Upper Nozzle	0.0	0.0%	0.0	0.0%
	Lower Nozzle	7.0	0.8%	1.3	0.7%
	Total	14.3	0.4%	2.6	0.7%

Note: Dose rates at 2 meter locations radially are 2 meters from the railcar. Dose rates at 2 meter locations axially are measured from the ends of the impact limiters.

Table 5.4-7 Detector Maximum Dose Rates for Directly Loaded Fuel in Accident Conditions

Detector	Source	Surface		1 meter	
		mrem/hr	RSD	mrem/hr	RSD
Top Axial	Fuel Neutron	31.2	0.5%	23.3	0.9%
	Fuel Gamma	1.8	2.6%	1.2	2.0%
	Fuel Hardware	1.5	4.6%	0.9	30.2%
	Fuel N-Gamma	0.5	1.3%	0.4	2.8%
	Upper Plenum	11.8	1.0%	6.2	1.0%
	Upper Nozzle	4.8	1.7%	2.0	2.0%
	Lower Nozzle	0.0	0.0%	0.0	0.0%
	Total	51.7	0.5%	34.1	1.1%
Radial	Fuel Neutron	1879.2	0.2%	684.8	0.2%
	Fuel Gamma	10.7	1.5%	5.8	0.9%
	Fuel Hardware	32.9	12.2%	13.9	11.7%
	Fuel N-Gamma	3.0	1.8%	1.5	1.1%
	Upper Plenum	0.0	0.0%	0.0	2.6%
	Upper Nozzle	0.0	0.0%	0.0	5.4%
	Lower Nozzle	0.0	44.5%	0.9	0.6%
	Total	1925.8	0.3%	707.1	0.3%
Bottom Axial	Fuel Neutron	139.9	0.3%	60.0	6.3%
	Fuel Gamma	19.6	1.3%	5.1	1.5%
	Fuel Hardware	5.9	4.7%	1.7	4.4%
	Fuel N-Gamma	2.5	1.1%	0.7	1.2%
	Upper Plenum	0.0	0.0%	0.0	0.0%
	Upper Nozzle	0.0	0.0%	0.0	0.0%
	Lower Nozzle	16.6	1.1%	4.4	1.3%
	Total	184.5	0.3%	71.9	5.3%

Note: The azimuthal maximum radial dose rates are 2011 (1.9%) and 770 (4.5%) mrem/hr at the surface and at 1 meter from the surface, respectively.

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6.0 CRITICALITY EVALUATION

6.1 Discussion and Results

The NAC-STC is designed to safely transport intact spent fuel assemblies in two configurations. Fuel assemblies may be sealed in a transportable storage canister (canistered), or placed directly into a fuel basket installed in the cask cavity (directly loaded). In the canistered configuration, the NAC-STC can transport up to 36 Yankee Class fuel assemblies and 24 Greater Than Class C waste canisters. Canistered Yankee Class fuel assemblies are described in Table 6.2-2. The design basis fuels for the directly loaded configuration are the Westinghouse, Combustion Engineering, Exxon/ANF/SPC and Framatome-Cogema PWR fuel assemblies described in Table 6.2-1. In the directly loaded configuration, the NAC-STC can transport 26 directly loaded PWR fuel assemblies. Greater Than Class C waste does not contain fissionable isotopes and does not require a criticality evaluation.

This chapter demonstrates that the NAC-STC with the design basis payloads, meets the criticality requirements of 10 CFR 71 Sections 71.55 and 71.59, and IAEA Safety Series ST-1. As demonstrated by the criticality analyses presented in Section 6.4 and summarized below, the NAC-STC is subcritical under all conditions and is assigned a nuclear criticality control transport index of 0 (N = 0) in accordance with 10 CFR 71.59(b).

6.1.1 Directly Loaded Fuel

The NAC-STC is designed to transport 26 directly loaded PWR fuel assemblies with an initial enrichment up to 4.2 wt % ^{235}U, with the exception of fuel assemblies meeting the geometric constraints of the 17 x 17 Framatome-Cogema AFA design, which is limited to 4.5 wt % ^{235}U. Criticality control in the NAC-STC is achieved using a flux trap principle. Each of the basket tubes in the NAC-STC are surrounded by four BORAL sheets which are held in place by steel cladding. The BORAL sheets have a minimum 0.02 g $^{10}B/cm^2$ loading in the core. The spacing of the basket tubes is maintained by the steel support disks. These disks provide water gap spacings between tubes of 1.64 inch and 3.46 inch. When the cask is flooded with water, fast neutrons leaking from the fuel assemblies are thermalized in the water gaps and are absorbed in the BORAL sheets before causing a fission in an adjacent fuel assembly.

The SCALE 4.3 CSAS25 (SCALE 4.3, Landers and Petrie, 1995) calculational sequence is used to perform the NAC-STC criticality analysis. This sequence includes KENO-Va (Petrie) Monte Carlo analysis to determine the NAC-STC effective neutron multiplication factor (k_{eff}) under normal and accident conditions. The 27 group neutron library is used in all calculations, including those used to evaluate the sensitivity of the package to a range of moderator density and center-to-center spacing. The principal characteristics of the directly loaded assemblies are shown in Table 6.2-1. The most reactive directly loaded fuel assembly is the Framatome-Cogema 17 x 17 having an enrichment of 4.5 wt % ^{235}U. The analyses yielded the following maximum results:

Normal Conditions:	$k_{eff} \pm \sigma$	k_s
Loading – Moderator inside and dry outside	0.92541 ± 0.00086	0.93948
Transport – Dry inside and moderator outside	0.44315 ± 0.00032	0.44379
Hypothetical Accident Conditions:		
Fully Moderated	0.93388 ± 0.00083	0.94794

Conservatisms contained in these analyses included: (1) 75 percent of the specified minimum ^{10}B loading in the BORAL; (2) infinite array of casks in the X-Y plane; (3) infinite fuel length with no inclusion of end leakage effects; (4) no structural material present in the assembly; (5) no dissolved boron in the cask cavity or surrounding loading or storage area; (6) no credit taken for fuel burnup or for the buildup of fission product neutron poisons; and (7) moderator in the pellet to fuel rod clad gap during accident evaluations.

6.1.2 Canistered Fuel

The NAC-STC may transport a transportable storage canister containing up to 36 design basis Yankee Class fuel assemblies. Criticality control in the canister basket is also achieved using the flux trap principle. The flux trap principle controls the reactivity in the interior of each of two basket configurations. In the first of the configurations, all fuel tubes are separated by a flux trap that is formed by surrounding the tube with four 0.01g $^{10}B/cm^2$ (minimum) areal density BORAL sheets, which are held in place by stainless steel covers. In the second configuration, the size of four fuel tubes (one outer tube in each quadrant of the basket, as shown in Figure 6.3-3) is increased by removing the BORAL sheets from the outside of the tubes. The remainder of the tubes have BORAL sheets on each of the four sides. The spacing of the basket tubes is maintained by the steel support disks. These disks provide water gap spacing between tubes of 0.75, 0.81 or 0.875 inches, depending on the tube placement within the basket. When the cask is flooded with water, fast neutrons leaking from the fuel assemblies are thermalized in the water gaps and are absorbed in the BORAL sheets before causing a fission in an adjacent fuel assembly.

The transportable storage canister may contain one or more Reconfigured Fuel Assemblies. The Reconfigured Fuel Assembly is designed to confine the Yankee Class spent fuel rods, or portions thereof, which are classified as failed fuel. The total number of full length rods in a reconfigured fuel assembly is less than the number contained in a Yankee Class fuel assembly (maximum of 64 versus 256 rods). Consequently, the reactivity of the Reconfigured Fuel Assembly, even with the most reactive fuel rods, is less than the design basis fuel assembly used in criticality (see Section 6.4.3.1).

The SCALE 4.3 CSAS25 (Scale 4.3, Landers and Petrie, 1995) calculational sequence is used to perform the NAC-STC canistered fuel criticality analysis, based on the use of the most reactive Yankee Class fuel assembly. This sequence includes KENO-Va (Petrie, 1995) Monte Carlo analysis to determine the NAC-STC effective neutron multiplication factor (k_{eff}) under normal and accident conditions. The 27 group ENDF/B-IV neutron cross-section library is used in all calculations, including those used to evaluate the sensitivity of the package to a range of moderator density and center-to-center spacing. The most reactive Yankee Class fuel is the United Nuclear Type A. The principal characteristics of this assembly are shown in Table 6.2-2. Normal and accident conditions for the transport cask containing the basket with four BORAL sheets on all fuel tubes were evaluated as shown below. The wet loading condition results are shown for information only. In normal loading of canistered fuel, the canister will be dry inside and out. Fuel loading in the canister will take place in the transfer cask. The analyses yielded the following maximum results:

Normal Transport:	$k_{eff} \pm \sigma$	k_s
Loading – Moderator inside and dry outside	0.8761 ± 0.0007	0.8942
Transport – Dry inside and moderator outside	0.4580 ± 0.0006	0.4760
Hypothetical Accident:		
Fully Moderated	0.8834 ± 0.0008	0.9014
Fully Moderated – Enlarged fuel tubes	0.9003 ± 0.0007	0.9183

Fully moderated includes water inside and outside of the cask, including the neutron shield region, and inside and outside of the fuel, including the fuel pellet and cladding gaps. Only the hypothetical accident condition is presented for the enlarged fuel tube case, since it represents the bounding configuration.

Conservatisms contained in these analyses included: (1) most reactive Yankee Class fuel assembly class with maximum U loading; (2) 75 percent of the specified minimum ^{10}B loading in the BORAL; (3) infinite array of casks in the X-Y plane; (4) infinite fuel length with no inclusion of end leakage effects; (5) no structural material present in the assembly; (6) no dissolved boron in the cask cavity or surrounding loading or storage area; (7) no credit taken for fuel burnup or for the buildup of fission product neutron poisons; and (8) moderator assumed in the gap between the pellet and fuel rod clad.

6.2 Package Fuel Loading

The NAC-STC can safely transport 26 directly loaded PWR fuel assemblies, or up to 36 Yankee Class fuel assemblies loaded in the transportable storage canister. The number of Yankee Class assemblies in the canister is limited by the total assembly weight of 30,600 pounds.

The directly loaded fuel assembly characteristics are presented in Table 6.2-1. The cask analysis identified similar reactivity for the Westinghouse 17 x 17 OFA fuel assembly at 4.2 wt % ^{235}U and the Framatome-Cogema AFA 17 x 17 assembly at 4.5 wt % ^{235}U. As described in Section 6.4.2.1, the reactivity of these assemblies was higher than the reactivity of the remaining fuel assemblies evaluated for direct loading. To establish a bounding reactivity condition, the fuel characteristic envelope (i.e., fuel geometric parameters and fuel mass) of the Framatome-Cogema AFA 17 x 17 fuel assembly was expanded. The assembly with the expanded parameters, labeled the AFAM, is more reactive than the remaining directly loaded fuel assemblies and is used as a design basis fuel.

The most reactive design basis Yankee Class fuel is the United Nuclear Type A assembly, as described in Section 6.4.3.1. This assembly is used in the criticality calculations for the canistered configuration of the NAC-STC. The major fuel classes to be transported in the canistered fuel configuration of the NAC-STC are presented in Table 6.2-2. Design parameters of the reconfigured Yankee Class assemblies are presented in Table 6.2-3. The Reconfigured Fuel Assembly is shown in Figures 6.2-1 and 6.2-2.

Fuel assemblies with zero burnup are used in these analyses. The fresh fuel assumption is conservative because the fuel becomes less reactive as burnup increases. The criticality evaluations for the transport configurations are performed, assuming that all of the fuel assembly rods are in place. Consequently, to preclude a potential increase in reactivity, due to empty fuel rod positions in a spent fuel assembly, any fuel rods removed from an assembly lattice must be replaced with solid rods fabricated from Zircaloy or stainless steel. Fuel rod positions may also be occupied by solid poison (shim) rods. Shim rods and solid Zircaloy or stainless steel fill rods will serve as parasitic absorber and/or displace moderator. These rods are modeled as fuel rods in the criticality evaluations. Unenriched fuel assemblies are not evaluated and may not be loaded into the NAC-STC in either the directly loaded or canistered fuel configuration. However, fuel assemblies with unenriched axial end blankets may be loaded.

Figure 6.2-1 Reconfigured Fuel Assembly

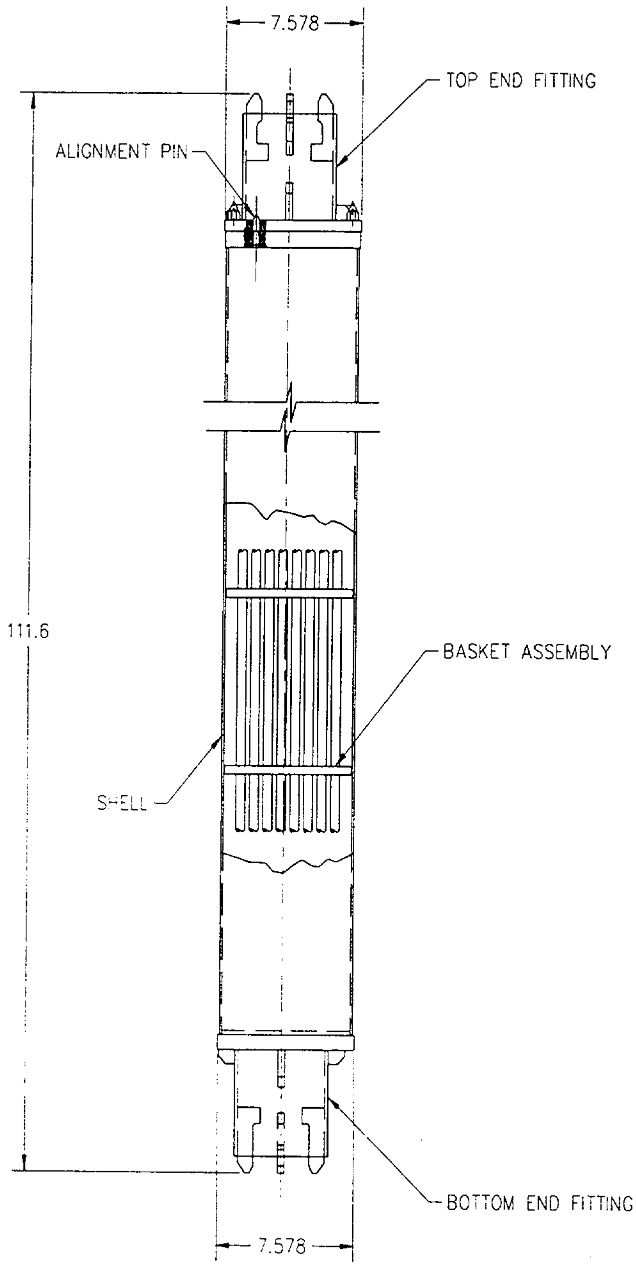

Figure 6.2-2 Reconfigured Fuel Assembly Cross-Section

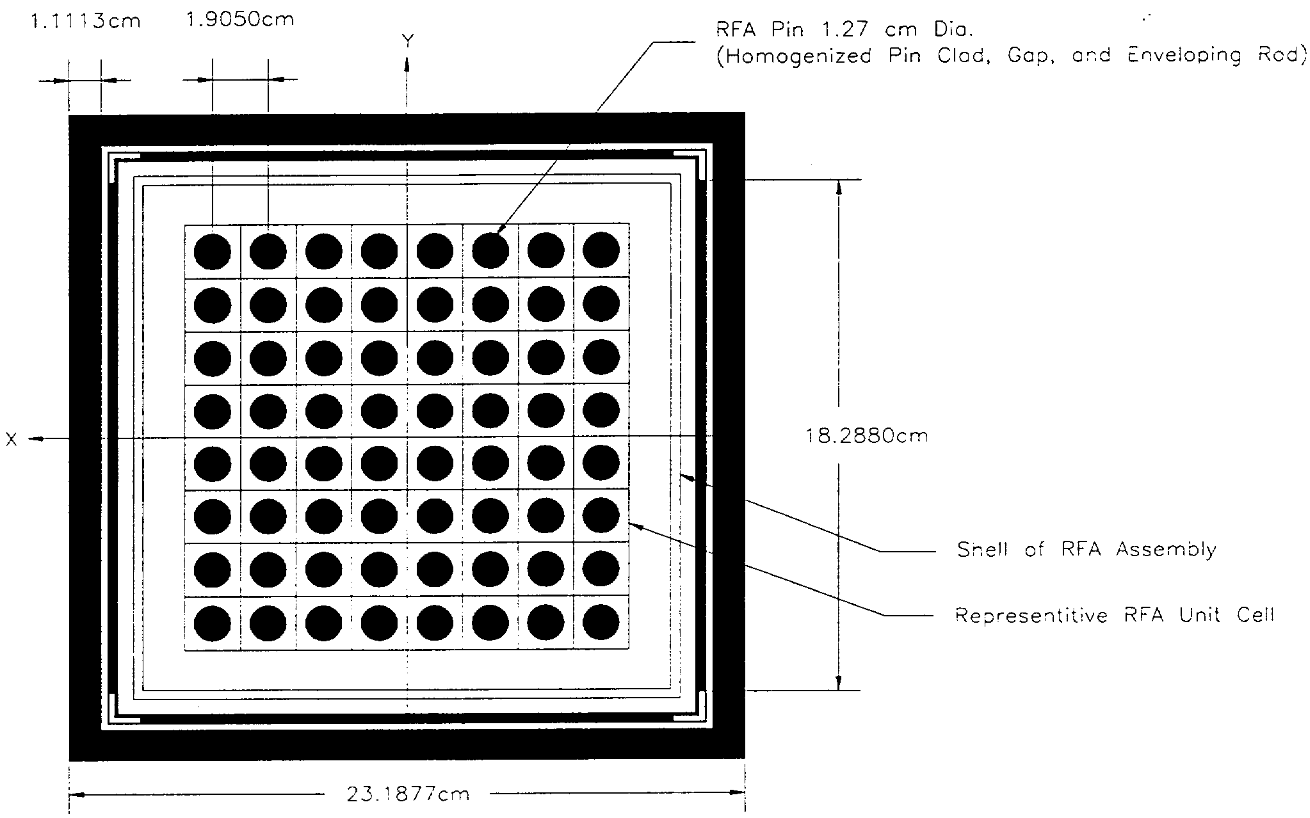

Table 6.2-1 Characteristics of Directly Loaded Fuel Assemblies

PWR Fuel Assembly Characteristics (Zirc-4 Clad)

Vendor	Array	Version	ID	Enrichment (wt % ^{235}U)	Max MTU[1]	Number of Fuel Rods	Pitch (in)	Rod Dia. (in)	Clad Thick. (in)	Pellet Dia (in)	Active Length (in)
CE	14 X 14	Std.	14A1	4.2	0.4037	176	0.5800	0.4400	0.0280	0.3765	137.0
CE	14 X 14	Ft Cal.	14A2	4.2	0.3772	176	0.5800	0.4400	0.0280	0.3765	128.0
Ex/ANF	14 X 14	CE	14A3	4.2	0.3814	176	0.5800	0.4400	0.0310	0.3700	134.0
WE	14 X 14	CE Model	14A4	4.2	0.4115	176	0.5800	0.4400	0.0260	0.3805	136.7
Ex/ANF	14 X 14	WE	14B1	4.2	0.3689	179	0.5560	0.4240	0.0300	0.3505	142.0
Ex/ANF	14 X 14	Praire Isl.	14B2	4.2	0.3741	179	0.5560	0.4170	0.0300	0.3505	144.0
WE	14 X 14	Std / ZCA	14B3	4.2	0.4144	179	0.5560	0.4220	0.0225	0.3674	145.2
WE	14 X 14	OFA	14B4	4.2	0.3612	179	0.5560	0.4000	0.0243	0.3444	144.0
WE	14 X 14	Std / ZCB	14B5	4.2	0.4144	179	0.5560	0.4220	0.0225	0.3674	145.2
Ex/ANF	15 X 15	WE	15A1	4.2	0.4410	204	0.5630	0.4240	0.0300	0.3565	144.0
WE	15 X 15	Std	15A2	4.2	0.4646	204	0.5630	0.4220	0.0242	0.3659	144.0
WE	15 X 15	Std / ZC	15A3	4.2	0.4646	204	0.5630	0.4220	0.0242	0.3659	144.0
WE	15 X 15	OFA	15A4	4.2	0.4646	204	0.5630	0.4220	0.0242	0.3659	144.0
CE	15 X 15	Palis.	15B1	4.2	0.4317	216	0.5500	0.4180	0.0260	0.3580	132.0
Ex/ANF	15 X 15	Palis	15B2	4.2	0.4310	216	0.5500	0.4170	0.0300	0.3580	131.8
CE	16 X 16	Lucie 2	16A1	4.2	0.4025	236	0.5060	0.3820	0.0250	0.3250	136.7
Ex/ANF	17 X 17	WE	17A1	4.2	0.4123	264	0.4960	0.3600	0.0250	0.3030	144.0
WE	17 X 17	Std	17A2	4.2	0.4671	264	0.4960	0.3740	0.0225	0.3225	144.0
WE	17 X 17	OFA	17A3	4.2	0.4282	264	0.4960	0.3600	0.0225	0.3088	144.0
WE	17 X 17	Vant 5	17A4	4.2	0.4282	264	0.4960	0.3600	0.0225	0.3088	144.0
FC	17 X 17	AFA	17A5	4.5	0.4669	264	0.4961	0.3740	0.0224	0.3224	144.0
FC	17 X 17	AFAM[2]	17A6	4.5	0.4693	264	0.5011	0.3714	0.0204	0.3230	144.25

Notes:
1.) Based on 95% theoretical density and the listed fuel assembly dimensions.
2.) Represents the AFA fuel assembly with expanded fuel characteristics.

6.3 Criticality Model Specification

6.3.1 Calculational Methodology

The SCALE 4.3 CSAS25 calculational sequence is used to perform the NAC-STC criticality analysis for the directly loaded (uncanistered) and the canistered transport configurations. This sequence includes: the SCALE Material Information Processor (Landers), BONAMI (Greene, 1995), NITAWL-II (Greene, 1995) and KENO-Va (Petrie, 1995). Material Information Processor generates number densities for standard compositions, prepares geometry data for resonance self-shielding, and creates data input files for the cross section processing codes. The BONAMI and NITAWL-II codes are used to prepare a resonance-corrected cross section library in AMPX working format. The KENO-Va code calculates the model k_{eff} using Monte Carlo techniques. The 27 group neutron library is used in all NAC-STC criticality calculations. The validation of the CSAS25 sequence and the method statistics are addressed in Section 6.5. The NAC-STC KENO-Va models are described in further detail below.

6.3.2 Description of Calculational Models

The NAC-STC KENO-Va model is derived from a radial slice of the cask at the central region. This section is the most reactive region due to the number of disks displacing water in the flux trap gap. The model is a stack of slices containing one aluminum disk, two identical water regions and one steel disk region (stack is aluminum, water, steel, water). For the directly loaded fuel configuration, the basket is modeled in each slice and contains 26 design basis fuel assemblies with a fuel density corresponding to 95% of the theoretical maximum. Enrichment varies from 4.2 wt % to 4.5 wt % ^{235}U. The fuel rod array is explicitly modeled in each of the 26 possible locations. For the canistered configuration, the basket model of each slice contains 36 Yankee Class design basis United Nuclear Type A fuel assemblies at 4.0 wt % ^{235}U enrichment, with a fuel density corresponding to 95% of theoretical. The fuel rod array is explicitly modeled in each of the 36 possible fuel locations.

Each basket slice is surrounded by the cask body shielding regions of steel, lead, steel, NS-4-FR and steel. Each cask slice is surrounded by a cuboid. The four slices are stacked into the KENO-Va global unit. Periodic boundary conditions are imposed on the top and bottom to simulate an infinite cylinder, and reflecting boundary conditions are imposed on the sides simulating an infinite number of casks in the X-Y plane. Moderator density is varied both in the cask cavity regions normally filled with water and in the exterior cuboid.

Cask center-to-center spacing is varied by the X-Y dimensions of the exterior cuboid. Analysis of both normal and accident conditions use the same models except the models for accident conditions assume that the radial neutron shielding (NS-4-FR) is replaced by the external moderator. These models are shown in Figures 6.3-1 and 6.3-2.

Figure 6.3-3 depicts the location of the four fuel tubes without BORAL sheet coverage. The enlarged fuel tubes are modeled as simple rectangular stainless steel boxes with an opening width of 7.99 (≈ 8.0) inches and a wall thickness of 0.048 inches.

6.3.3 Package Regional Densities

The densities used in the KENO-Va criticality analyses are:

Material	Density (g/cc)
UO_2	10.41
Zircaloy	6.56
H_2O	1.00 (0.9982)
Steel	7.92
Lead	11.34
Aluminum	2.70
BORAL (core)	2.62
NS-4-FR	1.63

6.3.3.1 Fuel Region

Fuel rod densities for normal operations conditions are:

Material	Element	Density (atoms/barn-cm)
UO_2 (4.0 wt % ^{235}U)	^{235}U	9.406×10^{-4}
	^{238}U	2.229×10^{-2}
	O	4.646×10^{-2}
UO_2 (4.5 wt % ^{235}U)	^{235}U	1.058×10^{-3}
	^{238}U	2.217×10^{-2}
	O	4.646×10^{-2}
Zircaloy	Zr	4.331×10^{-2}
Stainless Steel		8.724×10^{-2}
H_2O (0.9982 g/cm^3)	H	6.677×10^{-2}
	O	3.338×10^{-2}

6.4 Criticality Calculation

The licensing requirements for the shipment of fissile material are provided in 10 CFR 71.55 and 10 CFR 71.59.

10 CFR 71.55 and 10 CFR 71.59 require that the package remain subcritical under any credible condition, e.g. optimum interior/exterior moderation and reflection and credible configuration of the material. A criticality transport index is to be assigned to the fissile material package. This transport index reflects the number of packages (casks in this context) remaining subcritical in an array configuration.

Additional requirements imposed include the reduction in poison plate ^{10}B from 100 to 75 percent and water in the pellet-to-cladding gap.

Undamaged Cask

Compliance with the requirements of paragraphs (b) and (d) of 10 CFR 71.55 is shown by modeling an undamaged cask surrounded by water. Requirements of paragraphs (a) through (c) of 10 CFR 71.59 are satisfied by providing a value of "N" equal to infinity and a criticality transport index of 0 by imposing reflecting boundary conditions on the sides of the model simulating an infinite array of undamaged casks. Optimum interior and exterior moderation, including exterior full reflection by more than 20 cm of water, shows compliance with 10 CFR 55 paragraphs (b)(2), (b)(3) and (d)(3). Normal operating conditions for the canistered content transport cask include a dry canister cavity. The canister is loaded, dried, and seal welded inside a transfer cask. Only after the canister is dried and sealed is it placed into the transport cask. For conservatism the canistered configuration is assumed flooded during cask loading criticality evaluation. This method is identical to the loading analysis of the directly loaded cask configuration. A limited set of exterior moderator density and cask pitch criticality evaluations show compliance with 10 CFR 71 under dry cavity, transport conditions.

Damaged Cask

Compliance with the requirements of paragraph (e) of 10 CFR 71.55 is shown by modeling a damaged cask surrounded by water. Compliance with 10 CFR 71.59 is automatically demonstrated by imposing reflection boundary conditions on the sides of the model to simulate an infinite array of damaged casks, thereby resulting in a criticality transport index of 0. Optimum interior and exterior moderation, including exterior full reflection by more than 20 cm of water, shows compliance with 10 CFR 71.55 paragraphs (e)(2) and (e)(3) and 10 CFR 71.59 paragraph (a)(2).

A damaged transport cask is defined as having been subjected to the hypothetical accident conditions specified in 10 CFR 71. Under these conditions the cask containment is maintained, and the cavity, therefore, remains dry. However, to show the cask's capability to remain subcritical under optimum internal and external moderation, an internally wet cask is analyzed. During the accident, the radial neutron shield is assumed to be lost as a result of fire and is replaced by the external moderator. Even though the fuel is assumed to remain intact following the cask drop, the pellet-to-clad gap is assumed to be filled by the internal-to-cask moderator. Introducing additional moderator into the normally under-moderated fuel assembly lattice increases reactivity.

6.4.1 Fuel Loading Optimization

The NAC-STC cask is designed to transport design basis PWR fuel assemblies in two (2) configurations. The criticality evaluation for directly loaded, uncanistered fuel is presented in Section 6.4.2. The analysis for canistered Yankee Class fuel is presented in Section 6.4.3. These analyses illustrate that the maximum fuel loading along with the most reactive configuration have been analyzed for each configuration. The configuration of fresh fuel into the cask under water with no dissolved boron, and with the cask surrounded by water, is assumed to ensure that the maximum credible reactivity is simulated.

6.4.2 Criticality Results for Directly Loaded, Uncanistered Fuel

6.4.2.1 Most Reactive Assembly

A simplified KENO-Va calculation of the design basis assemblies for the directly loaded, uncanistered fuel described in Table 6.2-1, is performed to determine the most reactive assembly. In this simplified model, a unit cell of the NAC-STC basket with the steel and aluminum webbing properly spaced axially is described. Reflecting boundary conditions are imposed on the sides, top and bottom simulating an infinite array of basket cells. All fuel assemblies are at the same fuel density, 95% of the uranium oxide theoretical maximum. The k-infinity of the fuel assemblies in the NAC-STC basket are shown below. Also shown is the reactivity difference between the Westinghouse 17 x 17 OFA and the remaining evaluated assembly types. The difference is expressed as the ratio of the multiplication factor difference (Δk) and the Monte Carlo uncertainty.

Assembly	Enrichment wt % ^{235}U	k_{eff}	σ	Δk/σ
B&W 15x15 Mark B4	4.2	0.92051	0.00178	-5.09
B&W 17x17 Mark C	4.2	0.92371	0.00151	-3.88
CE 14x14	4.2	0.89363	0.00174	-20.66
CE 16x16 SYS 80	4.2	0.89376	0.00170	-21.06
West 14x14 Std	4.2	0.88147	0.00176	-27.33
West 14x14 OFA	4.2	0.89349	0.00180	-20.04
West 15x15	4.2	0.92326	0.00179	-3.53
West 17x17	4.2	0.91766	0.00180	-6.62
West 17x17 OFA	4.2	0.92957	0.00166	0.00
Exxon/ANF 14x14 CE	4.2	0.89413	0.00156	-22.72
Exxon/ANF 14x14 WE	4.2	0.87193	0.00169	-34.11
Exxon/ANF 15x15 WE	4.2	0.91629	0.00175	-7.59
Exxon/ANF 17x17 WE	4.2	0.92345	0.00172	-3.56
F-C AFA 17x17	4.2	0.91686	0.00171	-7.4
F-C AFA 17x17	4.5	0.93014	0.00163	0.3
F-C AFAM 17x17	4.2	0.92838	0.00185	-0.4
F-C AFAM 17x17	4.5	0.94089	0.00172	6.7

The most reactive fuel assemblies at 4.2 wt % ^{235}U are the Modified Framatome-Cogema AFA assembly (AFAM), and the Westinghouse 17 x 17 OFA. The standard 17 x 17 Westinghouse and AFA fuels are significantly lower in reactivity. Maximum reactivity is obtained from the 4.5 wt % ^{235}U enriched Framatome-Cogema fuel. Specific evaluations for fuel enriched above 4.2 wt % ^{235}U are shown in Section 6.4.2.5.

Mechanical perturbation and moderator density studies are performed with the 4.2 wt % ^{235}U enriched Westinghouse 17 x 17 OFA. While enrichments over 4.2 wt. % ^{235}U are allowed for the AFA fuel types, the reactivity trends versus basket parameters, component movement, and moderator density are applicable to the higher enriched fuel. Modification to the enrichment level and the adjustment in fuel cross-section parameters will modify the magnitude of the reactivity change produced by the perturbation, but follow the same trend. Section 6.4.2.5 contains analysis specific to the AFAM fuel type.

6.4.2.2 Most Reactive Mechanical Configuration

Using the full cask model with the 4.2 wt % ^{235}U enriched Westinghouse 17 x 17 OFA fuel assembly, an evaluation of the effect of different directly loaded basket perturbations is made. This criticality analysis determines the most reactive basket mechanical configuration by altering the nominal model with the design basis assembly and comparing the perturbed k_{eff} to the nominal result. If Δk_{eff} ($k_{perturbed}$-$k_{nominal}$) is positive, the tolerance causes an increase in reactivity. Conversely, if Δk_{eff} is negative, the tolerance causes a decrease in reactivity. To account for the statistical nature of the Monte Carlo analysis, and to determine if the change in reactivity is statistically significant, the Δk_{eff} is divided by the Monte Carlo uncertainty (σ) to arrive at a weight reactivity difference ($\Delta k_{eff}/\sigma$). Two sets of perturbations are assessed in the evaluation of criticality control: fabrication tolerances and component movement within the basket.

Four major fabrication tolerances are evaluated: 1) The fuel tube opening; 2) The disk opening; 3) The disk thickness; and, 4) The disk opening placement. The tolerances applied in the evaluation are ± 0.0762 cm for the tube opening, ± 0.0508 cm on the disk thickness, and ± 0.0381 cm on the disk opening size. The disk opening location tolerance is within a 0.0381 cm radius circle from the nominal location. The tolerance analysis results are:

Analysis	k_{eff}	σ	Δk_{eff}	$\Delta k_{eff}/\sigma$
Nominal Basket	0.90143	0.00090	----	----
Geometric Tolerances				
Min Tube	0.89494	0.00089	-0.00649	-7.292
Max Tube	0.90485	0.00085	0.00342	4.024
Min Disk Opening	0.89955	0.00087	-0.00188	-2.161
Max Disk Opening	0.90002	0.00086	-0.00141	-1.640
Shift Openings In	0.90169	0.00088	0.00026	0.295
Shift Openings Out	0.89799	0.00084	-0.00344	-4.095
Min Disk Thickness	0.89900	0.00087	-0.00243	-2.793
Max Disk Thickness	0.90073	0.00087	-0.00070	-0.805

Based on reactive analysis, the only statistically significant change in reactivity occurs due to an increase in tube opening width. Increasing the fuel tube opening brings more moderator into the gap between the assembly and the tube lowering the efficiency of the BORAL sheets, hence increasing the reactivity of the system.

Two major component movements within the basket are evaluated: the assembly within the tube and the tube within the basket. Component movement is evaluated toward the top, right, top right, cask center, and cask periphery. Due to symmetry of the basket the remaining directions do not require analysis. To complete the analysis sequence, a combined radially inward shift of both fuel tube and assembly are evaluated.

As shown in the following table, based on the mechanical perturbation analysis, the maximum reactivity configuration of the basket is one in which both the fuel tube and fuel assembly are shifted toward the cask center.

Analysis	k_{eff}	σ	Δk_{eff}	$\Delta k_{eff}/\sigma$
Nominal Basket	0.90143	0.00090	----	----
Mechanical Perturbations				
Assembly Shift Top Right	0.89811	0.00119	-0.00332	-2.790
Assembly Shift Top	0.89788	0.00122	-0.00355	-2.910
Assembly Shift Right	0.89763	0.00120	-0.00380	-3.167
Assembly Shift Radial In	0.90245	0.00130	0.00102	0.785
Assembly Shift Radial Out	0.89556	0.00119	-0.00587	-4.933
Fuel Tube Shift Top Right	0.89931	0.00124	-0.00212	-1.710
Fuel Tube Shift Top	0.90174	0.00118	0.00031	0.263
Fuel Tube Shift Right	0.89869	0.00121	-0.00274	-2.264
Fuel Tube Shift Radial In	0.90363	0.00126	0.00220	1.746
Fuel Tube Shift Radial Out	0.89361	0.00120	-0.00782	-6.517
Combined Analysis				
Tube + Assembly Radial In	0.90867	0.00120	0.00724	6.033

Thus, the following most reactive mechanical configuration is imposed on the NAC-STC directly loaded cask model: assemblies and fuel tubes moved toward the center of the basket, and maximum fuel tube opening.

6.4.2.3 Normal Conditions

Criticality results under normal conditions include variations in moderator density from 1.0 g/cc to 0.1 g/cc and cask center-to-center spacing from 250 cm (touching) to 300 cm. The results are shown in Tables 6.4-1 and 6.4-2. Table 6.4-1 shows the expected reactivity conditions during loading, i.e., wet inside and outside, as well as variation in moderator density due to draining and drying. Table 6.4-1 shows that cask reactivity is relatively insensitive to variations in cask center-to-center spacing. This results in a k_{eff} of 0.9129 ± 0.0009. The CSAS25 input and output for this case is shown in Figure 6.6-1. Simultaneous variation in moderator density inside and outside the cask shows a monotonic decrease in reactivity. There appears to be no optimum reactivity at low density conditions. The maximum k_{eff} in the dry situation is 0.4929 ± 0.0013, at a cask pitch of 300 cm.

Table 6.4-2 shows the expected reactivity conditions during normal transport, i.e., dry inside and possibly wet outside. When the cask cavity is dry, k_{eff} of the package is very low and is insensitive to variations of moderator density outside and cask center-to-center spacing. The maximum k_{eff} for this situation is 0.4096 ± 0.0009, at a cask pitch of 270 cm.

Including statistical and method uncertainties, all results for the normal condition are below the 0.95 NRC criticality safety limit. Thus, compliance with 10 CFR 71.55 (b) and (d) as well as 10 CFR 71.75 (a) is demonstrated.

6.4.2.4 Hypothetical Accident Conditions

Criticality results under hypothetical accident conditions include variations in exterior moderator density from 1.0 g/cc to 0.1 g/cc (dry) as well as cask center-to-center spacing from 250 cm (touching) to 300 cm. The results are shown in Table 6.4-3. Under accident conditions, moderator is allowed in the neutron shield region and outside the cask. Again, with the cask cavity dry, the k_{eff} of the package is low and insensitive to moderator density and cask spacing variation. The maximum k_{eff} for this situation is 0.9190 ± 0.0009. The CSAS25 input and output for this case is shown in Figure 6.6-2.

Including statistical and method uncertainties, all results for the accident condition are well below the 0.95 NRC criticality safety limit. Thus, compliance with 10 CFR 71.55 (e) and 10 CFR 71.75 (b) is demonstrated.

6.4.2.5 High Enrichment Evaluation, 4.5 wt% ^{235}U

As shown in Section 6.4.2.1, the maximum reactivity directly loaded fuel assemblies are the 4.5 wt. % ^{235}U enriched Framatome-Cogema 17x17 configurations identified as type AFA and AFAM. The AFA fuel type at 4.5 wt. % ^{235}U is similar in reactivity to that of the Westinghouse 17x17 OFA at 4.2 wt. % ^{235}U. The modified version of the Framatome-Cogema fuel assembly, labeled AFAM, raises the fissile mass and moderator to fuel ratio, both of which increase system reactivity. Increasing the pellet diameter and active fuel length raises the fissile material mass in the assembly. The moderator-to-fuel ratio is increased by reducing the fuel rod outer diameter and the fuel clad and guide tube thickness. To provide maximum directly loaded fuel assembly reactivities, the AFAM assembly is evaluated in the cask model at the worst-case configuration documented in Section 6.4.2.2. This configuration involves a shifted radial inward fuel assembly and fuel tube with a maximum tolerance tube opening. Evaluations are performed at normal and accident conditions. Accident conditions involve flooding the pellet to clad gap and assume removal of the neutron shield. As documented in Sections 6.4.2.3 and 6.4.2.4, no statistically significant differences in reactivity occur as a function of cask spacing and exterior moderator density.

When flooding 100% of the pellet to clad gaps, in the under-moderated fuel assembly lattice during hypothetical accident condition, variations in reactivity may be seen due to changes in fuel pellet diameter (i.e., an increased pellet diameter displaces moderator and may result in a combined decrease in system reactivity). For the modified AFA assembly (AFAM) the majority of reactivity increase observed is the result of an increased fuel rod pitch. Modification to the pellet diameter, within the range expected from a standard PWR fuel assembly (± 0.0005 inch), does not produce a resolvable impact on system reactivity. Since the increased pellet diameter provides for a larger fissile mass in the typically dry pellet to clad gap configuration, the increased pellet diameter was retained for the flooded gap analysis.

Normal Conditions:	$k_{eff} \pm \sigma$	k_s
Loading – Moderator inside and dry outside	0.92541 ± 0.00086	0.93948
Transport – Dry inside and moderator outside	0.44315 ± 0.00032	0.44379
Hypothetical Accident Conditions:		
Fully Moderated	0.93388 ± 0.00083	0.94794

To satisfy 10 CFR 71.55(b)(3), an analysis of the reflection of the containment system (inner shell) by water is performed for a single cask. This evaluation resulted in k_{eff} values of 0.92473 for a single flooded intact cask fully water reflected and 0.92454 for a containment system fully water reflected. There is no statistically significant difference between the cases.

6.4.3 Criticality Results for Canistered Yankee Class Fuel

This section establishes the most reactive Yankee Class fuel and the most reactive configuration of the fuel within the canister basket. These results are used to calculate the effective neutron multiplication factor for the transfer cask and storage cask assuming full moderation. Sections 6.4.3.2 through 6.4.3.4 contain the results for the basket in the transport configuration without enlarged fuel tubes, while Section 6.4.3.5 extends the evaluation results to the basket with four enlarged fuel tubes.

6.4.3.1 Most Reactive Assembly

A simplified KENO-Va calculation of the Yankee Class design basis assemblies, described in Table 6.2-2, is performed to determine the most reactive assembly. In this simplified model, a unit cell of the NAC-STC canister basket, with the stainless steel and aluminum webbing properly spaced axially, is described. Reflecting boundary conditions are imposed on the sides, top and bottom simulating an infinite array of basket cells. Using the basket cell model, a k_{eff} value was obtained for each assembly type. The results of the evaluation are:

Assembly	Initial Enrichment	k_{eff}	σ
Westinghouse Type A	4.94 wt% ^{235}U	0.8642	0.00105
Westinghouse Type B	4.94 wt% ^{235}U	0.8664	0.00102
United Nuclear Type A	4.00 wt% ^{235}U	0.8974	0.00087
United Nuclear Type B	4.00 wt% ^{235}U	0.8974	0.00106
Exxon - ANF Type A	4.00 wt% ^{235}U	0.8870	0.00111
Exxon - ANF Type B	4.00 wt% ^{235}U	0.8877	0.00111
Combustion Engineering Type A	3.90 wt% ^{235}U	0.8943	0.00060
Combustion Engineering Type B	3.90 wt% ^{235}U	0.8939	0.00163

This table shows that either the United Nuclear Type A or Type B assembly has the highest multiplication factor of the Yankee class fuel vendor categories. As shown in the table, even though the Type A assembly has an additional fuel rod, it is difficult to resolve the difference between Type A and Type B fuel assemblies. However, since the United Nuclear Type A has the highest UO_2 mass, this assembly is selected as the most reactive design basis fuel assembly and is used in subsequent cask criticality analysis.

The basket cell model described above is applied to determine the most reactive Reconfigured Fuel Assembly configuration. Based on the rod parameters for the Yankee type reconfigured assembly in Table 6.2-3, only two unique types of fuel rods are modeled. One representing the CE, Exxon, and UNC fuel rods with Zircaloy clad, and the other representing the Westinghouse steel clad fuel rods. The CE, Exxon, and UNC fuel rod group is evaluated at a bounding enrichment of 4.0 wt % ^{235}U. To ensure a maximum reactivity calculation the reconfigured assembly is modeled once with a full load, 64 rods, and once with a half load, 32 rods. The 32 rod configuration consists of evenly distributed rods in the 64 tube lattice. The reactivity evaluation of the Reconfigured Fuel Assembly assumes water ingress into the tube to rod gap and into the rod to fuel pellet gap. The maximum reactivity CSAS25 input and output for the Reconfigured Fuel Assembly evaluation are presented in Figure 6.6-7.

Configuration	Initial Enrichment	Number of Rods	k_{eff}	σ
Intact United Nuclear Type A Assembly	4.0 wt % ^{235}U	237	0.8974	0.0009
Reconfigured - Zircaloy Clad Fuel Rods	4.0 wt % ^{235}U	64	0.6280	0.0007
Reconfigured - Zircaloy Clad Fuel Rods	4.0 wt % ^{235}U	32	0.4458	0.0006
Reconfigured - Steel Clad Fuel Rods	4.94 wt % ^{235}U	64	0.6145	0.0006

Based on this evaluation, the reconfigured assembly composed of 64 Zircaloy clad fuel rods is the most limiting reconfigured assembly. Its reactivity is significantly lower than that of the limiting intact assembly.

6.4.3.2 Most Reactive Mechanical Configuration

Using the fuel/basket model with the design basis fuel assembly, an evaluation of the effect of different NAC-STC basket perturbations is made. This criticality analysis determines the most reactive basket mechanical configuration by altering the nominal fuel/basket model with the design basis assembly and comparing the perturbed k_{eff} to the nominal result. If Δk_{eff} ($k_{perturbed}$ - $k_{nominal}$) is positive, the tolerance causes an increase in reactivity. Conversely, if Δk_{eff} is negative, the tolerance causes a decrease in reactivity. Two sets of perturbations are assessed in this evaluation of the criticality control: fabrication tolerances and component movement within the basket.

Four major fabrication tolerances are evaluated: the fuel tube opening, the disk opening, the disk thickness and the disk opening placement. Modifications to the nominal fuel/basket model dimensions are made based on the basket and fuel tube tolerances. The tolerances applied in this evaluation are ±0.0762 cm for the tube opening, ±0.0508 cm for the disk thickness, and ±0.0381 cm on the disk fuel tube opening size. The disk opening location tolerance is within a 0.0381 cm radius circle from the nominal position. The tolerance analysis results are:

Analysis	k_{eff}	σ	Δk_{eff}
Nominal	0.8981	0.0007	-
Fuel Tube Maximum Opening	0.9018	0.0007	0.0037
Fuel Tube Minimum Opening	0.8916	0.0007	-0.0065
Disk Maximum Opening	0.8972	0.0007	-0.0009
Disk Minimum Opening	0.8991	0.0008	0.0010
Disk Maximum Thickness	0.8987	0.0008	0.0006
Disk Minimum Thickness	0.8972	0.0008	-0.0009
Loose Packed Disk Opening	0.8974	0.0008	-0.0007
Close Packed Disk Opening	0.8993	0.0007	0.0012

The results show that the most reactive set of basket tolerances are maximum fuel tube opening, minimum disk opening, maximum disk thickness, and minimum (close packed) disk opening placement.

Increasing the fuel tube opening brings more moderator into the gap between the assembly and the tube lowering the efficiency of the BORAL sheets, hence increasing the reactivity of the system. Minimizing the disk opening and maximizing the disk thickness removes water from the flux trap, consequently increasing k_{eff}. Finally, decreasing the web thickness, decreases the flux trap size and also moves assemblies closer together producing an increase in k_{eff}. With respect to fabrication tolerances, this is the most reactive configuration.

Two major component movements within the basket are evaluated: the assembly within the tube and the tube within the basket. Unique to this package is the Yankee Class diagonally symmetric fuel assembly. Consequently, movement toward three corners must be evaluated as opposed to one corner for a fully symmetric assembly. This assembly produces five movement perturbations: fuel tube movement to the upper right corner, the upper left corner, the lower left corner and side to side. Shown below are the assembly movement analysis results.

Assembly Movement	Boundary Conditions	k_{eff}	σ	Δk_{eff}
Nominal	Reflective	0.8981	0.0007	-
Upper Right Corner	Mirrored	0.8954	0.0007	-0.0027
Upper Right Corner	Periodic	0.8943	0.0007	-0.0038
Lower Left Corner	Mirrored	0.8977	0.0007	-0.0004
Lower Left Corner	Periodic	0.8978	0.0008	-0.0003
Upper Left Corner	Mirrored	0.8963	0.0007	-0.0018
Upper Left Corner	Periodic	0.8961	0.0008	-0.0020
Right Side	Mirrored	0.8949	0.0007	-0.0032
Right Side	Periodic	0.8951	0.0007	-0.0030
Left Side	Mirrored	0.8978	0.0007	-0.0003
Left Side	Periodic	0.8972	0.0007	-0.0009

These results show that the most reactive assembly position is centered within the basket tube.

Similar to the fuel assembly movement analysis, five possible fuel tube movements are evaluated: the upper right corner, the upper left corner, the lower left corner and side to side. Mirror and periodic boundary conditions on the sides of the model are evaluated. Shown below are the tube movement evaluations.

Tube Movement	Boundary Conditions	k_{eff}	σ	Δk_{eff}
Nominal	Reflective	0.8981	0.0007	-
Upper Right Corner	Mirrored	0.8999	0.0007	0.0018
Upper Right Corner	Periodic	0.8979	0.0007	-0.0002
Lower Left Corner	Mirrored	0.8984	0.0008	0.0003
Lower Left Corner	Periodic	0.8962	0.0007	-0.0019
Upper Left Corner	Mirrored	0.8991	0.0008	0.0010
Upper Left Corner	Periodic	0.8959	0.0007	-0.0022
Right Side	Mirrored	0.9005	0.0008	0.0024
Right Side	Periodic	0.8966	0.0007	-0.0015
Left Side	Mirrored	0.8968	0.0007	-0.0013
Left Side	Periodic	0.8976	0.0007	-0.0005

These results indicate that the most reactive fuel tube location is shifted to the right side of the tube with mirrored boundary conditions. This result is reasonable given the orientation of the assembly. Shifting the tube to the right side with mirrored boundary conditions moves a complete fuel rod row of two assemblies closer together, hence, pushing the largest amount of fuel together and minimizing the flux trap gap between tubes. In general, these results show that moving the tubes towards each other with the fuel assembly centered in the tube is the most reactive component configuration.

Based on the canistered fuel/basket model, the most reactive mechanical configuration occurs with the assemblies centered in the tubes, fuel tubes moved toward the center of the basket, maximum fuel tube opening, minimum disk opening, maximum disk thickness and close packed disk opening locations. The most reactive configuration documented by the fuel/basket analysis serves as the base model for the normal and accident analyses optimum moderation studies.

Directly loaded basket analyses indicate that the assembly centered in tube configuration may not represent the most reactive configuration in the cask analysis. The fuel/basket model clusters the fuel in groups of four (mirrored boundary), or shifts the fuel to one side of the tube (periodic boundary) and therefore does not represent the closest fuel material approach feasible in a radial inward moved model. To document the maximum reactivity configuration both tube and assembly movement analysis are repeated in the full cask model. The k_{eff} of these analysis are compared to the nominal cask model:

Position	k_{eff}	σ	Δk_{eff}
Nominal	0.8637	0.0007	---
Tubes Moved Toward the Basket Center	0.8689	0.0008	0.0052
Tubes Moved Toward the Basket Shell	0.8596	0.0008	-0.0041
Assemblies Moved Toward the Basket Center	0.8677	0.0007	0.0040
Assemblies Moved Toward the Basket Shell	0.8590	0.0008	-0.0047

Based on the cask analysis of the basket model without enlarged fuel tubes, moving the assembly toward the cask center configuration adds a Δk_{eff} of 0.004 to the reactivity of the nominal configuration. The model documented as the worst-case mechanical configuration in the fuel/basket and enlarged fuel tube evaluations is not adjusted from its assembly-centered configuration. The Δk_{eff} associated with the assembly movement is accounted for by adding the Δk_{eff} of 0.004 to the KENO-Va neutron multiplication factor (k_{eff}) during k_s calculations.

6.4.3.3 Normal Conditions

Yankee Class fuel assemblies will be sealed inside a canister that is welded shut. Consequently, the canistered fuel is dry under normal conditions of loading and transport. Criticality results under normal conditions exclude variations in moderator density, but include cask center-to-center spacing from 250 cm (touching) to 300 cm. Moderator density is taken to be 0.0001 g/cc (dry). The results for normal conditions of transport are shown in Table 6.4-4. Table 6.4-4 shows that cask reactivity is relatively insensitive to variations in cask center-to-center spacing. This results in a k_{eff} of 0.4580 ± 0.0006. The CSAS25 input and output for this case is shown in Figures 6.6-3 and 6.6-4, respectively. For conservatism a cask criticality analysis of a flooded, nominal condition, cask array is performed. The maximum reactivity for this configuration is a k_{eff} of 0.8761± 0.0007.

Including statistical and method uncertainties, all results for the normal condition are below the 0.95 NRC criticality safety limit. Thus, compliance with 10 CFR 71.55 (b) and (d) as well as 10 CFR 71.75 (a) is demonstrated.

6.4.3.4 Hypothetical Accident Conditions

Criticality results under hypothetical accident conditions include variations in moderator density from 1.0 g/cc to 0.1 g/cc (dry) as well as cask center-to-center spacing from 250.698 cm (touching) to 300 cm. The results are shown in Table 6.4-5. Under accident conditions, the cask and fuel is considered to be fully moderated as described in Section 6.1.2. The maximum k_{eff}, including uncertainties, for this situation is 0.9014. The CSAS25 input and output for this case is shown in Figures 6.6-5 and 6.6-6, respectively.

Including statistical and method uncertainties, all results for the accident condition are well below the 0.95 NRC criticality safety limit. Thus, compliance with 10 CFR 71.55 (e) is demonstrated.

6.4.3.5 Hypothetical Accident Evaluation for a Basket Containing Enlarged Fuel Tubes

The maximum reactivity, fully moderated, cask model is evaluated with four enlarged fuel tubes replacing the standard (BORAL sheets on four sides) fuel tube on the basket periphery. As expected, the reactivity of these systems increases slightly due the increased neutron interaction between fuel tubes in those locations where BORAL sheets were removed. Adjusting for the 0.004 Δk_{eff} associated with the assembly movement in the tubes, results in a maximum bias and

0.004 Δk_{eff} associated with the assembly movement in the tubes, results in a maximum bias and uncertainty adjusted k_{eff} (k_s) of 0.9183 for the hypothetical accident condition involving full moderator intrusion. Transport maximum reactivities for the enlarged fuel tube basket are, therefore, well below the 0.95 criticality safety limit.

Table 6.4-1 Criticality Results for Normal Conditions of Direct Fuel Loading

Cask Pitch	H_2O Inside	H_2O Outside	Neutron Shield	^{10}B	k_{eff}	σ	k_s
250 cm	1.0	1.0	No	Yes	0.91291	0.00086	0.92698
270 cm	1.0	1.0	No	Yes	0.91137	0.00085	0.92543
300 cm	1.0	1.0	No	Yes	0.91086	0.00087	0.92493
250 cm	0.8	0.8	No	Yes	0.84595	0.00083	0.86001
270 cm	0.8	0.8	No	Yes	0.84564	0.00083	0.85970
300 cm	0.8	0.8	No	Yes	0.84631	0.00083	0.86037
250 cm	0.6	0.6	No	Yes	0.76900	0.00114	0.78319
270 cm	0.6	0.6	No	Yes	0.76642	0.00110	0.78059
300 cm	0.6	0.6	No	Yes	0.76671	0.00117	0.78092
250 cm	0.4	0.4	No	Yes	0.67331	0.00106	0.68746
270 cm	0.4	0.4	No	Yes	0.67276	0.00104	0.68691
300 cm	0.4	0.4	No	Yes	0.67441	0.00110	0.68858
250 cm	0.2	0.2	No	Yes	0.55708	0.00121	0.57131
270 cm	0.2	0.2	No	Yes	0.55593	0.00120	0.57015
300 cm	0.2	0.2	No	Yes	0.55529	0.00110	0.56946
250 cm	0.1	0.1	No	Yes	0.49153	0.00123	0.50577
270 cm	0.1	0.1	No	Yes	0.49294	0.00130	0.50722
300 cm	0.1	0.1	No	Yes	0.49293	0.00134	0.50723

Table 6.4-2 Criticality Results for Normal Conditions of Transport of Directly Loaded Fuel

Cask Pitch	H_2O Inside	H_2O Outside	Neutron Shield	^{10}B	k_{eff}	σ	k_s
250 cm	0.0001	1.0	Yes	No	0.40726	0.00084	0.42132
270 cm	0.0001	1.0	Yes	No	0.40776	0.00106	0.42191
300 cm	0.0001	1.0	Yes	No	0.40638	0.00086	0.42045
250 cm	0.0001	0.8	Yes	No	0.40775	0.00096	0.42186
270 cm	0.0001	0.8	Yes	No	0.40756	0.00092	0.42165
300 cm	0.0001	0.8	Yes	No	0.40704	0.00100	0.42117
250 cm	0.0001	0.6	Yes	No	0.40862	0.00085	0.42268
270 cm	0.0001	0.6	Yes	No	0.40788	0.00085	0.42194
300 cm	0.0001	0.6	Yes	No	0.40823	0.00081	0.42228
250 cm	0.0001	0.4	Yes	No	0.40805	0.00091	0.42214
270 cm	0.0001	0.4	Yes	No	0.40706	0.00080	0.42111
300 cm	0.0001	0.4	Yes	No	0.40580	0.00091	0.41989
250 cm	0.0001	0.2	Yes	No	0.40931	0.00092	0.42340
270 cm	0.0001	0.2	Yes	No	0.40933	0.00098	0.42345
300 cm	0.0001	0.2	Yes	No	0.40683	0.00082	0.42088
250 cm	0.0001	0.1	Yes	No	0.40663	0.00085	0.42069
270 cm	0.0001	0.1	Yes	No	0.40955	0.00094	0.42365
300 cm	0.0001	0.1	Yes	No	0.40796	0.00091	0.42205

Table 6.4-3 Criticality Results for Directly Loaded Fuel in Hypothetical Accident Conditions

Cask Pitch	H_2O Inside	H_2O Outside	Neutron Shield	^{10}B	k_{eff}	σ	k_s
250 cm	1.0	1.0	No	Yes	0.91902	0.00085	0.93308
270 cm	1.0	1.0	No	Yes	0.91787	0.00086	0.93194
300 cm	1.0	1.0	No	Yes	0.91799	0.00087	0.93206
250 cm	0.8	0.8	No	Yes	0.85275	0.00084	0.86681
270 cm	0.8	0.8	No	Yes	0.85247	0.00085	0.86653
300 cm	0.8	0.8	No	Yes	0.85157	0.00087	0.86564
250 cm	0.6	0.6	No	Yes	0.77755	0.00084	0.79161
270 cm	0.6	0.6	No	Yes	0.77531	0.00084	0.78937
300 cm	0.6	0.6	No	Yes	0.77623	0.00083	0.79029
250 cm	0.4	0.4	No	Yes	0.67887	0.00075	0.69290
270 cm	0.4	0.4	No	Yes	0.67727	0.00105	0.69142
300 cm	0.4	0.4	No	Yes	0.68166	0.00099	0.69578
250 cm	0.2	0.2	No	Yes	0.56011	0.00059	0.57409
270 cm	0.2	0.2	No	Yes	0.55940	0.00118	0.57361
300 cm	0.2	0.2	No	Yes	0.56053	0.00119	0.57475
250 cm	0.1	0.1	No	Yes	0.49514	0.00044	0.50908
270 cm	0.1	0.1	No	Yes	0.49439	0.00135	0.50870
300 cm	0.1	0.1	No	Yes	0.49446	0.00122	0.50870

Table 6.4-4 Criticality Results for Normal Conditions of Transport of Canistered Fuel

Cask Pitch (cm)	H_2O Interior	H_2O Exterior	Neutron Shield	^{10}B	k_{eff}	σ	k_s
250.698	0.0001	1.0	Yes	75.0%	0.4573	0.00067	0.4753
270	0.0001	1.0	Yes	75.0%	0.4557	0.00062	0.4737
300	0.0001	1.0	Yes	75.0%	0.4566	0.00066	0.4746
250.698	0.0001	0.8	Yes	75.0%	0.4569	0.00068	0.4749
270	0.0001	0.8	Yes	75.0%	0.4564	0.00071	0.4744
300	0.0001	0.8	Yes	75.0%	0.4566	0.00064	0.4746
250.698	0.0001	0.6	Yes	75.0%	0.4580	0.00064	0.4760
270	0.0001	0.6	Yes	75.0%	0.4570	0.00069	0.4750
300	0.0001	0.6	Yes	75.0%	0.4579	0.00066	0.4759
250.698	0.0001	0.4	Yes	75.0%	0.4573	0.00046	0.4752
270	0.0001	0.4	Yes	75.0%	0.4575	0.00049	0.4755
300	0.0001	0.4	Yes	75.0%	0.4566	0.0006	0.4746
250.698	0.0001	0.2	Yes	75.0%	0.4557	0.00063	0.4737
270	0.0001	0.2	Yes	75.0%	0.4577	0.00073	0.4758
300	0.0001	0.2	Yes	75.0%	0.4576	0.00067	0.4756
250.698	0.0001	0.1	Yes	75.0%	0.4562	0.00061	0.4742
270	0.0001	0.1	Yes	75.0%	0.4566	0.00068	0.4746
300	0.0001	0.1	Yes	75.0%	0.4572	0.00067	0.4752

Table 6.4-5 Criticality Results for Canistered Fuel Hypothetical Accident Conditions

Cask Pitch (cm)	H_2O Interior	H_2O Exterior	Neutron Shield	^{10}B	k_{eff}	σ	k_s
250.698	1.0	1.0	No	75.0%	0.8830	0.00074	0.9011
270	1.0	1.0	No	75.0%	0.8819	0.00075	0.8999
300	1.0	1.0	No	75.0%	0.8834	0.00075	0.9014
250.698	0.8	0.8	No	75.0%	0.8328	0.0008	0.8509
270	0.8	0.8	No	75.0%	0.8334	0.00083	0.8514
300	0.8	0.8	No	75.0%	0.8312	0.00084	0.8493
250.698	0.6	0.6	No	75.0%	0.7725	0.00089	0.7906
270	0.6	0.6	No	75.0%	0.7728	0.00089	0.7908
300	0.6	0.6	No	75.0%	0.7742	0.0009	0.7923
250.698	0.4	0.4	No	75.0%	0.6994	0.00094	0.7175
270	0.4	0.4	No	75.0%	0.6997	0.00107	0.7178
300	0.4	0.4	No	75.0%	0.6973	0.00103	0.7154
250.698	0.2	0.2	No	75.0%	0.6086	0.00121	0.6268
270	0.2	0.2	No	75.0%	0.6113	0.00113	0.6295
300	0.2	0.2	No	75.0%	0.6098	0.0005	0.6278
250.698	0.1	0.1	No	75.0%	0.5585	0.0009	0.5766
270	0.1	0.1	No	75.0%	0.5578	0.00097	0.5759
300	0.1	0.1	No	75.0%	0.5580	0.00094	0.5761

SCALE 4.3 package. Trending in k_{eff} was evaluated for the following independent variables: wt % ^{235}U, rod pitch, H/U volume ratio, average neutron group causing fission, ^{10}B loading for flux trap cases, and flux trap gap thickness. No statistically significant trends were found, and a constant bias with associated uncertainty was determined for criticality evaluation.

Both the NUREG/CR-6361 and the NAC approach to criticality evaluation start with ANSI/ANS-8.17 criticality safety criterion. This criterion is:

$$k_s \leq k_c - \Delta k_s - \Delta k_c - \Delta k_m \qquad (1)$$

where:

k_s = calculated allowable maximum multiplication factor, k_{eff}, of the system being evaluated for all normal or credible abnormal conditions or events.

k_c = mean k_{eff} that results from a calculation of benchmark criticality experiments using a particular calculation method. If the calculated k_{eff} values for the criticality experiments exhibit a trend with an independent parameter, then k_c shall be determined by extrapolation based on best fit to calculated values. Criticality experiments used as benchmarks in computing k_c should have physical compositions, configurations, and nuclear characteristics (including reflectors) similar to those of the system being evaluated.

Δk_s = allowance for:

a) statistical or convergence uncertainties, or both, in computation of k_s,
b) material and fabrication tolerances, and
c) geometric or material representations used in computational method.

Δk_c = margin for uncertainty in k_c which includes allowance for:

a) uncertainties in critical experiments,
b) statistical or convergence uncertainties, or both, in computation of k_c,
c) uncertainties resulting from extrapolation of k_c outside range of experimental data, and
d) uncertainties resulting from limitations in geometrical or material representations used in computational method.

Δk_m = arbitrary administrative margin to ensure subcriticality of k_s.

The various uncertainties are combined statistically if they are independent. Correlated uncertainties are combined by addition.

Equation 1 can be rewritten as:

$$k_s \leq 1 - \Delta k_m - \Delta k_s - (1-k_c) - \Delta k_c \qquad (2)$$

Noting that the definition of the bias is $\beta = 1-k_c$, Equation 2 can be written as:

$$k_s + \Delta k_s \leq 1-\Delta k_m - \beta - \Delta\beta \qquad (3)$$

where $\Delta\beta = \Delta k_c$. Thus, the maximum allowable value for k_{eff} plus uncertainties in the system being analyzed must be below 1 minus an administrative margin (typically 0.05), the bias and the uncertainty in the bias. This can also be written as:

$$k_s + \Delta k_s \leq USL \qquad (4)$$

where,

$$USL \equiv 1 - \Delta k_m - \beta - \Delta\beta \qquad (5)$$

This is the Upper Safety Limit criterion as described in Section 4 of NUREG/CR-6361. Two methods are prescribed for the statistical determination of the USL: Confidence Band with Administrative Margin (USL-1) and Single Sided Uniform with Close Approach (USL-2). In the first method, $\Delta k_m = 0.05$ and a lower confidence band (usually 95%) is specified based on a linear regression of k_{eff} as a function of some system parameter. In the second method, the arbitrary administrative margin is set to zero and a uniform lower tolerance band is determined based on a linear regression. Thus, the second method provides a criticality safety margin that is generally less than 0.05. In cases where there are a limited number of data points, this method may indicate the need for a larger administrative margin. In both cases, all the significant system parameters need to be studied to determine the strongest correlation.

In the Section 6.5.1 and 6.5.2 analyses, the bias and uncertainties are applied directly to the estimate of the system k_{eff}. Noting that the NRC requires a 5% subcriticality margin (Δk_m = 0.05), Equation 3 can be rewritten applying the bias and uncertainty in the bias to the k_{eff} of the system being analyzed as:

$$k_s + \Delta k_s + \beta + \Delta\beta \leq 0.95 \qquad (6)$$

In Equation 6, the method bias and all uncertainties are added to k_s. This is the maximum k_{eff} criterion defined in Section 6.5.2.

To this point, both the USL criterion and maximum k_{eff} criterion are equivalent. The effects of trending in the bias or the uncertainty in the bias can be directly incorporated into either equation 5 or equation 6. Trending is established by performing a regression analysis of k_{eff} as a function of the principle system variables such as: enrichment, rod pitch, H to U ratio, average group of fission, ^{10}B absorber loading and flux trap gap spacing. Usually, simple linear regression is performed, and the line with the greatest correlation is used to functionalize β. This is the approach recommended in NUREG/CR-6361. However, if no strong correlation can be determined, then a constant bias adjustment can be made. This is typically done with a one-side tolerance factor that guarantees 95% confidence in the uncertainty in the bias. This is the approach taken in the NAC criticality analysis.

Both NUREG/CR-6361 and the NAC methodology performed regression analysis on key system parameters. For all the major system parameters, the NAC methodology found no strong correlation. This is based on the observation that the correlation coefficients are all much less than ± 1. Thus, a constant bias with a 95/95 confidence factor is applied to the system k_{eff}. The NAC methodology's statistical analysis of the k_{eff} results produced a bias of 0.0052 and a 95/95 uncertainty of 0.0087. Adding the two together and subtracting from 0.95, yields an effective constant USL of 0.9361.

To assure compliance with NUREG/CR-6361, an upper safety limit is generated using USLSTATS and is compared to the constant NAC methodology bias and bias uncertainty used in Section 6.5.2.

To evaluate the relative importance of the trend analysis to the upper safety limits, correlation coefficients are required for all independent parameters. Table 6.5.2 contains the correlation coefficients, R, for each linear fit of k_{eff} versus experimental parameter (data is extracted from Figure 6.5.2 through Figure 6.5.7 by taking the square root of the listed R^2 value). Based on the highest correlation coefficient and the method presented in NUREG/CR-6361, a USL will be established based on the variation of k_{eff} with enrichment. Note that even the enrichment function shows a low statistical correlation coefficient (an $|R|$ equal or near 1 would indicate a good fit). The output generated by USLSTATS is shown in Figure 6.5.8.

The NAC methodology applied USL of 0.9361 bounds the calculated upper safety limits for all enrichment values above 3 wt % ^{235}U. Since the maximum reactivities are calculated at enrichments well above this level, the existing bias bounds the NUREG calculated USL. The parameters of the most reactive fuel element analysis are listed in Table 6.5-3.

Figure 6.5-1 KENO-Va Validation - 27 Group Library Results Frequency Distribution of K_{eff} Values

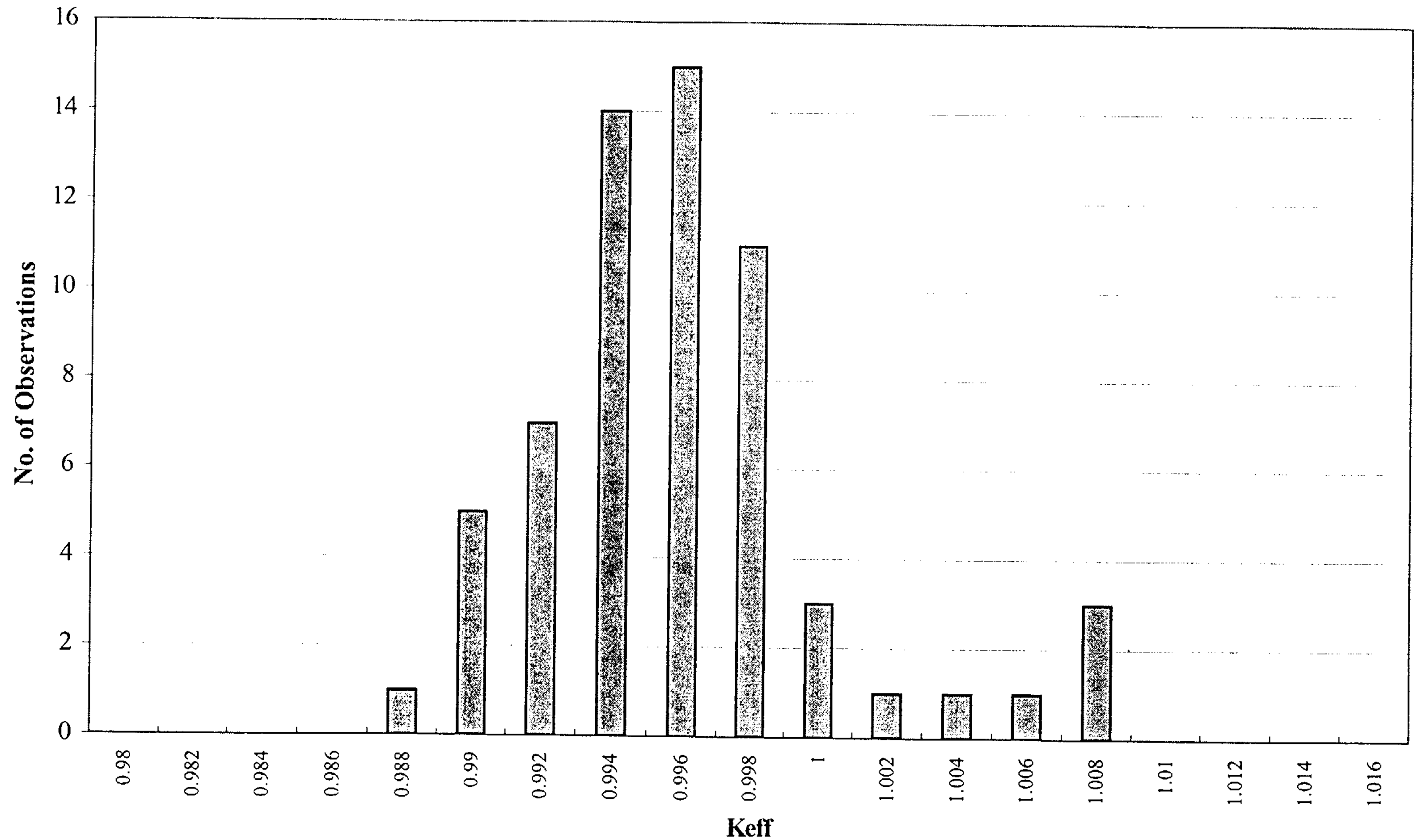

Figure 6.5-2 KENO-Va Validation -27 Group Library K_{eff} versus Enrichment

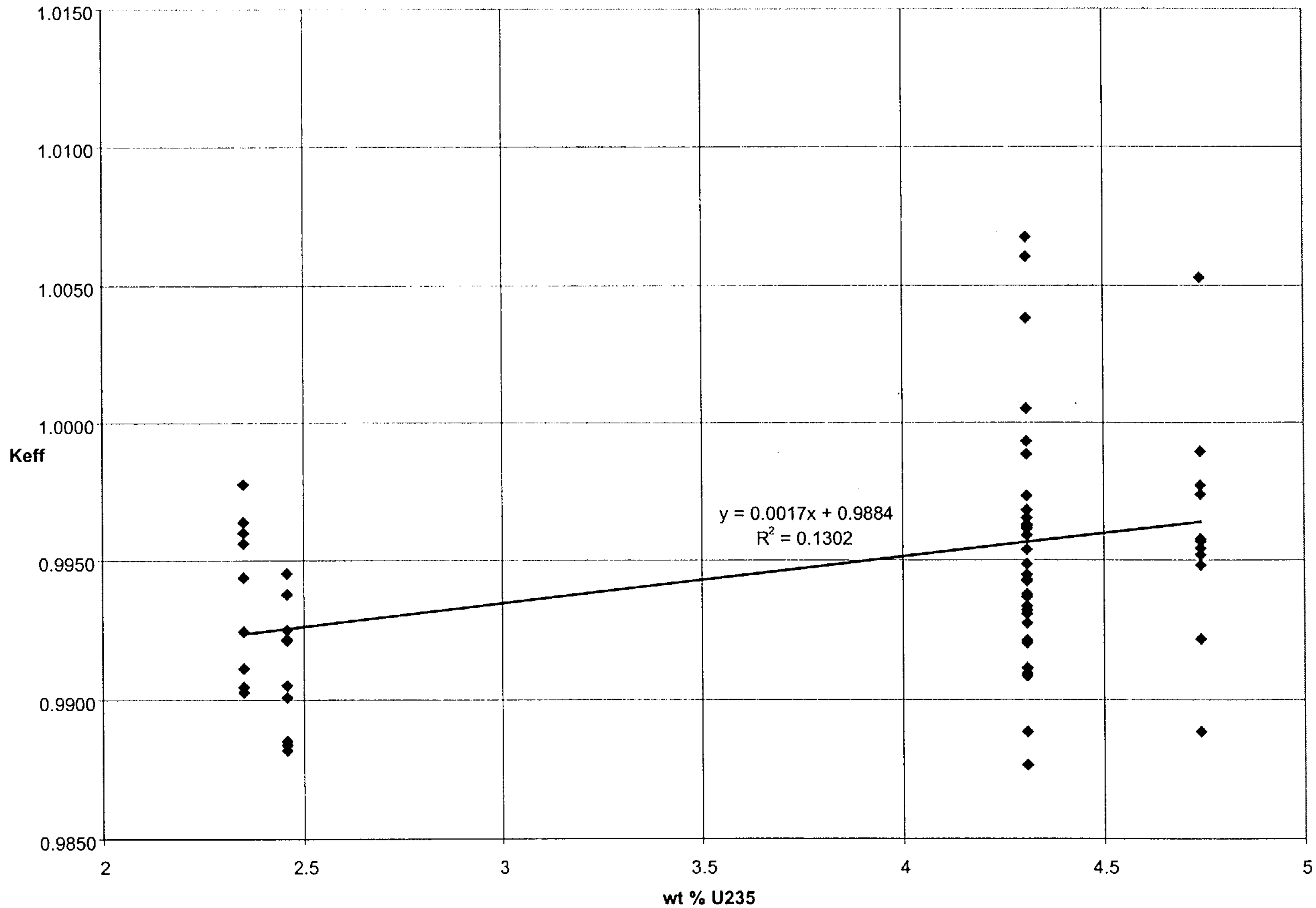

Figure 6.5-3 KENO-Va Validation - 27 Group Library K_{eff} versus Rod Pitch

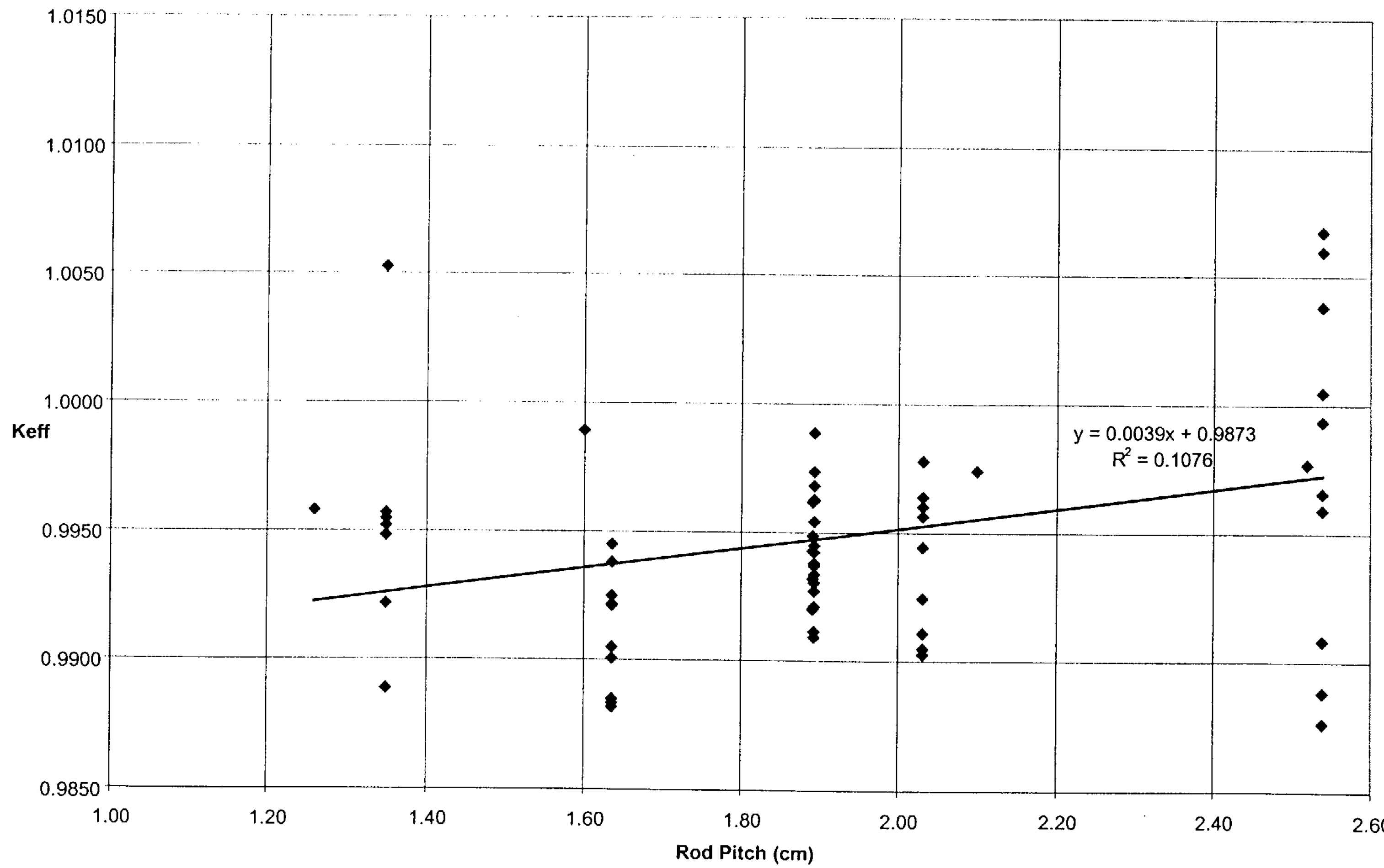

Figure 6.5-4 KENO-Va Validation -27 Group Library K_{eff} versus H/U Volume Ratio

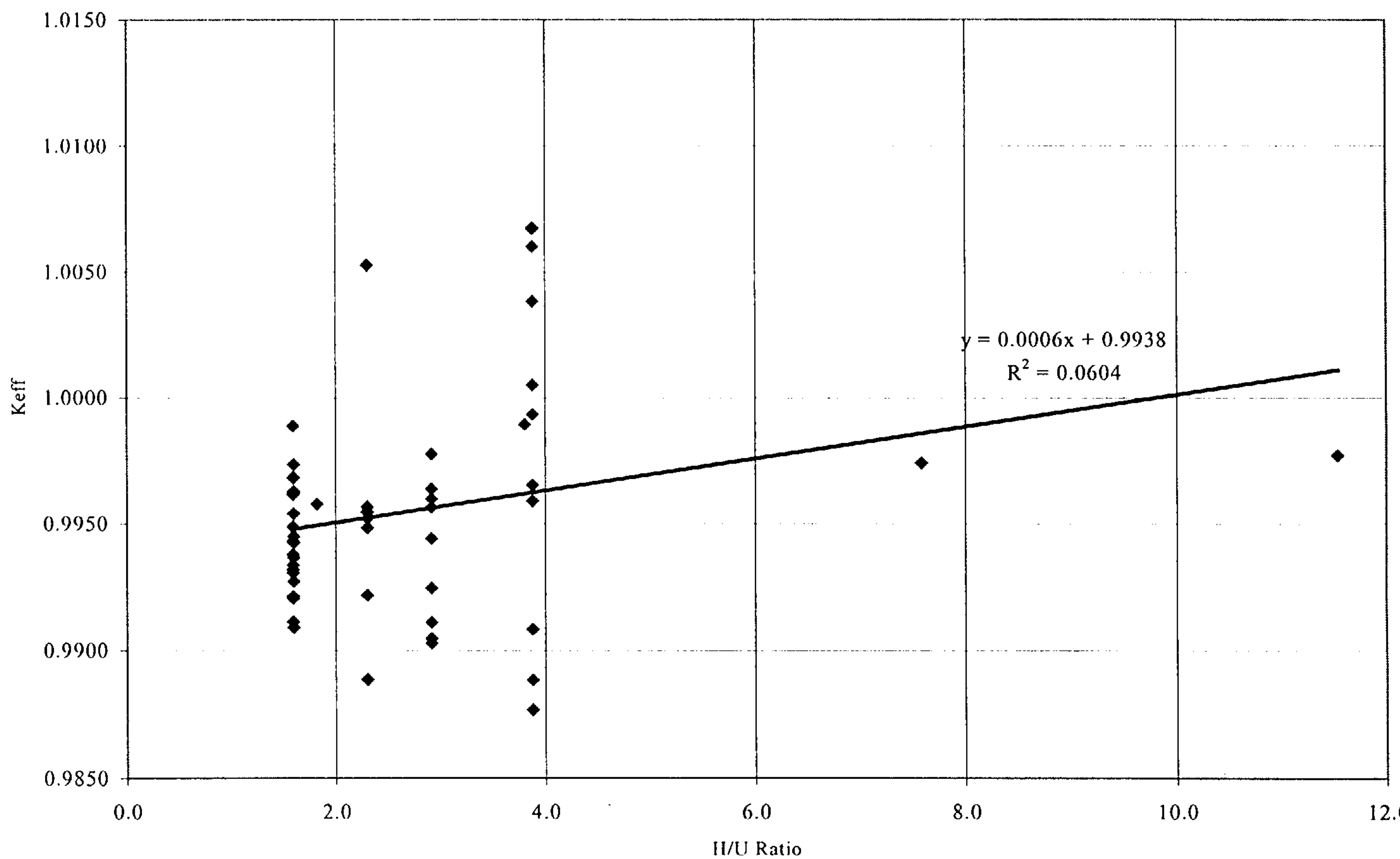

Figure 6.5-5 KENO-Va Validation -27 Group Library K_{eff} versus Average Group of Fission

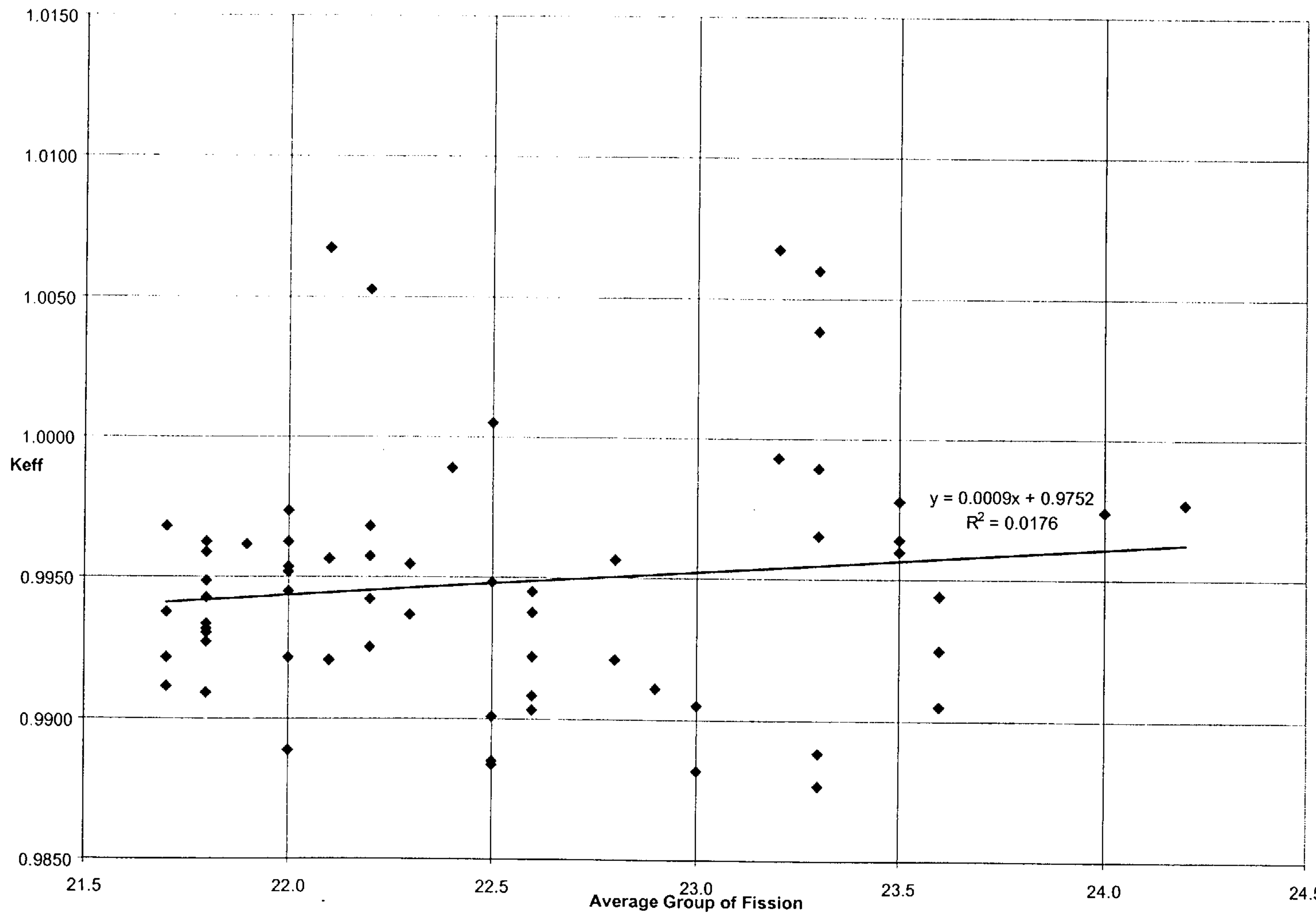

Figure 6.5-6 KENO-Va Validation - 27 Group Library K_{eff} versus ^{10}B Loading For Flux Trap Criticals

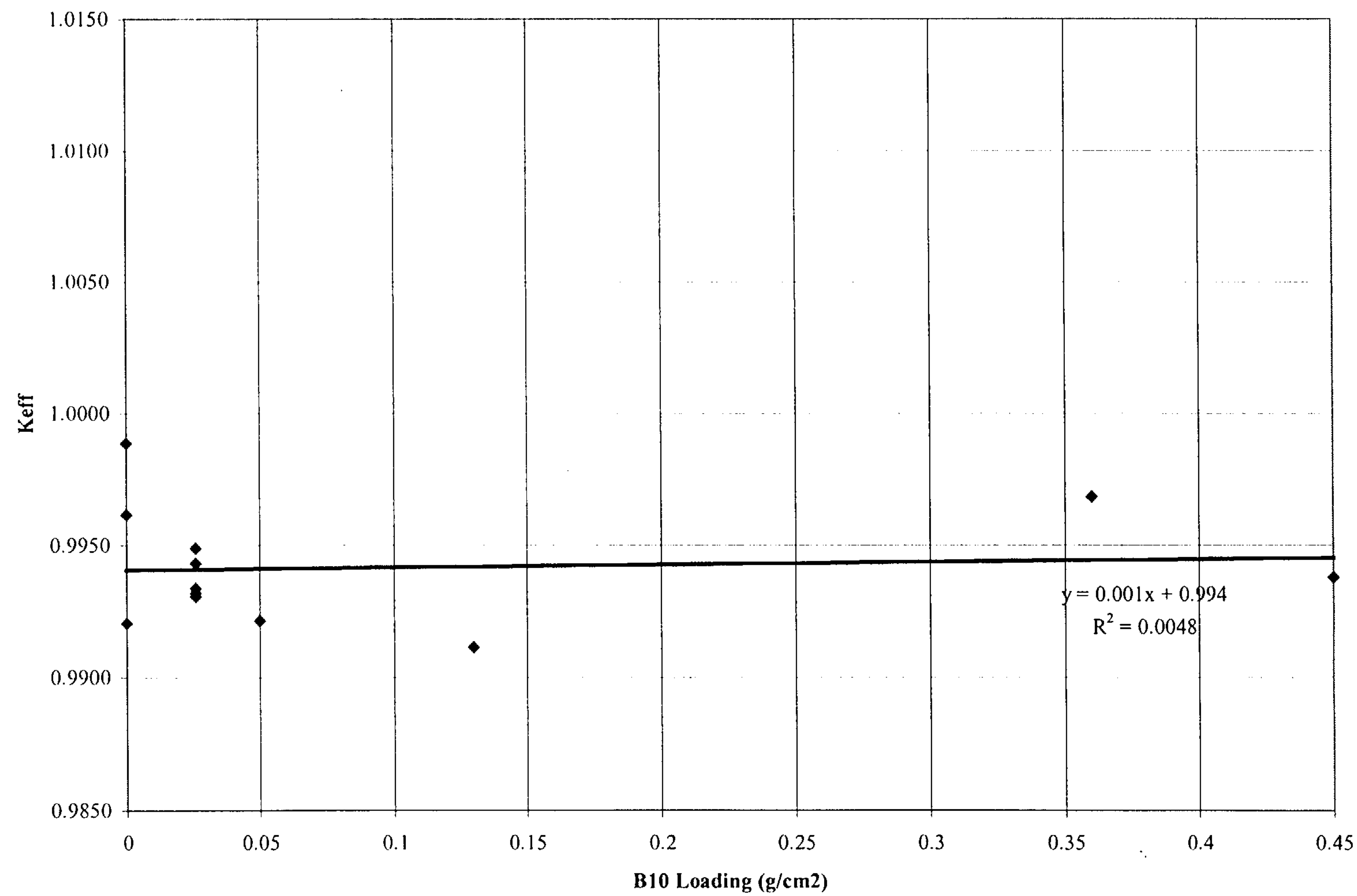

Figure 6.5-7 KENO-Va Validation -27 Group Library Results K_{eff} versus Flux Trap Critical Gap Thickness

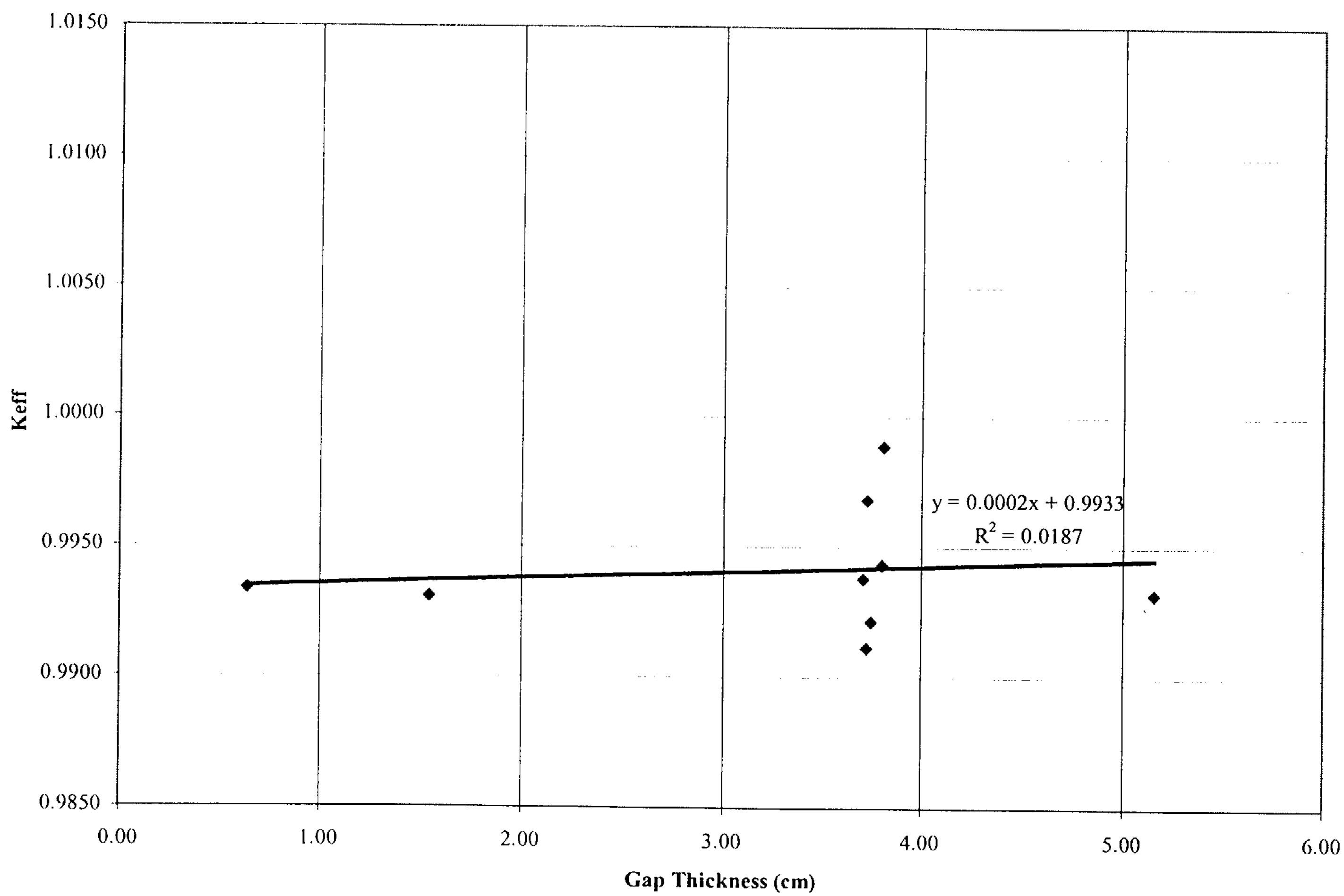

Figure 6.5-8 USLSTATS Output for Fuel Enrichment Study

```
uslstats: a utility to calculate upper subcritical
limits for criticality safety applications

****************************************************************************
Version 1.3.4, February 12, 1998
Oak Ridge National Laboratory
****************************************************************************


Input to statistical treatment from file:EN_KEFF.TXT

Title: 63 LWR CRITICAL EXPERIMENT KEFF VS ENRICHMENT

Proportion of the population = .995
Confidence of fit            = .950
Confidence on proportion     = .950
Number of observations       =   63
Minimum value of closed band =    0.00
Maximum value of closed band =    0.00
Administrative margin        =    0.05
```

independent variable - x	dependent variable - y	deviation in y
2.35000E+00	9.96400E-01	1.00000E-03
2.35000E+00	9.94400E-01	1.00000E-03
2.35000E+00	9.90500E-01	1.00000E-03
2.35000E+00	9.96000E-01	1.10000E-03
2.35000E+00	9.97800E-01	1.00000E-03
2.35000E+00	9.92500E-01	1.00000E-03
2.35000E+00	9.90300E-01	9.00000E-04
2.35000E+00	9.95700E-01	1.00000E-03
2.35000E+00	9.91100E-01	1.00000E-03
2.46000E+00	9.92100E-01	1.10000E-03
2.46000E+00	9.92500E-01	9.00000E-04
2.46000E+00	9.93800E-01	9.00000E-04
2.46000E+00	9.90500E-01	1.00000E-03
2.46000E+00	9.88200E-01	1.00000E-03
2.46000E+00	9.94500E-01	1.00000E-03
2.46000E+00	9.92200E-01	1.00000E-03
2.46000E+00	9.88500E-01	1.00000E-03
2.46000E+00	9.88400E-01	1.00000E-03
2.46000E+00	9.90100E-01	9.00000E-04
4.31000E+00	9.95400E-01	1.40000E-03
4.31000E+00	9.94500E-01	1.30000E-03
4.31000E+00	9.97400E-01	1.30000E-03
4.31000E+00	9.96300E-01	1.30000E-03
4.31000E+00	9.92700E-01	1.20000E-03
4.31000E+00	9.90900E-01	1.20000E-03
4.31000E+00	9.96200E-01	1.20000E-03
4.31000E+00	9.93700E-01	1.30000E-03
4.31000E+00	9.94200E-01	1.20000E-03
4.31000E+00	9.96800E-01	1.20000E-03
4.31000E+00	9.87700E-01	2.30000E-03
4.31000E+00	9.99300E-01	1.20000E-03
4.31000E+00	1.00600E+00	2.20000E-03
4.31000E+00	9.96500E-01	1.10000E-03
4.31000E+00	1.00680E+00	2.10000E-03
4.31000E+00	1.00380E+00	1.20000E-03
4.31000E+00	9.88900E-01	1.10000E-03
4.31000E+00	9.95900E-01	1.10000E-03
4.31000E+00	1.00670E+00	1.00000E-03
4.31000E+00	1.00050E+00	1.10000E-03
4.31000E+00	9.90800E-01	1.10000E-03
4.31000E+00	9.98900E-01	1.20000E-03
4.31000E+00	9.92100E-01	1.20000E-03
4.31000E+00	9.91100E-01	1.20000E-03
4.31000E+00	9.96800E-01	1.30000E-03
4.31000E+00	9.93800E-01	1.20000E-03
4.31000E+00	9.93400E-01	1.00000E-03
4.31000E+00	9.93100E-01	1.00000E-03
4.31000E+00	9.94300E-01	1.00000E-03
4.31000E+00	9.93200E-01	1.00000E-03
4.31000E+00	9.94900E-01	1.00000E-03
4.31000E+00	9.92000E-01	1.00000E-03
4.31000E+00	9.96200E-01	1.00000E-03
4.74000E+00	9.92200E-01	1.30000E-03
4.74000E+00	9.88900E-01	1.30000E-03
4.74000E+00	9.95700E-01	1.30000E-03
4.74000E+00	1.00530E+00	1.10000E-03
4.74000E+00	9.95500E-01	1.20000E-03
4.74000E+00	9.94800E-01	1.30000E-03
4.74000E+00	9.95800E-01	1.20000E-03
4.74000E+00	9.95200E-01	1.20000E-03
4.74000E+00	9.98900E-01	1.30000E-03
4.74000E+00	9.97400E-01	1.20000E-03
4.74000E+00	9.97700E-01	1.10000E-03

```
chi =  2.1587 (upper bound = 9.49). The data tests normal.


Output from statistical treatment
```

Figure 6.5-8 USLSTATS Output for Fuel Enrichment Study (Continued)

```
63 LWR CRITICAL EXPERIMENT KEFF VS ENRICHMENT

Number of data points (n)                            63
Linear regression, k(X)                            0.9884 + ( 1.6748E-03)*X
Confidence on fit (1-gamma) [input]                 95.0%
Confidence on proportion (alpha) [input]            95.0%
Proportion of population falling above
lower tolerance interval (rho) [input]              99.5%
Minimum value of X                                     2.3500
Maximum value of X                                     4.7400
Average value of X                                     3.81143
Average value of k                                   0.99482
Minimum value of k                                   0.98770
Variance of fit, s(k,X)^2                           1.6973E-05
Within variance, s(w)^2                             1.4306E-06
Pooled variance, s(p)^2                             1.8404E-05
Pooled std. deviation, s(p)                         4.2900E-03
C(alpha,rho)*s(p)                                   1.5488E-02
student-t @ (n-2,1-gamma)                           1.67078E+00
Confidence band width, W                            7.3606E-03
Minimum margin of subcriticality, C*s(p)-W          8.1273E-03

Upper subcritical limits: (  2.35000 <= X <=    4.74000)
***** *********** *******

USL Method 1 (Confidence Band with
Administrative Margin)            USL1 = 0.9311 + ( 1.6748E-03)*X

USL Method 2 (Single-Sided Uniform
Width Closed Interval Approach)   USL2 = 0.9729 + ( 1.6748E-03)*X


USLs Evaluated Over Range of Parameter X:
**** ********* **** ***** ** ********* **

X:    2.35    2.69    3.03    3.37    3.72    4.06    4.40    4.74
-----------------------------------------------------------------
USL-1:  0.9350 0.9356 0.9362 0.9367 0.9373 0.9379 0.9384 0.9390
USL-2:  0.9769 0.9775 0.9780 0.9786 0.9792 0.9797 0.9803 0.9809
-----------------------------------------------------------------

*****************************************************************************
Thus spake USLSTATS
Finis.
```

Table 6.5-1 KENO-Va and 27 Group Library Validation Statistics

Criticals	Configuration	wt % ^{235}U	Pitch (cm)	Clad OD (cm)	Pellet OD (cm)	H/U	Sol. B (ppm)	Poison	g ^{10}B/cm^2	Gap(cm)	Gap Den.	Average FissionGroup	K_{eff}	σ
Set 1														
B&W-I	Cylindrical	2.46	1.636	1.206	1.03	1.6	0	na	na	0		22.8	0.9921	0.0011
B&W-II	3X3-14X14	2.46	1.636	1.206	1.03	1.6	1037	na	na	0		22.2	0.9925	0.0009
B&W-III	3X3-14X14	2.46	1.636	1.206	1.03	1.6	764	na	na	1.636		22.6	0.9938	0.0009
B&W-IX	3X3-14X14	2.46	1.636	1.206	1.03	1.6	0	na	na	6.543		23	0.9905	0.0010
B&W-X	3X3-14X14	2.46	1.636	1.206	1.03	1.6	143	na	na	4.907		23	0.9882	0.0010
B&W-XI	3X3-14X14	2.46	1.636	1.206	1.03	1.6	514	Steel	0	1.636		22.6	0.9945	0.0010
B&W-XIII	3X3-14X14	2.46	1.636	1.206	1.03	1.6	15	B-Al	0.0052	1.636		22.6	0.9922	0.0010
B&W-XIV	3X3-14X14	2.46	1.636	1.206	1.03	1.6	92	B-Al	0.0040	1.636		22.5	0.9885	0.0010
B&W-XVII	3X3-14X14	2.46	1.636	1.206	1.03	1.6	487	B-Al	0.0008	1.636		22.5	0.9884	0.0010
B&W-XIX	3X3-14X14	2.46	1.636	1.206	1.03	1.6	634	B-Al	0.0003	1.636		22.5	0.9901	0.0009
												Average	0.9911	0.0023
Set 2														
PNL-043	17X13 Lattice	4.31	1.892	1.415	1.265	1.6	0	na	na	na	na	22.0	0.9954	0.0014
PNL-044	16X14 Lattice	4.31	1.892	1.415	1.265	1.6	0	na	na	na	na	22.0	0.9945	0.0013
PNL-045	14X16 Lattice	4.31	1.892	1.415	1.265	1.6	0	na	na	na	na	22.0	0.9974	0.0013
PNL-046	12x19 Lattice	4.31	1.892	1.415	1.265	1.6	0	na	na	na	na	22.0	0.9963	0.0013
PNL-087	4 11X14 Arrays	4.31	1.892	1.415	1.265	1.6	0	BORAL	0.066	2.83		21.8	0.9927	0.0012
PNL-079	4 11X14 Arrays	4.31	1.892	1.415	1.265	1.6	0	BORAL	0.030	2.83		21.8	0.9909	0.0012
PNL-093	4 11X14 Arrays	4.31	1.892	1.415	1.265	1.6	0	BORAL	0.026	2.83		21.8	0.9962	0.0012
PNL-115	4 9X12 Arrays	4.31	1.892	1.415	1.265	1.6	0	Aluminum	0	2.83		22.3	0.9937	0.0013
PNL-064	4 9X12 Arrays	4.31	1.892	1.415	1.265	1.6	0	Steel (.302)	0	2.83		22.2	0.9942	0.0012
PNL-071	4 9X12 Arrays	4.31	1.892	1.415	1.265	1.6	0	Steel (.485)	0	2.83		22.2	0.9968	0.0012
												Average	0.9948	0.0020

Table 6.5-1 KENO-Va and 27 Group Library Validation Statistics (continued)

Criticals	Configuration	wt % ^{235}U	Pitch (cm)	Clad OD (cm)	Pellet OD (cm)	H/U	Sol. B (ppm)	Poison	g $^{10}B/cm^2$	Gap(cm)	Gap Den.	Average Fission Group	K_{eff}	σ
Set 3										Cluster	Wall/Cluster			
PNL-STA	3X1 St Refl.	2.35	2.032	1.27	1.1176	2.9	0	na	na	10.65	0.00	23.5	0.9964	0.0010
PNL-STB	3X1 St Refl.	2.35	2.032	1.27	1.1176	2.9	0	na	na	11.20	1.32	23.6	0.9944	0.0010
PNL-STC	3X1 St Refl.	2.35	2.032	1.27	1.1176	2.9	0	na	na	10.36	2.62	23.6	0.9905	0.0010
PNL-PBA	3X1 Pb Refl.	2.35	2.032	1.27	1.1176	2.9	0	na	na	13.84	0.00	23.5	0.9960	0.0011
PNL-PBB	3X1 Pb Refl.	2.35	2.032	1.27	1.1176	2.9	0	na	na	13.72	0.66	23.5	0.9978	0.0010
PNL_PBC	3X1 Pb Refl.	2.35	2.032	1.27	1.1176	2.9	0	na	na	11.25	2.62	23.6	0.9925	0.0010
PNL-DUA	3X1 DU Refl.	2.35	2.032	1.27	1.1176	2.9	0	na	na	11.83	0.00	22.6	0.9903	0.0009
PNL-DUB	3X1 DU Refl.	2.35	2.032	1.27	1.1176	2.9	0	na	na	14.11	1.96	22.8	0.9957	0.0010
PNL-DUC	3X1 DU Refl.	2.35	2.032	1.27	1.1176	2.9	0	na	na	13.70	2.62	22.9	0.9911	0.0010
PNL-H20	3X1 H2O Refl	4.31	2.54	1.415	1.265	3.9	0	na	na	8.24	inf	23.3	0.9877	0.0023
PNL-ST0	3X1 St Refl.	4.31	2.54	1.415	1.265	3.9	0	na	na	12.89	0	23.2	0.9993	0.0012
PNL-ST1	3X1 St Refl.	4.31	2.54	1.415	1.265	3.9	0	na	na	14.12	1.32	23.3	1.0060	0.0022
PNL-ST26	3X1 St Refl.	4.31	2.54	1.415	1.265	3.9	0	na	na	12.44	2.62	23.3	0.9965	0.0011
PNL-PB0	3X1 Pb Refl.	4.31	2.54	1.415	1.265	3.9	0	na	na	20.62	0	23.2	1.0068	0.0021
PNL-PB13	3X1 Pb Refl.	4.31	2.54	1.415	1.265	3.9	0	na	na	19.04	1.32	23.3	1.0038	0.0012
PNL-PB5	3X1 Pb Refl.	4.31	2.54	1.415	1.265	3.9	0	na	na	10.3	5.41	23.3	0.9889	0.0011
PNL-DU0	3X1 DU Refl.	4.31	2.54	1.415	1.265	3.9	0	na	na	15.38	0	21.8	0.9959	0.0011
PNL-DU13	3X1 DU Refl.	4.31	2.54	1.415	1.265	3.9	0	na	na	19.04	1.32	22.1	1.0067	0.0010
PNL-DU39	3X1 DU Refl.	4.31	2.54	1.415	1.265	3.9	0	na	na	18.05	3.91	22.5	1.0005	0.0011
PNL-DU54	3X1 DU Refl.	4.31	2.54	1.415	1.265	3.9	0	na	na	13.49	5.41	22.6	0.9908	0.0011
												Average	0.9964	0.0060

Table 6.5-1 KENO-Va and 27 Group Library Validation Statistics (continued)

Criticals	Configuration	wt % ^{235}U	Pitch (cm)	Clad OD (cm)	Pellet OD (cm)	H/U	Sol. B (ppm)	Poison	g $^{10}B/cm^2$	Gap(cm)	Gap Den.	Average Fission Group	K_{eff}	σ
Set 4														
PNL-229	2x2 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	Aluminum	0	3.81	0.9982	22.4	0.9989	0.0012
PNL-230	2x2 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	BORAL	0.05	3.75	0.9982	21.7	0.9921	0.0012
PNL-228	2x2 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	BORAL	0.13	3.73	0.9982	21.7	0.9911	0.0012
PNL-214	2x2 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	BORAL	0.36	3.73	0.9982	21.7	0.9968	0.0013
PNL-231	2x2 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	BORAL	0.45	3.71	0.9982	21.7	0.9938	0.0012
PNL-127	2x1 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	BORAL	0.026	0.64	0.9982	21.8	0.9934	0.0010
PNL-126	2x1 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	BORAL	0.026	1.54	0.9982	21.8	0.9931	0.0010
PNL-123	2x1 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	BORAL	0.026	3.80	0.9982	21.8	0.9943	0.0010
PNL-125	2x1 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	BORAL	0.026	5.16	0.9982	21.8	0.9932	0.0010
PNL-124	2x1 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	BORAL	0.026	INF	0.9982	21.8	0.9949	0.0010
PNL-123-S	2x1 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	Steel	0	3.80	0.9982	22.1	0.9920	0.0010
PNL-124-S	2x1 Flux Trap	4.31	1.89	1.415	1.265	1.6	0	Steel	0	INF	0.9982	21.9	0.9962	0.0010
												Average	0.9941	0.0022
Set 5														
VCML	2x2 Water Gap	4.74	1.35	0.94	0.79	2.3	0	na	na	1.90	0	22.0	0.9922	0.0013
VCML	2x2 Water Gap	4.74	1.35	0.94	0.79	2.3	0	na	na	1.90	0.0323	22.0	0.9889	0.0013
VCML	2x2 Water Gap	4.74	1.35	0.94	0.79	2.3	0	na	na	1.90	0.2879	22.1	0.9957	0.0013
VCML	2x2 Water Gap	4.74	1.35	0.94	0.79	2.3	0	na	na	1.90	0.5540	22.2	1.0053	0.0011
VCML	2x2 Water Gap	4.74	1.35	0.94	0.79	2.3	0	na	na	2.50	0.9982	22.3	0.9955	0.0012
VCML	2x2 Water Gap	4.74	1.35	0.94	0.79	2.3	0	na	na	5.00	0.9982	22.5	0.9948	0.0013
VCML	Square Lattice	4.74	1.26	0.94	0.79	1.8	0	na	na	na	na	22.2	0.9958	0.0012
VCML	Square Lattice	4.74	1.35	0.94	0.79	2.3	0	na	na	na	na	22.0	0.9952	0.0012
VCML	Square Lattice	4.74	1.60	0.94	0.79	3.8	0	na	na	na	na	23.3	0.9989	0.0013
VCML	Square Lattice	4.74	2.10	0.94	0.79	7.6	0	na	na	na	na	24.0	0.9974	0.0012
VCML	Square Lattice	4.74	2.52	0.94	0.79	11.5	0	na	na	na	na	24.2	0.9977	0.0011
												Average	0.9961	0.0041

Table 6.5-2 Correlation Coefficient for Linear Curve-Fit of Critical Benchmarks

Correlation Studied	Correlation Coefficient (R)
k_{eff} versus enrichment	0.361
k_{eff} versus rod pitch	0.328
k_{eff} versus H/U volume ratio	0.246
k_{eff} versus ^{10}B loading	0.069
k_{eff} versus average group causing fission	0.133
k_{eff} versus flux gap thickness	0.137

Table 6.5-3 Most Reactive Configuration System Parameters

Parameters	Value
Enrichment (wt % ^{235}U)	4.0
Rod pitch (cm)	1.1887
H/U volume ratio	1.52
^{10}B loading (g/cm^2)	0.01
Average group causing fission	21.6[1]
Flux gap thickness (cm)	1.9 to 2.25

1. Value is 21.7 for the maximum reactivity for the enlarged fuel tube case.

Figure 6.6-8 CSAS25 Input/Output for Enlarged Tube Model (continued)

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TRANSPORT CRITICALITY: NORMAL CONDITIONS (PITCH = 300 CM) (IVF = 1.0) (EVF = 1.0

                               FREQUENCY FOR GENERATIONS  754 TO 1003
0.8183 TO 0.8213     *
0.8213 TO 0.8243
0.8243 TO 0.8273
0.8273 TO 0.8303     *
0.8303 TO 0.8333     *
0.8333 TO 0.8363
0.8363 TO 0.8392
0.8392 TO 0.8422
0.8422 TO 0.8452
0.8452 TO 0.8482
0.8482 TO 0.8512     ****
0.8512 TO 0.8542     *
0.8542 TO 0.8572     *
0.8572 TO 0.8602
0.8602 TO 0.8632     ****
0.8632 TO 0.8662     ********
0.8662 TO 0.8691     **********
0.8691 TO 0.8721     ****
0.8721 TO 0.8751     ***
0.8751 TO 0.8781     ****
0.8781 TO 0.8811     ********
0.8811 TO 0.8841     *******
0.8841 TO 0.8871     **************
0.8871 TO 0.8901     ********
0.8901 TO 0.8931     ***********
0.8931 TO 0.8960     *******************
0.8960 TO 0.8990     *************
0.8990 TO 0.9020     *******
0.9020 TO 0.9050     *************
0.9050 TO 0.9080     **************
0.9080 TO 0.9110     ************
0.9110 TO 0.9140     *************
0.9140 TO 0.9170     ***********
0.9170 TO 0.9200     *********
0.9200 TO 0.9229     *****
0.9229 TO 0.9259     *****
0.9259 TO 0.9289     **********
0.9289 TO 0.9319     ******
0.9319 TO 0.9349     *****
0.9349 TO 0.9379     ****
0.9379 TO 0.9409     ****
0.9409 TO 0.9439     **
0.9439 TO 0.9469
0.9469 TO 0.9499     *
0.9499 TO 0.9528     *
0.9528 TO 0.9558     *
0.9558 TO 0.9588     **
0.9588 TO 0.9618     *
0.9618 TO 0.9648
0.9648 TO 0.9678     *
0.9678 TO 0.9708     *


************************************************************************************************************************

          CONGRATULATIONS!  YOU HAVE  SUCCESSFULLY TRAVERSED THE PERILOUS PATH THROUGH KENO V IN  20.77833 MINUTES

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Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel

```
PRIMARY MODULE ACCESS AND INPUT RECORD ( SCALE DRIVER - 95/03/29 - 09:06:37 )
   MODULE CSAS25   WILL BE CALLED
     NAC-STC Directly Loaded; Wet Fuel-Pellet Gap; 100% Fuel Geometry Offset; 0 Enric
     ' Interior Water Density 1 g/cc, Exterior Water Density 0.00001 g/cc
     27GROUPNDF4 LATTICECELL
     'FUEL
     UO2 1 0.95 293 92235 4.5 92238 95.5 END
     'CLAD
     ZIRCALLOY 2 1 293 END
     'H2O CASK INTERIOR
     H2O 3 1 293 END
     'AL DISK
     AL 4 1 293 END
     'CASK / DISK STEEL
     SS304 5 1 293 END
     'BORAL SHEETS
     AL 6 DEN=2.6226 0.5738 293 END
     B-10 6 DEN=2.6226 0.045 293 END
     B-11 6 DEN=2.6226 0.2735 293 END
     C 6 DEN=2.6226 0.0926 293 END
     'LEAD SHIELD
     PB 7 1 293.0 END
     'NS4FR SHIELD
     B-10 8 0 8.553-5 293 END
     B-11 8 0 3.422-4 293 END
     AL 8 0 7.763-3 293 END
     H 8 0 5.854-2 293 END
     O 8 0 2.609-2 293 END
     C 8 0 2.264-2 293 END
     N 8 0 1.394-3 293 END
     'CASK EXTERIOR WATER
     H2O 9 0.00001 293 END
     'PELLET CLAD GAP WATER
     H2O 10 1 293 END
     END COMP
     SQUAREPITCH 1.2728 0.8204 1 3 0.9434 2 0.8398 10 END
     NAC-STC Directly Loaded; Wet Fuel-Pellet Gap; 100% Fuel Geometry Offset; 0 Enric
     READ PARAM RUN=YES PLT=NO TME=5000 GEN=803 NPG=1000 END PARAM
     READ GEOM
     UNIT 1
     COM='FUEL PIN CELL - FOR WATER ELEVATION'
     CYLINDER 1 1 0.4102 2P2.3749
     CYLINDER 10 1 0.4199 2P2.3749
     CYLINDER 2 1 0.4717 2P2.3749
     CUBOID 3 1 4P0.6364 2P2.3749
     UNIT 2
     COM='GUIDE/INSTRUMENT TUBE CELL - FOR WATER ELEVATION'
     CYLINDER 3 1 0.5644 2P2.3749
     CYLINDER 2 1 0.5992 2P2.3749
     CUBOID 3 1 4P0.6364 2P2.3749
     UNIT 3
     COM='FUEL PIN CELL - FOR STEEL DISK ELEVATION'
     CYLINDER 1 1 0.4102 2P0.6350
     CYLINDER 10 1 0.4199 2P0.6350
     CYLINDER 2 1 0.4717 2P0.6350
     CUBOID 3 1 4P0.6364 2P0.6350
     UNIT 4
     COM='GUIDE/INSTRUMENT TUBE CELL - FOR STEEL DISK ELEVATION'
     CYLINDER 3 1 0.5644 2P0.6350
     CYLINDER 2 1 0.5992 2P0.6350
     CUBOID 3 1 4P0.6364 2P0.6350
     UNIT 5
     COM='FUEL PIN CELL - FOR AL DISK ELEVATION'
     CYLINDER 1 1 0.4102 2P0.7938
     CYLINDER 10 1 0.4199 2P0.7938
     CYLINDER 2 1 0.4717 2P0.7938
     CUBOID 3 1 4P0.6364 2P0.7938
     UNIT 6
     COM='GUIDE/INSTRUMENT TUBE CELL   FOR AL DISK ELEVATION'
     CYLINDER 3 1 0.5644 2P0.7938
     CYLINDER 2 1 0.5992 2P0.7938
     CUBOID 3 1 4P0.6364 2P0.7938
     UNIT 21
     COM='ASSEMBLY - FOR WATER ELEVATION'
     ARRAY 1 -10.8188 -10.8188 -2.3749
     UNIT 22
     COM='ASSEMBLY - FOR STEEL DISK ELEVATION'
     ARRAY 2 -10.8188 -10.8188 -0.635
     UNIT 23
     COM='ASSEMBLY - FOR AL DISK ELEVATION'
     ARRAY 3 -10.8188 -10.8188 -0.7938
     UNIT 31
     COM='X-X BORAL SHEET - FOR WATER ELEVATION'
     CUBOID 6 1 2P10.3886 2P0.0635 2P2.3749
     CUBOID 4 1 2P10.3886 2P0.0951 2P2.3749
     UNIT 32
     COM='Y-Y BORAL SHEET - FOR WATER ELEVATION'
     CUBOID 6 1 2P0.0635 2P10.3886 2P2.3749
     CUBOID 4 1 2P0.0951 2P10.3886 2P2.3749
     UNIT 33
     COM='X-X BORAL SHEET - FOR STEEL DISK ELEVATION'
     CUBOID 6 1 2P10.3886 2P0.0635 2P0.6350
     CUBOID 4 1 2P10.3886 2P0.0951 2P0.6350
     UNIT 34
     COM='Y-Y BORAL SHEET - FOR STEEL DISK ELEVATION'
     CUBOID 6 1 2P0.0635 2P10.3886 2P0.6350
     CUBOID 4 1 2P0.0951 2P10.3886 2P0.6350
```

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

```
UNIT 35
COM='X-X BORAL SHEET - FOR AL DISK ELEVATION'
CUBOID 6 1 2P10.3886 2P0.0635 2P0.7938
CUBOID 4 1 2P10.3886 2P0.0951 2P0.7938
UNIT 36
COM='Y-Y BORAL SHEET - FOR AL DISK ELEVATION'
CUBOID 6 1 2P0.0635 2P10.3886 2P0.7938
CUBOID 4 1 2P0.0951 2P10.3886 2P0.7938
UNIT 40
COM='FUEL TUBE - FOR WATER ELEVATION (B)'
CUBOID 3 1 4P11.1887 2P2.3749
HOLE 21 0 -0.3698 0
CUBOID 5 1 4P11.3101 2P2.3749
CUBOID 3 1 4P11.5006 2P2.3749
HOLE 31 0 11.4054 0
HOLE 31 0 -11.4054 0
HOLE 32 11.4054 0 0
HOLE 32 -11.4054 0 0
CUBOID 5 1 4P11.5461 2P2.3749
UNIT 41
COM='FUEL TUBE - FOR WATER ELEVATION (T)'
CUBOID 3 1 4P11.1887 2P2.3749
HOLE 21 0 0.3698 0
CUBOID 5 1 4P11.3101 2P2.3749
CUBOID 3 1 4P11.5006 2P2.3749
HOLE 31 0 11.4054 0
HOLE 31 0 -11.4054 0
HOLE 32 11.4054 0 0
HOLE 32 -11.4054 0 0
CUBOID 5 1 4P11.5461 2P2.3749
UNIT 42
COM='FUEL TUBE - FOR WATER ELEVATION (BL)'
CUBOID 3 1 4P11.1887 2P2.3749
HOLE 21 -0.3698 -0.3698 0
CUBOID 5 1 4P11.3101 2P2.3749
CUBOID 3 1 4P11.5006 2P2.3749
HOLE 31 0 11.4054 0
HOLE 31 0 -11.4054 0
HOLE 32 11.4054 0 0
HOLE 32 -11.4054 0 0
CUBOID 5 1 4P11.5461 2P2.3749
UNIT 43
COM='FUEL TUBE - FOR WATER ELEVATION (BR)'
CUBOID 3 1 4P11.1887 2P2.3749
HOLE 21 0.3698 -0.3698 0
CUBOID 5 1 4P11.3101 2P2.3749
CUBOID 3 1 4P11.5006 2P2.3749
HOLE 31 0 11.4054 0
HOLE 31 0 -11.4054 0
HOLE 32 11.4054 0 0
HOLE 32 -11.4054 0 0
CUBOID 5 1 4P11.5461 2P2.3749
UNIT 44
COM='FUEL TUBE - FOR WATER ELEVATION (TL)'
CUBOID 3 1 4P11.1887 2P2.3749
HOLE 21 -0.3698 0.3698 0
CUBOID 5 1 4P11.3101 2P2.3749
CUBOID 3 1 4P11.5006 2P2.3749
HOLE 31 0 11.4054 0
HOLE 31 0 -11.4054 0
HOLE 32 11.4054 0 0
HOLE 32 -11.4054 0 0
CUBOID 5 1 4P11.5461 2P2.3749
UNIT 45
COM='FUEL TUBE - FOR WATER ELEVATION (TR)'
CUBOID 3 1 4P11.1887 2P2.3749
HOLE 21 0.3698 0.3698 0
CUBOID 5 1 4P11.3101 2P2.3749
CUBOID 3 1 4P11.5006 2P2.3749
HOLE 31 0 11.4054 0
HOLE 31 0 -11.4054 0
HOLE 32 11.4054 0 0
HOLE 32 -11.4054 0 0
CUBOID 5 1 4P11.5461 2P2.3749
UNIT 50
COM='FUEL TUBE - FOR STEEL DISK ELEVATION (B)'
CUBOID 3 1 4P11.1887 2P0.6350
HOLE 22 0 -0.3698 0
CUBOID 5 1 4P11.3101 2P0.6350
CUBOID 3 1 4P11.5006 2P0.6350
HOLE 33 0 11.4054 0
HOLE 33 0 -11.4054 0
HOLE 34 11.4054 0 0
HOLE 34 -11.4054 0 0
CUBOID 5 1 4P11.5461 2P0.6350
UNIT 51
COM='FUEL TUBE - FOR STEEL DISK ELEVATION (T)'
CUBOID 3 1 4P11.1887 2P0.6350
HOLE 22 0 0.3698 0
CUBOID 5 1 4P11.3101 2P0.6350
CUBOID 3 1 4P11.5006 2P0.6350
HOLE 33 0 11.4054 0
HOLE 33 0 -11.4054 0
HOLE 34 11.4054 0 0
HOLE 34 -11.4054 0 0
CUBOID 5 1 4P11.5461 2P0.6350
UNIT 52
```

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

```
COM='FUEL TUBE - FOR STEEL DISK ELEVATION (BL)'
CUBOID 3 1 4P11.1887 2P0.6350
HOLE 22 -0.3698 -0.3698 0
CUBOID 5 1 4P11.3101 2P0.6350
CUBOID 3 1 4P11.5006 2P0.6350
HOLE 33 0 11.4054 0
HOLE 33 0 -11.4054 0
HOLE 34 11.4054 0 0
HOLE 34 -11.4054 0 0
CUBOID 5 1 4P11.5461 2P0.6350
UNIT 53
COM='FUEL TUBE - FOR STEEL DISK ELEVATION (BR)'
CUBOID 3 1 4P11.1887 2P0.6350
HOLE 22 0.3698 -0.3698 0
CUBOID 5 1 4P11.3101 2P0.6350
CUBOID 3 1 4P11.5006 2P0.6350
HOLE 33 0 11.4054 0
HOLE 33 0 -11.4054 0
HOLE 34 11.4054 0 0
HOLE 34 -11.4054 0 0
CUBOID 5 1 4P11.5461 2P0.6350
UNIT 54
COM='FUEL TUBE - FOR STEEL DISK ELEVATION (TL)'
CUBOID 3 1 4P11.1887 2P0.6350
HOLE 22 -0.3698 0.3698 0
CUBOID 5 1 4P11.3101 2P0.6350
CUBOID 3 1 4P11.5006 2P0.6350
HOLE 33 0 11.4054 0
HOLE 33 0 -11.4054 0
HOLE 34 11.4054 0 0
HOLE 34 -11.4054 0 0
CUBOID 5 1 4P11.5461 2P0.6350
UNIT 55
COM='FUEL TUBE - FOR STEEL DISK ELEVATION (TR)'
CUBOID 3 1 4P11.1887 2P0.6350
HOLE 22 0.3698 0.3698 0
CUBOID 5 1 4P11.3101 2P0.6350
CUBOID 3 1 4P11.5006 2P0.6350
HOLE 33 0 11.4054 0
HOLE 33 0 -11.4054 0
HOLE 34 11.4054 0 0
HOLE 34 -11.4054 0 0
CUBOID 5 1 4P11.5461 2P0.6350
UNIT 60
COM='FUEL TUBE - FOR AL DISK ELEVATION (B)'
CUBOID 3 1 4P11.1887 2P0.7938
HOLE 23 0 -0.3698 0
CUBOID 5 1 4P11.3101 2P0.7938
CUBOID 3 1 4P11.5006 2P0.7938
HOLE 35 0 11.4054 0
HOLE 35 0 -11.4054 0
HOLE 36 11.4054 0 0
HOLE 36 -11.4054 0 0
CUBOID 5 1 4P11.5461 2P0.7938
UNIT 61
COM='FUEL TUBE - FOR AL DISK ELEVATION (T)'
CUBOID 3 1 4P11.1887 2P0.7938
HOLE 23 0 0.3698 0
CUBOID 5 1 4P11.3101 2P0.7938
CUBOID 3 1 4P11.5006 2P0.7938
HOLE 35 0 11.4054 0
HOLE 35 0 -11.4054 0
HOLE 36 11.4054 0 0
HOLE 36 -11.4054 0 0
CUBOID 5 1 4P11.5461 2P0.7938
UNIT 62
COM='FUEL TUBE - FOR AL DISK ELEVATION (BL)'
CUBOID 3 1 4P11.1887 2P0.7938
HOLE 23 -0.3698 -0.3698 0
CUBOID 5 1 4P11.3101 2P0.7938
CUBOID 3 1 4P11.5006 2P0.7938
HOLE 35 0 11.4054 0
HOLE 35 0 -11.4054 0
HOLE 36 11.4054 0 0
HOLE 36 -11.4054 0 0
CUBOID 5 1 4P11.5461 2P0.7938
UNIT 63
COM='FUEL TUBE - FOR AL DISK ELEVATION (BR)'
CUBOID 3 1 4P11.1887 2P0.7938
HOLE 23 0.3698 -0.3698 0
CUBOID 5 1 4P11.3101 2P0.7938
CUBOID 3 1 4P11.5006 2P0.7938
HOLE 35 0 11.4054 0
HOLE 35 0 -11.4054 0
HOLE 36 11.4054 0 0
HOLE 36 -11.4054 0 0
CUBOID 5 1 4P11.5461 2P0.7938
UNIT 64
COM='FUEL TUBE - FOR AL DISK ELEVATION (TL)'
CUBOID 3 1 4P11.1887 2P0.7938
HOLE 23 -0.3698 0.3698 0
CUBOID 5 1 4P11.3101 2P0.7938
CUBOID 3 1 4P11.5006 2P0.7938
HOLE 35 0 11.4054 0
HOLE 35 0 -11.4054 0
HOLE 36 11.4054 0 0
HOLE 36 -11.4054 0 0
```

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

```
CUBOID 5 1 4P11.5461 2P0.7938
UNIT 65
COM='FUEL TUBE - FOR AL DISK ELEVATION (TR)'
CUBOID 3 1 4P11.1887 2P0.7938
HOLE 23 0.3698 0.3698 0
CUBOID 5 1 4P11.3101 2P0.7938
CUBOID 3 1 4P11.5006 2P0.7938
HOLE 35 0 11.4054 0
HOLE 35 0 -11.4054 0
HOLE 36 11.4054 0 0
HOLE 36 -11.4054 0 0
CUBOID 5 1 4P11.5461 2P0.7938
UNIT 70
COM='DISK OPENING - FOR WATER ELEVATION (B)'
CUBOID 3 1 4P11.7272 2P2.3749
HOLE 40 0 -0.181 0
UNIT 71
COM='DISK OPENING - FOR WATER ELEVATION (T)'
CUBOID 3 1 4P11.7272 2P2.3749
HOLE 41 0 0.181 0
UNIT 72
COM='DISK OPENING - FOR WATER ELEVATION (BL)'
CUBOID 3 1 4P11.7272 2P2.3749
HOLE 42 -0.181 -0.181 0
UNIT 73
COM='DISK OPENING - FOR WATER ELEVATION (BR)'
CUBOID 3 1 4P11.7272 2P2.3749
HOLE 43 0.181 -0.181 0
UNIT 74
COM='DISK OPENING - FOR WATER ELEVATION (TL)'
CUBOID 3 1 4P11.7272 2P2.3749
HOLE 44 -0.181 0.181 0
UNIT 75
COM='DISK OPENING - FOR WATER ELEVATION (TR)'
CUBOID 3 1 4P11.7272 2P2.3749
HOLE 45 0.181 0.181 0
UNIT 80
COM='DISK OPENING - FOR STEEL DISK ELEVATION (B)'
CUBOID 3 1 4P11.7272 2P0.6350
HOLE 50 0 -0.181 0
UNIT 81
COM='DISK OPENING - FOR STEEL DISK ELEVATION (T)'
CUBOID 3 1 4P11.7272 2P0.6350
HOLE 51 0 0.181 0
UNIT 82
COM='DISK OPENING - FOR STEEL DISK ELEVATION (BL)'
CUBOID 3 1 4P11.7272 2P0.6350
HOLE 52 -0.181 -0.181 0
UNIT 83
COM='DISK OPENING - FOR STEEL DISK ELEVATION (BR)'
CUBOID 3 1 4P11.7272 2P0.6350
HOLE 53 0.181 -0.181 0
UNIT 84
COM='DISK OPENING - FOR STEEL DISK ELEVATION (TL)'
CUBOID 3 1 4P11.7272 2P0.6350
HOLE 54 -0.181 0.181 0
UNIT 85
COM='DISK OPENING - FOR STEEL DISK ELEVATION (TR)'
CUBOID 3 1 4P11.7272 2P0.6350
HOLE 55 0.181 0.181 0
UNIT 90
COM='DISK OPENING - FOR AL DISK ELEVATION (B)'
CUBOID 3 1 4P11.7272 2P0.7938
HOLE 60 0 -0.181 0
UNIT 91
COM='DISK OPENING - FOR AL DISK ELEVATION (T)'
CUBOID 3 1 4P11.7272 2P0.7938
HOLE 61 0 0.181 0
UNIT 92
COM='DISK OPENING - FOR AL DISK ELEVATION (BL)'
CUBOID 3 1 4P11.7272 2P0.7938
HOLE 62 -0.181 -0.181 0
UNIT 93
COM='DISK OPENING - FOR AL DISK ELEVATION (BR)'
CUBOID 3 1 4P11.7272 2P0.7938
HOLE 63 0.181 -0.181 0
UNIT 94
COM='DISK OPENING - FOR AL DISK ELEVATION (TL)'
CUBOID 3 1 4P11.7272 2P0.7938
HOLE 64 -0.181 0.181 0
UNIT 95
COM='DISK OPENING - FOR AL DISK ELEVATION (TR)'
CUBOID 3 1 4P11.7272 2P0.7938
HOLE 65 0.181 0.181 0
UNIT 101
COM='BASKET STRUCTURE IN TRANPORT CASK - WATER ELEVATION'
CYLINDER 3 1 90.17 2P2.3749
HOLE 75 -58.9864 -40.7822 0
HOLE 75 -58.9864 -13.5941 0
HOLE 73 -58.9864 13.5941 0
HOLE 73 -58.9864 40.7822 0
HOLE 75 -27.1882 -67.9704 0
HOLE 75 -27.1882 -40.7822 0
HOLE 75 -27.1882 -13.5941 0
HOLE 73 -27.1882 13.5941 0
HOLE 73 -27.1882 40.7822 0
HOLE 73 -27.1882 67.9704 0
```

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

```
HOLE 71 0 -67.9704 0
HOLE 71 0 -40.7822 0
HOLE 71 0 -13.5941 0
HOLE 70 0 13.5941 0
HOLE 70 0 40.7822 0
HOLE 70 0 67.9704 0
HOLE 74 27.1882 -67.9704 0
HOLE 74 27.1882 -40.7822 0
HOLE 74 27.1882 -13.5941 0
HOLE 72 27.1882 13.5941 0
HOLE 72 27.1882 40.7822 0
HOLE 72 27.1882 67.9704 0
HOLE 74 58.9864 -40.7822 0
HOLE 74 58.9864 -13.5941 0
HOLE 72 58.9864 13.5941 0
HOLE 72 58.9864 40.7822 0
CYLINDER 5 1 93.98 2P2.3749
CYLINDER 7 1 103.43 2P2.3749
CYLINDER 5 1 110.11 2P2.3749
CYLINDER 9 1 124.12 2P2.3749
CYLINDER 9 1 124.44 2P2.3749
CYLINDER 5 1 125.07 2P2.3749
CUBOID 9 1 4P125.07 2P2.3749
UNIT 102
COM='BASKET STRUCTURE IN TRANPORT CASK - ST DISK ELEVATION'
CYLINDER 5 1 89.99 2P0.6350
HOLE 85 -58.9864 -40.7822 0
HOLE 85 -58.9864 -13.5941 0
HOLE 83 -58.9864 13.5941 0
HOLE 83 -58.9864 40.7822 0
HOLE 85 -27.1882 -67.9704 0
HOLE 85 -27.1882 -40.7822 0
HOLE 85 -27.1882 -13.5941 0
HOLE 83 -27.1882 13.5941 0
HOLE 83 -27.1882 40.7822 0
HOLE 83 -27.1882 67.9704 0
HOLE 81 0 -67.9704 0
HOLE 81 0 -40.7822 0
HOLE 81 0 -13.5941 0
HOLE 80 0 13.5941 0
HOLE 80 0 40.7822 0
HOLE 80 0 67.9704 0
HOLE 84 27.1882 -67.9704 0
HOLE 84 27.1882 -40.7822 0
HOLE 84 27.1882 -13.5941 0
HOLE 82 27.1882 13.5941 0
HOLE 82 27.1882 40.7822 0
HOLE 82 27.1882 67.9704 0
HOLE 84 58.9864 -40.7822 0
HOLE 84 58.9864 -13.5941 0
HOLE 82 58.9864 13.5941 0
HOLE 82 58.9864 40.7822 0
CYLINDER 3 1 90.17 2P0.6350
CYLINDER 5 1 93.98 2P0.6350
CYLINDER 7 1 103.43 2P0.6350
CYLINDER 5 1 110.11 2P0.6350
CYLINDER 9 1 124.12 2P0.6350
CYLINDER 9 1 124.44 2P0.6350
CYLINDER 5 1 125.07 2P0.6350
CUBOID 9 1 4P125.07 2P0.6350
UNIT 103
COM='BASKET STRUCTURE IN TRANPORT CASK - AL DISK ELEVATION'
CYLINDER 4 1 89.73 2P0.7938
HOLE 95 -58.9864 -40.7822 0
HOLE 95 -58.9864 -13.5941 0
HOLE 93 -58.9864 13.5941 0
HOLE 93 -58.9864 40.7822 0
HOLE 95 -27.1882 -67.9704 0
HOLE 95 -27.1882 -40.7822 0
HOLE 95 -27.1882 -13.5941 0
HOLE 93 -27.1882 13.5941 0
HOLE 93 -27.1882 40.7822 0
HOLE 93 -27.1882 67.9704 0
HOLE 91 0 -67.9704 0
HOLE 91 0 -40.7822 0
HOLE 91 0 -13.5941 0
HOLE 90 0 13.5941 0
HOLE 90 0 40.7822 0
HOLE 90 0 67.9704 0
HOLE 94 27.1882 -67.9704 0
HOLE 94 27.1882 -40.7822 0
HOLE 94 27.1882 -13.5941 0
HOLE 92 27.1882 13.5941 0
HOLE 92 27.1882 40.7822 0
HOLE 92 27.1882 67.9704 0
HOLE 94 58.9864 -40.7822 0
HOLE 94 58.9864 -13.5941 0
HOLE 92 58.9864 13.5941 0
HOLE 92 58.9864 40.7822 0
CYLINDER 3 1 90.17 2P0.7938
CYLINDER 5 1 93.98 2P0.7938
CYLINDER 7 1 103.43 2P0.7938
CYLINDER 5 1 110.11 2P0.7938
CYLINDER 9 1 124.12 2P0.7938
CYLINDER 9 1 124.44 2P0.7938
CYLINDER 5 1 125.07 2P0.7938
CUBOID 9 1 4P125.07 2P0.7938
```

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

```
GLOBAL UNIT 104
COM='DISK SLICE STACK'
ARRAY 4 -125.07 -125.07 0
CUBOID 9 1 4P125.08 12.3573 0
END GEOM
READ ARRAY
ARA=1 NUX=17 NUY=17 NUZ=1 FILL
 34R1
 5R1 2 2R1 2 2R1 2 5R1
 3R1 2 9R1 2 3R1
 17R1
2R1 2 2R1 2 2R1 2 2R1 2 2R1 2 2R1
 34R1
2R1 2 2R1 2 2R1 2 2R1 2 2R1 2 2R1
 34R1
2R1 2 2R1 2 2R1 2 2R1 2 2R1 2 2R1
 17R1
 3R1 2 9R1 2 3R1
 5R1 2 2R1 2 2R1 2 5R1
 34R1
END FILL
ARA=2 NUX=17 NUY=17 NUZ=1 FILL
 34R3
 5R3 4 2R3 4 2R3 4 5R3
 3R3 4 9R3 4 3R3
 17R3
2R3 4 2R3 4 2R3 4 2R3 4 2R3 4 2R3
 34R3
2R3 4 2R3 4 2R3 4 2R3 4 2R3 4 2R3
 34R3
2R3 4 2R3 4 2R3 4 2R3 4 2R3 4 2R3
 17R3
 3R3 4 9R3 4 3R3
 5R3 4 2R3 4 2R3 4 5R3
 34R3
END FILL
ARA=3 NUX=17 NUY=17 NUZ=1 FILL
 34R5
 5R5 6 2R5 6 2R5 6 5R5
 3R5 6 9R5 6 3R5
 17R5
2R5 6 2R5 6 2R5 6 2R5 6 2R5 6 2R5
 34R5
2R5 6 2R5 6 2R5 6 2R5 6 2R5 6 2R5
 34R5
2R5 6 2R5 6 2R5 6 2R5 6 2R5 6 2R5
 17R5
 3R5 6 9R5 6 3R5
 5R5 6 2R5 6 2R5 6 5R5
 34R5
END FILL
ARA=4 NUX=1 NUY=1 NUZ=4 FILL 101 102 101 103 END FILL
END ARRAY
READ BOUNDS ZFC=PER YXF=MIRROR END BOUNDS
READ PLOT
TTL='XY SLICE OF CASK - ST DISK ELEVATION'
SCR=YES PIC=MAT LPI=10
XUL=-120.0 YUL=120.0 ZUL=5.5 XLR=120.0 YLR=-120.0 ZLR=5.5
UAX=1.0 VDN=-1.0 NAX=1500 END
TTL='XY SLICE CASK CENTER AREA ST DISK ELEVATION'
SCR=YES PIC=MAT LPI=10
XUL=-27.0 YUL=27.0 ZUL=5.5 XLR=27.0 YLR=-27.0 ZLR=5.5
UAX=1.0 VDN=-1.0 NAX=1500 END
END PLOT
END DATA

  SECONDARY MODULE 000008    HAS BEEN CALLED.

  MODULE 000008    IS FINISHED. COMPLETION CODE     0. CPU TIME USED      1.37 (SECONDS).

  SECONDARY MODULE 000002    HAS BEEN CALLED.

  MODULE 000002    IS FINISHED. COMPLETION CODE     0. CPU TIME USED      6.49 (SECONDS).

  SECONDARY MODULE 000009    HAS BEEN CALLED.

  MODULE 000009    IS FINISHED. COMPLETION CODE     0. CPU TIME USED    672.94 (SECONDS).

  MODULE CSAS25    IS FINISHED. COMPLETION CODE     0. CPU TIME USED    686.79 (SECONDS).

THE FOLLOWING DATA CARDS PRECEDE AN = CARD

  EXECUTION TERMINATED DUE TO ERRORS
```

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

```
NAC-STC DIRECTLY LOADED; WET FUEL-PELLET GAP; 100% FUEL GEOMETRY OFFSET; 0 ENRIC


**** PROBLEM PARAMETERS ****

LIB 27GROUPNDF4  LIBRARY
MXX              10 MIXTURES
MSC              19 COMPOSITION SPECIFICATIONS
IZM               4 MATERIAL ZONES
GE  LATTICECELL   GEOMETRY
MORE              0 0/1 DO NOT READ/READ OPTIONAL PARAMETER DATA
MSLN              0 FUEL SOLUTIONS


**** PROBLEM COMPOSITION DESCRIPTION ****

SC  UO2           STANDARD COMPOSITION
MX                1 MIXTURE NO.
VF           0.9500 VOLUME FRACTION
ROTH        10.9600 THEORETICAL DENSITY
NEL               2 NO. ELEMENTS
ICP               1 0/1 MIXTURE/COMPOUND
TEMP          293.0 DEG KELVIN
              92000        1.00 ATOM/MOLECULE
                                 92235      4.500 WT%
                                 92238     95.500 WT%
               8016        2.00 ATOMS/MOLECULE

'CLAD
    END

    SC  ZIRCALLOY     STANDARD COMPOSITION
    MX                2 MIXTURE NO.
    VF           1.0000 VOLUME FRACTION
    ROTH         6.5600 THEORETICAL DENSITY
    NEL               1 NO. ELEMENTS
    ICP               1 0/1 MIXTURE/COMPOUND
    TEMP          293.0 DEG KELVIN
                  40302        1.00 ATOM/MOLECULE

'H2O CASK INTERIOR
    END

    SC  H2O           STANDARD COMPOSITION
    MX                3 MIXTURE NO.
    VF           1.0000 VOLUME FRACTION
    ROTH         0.9982 THEORETICAL DENSITY
    NEL               2 NO. ELEMENTS
    ICP               1 0/1 MIXTURE/COMPOUND
    TEMP          293.0 DEG KELVIN
                   1001        2.00 ATOMS/MOLECULE
                   8016        1.00 ATOM/MOLECULE

'AL DISK
    END

    SC  AL            STANDARD COMPOSITION
    MX                4 MIXTURE NO.
    VF           1.0000 VOLUME FRACTION
    ROTH         2.7020 THEORETICAL DENSITY
    NEL               1 NO. ELEMENTS
    ICP               1 0/1 MIXTURE/COMPOUND
    TEMP          293.0 DEG KELVIN
                  13027        1.00 ATOM/MOLECULE

'CASK / DISK STEEL
    END

    SC  SS304         STANDARD COMPOSITION
    MX                5 MIXTURE NO.
    VF           1.0000 VOLUME FRACTION
    ROTH         7.9200 THEORETICAL DENSITY
    NEL               4 NO. ELEMENTS
    ICP               0 0/1 MIXTURE/COMPOUND
    TEMP          293.0 DEG KELVIN
                  24304    19.000 WT%
                  25055     2.000 WT%
                  26304    69.500 WT%
                  28304     9.500 WT%

'BORAL SHEETS
    END

    SC  AL            STANDARD COMPOSITION
    MX                6 MIXTURE NO.
    VF           0.5738 VOLUME FRACTION
    ROTH         2.6226 SPECIFIED DENSITY
    NEL               1 NO. ELEMENTS
    ICP               1 0/1 MIXTURE/COMPOUND
    TEMP          293.0 DEG KELVIN
                  13027        1.00 ATOM/MOLECULE
    END

    SC  B-10          STANDARD COMPOSITION
    MX                6 MIXTURE NO.
    VF           0.0450 VOLUME FRACTION
    ROTH         2.6226 SPECIFIED DENSITY
```

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

```
    NEL             1 NO. ELEMENTS
    ICP             1 0/1 MIXTURE/COMPOUND
    TEMP        293.0 DEG KELVIN
                 5010      1.00 ATOM/MOLECULE
    END

    SC  B-11          STANDARD COMPOSITION
    MX              6 MIXTURE NO.
    VF         0.2735 VOLUME FRACTION
    ROTH       2.6226 SPECIFIED DENSITY
    NEL             1 NO. ELEMENTS
    ICP             1 0/1 MIXTURE/COMPOUND
    TEMP        293.0 DEG KELVIN
                 5011      1.00 ATOM/MOLECULE
    END

    SC  C             STANDARD COMPOSITION
    MX              6 MIXTURE NO.
    VF         0.0926 VOLUME FRACTION
    ROTH       2.6226 SPECIFIED DENSITY
    NEL             1 NO. ELEMENTS
    ICP             1 0/1 MIXTURE/COMPOUND
    TEMP        293.0 DEG KELVIN
                 6012      1.00 ATOM/MOLECULE

'LEAD SHIELD
    END

    SC  PB            STANDARD COMPOSITION
    MX              7 MIXTURE NO.
    VF         1.0000 VOLUME FRACTION
    ROTH      11.3440 THEORETICAL DENSITY
    NEL             1 NO. ELEMENTS
    ICP             1 0/1 MIXTURE/COMPOUND
    TEMP        293.0 DEG KELVIN
                82000      1.00 ATOM/MOLECULE

'NS4FR SHIELD
    END

    SC  B-10          STANDARD COMPOSITION
    MX              8 MIXTURE NO.
    DEN    8.5530E-05 ATOMIC DENSITY
    ROTH       1.0000 THEORETICAL DENSITY
    NEL             1 NO. ELEMENTS
    ICP             1 0/1 MIXTURE/COMPOUND
    TEMP        293.0 DEG KELVIN
                 5010      1.00 ATOM/MOLECULE
    END

    SC  B-11          STANDARD COMPOSITION
    MX              8 MIXTURE NO.
    DEN    3.4220E-04 ATOMIC DENSITY
    ROTH       1.0000 THEORETICAL DENSITY
    NEL             1 NO. ELEMENTS
    ICP             1 0/1 MIXTURE/COMPOUND
    TEMP        293.0 DEG KELVIN
                 5011      1.00 ATOM/MOLECULE
    END

    SC  AL            STANDARD COMPOSITION
    MX              8 MIXTURE NO.
    DEN    7.7630E-03 ATOMIC DENSITY
    ROTH       2.7020 THEORETICAL DENSITY
    NEL             1 NO. ELEMENTS
    ICP             1 0/1 MIXTURE/COMPOUND
    TEMP        293.0 DEG KELVIN
                13027      1.00 ATOM/MOLECULE
    END

    SC  H             STANDARD COMPOSITION
    MX              8 MIXTURE NO.
    DEN    5.8540E-02 ATOMIC DENSITY
    ROTH       1.0000 THEORETICAL DENSITY
    NEL             1 NO. ELEMENTS
    ICP             1 0/1 MIXTURE/COMPOUND
    TEMP        293.0 DEG KELVIN
                 1001      1.00 ATOM/MOLECULE
    END

    SC  O             STANDARD COMPOSITION
    MX              8 MIXTURE NO.
    DEN    2.6090E-02 ATOMIC DENSITY
    ROTH       1.0000 THEORETICAL DENSITY
    NEL             1 NO. ELEMENTS
    ICP             1 0/1 MIXTURE/COMPOUND
    TEMP        293.0 DEG KELVIN
                 8016      1.00 ATOM/MOLECULE
    END

    SC  C             STANDARD COMPOSITION
    MX              8 MIXTURE NO.
    DEN    2.2640E-02 ATOMIC DENSITY
    ROTH       2.1000 THEORETICAL DENSITY
    NEL             1 NO. ELEMENTS
    ICP             1 0/1 MIXTURE/COMPOUND
    TEMP        293.0 DEG KELVIN
```

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

```
                6012      1.00 ATOM/MOLECULE
    END

    SC  N             STANDARD COMPOSITION
    MX              8 MIXTURE NO.
    DEN   1.3940E-03 ATOMIC DENSITY
    ROTH      1.0000 THEORETICAL DENSITY
    NEL            1 NO. ELEMENTS
    ICP            1 0/1 MIXTURE/COMPOUND
    TEMP       293.0 DEG KELVIN
                7014      1.00 ATOM/MOLECULE

'CASK EXTERIOR WATER
    END

    SC  H2O           STANDARD COMPOSITION
    MX              9 MIXTURE NO.
    VF        0.0000 VOLUME FRACTION
    ROTH      0.9982 THEORETICAL DENSITY
    NEL            2 NO. ELEMENTS
    ICP            1 0/1 MIXTURE/COMPOUND
    TEMP       293.0 DEG KELVIN
                1001      2.00 ATOMS/MOLECULE
                8016      1.00 ATOM/MOLECULE

'PELLET CLAD GAP WATER
    END

    SC  H2O           STANDARD COMPOSITION
    MX             10 MIXTURE NO.
    VF        1.0000 VOLUME FRACTION
    ROTH      0.9982 THEORETICAL DENSITY
    NEL            2 NO. ELEMENTS
    ICP            1 0/1 MIXTURE/COMPOUND
    TEMP       293.0 DEG KELVIN
                1001      2.00 ATOMS/MOLECULE
                8016      1.00 ATOM/MOLECULE
    END


    **** PROBLEM GEOMETRY ****

    CTP SQUAREPITCH  CELL TYPE
    PITCH      1.2728 CM CENTER TO CENTER SPACING
    FUELOD     0.8204 CM FUEL DIAMETER OR SLAB THICKNESS
    MFUEL           1 MIXTURE NO. OF FUEL
    MMOD            3 MIXTURE NO. OF MODERATOR
    CLADOD     0.9434 CM CLAD OUTER DIAMETER
    MCLAD           2 MIXTURE NO. OF CLAD
    GAPOD      0.8398 CM GAP OUTER DIAMETER
    MGAP           10 MIXTURE NO. OF GAP

    ZONE SPECIFICATIONS FOR LATTICECELL GEOMETRY

                ZONE  1 IS FUEL
                ZONE  2 IS GAP
                ZONE  3 IS CLAD
                ZONE  4 IS MOD
```

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

```
LOGICAL ASSIGNMENTS

MASTER LIBRARY    11
WORKING LIBRARY    0
SCRATCH FILE      18
NEW LIBRARY        1

P R O B L E M   D E S C R I P T I O N

IGR--GEOMETRY (0/1/2/3--INF MED/SLAB/CYL/SPHERE              2

IZM--NUMBER OF ZONES OR MATERIAL REGIONS                    10

MS--MIXING TABLE LENGTH                                     27

IBL--SHIELDED CROSS SECTION EDIT OPTION (0/1--NO/YES)        0

IBR--BONDARENKO FACTOR EDIT OPTION (0/1--NO/YES)             0

ISSOPT--DANCOFF FACTOR OPTION                                0

CONVERGENCE CRITERION     1.00000E-03

GEOMETRY CORRECTION FACTOR FOR WIGNER RATIONAL APPROXIMATION  1.350E+00

        3Q ARRAY HAS      27 ENTRIES.

        4Q ARRAY HAS      27 ENTRIES.

        5Q ARRAY HAS      27 ENTRIES.

        6Q ARRAY HAS      10 ENTRIES.

        7Q ARRAY HAS      10 ENTRIES.

        8Q ARRAY HAS      10 ENTRIES.

        9Q ARRAY HAS      10 ENTRIES.

       10Q ARRAY HAS      27 ENTRIES.

       11Q ARRAY HAS      10 ENTRIES.

M I X I N G   T A B L E
```

ENTRY	MIXTURE	ISOTOPE	NUMBER DENSITY	NEW IDENTIFIER
1	1	92235	1.05821E-03	1092235
2	1	92238	2.21739E-02	1092238
3	1	8016	4.64643E-02	1008016
4	3	8016	3.33846E-02	3008016
5	8	8016	2.60900E-02	8008016
6	9	8016	3.33846E-07	9008016
7	10	8016	3.33846E-02	10008016
8	2	40302	4.33078E-02	2040302
9	3	1001	6.67692E-02	3001001
10	8	1001	5.85400E-02	8001001
11	9	1001	6.67692E-07	9001001
12	10	1001	6.67692E-02	10001001
13	4	13027	6.03066E-02	4013027
14	6	13027	3.35871E-02	6013027
15	8	13027	7.76300E-03	8013027
16	5	24304	1.74286E-02	5024304
17	5	25055	1.73633E-03	5025055
18	5	26304	5.93579E-02	5026304
19	5	28304	7.72070E-03	5028304
20	6	5010	7.09799E-03	6005010
21	8	5010	8.55300E-05	8005010
22	6	5011	3.92356E-02	6005011
23	8	5011	3.42200E-04	8005011
24	6	6012	1.21874E-02	6006012
25	8	6012	2.26400E-02	8006012
26	7	82000	3.29690E-02	7082000
27	8	7014	1.39400E-03	8007014

GEOMETRY AND MATERIAL DESCRIPTION

ZONE	MIXTURE	OUTER DIMENSION	TEMPERATURE	EXTRA XS	TYPE (0/1--FUEL/MOD)
1	1	4.10200E-01	2.93000E+02	1.23440E+00	0
2	10	4.19900E-01	2.93000E+02	0.00000E+00	0
3	2	4.71700E-01	2.93000E+02	6.63851E+00	0
4	3	7.18100E-01	2.93000E+02	0.00000E+00	0
5	4	5.71810E+00	2.93000E+02	0.00000E+00	0
6	5	1.07181E+01	2.93000E+02	0.00000E+00	0
7	6	1.57181E+01	2.93000E+02	0.00000E+00	0
8	7	2.07181E+01	2.93000E+02	0.00000E+00	0
9	8	2.57181E+01	2.93000E+02	0.00000E+00	0
10	9	3.07181E+01	2.93000E+02	0.00000E+00	0

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

```
NAC-STC DIRECTLY LOADED; WET FUEL-PELLET GAP; 100% FUEL GEOMETRY OFFSET; 0 ENRIC

****** NUMERIC PARAMETERS ******

TME   MAXIMUM PROBLEM TIME (MIN)                ******
TBA   TIME PER GENERATION (MIN)                 0.50
GEN   NUMBER OF GENERATIONS                     803
NPG   NUMBER PER GENERATION                     1000
NSK   NUMBER OF GENERATIONS TO BE SKIPPED       3
BEG   BEGINNING GENERATION NUMBER               1
RES   GENERATIONS BETWEEN CHECKPOINTS           0
X1D   NUMBER OF EXTRA 1-D CROSS SECTIONS        1
NBK   NEUTRON BANK SIZE                         1025
XNB   EXTRA POSITIONS IN NEUTRON BANK           0
NFB   FISSION BANK SIZE                         1000
XFB   EXTRA POSITIONS IN FISSION BANK           0
WTA   DEFAULT VALUE OF WEIGHT AVERAGE           0.5000
WTH   WEIGHT HIGH FOR SPLITTING                 3.0000
WTL   WEIGHT LOW FOR RUSSIAN ROULETTE           0.3333
RND   STARTING RANDOM NUMBER                    BB827100001
NB8   NUMBER OF D.A. BLOCKS ON UNIT  8          200
NL8   LENGTH OF D.A. BLOCKS ON UNIT  8          512
ADJ   MODE OF CALCULATION                       FORWARD
      INPUT DATA WRITTEN ON RESTART UNIT        NO
      BINARY DATA INTERFACE                     YES
```

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

```
*****************************************************************************************************
*****************************************************************************************************
***                                                                                               ***
***                 NAC-STC DIRECTLY LOADED; WET FUEL-PELLET GAP; 100% FUEL GEOMETRY OFFSET; 0 ENRIC***
***                                                                                               ***
*****************************************************************************************************
***                          ******     LOGICAL PARAMETERS       ******                           ***
***                                                                                               ***
***  RUN  EXECUTE PROBLEM AFTER CHECKING DATA    YES          PLT  PLOT PICTURE MAP(S)          NO ***
***                                                                                               ***
***  FLX  COMPUTE FLUX                            NO          FDN  COMPUTE FISSION DENSITIES    NO ***
***                                                                                               ***
***  SMU  COMPUTE AVG UNIT SELF-MULTIPLICATION    NO          NUB  COMPUTE NU-BAR & AVG FISSION GROUP   YES ***
***                                                                                               ***
***  MKU  COMPUTE MATRIX K-EFF BY UNIT NUMBER     NO          MKP  COMPUTE MATRIX K-EFF BY UNIT LOCATION   NO ***
***                                                                                               ***
***  CKU  COMPUTE COFACTOR K-EFF BY UNIT NUMBER   NO          CKP  COMPUTE COFACTOR K-EFF BY UNIT LOCATION  NO ***
***                                                                                               ***
***  FMU  PRINT FISS PROD MATRIX BY UNIT NUMBER   NO          FMP  PRINT FISS PROD MATRIX BY UNIT LOCATION  NO ***
***                                                                                               ***
***  MKH  COMPUTE MATRIX K-EFF BY HOLE NUMBER     NO          MKA  COMPUTE MATRIX K-EFF BY ARRAY NUMBER   NO ***
***                                                                                               ***
***  CKH  COMPUTE COFACTOR K-EFF BY HOLE NUMBER   NO          CKA  COMPUTE COFACTOR K-EFF BY ARRAY NUMBER  NO ***
***                                                                                               ***
***  FMH  PRINT FISS PROD MATRIX BY HOLE NUMBER   NO          FMA  PRINT FISS PROD MATRIX BY ARRAY NUMBER  NO ***
***                                                                                               ***
***  HHL  COLLECT MATRIX BY HIGHEST HOLE LEVEL    NO          HAL  COLLECT MATRIX BY HIGHEST ARRAY LEVEL   NO ***
***                                                                                               ***
***  AMX  PRINT ALL MIXED CROSS SECTIONS          NO          FAR  PRINT FIS. AND ABS. BY REGION   NO ***
***                                                                                               ***
***  XS1  PRINT 1-D MIXTURE X-SECTIONS            NO          GAS  PRINT FAR BY GROUP           NO ***
***                                                                                               ***
***  XS2  PRINT 2-D MIXTURE X-SECTIONS            NO          PAX  PRINT XSEC-ALBEDO CORRELATION TABLES   NO ***
***                                                                                               ***
***  XAP  PRINT MIXTURE ANGLES & PROBABILITIES    NO          PWT  PRINT WEIGHT AVERAGE ARRAY   NO ***
***                                                                                               ***
***  PKI  PRINT FISSION SPECTRUM                  NO          PGM  PRINT INPUT GEOMETRY         NO ***
***                                                                                               ***
***  P1D  PRINT EXTRA 1-D CROSS SECTIONS          NO          BUG  PRINT DEBUG INFORMATION      NO ***
***                                                                                               ***
***                                                           TRK  PRINT TRACKING INFORMATION   NO ***
***                                                                                               ***
***                                                                                               ***
*****************************************************************************************************
*****************************************************************************************************
*****************************************************************************************************
                                   PARAMETER INPUT COMPLETED

                    ........    0 IO'S WERE USED READING THE PARAMETER DATA      ........

                    *************** DATA READING COMPLETED ***************
```

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

```
                          NAC-STC DIRECTLY LOADED; WET FUEL-PELLET GAP; 100% FUEL GEOMETRY OFFSET; 0 ENRIC

                                              MIXING TABLE

                                   NUMBER OF SCATTERING ANGLES =  2
                                CROSS SECTION MESSAGE THRESHOLD =3.0E-05

MIXTURE =      1         DENSITY(G/CC) =  10.412
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA      AWT              NUCLIDE TITLE
   1008016  4.64643E-02  1.18493E-01   8016    15.9904     OXYGEN-16      ENDF/B-IV MAT 1276                          UPDATED
08/12/94
   1092235  1.05821E-03  3.96678E-02  92235   235.0441     URANIUM-235    ENDF/B-IV MAT 1261                          UPDATED
08/12/94
   1092238  2.21739E-02  8.41839E-01  92238   238.0510     URANIUM-238    ENDF/B-IV MAT 1262                          UPDATED
08/12/94

MIXTURE =      2         DENSITY(G/CC) =  6.5600
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA      AWT              NUCLIDE TITLE
   2040302  4.33078E-02  1.00000E+00  40000    91.2196     ZIRCALLOY      ENDF/B-IV MAT 1284                          UPDATED
08/12/94

MIXTURE =      3         DENSITY(G/CC) = 0.99817
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA      AWT              NUCLIDE TITLE
   3001001  6.67692E-02  1.11927E-01   1001     1.0077     HYDROGEN       ENDF/B-IV MAT 1269/THRM1002                 UPDATED
08/12/94
   3008016  3.33846E-02  8.88074E-01   8016    15.9904     OXYGEN-16      ENDF/B-IV MAT 1276                          UPDATED
08/12/94

MIXTURE =      4         DENSITY(G/CC) =  2.7020
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA      AWT              NUCLIDE TITLE
   4013027  6.03066E-02  1.00000E+00  13027    26.9818    AL-27 1193 218 GP 040375(5)                                 UPDATED
08/12/94

MIXTURE =      5         DENSITY(G/CC) =  7.9200
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA      AWT              NUCLIDE TITLE
   5024304  1.74286E-02  1.90000E-01  24000    51.9957    CR 1191 WT SS-304(1/EST) P-3 293K SP=5+4(42375)'            UPDATED
08/12/94
   5025055  1.73633E-03  1.99999E-02  25055    54.9379     MANGANESE-55   ENDF/B-IV MAT 1197                          UPDATED
08/12/94
   5026304  5.93579E-02  6.95000E-01  26000    55.8447    FE 1192 WT SS-304(1/EST) P-3 293K SP=5+4(42375)'            UPDATED
08/12/94
   5028304  7.72070E-03  9.50001E-02  28000    58.6872    NI 1190 WT SS-304(1/EST) P-3 293K SP=5+4(42375)'            UPDATED
08/12/94

MIXTURE =      6         DENSITY(G/CC) =  2.5830
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA      AWT              NUCLIDE TITLE
   6005010  7.09799E-03  4.56901E-02   5010    10.0130    B-10 1273 218NGP 042375 P-3 293K                            UPDATED
08/12/94
   6005011  3.92356E-02  2.77698E-01   5011    11.0096     BORON-11       ENDF/B-IV MAT 1160                          UPDATED
08/12/94
   6006012  1.21874E-02  9.40196E-02   6000    12.0001     CARBON-12      ENDF/B-IV MAT 1274/THRM1065                 UPDATED
08/12/94
   6013027  3.35871E-02  5.82592E-01  13027    26.9818    AL-27 1193 218 GP 040375(5)                                 UPDATED
08/12/94

MIXTURE =      7         DENSITY(G/CC) =  11.344
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA      AWT              NUCLIDE TITLE
   7082000  3.29690E-02  1.00000E+00  82000   207.2100    PB   1288 218NGP 042375 P-3 293K                            UPDATED
08/12/94

MIXTURE =      8         DENSITY(G/CC) =  1.6298
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA      AWT              NUCLIDE TITLE
   8001001  5.85400E-02  6.01023E-02   1001     1.0077     HYDROGEN       ENDF/B-IV MAT 1269/THRM1002                 UPDATED
08/12/94
   8005010  8.55300E-05  8.72589E-04   5010    10.0130    B-10 1273 218NGP 042375 P-3 293K                            UPDATED
08/12/94
   8005011  3.42200E-04  3.83863E-03   5011    11.0096     BORON-11       ENDF/B-IV MAT 1160                          UPDATED
08/12/94
   8006012  2.26400E-02  2.76813E-01   6000    12.0001     CARBON-12      ENDF/B-IV MAT 1274/THRM1065                 UPDATED
08/12/94
   8007014  1.39400E-03  1.98893E-02   7014    14.0033     NITROGEN-14    ENDF/B-IV MAT 1275                          UPDATED
08/12/94
   8008016  2.60900E-02  4.25068E-01   8016    15.9904     OXYGEN-16      ENDF/B-IV MAT 1276                          UPDATED
08/12/94
   8013027  7.76300E-03  2.13416E-01  13027    26.9818    AL-27 1193 218 GP 040375(5)                                 UPDATED
08/12/94

MIXTURE =      9         DENSITY(G/CC) = 0.99817E-05
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA      AWT              NUCLIDE TITLE
   9001001  6.67692E-07  1.11927E-01   1001     1.0077     HYDROGEN       ENDF/B-IV MAT 1269/THRM1002                 UPDATED
08/12/94
   9008016  3.33846E-07  8.88073E-01   8016    15.9904     OXYGEN-16      ENDF/B-IV MAT 1276                          UPDATED
08/12/94

MIXTURE =     10         DENSITY(G/CC) = 0.99817
   NUCLIDE   ATOM-DENS.   WGT. FRAC.     ZA      AWT              NUCLIDE TITLE
  10001001  6.67692E-02  1.11927E-01   1001     1.0077     HYDROGEN       ENDF/B-IV MAT 1269/THRM1002                 UPDATED
08/12/94
  10008016  3.33846E-02  8.88074E-01   8016    15.9904     OXYGEN-16      ENDF/B-IV MAT 1276                          UPDATED
08/12/94


                         3001001      HYDROGEN       ENDF/B-IV MAT 1269/THRM1002             UPDATED 08/12/94
                         8001001      HYDROGEN       ENDF/B-IV MAT 1269/THRM1002             UPDATED 08/12/94
                         9001001      HYDROGEN       ENDF/B-IV MAT 1269/THRM1002             UPDATED 08/12/94
```

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

```
10001001    HYDROGEN       ENDF/B-IV MAT 1269/THRM1002            UPDATED 08/12/94
 6005010   B-10 1273 218NGP 042375 P-3 293K                       UPDATED 08/12/94
 8005010   B-10 1273 218NGP 042375 P-3 293K                       UPDATED 08/12/94
 6005011    BORON-11       ENDF/B-IV MAT 1160                     UPDATED 08/12/94
 8005011    BORON-11       ENDF/B-IV MAT 1160                     UPDATED 08/12/94
 6006012    CARBON-12      ENDF/B-IV MAT 1274/THRM1065            UPDATED 08/12/94
 8006012    CARBON-12      ENDF/B-IV MAT 1274/THRM1065            UPDATED 08/12/94
 8007014    NITROGEN-14    ENDF/B-IV MAT 1275                     UPDATED 08/12/94
 1008016    OXYGEN-16      ENDF/B-IV MAT 1276                     UPDATED 08/12/94
 3008016    OXYGEN-16      ENDF/B-IV MAT 1276                     UPDATED 08/12/94
 8008016    OXYGEN-16      ENDF/B-IV MAT 1276                     UPDATED 08/12/94
 9008016    OXYGEN-16      ENDF/B-IV MAT 1276                     UPDATED 08/12/94
10008016    OXYGEN-16      ENDF/B-IV MAT 1276                     UPDATED 08/12/94
 4013027   AL-27 1193 218 GP 040375(5)                            UPDATED 08/12/94
 6013027   AL-27 1193 218 GP 040375(5)                            UPDATED 08/12/94
 8013027   AL-27 1193 218 GP 040375(5)                            UPDATED 08/12/94
 5024304   CR 1191 WT SS-304(1/EST) P-3 293K SP=5+4(42375)'       UPDATED 08/12/94
 5025055    MANGANESE-55   ENDF/B-IV MAT 1197                     UPDATED 08/12/94
 5026304   FE 1192 WT SS-304(1/EST) P-3 293K SP=5+4(42375)'       UPDATED 08/12/94
 5028304   NI 1190 WT SS-304(1/EST) P-3 293K SP=5+4(42375)'       UPDATED 08/12/94
 2040302    ZIRCALLOY      ENDF/B-IV MAT 1284                     UPDATED 08/12/94
 7082000   PB   1288 218NGP 042375 P-3 293K                       UPDATED 08/12/94
 1092235    URANIUM-235    ENDF/B-IV MAT 1261                     UPDATED 08/12/94
 1092238    URANIUM-238    ENDF/B-IV MAT 1262                     UPDATED 08/12/94

KENO MESSAGE NUMBER K5-222     1 TRANSFERS FOR MIXTURE     3 WERE CORRECTED FOR BAD MOMENTS.

KENO MESSAGE NUMBER K5-222     2 TRANSFERS FOR MIXTURE     9 WERE CORRECTED FOR BAD MOMENTS.

KENO MESSAGE NUMBER K5-222     1 TRANSFERS FOR MIXTURE    10 WERE CORRECTED FOR BAD MOMENTS.

                ........    0 IO'S WERE USED MIXING CROSS-SECTIONS      ........

                 1-D CROSS SECTION ARRAY ID NUMBERS
                    1  2002  1452    27    18  1018

                ........    0 IO'S WERE USED PREPARING THE CROSS SECTIONS    ........
```

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

```
************************************************************************************************
***                                                                                          ***
***       NAC-STC DIRECTLY LOADED; WET FUEL-PELLET GAP; 100% FUEL GEOMETRY OFFSET; 0 ENRIC   ***
***                                                                                          ***
************************************************************************************************
************************************************************************************************
***                                                                                          ***
***                         ****** ADDITIONAL INFORMATION ******                             ***
***                                                                                          ***
*** NUMBER OF ENERGY GROUPS                  27       USE LATTICE GEOMETRY                YES ***
***                                                                                          ***
*** NO. OF FISSION SPECTRUM SOURCE GROUP  1           GLOBAL ARRAY NUMBER                   4 ***
***                                                                                          ***
*** NO. OF SCATTERING ANGLES IN XSECS     2           NUMBER OF UNITS IN THE GLOBAL X DIR.  1 ***
***                                                                                          ***
*** ENTRIES/NEUTRON IN THE NEUTRON BANK  25           NUMBER OF UNITS IN THE GLOBAL Y DIR.  1 ***
***                                                                                          ***
*** ENTRIES/NEUTRON IN THE FISSION BANK  18           NUMBER OF UNITS IN THE GLOBAL Z DIR.  4 ***
***                                                                                          ***
*** NUMBER OF MIXTURES USED               9           USE A GLOBAL REFLECTOR              YES ***
***                                                                                          ***
*** NUMBER OF BIAS ID'S USED              1           USE NESTED HOLES                    YES ***
***                                                                                          ***
*** NUMBER OF DIFFERENTIAL ALBEDOS USED   0           NUMBER OF HOLES                     186 ***
***                                                                                          ***
*** TOTAL INPUT GEOMETRY REGIONS        154           MAXIMUM HOLE NESTING LEVEL            3 ***
***                                                                                          ***
*** NUMBER OF GEOMETRY REGIONS USED     154           USE NESTED ARRAYS                   YES ***
***                                                                                          ***
*** LARGEST GEOMETRY UNIT NUMBER        104           NUMBER OF ARRAYS USED                 4 ***
***                                                                                          ***
*** LARGEST ARRAY NUMBER                  4           MAXIMUM ARRAY NESTING LEVEL           2 ***
***                                                                                          ***
***                                                                                          ***
*** +X BOUNDARY CONDITION            MIRROR           -X BOUNDARY CONDITION            MIRROR ***
***                                                                                          ***
*** +Y BOUNDARY CONDITION            MIRROR           -Y BOUNDARY CONDITION            MIRROR ***
***                                                                                          ***
*** +Z BOUNDARY CONDITION               PER           -Z BOUNDARY CONDITION               PER ***
***                                                                                          ***
************************************************************************************************
```

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

```
*****************************************************************************************
***                                                                                   ***
***        NAC-STC DIRECTLY LOADED; WET FUEL-PELLET GAP; 100% FUEL GEOMETRY OFFSET; 0 ENR***
***                                                                                   ***
*****************************************************************************************
*****************************************************************************************
***                                                                                   ***
***                    ****** SPACE AND SUPERGROUP INFORMATION ******                 ***
***                                                                                   ***
***       100000 WORDS IS THE TOTAL SPACE AVAILABLE.                                  ***
***                                                                                   ***
***        53021 WORDS WERE USED FOR NON-SUPERGROUP STORAGE.                          ***
***                                                                                   ***
***        46979 WORDS OF STORAGE ARE AVAILABLE FOR SUPERGROUPED DATA.                ***
***                                                                                   ***
***        99620 WORDS OF STORAGE ARE AVAILABLE FOR CONSTRUCTING THE SUPERGROUPS.     ***
***                                                                                   ***
***        46919 WORDS OF STORAGE ARE AVAILABLE TO EACH SUPERGROUP.                   ***
***                                                                                   ***
***         1180 WORDS ARE NEEDED FOR THE LARGEST GROUP.                              ***
***                                                                                   ***
***        54417 WORDS OF STORAGE IS SUFFICIENT TO RUN THIS PROBLEM.                  ***
***                                                                                   ***
***        65927 WORDS OF STORAGE WILL ALLOW THE PROBLEM TO RUN WITH ONE SUPERGROUP.  ***
***                                                                                   ***
***        66208 WORDS OF STORAGE WILL BE USED TO RUN THIS PROBLEM.                   ***
***                                                                                   ***
*****************************************************************************************
*****************************************************************************************
***                                                                                   ***
***                      STARTING      ENDING       XSEC       ALBEDO      TOTAL      ***
***    SUPERGROUP         GROUP        GROUP       LENGTH      LENGTH      LENGTH     ***
***                                                                                   ***
***                                                                                   ***
***         1               1            27         2523          0        12846      ***
***                                                                                   ***
*****************************************************************************************

              ........     0 IO'S WERE USED IN SUPERGROUPING      ........

              ***********************************************************
              **                                                       **
              **   ARRAY      UNITS IN   UNITS IN   UNITS IN   NESTING **
              **   NUMBER      X DIR.     Y DIR.     Z DIR.     LEVEL  **
              **                                                       **
              **     1          17         17          1          2    **
              **                                                       **
              **     2          17         17          1          2    **
              **                                                       **
              **     3          17         17          1          2    **
              **                                                       **
              **     4 GLOBAL    1          1          4          1    **
              **                                                       **
              ***********************************************************

              ........     0 IO'S WERE USED LOADING THE DATA      ........
```

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

NAC-STC DIRECTLY LOADED; WET FUEL-PELLET GAP; 100% FUEL GEOMETRY OFFSET; 0 ENRIC

GENERATION	GENERATION K-EFFECTIVE	ELAPSED TIME MINUTES	AVERAGE K-EFFECTIVE	AVG K-EFF DEVIATION	MATRIX K-EFFECTIVE	MATRIX K-EFF DEVIATION
KENO MESSAGE NUMBER K5-132		WARNING....ONLY	922 INDEPENDENT FISSION POINTS WERE GENERATED			
1	8.42775E-01	4.89833E-01	1.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
KENO MESSAGE NUMBER K5-132		WARNING....ONLY	973 INDEPENDENT FISSION POINTS WERE GENERATED			
2	8.59256E-01	5.03500E-01	1.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
3	9.81674E-01	5.17333E-01	9.81674E-01	0.00000E+00	0.00000E+00	0.00000E+00
4	9.36266E-01	5.32000E-01	9.58970E-01	2.27041E-02	0.00000E+00	0.00000E+00
5	9.32953E-01	5.46500E-01	9.50297E-01	1.57173E-02	0.00000E+00	0.00000E+00
6	9.22000E-01	5.60333E-01	9.43223E-01	1.31743E-02	0.00000E+00	0.00000E+00
7	8.90982E-01	5.75000E-01	9.32775E-01	1.46049E-02	0.00000E+00	0.00000E+00
8	9.58241E-01	5.88667E-01	9.37019E-01	1.26576E-02	0.00000E+00	0.00000E+00
9	9.58604E-01	6.02333E-01	9.40103E-01	1.11332E-02	0.00000E+00	0.00000E+00
10	9.31171E-01	6.16167E-01	9.38986E-01	9.70606E-03	0.00000E+00	0.00000E+00
11	9.14921E-01	6.29833E-01	9.36312E-01	8.96786E-03	0.00000E+00	0.00000E+00
12	8.89081E-01	6.43667E-01	9.31589E-01	9.30837E-03	0.00000E+00	0.00000E+00
13	8.96803E-01	6.58333E-01	9.28427E-01	8.99403E-03	0.00000E+00	0.00000E+00
14	9.29014E-01	6.72000E-01	9.28476E-01	8.21053E-03	0.00000E+00	0.00000E+00
15	9.17850E-01	6.85667E-01	9.27658E-01	7.59669E-03	0.00000E+00	0.00000E+00
16	9.67038E-01	6.99500E-01	9.30471E-01	7.57478E-03	0.00000E+00	0.00000E+00
17	9.04308E-01	7.13167E-01	9.28727E-01	7.26425E-03	0.00000E+00	0.00000E+00
18	8.82455E-01	7.26833E-01	9.25835E-01	7.38491E-03	0.00000E+00	0.00000E+00
19	9.23019E-01	7.40667E-01	9.25669E-01	6.93889E-03	0.00000E+00	0.00000E+00
20	9.26944E-01	7.54333E-01	9.25740E-01	6.54243E-03	0.00000E+00	0.00000E+00
21	9.26825E-01	7.68167E-01	9.25797E-01	6.18878E-03	0.00000E+00	0.00000E+00
22	9.51700E-01	7.81833E-01	9.27092E-01	6.01235E-03	0.00000E+00	0.00000E+00
23	9.31857E-01	7.95500E-01	9.27319E-01	5.72338E-03	0.00000E+00	0.00000E+00
24	9.45504E-01	8.08333E-01	9.28146E-01	5.51927E-03	0.00000E+00	0.00000E+00
25	9.48368E-01	8.23000E-01	9.29025E-01	5.34664E-03	0.00000E+00	0.00000E+00
26	9.29654E-01	8.36833E-01	9.29051E-01	5.11908E-03	0.00000E+00	0.00000E+00
27	8.95124E-01	8.50500E-01	9.27694E-01	5.09414E-03	0.00000E+00	0.00000E+00
28	9.51964E-01	8.63333E-01	9.28628E-01	4.98251E-03	0.00000E+00	0.00000E+00
29	9.46722E-01	8.77000E-01	9.29298E-01	4.84104E-03	0.00000E+00	0.00000E+00
30	9.07429E-01	8.89833E-01	9.28517E-01	4.72987E-03	0.00000E+00	0.00000E+00
31	9.19008E-01	9.03667E-01	9.28189E-01	4.57562E-03	0.00000E+00	0.00000E+00
32	9.23612E-01	9.16333E-01	9.28036E-01	4.42310E-03	0.00000E+00	0.00000E+00
33	9.32488E-01	9.31000E-01	9.28180E-01	4.28045E-03	0.00000E+00	0.00000E+00
34	9.03881E-01	9.43833E-01	9.27421E-01	4.21352E-03	0.00000E+00	0.00000E+00
35	9.62378E-01	9.56667E-01	9.28480E-01	4.21899E-03	0.00000E+00	0.00000E+00
36	8.97305E-01	9.70333E-01	9.27563E-01	4.19447E-03	0.00000E+00	0.00000E+00
37	9.73499E-01	9.83167E-01	9.28875E-01	4.27911E-03	0.00000E+00	0.00000E+00
38	9.15334E-01	9.97000E-01	9.28499E-01	4.17552E-03	0.00000E+00	0.00000E+00
39	9.46079E-01	1.01067E+00	9.28974E-01	4.08880E-03	0.00000E+00	0.00000E+00
40	9.66997E-01	1.02450E+00	9.29975E-01	4.10360E-03	0.00000E+00	0.00000E+00
41	9.39366E-01	1.03717E+00	9.30216E-01	4.00424E-03	0.00000E+00	0.00000E+00
42	9.67038E-01	1.05000E+00	9.31136E-01	4.00995E-03	0.00000E+00	0.00000E+00
			. . . .			
768	9.46328E-01	1.07178E+01	9.33891E-01	8.50544E-04	0.00000E+00	0.00000E+00
769	9.59888E-01	1.07317E+01	9.33925E-01	8.50111E-04	0.00000E+00	0.00000E+00
770	9.59446E-01	1.07462E+01	9.33958E-01	8.49653E-04	0.00000E+00	0.00000E+00
771	9.79919E-01	1.07600E+01	9.34018E-01	8.50650E-04	0.00000E+00	0.00000E+00
772	9.06141E-01	1.07728E+01	9.33981E-01	8.50315E-04	0.00000E+00	0.00000E+00
773	9.42108E-01	1.07865E+01	9.33992E-01	8.49277E-04	0.00000E+00	0.00000E+00
774	9.46554E-01	1.07993E+01	9.34008E-01	8.48332E-04	0.00000E+00	0.00000E+00
775	9.31532E-01	1.08122E+01	9.34005E-01	8.47240E-04	0.00000E+00	0.00000E+00
776	9.55431E-01	1.08258E+01	9.34033E-01	8.46598E-04	0.00000E+00	0.00000E+00
777	9.00955E-01	1.08387E+01	9.33990E-01	8.46581E-04	0.00000E+00	0.00000E+00
778	9.18847E-01	1.08525E+01	9.33970E-01	8.45715E-04	0.00000E+00	0.00000E+00
779	9.18019E-01	1.08652E+01	9.33950E-01	8.44875E-04	0.00000E+00	0.00000E+00
780	9.58540E-01	1.08780E+01	9.33981E-01	8.44380E-04	0.00000E+00	0.00000E+00
781	9.33157E-01	1.08900E+01	9.33980E-01	8.43296E-04	0.00000E+00	0.00000E+00
782	9.41474E-01	1.09037E+01	9.33990E-01	8.42269E-04	0.00000E+00	0.00000E+00
783	9.81031E-01	1.09157E+01	9.34050E-01	8.43344E-04	0.00000E+00	0.00000E+00
784	9.34474E-01	1.09302E+01	9.34051E-01	8.42265E-04	0.00000E+00	0.00000E+00
785	9.61076E-01	1.09430E+01	9.34085E-01	8.41896E-04	0.00000E+00	0.00000E+00
786	9.36456E-01	1.09568E+01	9.34088E-01	8.40827E-04	0.00000E+00	0.00000E+00
787	9.33709E-01	1.09705E+01	9.34088E-01	8.39755E-04	0.00000E+00	0.00000E+00
788	9.36210E-01	1.09842E+01	9.34091E-01	8.38690E-04	0.00000E+00	0.00000E+00
789	9.18046E-01	1.09980E+01	9.34070E-01	8.37872E-04	0.00000E+00	0.00000E+00
790	9.03295E-01	1.10117E+01	9.34031E-01	8.37719E-04	0.00000E+00	0.00000E+00
791	9.24554E-01	1.10255E+01	9.34019E-01	8.36743E-04	0.00000E+00	0.00000E+00
792	9.63797E-01	1.10392E+01	9.34057E-01	8.36533E-04	0.00000E+00	0.00000E+00
793	9.54726E-01	1.10520E+01	9.34083E-01	8.35883E-04	0.00000E+00	0.00000E+00
794	9.23635E-01	1.10657E+01	9.34070E-01	8.34931E-04	0.00000E+00	0.00000E+00
795	9.41438E-01	1.10785E+01	9.34079E-01	8.33929E-04	0.00000E+00	0.00000E+00
796	8.87331E-01	1.10932E+01	9.34020E-01	8.34957E-04	0.00000E+00	0.00000E+00
797	9.41992E-01	1.11060E+01	9.34030E-01	8.33966E-04	0.00000E+00	0.00000E+00
798	9.52630E-01	1.11197E+01	9.34054E-01	8.33246E-04	0.00000E+00	0.00000E+00
799	9.12950E-01	1.11343E+01	9.34027E-01	8.32621E-04	0.00000E+00	0.00000E+00
800	9.10958E-01	1.11482E+01	9.33998E-01	8.32079E-04	0.00000E+00	0.00000E+00
801	9.14560E-01	1.11610E+01	9.33974E-01	8.31393E-04	0.00000E+00	0.00000E+00
802	9.42908E-01	1.11747E+01	9.33985E-01	8.30428E-04	0.00000E+00	0.00000E+00
803	8.95273E-01	1.11883E+01	9.33937E-01	8.30798E-04	0.00000E+00	0.00000E+00

KENO MESSAGE NUMBER K5-123 EXECUTION TERMINATED DUE TO COMPLETION OF THE SPECIFIED NUMBER OF GENERATIONS.

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

NAC-STC DIRECTLY LOADED; WET FUEL-PELLET GAP; 100% FUEL GEOMETRY OFFSET; 0 ENRIC

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LIFETIME =  3.80463E-05 + OR -  7.45568E-08            GENERATION TIME =  2.68138E-05 + OR -  3.95380E-08
NU BAR   =  2.43935E+00 + OR -  6.92015E-05       AVERAGE FISSION GROUP =  2.19694E+01 + OR -  4.03476E-03
              ENERGY(EV) OF THE AVERAGE LETHARGY CAUSING FISSION =  2.33262E-01 + OR -  7.60910E-04
```

NO. OF INITIAL GENERATIONS SKIPPED	AVERAGE K-EFFECTIVE	DEVIATION	67 PER CENT CONFIDENCE INTERVAL	95 PER CENT CONFIDENCE INTERVAL	99 PER CENT CONFIDENCE INTERVAL	NUMBER OF HISTORIES
3	0.93388	+ OR - 0.00083	0.93305 TO 0.93471	0.93222 TO 0.93554	0.93139 TO 0.93637	800000
4	0.93387	+ OR - 0.00083	0.93304 TO 0.93470	0.93221 TO 0.93554	0.93138 TO 0.93637	799000
5	0.93388	+ OR - 0.00083	0.93304 TO 0.93471	0.93221 TO 0.93554	0.93138 TO 0.93637	798000
6	0.93389	+ OR - 0.00083	0.93306 TO 0.93472	0.93222 TO 0.93556	0.93139 TO 0.93639	797000
7	0.93394	+ OR - 0.00083	0.93311 TO 0.93478	0.93228 TO 0.93561	0.93145 TO 0.93644	796000
8	0.93391	+ OR - 0.00083	0.93308 TO 0.93475	0.93225 TO 0.93558	0.93142 TO 0.93641	795000
9	0.93388	+ OR - 0.00083	0.93305 TO 0.93472	0.93222 TO 0.93555	0.93138 TO 0.93638	794000
10	0.93389	+ OR - 0.00083	0.93305 TO 0.93472	0.93222 TO 0.93555	0.93138 TO 0.93639	793000
11	0.93391	+ OR - 0.00083	0.93308 TO 0.93474	0.93224 TO 0.93558	0.93141 TO 0.93641	792000
12	0.93397	+ OR - 0.00083	0.93313 TO 0.93480	0.93230 TO 0.93563	0.93146 TO 0.93647	791000
17	0.93404	+ OR - 0.00084	0.93320 TO 0.93487	0.93236 TO 0.93571	0.93153 TO 0.93654	786000
22	0.93411	+ OR - 0.00084	0.93327 TO 0.93495	0.93244 TO 0.93579	0.93160 TO 0.93663	781000
27	0.93414	+ OR - 0.00084	0.93330 TO 0.93498	0.93246 TO 0.93582	0.93161 TO 0.93666	776000
			⋮			
772	0.93283	+ OR - 0.00390	0.92893 TO 0.93673	0.92503 TO 0.94062	0.92114 TO 0.94452	31000
777	0.93235	+ OR - 0.00435	0.92800 TO 0.93670	0.92364 TO 0.94106	0.91929 TO 0.94541	26000
782	0.93195	+ OR - 0.00515	0.92680 TO 0.93711	0.92165 TO 0.94226	0.91649 TO 0.94742	21000
787	0.92652	+ OR - 0.00555	0.92097 TO 0.93207	0.91542 TO 0.93762	0.90986 TO 0.94317	16000
792	0.92531	+ OR - 0.00693	0.91838 TO 0.93224	0.91145 TO 0.93917	0.90452 TO 0.94610	11000
797	0.92155	+ OR - 0.00885	0.91270 TO 0.93039	0.90385 TO 0.93924	0.89501 TO 0.94808	6000

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

NAC-STC DIRECTLY LOADED; WET FUEL-PELLET GAP; 100% FUEL GEOMETRY OFFSET; 0 ENRIC

PLOT OF AVERAGE K-EFFECTIVE BY GENERATION RUN.
THE LINE REPRESENTS K-EFF = 0.9339 + OR - 0.0008 WHICH OCCURS FOR 803 GENERATIONS RUN.

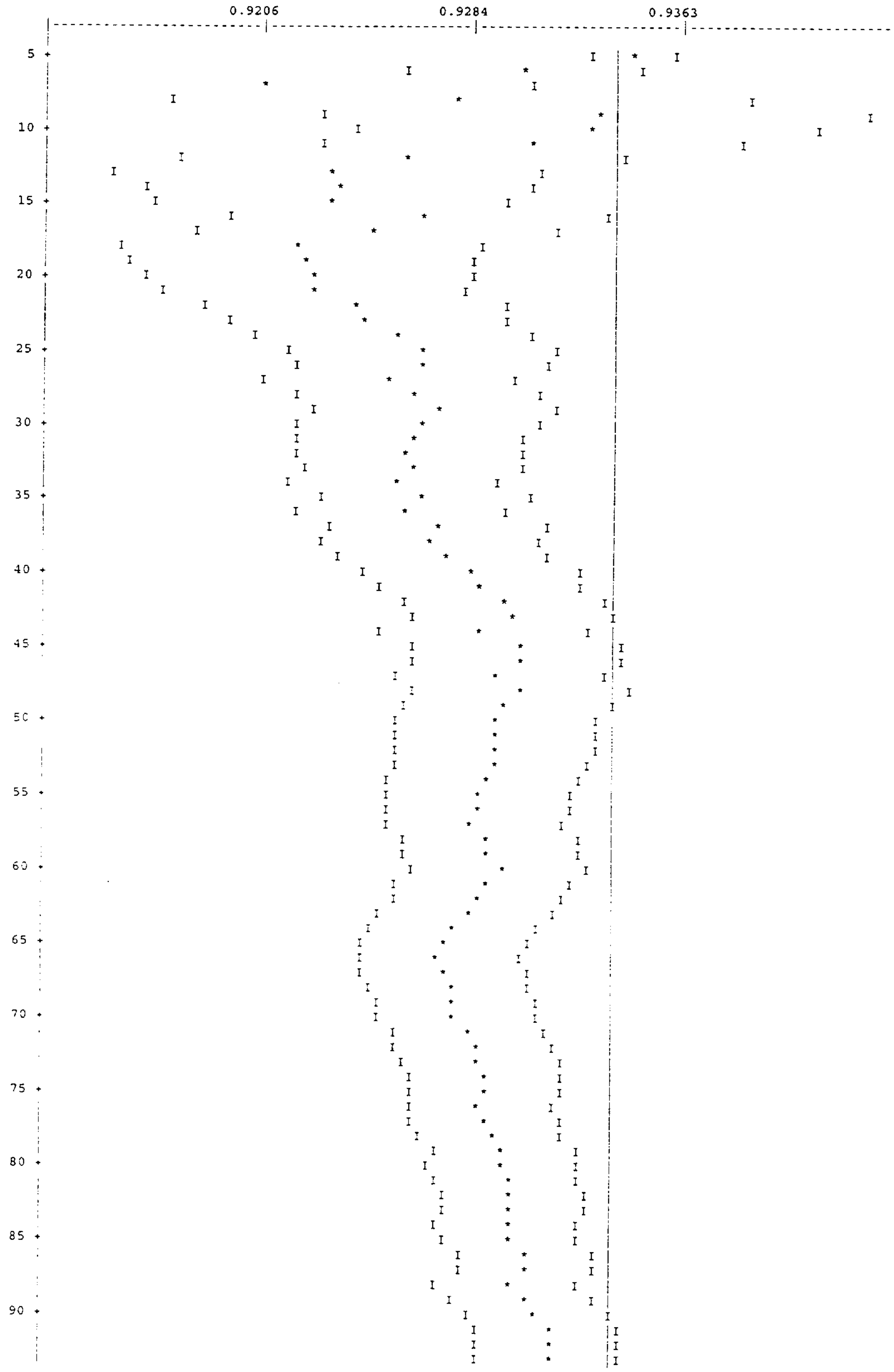

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

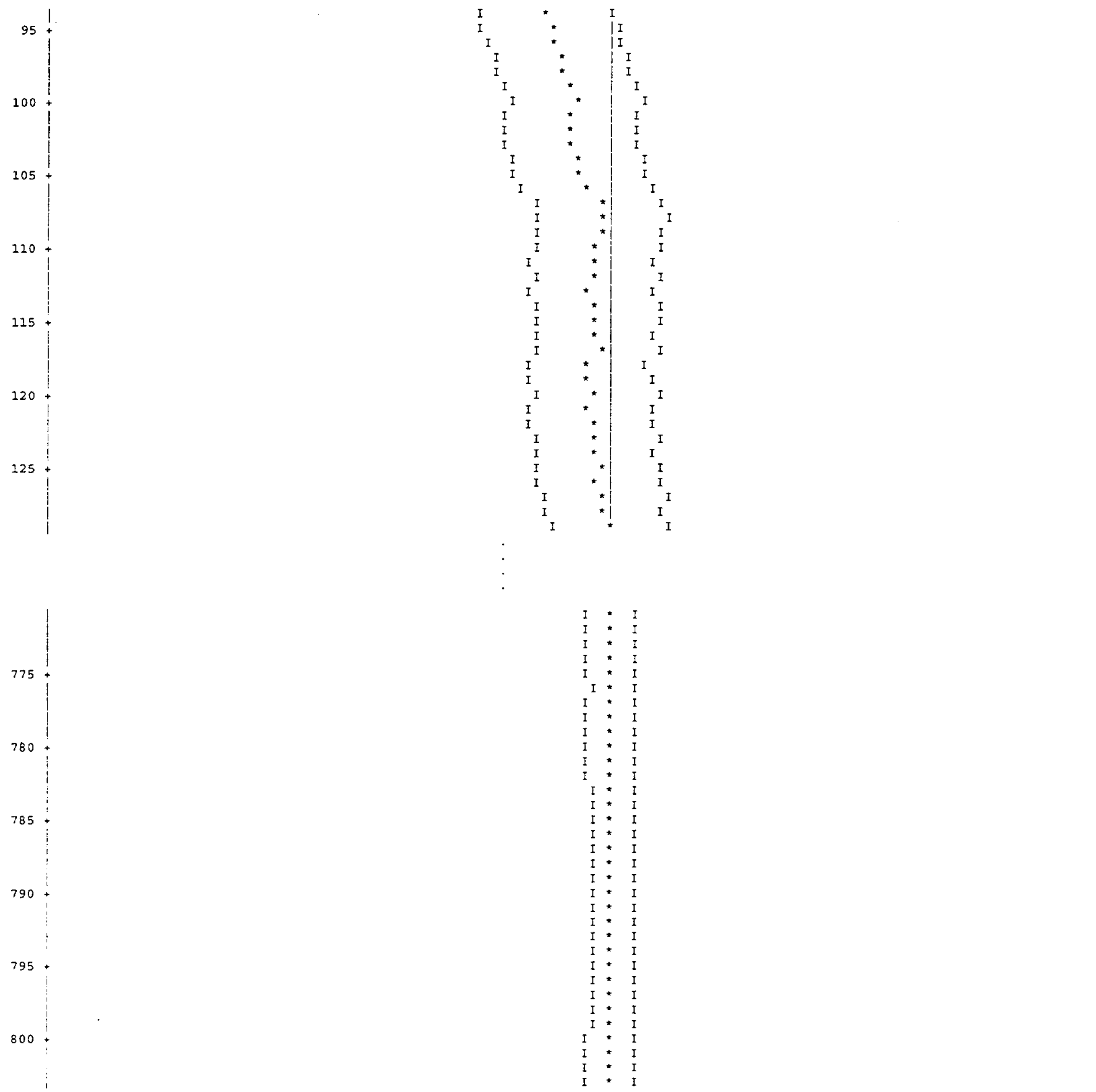

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

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          NAC-STC DIRECTLY LOADED; WET FUEL-PELLET GAP; 100% FUEL GEOMETRY OFFSET; 0 ENRIC

                              FREQUENCY FOR GENERATIONS    4 TO  803
0.8689 TO 0.8733      ***
0.8733 TO 0.8776      ***
0.8776 TO 0.8820      ****
0.8820 TO 0.8864      *******
0.8864 TO 0.8907      ************
0.8907 TO 0.8951      *********
0.8951 TO 0.8995      ***************
0.8995 TO 0.9038      ************************
0.9038 TO 0.9082      ******************************
0.9082 TO 0.9125      *******************************
0.9125 TO 0.9169      **************************************************
0.9169 TO 0.9213      *********************************************
0.9213 TO 0.9256      *************************************************************
0.9256 TO 0.9300      ***************************************************************
0.9300 TO 0.9344      ***********************************************************
0.9344 TO 0.9387      ***************************************************
0.9387 TO 0.9431      ***********************************************************
0.9431 TO 0.9475      **********************************************************
0.9475 TO 0.9518      ******************************************
0.9518 TO 0.9562      ******************************************
0.9562 TO 0.9605      **************************
0.9605 TO 0.9649      *************************
0.9649 TO 0.9693      ****************************
0.9693 TO 0.9736      *****************
0.9736 TO 0.9780      ********
0.9780 TO 0.9824      ***********
0.9824 TO 0.9867      *****
0.9867 TO 0.9911      ******
0.9911 TO 0.9955      **
0.9955 TO 0.9998
0.9998 TO 1.0042      **
1.0042 TO 1.0086      **

NAC-STC DIRECTLY LOADED; WET FUEL-PELLET GAP; 100% FUEL GEOMETRY OFFSET; 0 ENRIC

                              FREQUENCY FOR GENERATIONS  204 TO  803
0.8689 TO 0.8733      ***
0.8733 TO 0.8776      *
0.8776 TO 0.8820      ***
0.8820 TO 0.8864      ****
0.8864 TO 0.8907      *********
0.8907 TO 0.8951      ******
0.8951 TO 0.8995      *******
0.8995 TO 0.9038      ********************
0.9038 TO 0.9082      ***********************
0.9082 TO 0.9125      **************************
0.9125 TO 0.9169      ************************************
0.9169 TO 0.9213      *************************************
0.9213 TO 0.9256      ****************************************************
0.9256 TO 0.9300      ******************************************
0.9300 TO 0.9344      ***********************************************
0.9344 TO 0.9387      *************************************
0.9387 TO 0.9431      ***********************************************
0.9431 TO 0.9475      *******************************************
0.9475 TO 0.9518      *****************************
0.9518 TO 0.9562      **********************************
0.9562 TO 0.9605      *********************
0.9605 TO 0.9649      ******************
0.9649 TO 0.9693      ******************
0.9693 TO 0.9736      ************
0.9736 TO 0.9780      ****
0.9780 TO 0.9824      ********
0.9824 TO 0.9867      ***
0.9867 TO 0.9911      ****
0.9911 TO 0.9955      **
0.9955 TO 0.9998
0.9998 TO 1.0042      **
1.0042 TO 1.0086      **
```

Figure 6.6-9 CSAS25 Input / Output for Framatome-Cogema AFA Fuel (Continued)

```
NAC-STC DIRECTLY LOADED; WET FUEL-PELLET GAP; 100% FUEL GEOMETRY OFFSET; 0 ENRIC

                               FREQUENCY FOR GENERATIONS  404 TO  803
0.8689 TO 0.8733     ***
0.8733 TO 0.8776
0.8776 TO 0.8820     ***
0.8820 TO 0.8864     ***
0.8864 TO 0.8907     ******
0.8907 TO 0.8951     ****
0.8951 TO 0.8995     ***
0.8995 TO 0.9038     ************
0.9038 TO 0.9082     ****************
0.9082 TO 0.9125     **************
0.9125 TO 0.9169     **********************
0.9169 TO 0.9213     ***********************
0.9213 TO 0.9256     ************************************
0.9256 TO 0.9300     ************************
0.9300 TO 0.9344     ********************************
0.9344 TO 0.9387     *************************
0.9387 TO 0.9431     ***********************************
0.9431 TO 0.9475     *******************************
0.9475 TO 0.9518     *********************
0.9518 TO 0.9562     ********************
0.9562 TO 0.9605     **************
0.9605 TO 0.9649     ************
0.9649 TO 0.9693     *************
0.9693 TO 0.9736     ******
0.9736 TO 0.9780     ****
0.9780 TO 0.9824     *******
0.9824 TO 0.9867     ***
0.9867 TO 0.9911     ****
0.9911 TO 0.9955     *
0.9955 TO 0.9998
0.9998 TO 1.0042     *
1.0042 TO 1.0086     **
```

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NAC-STC DIRECTLY LOADED; WET FUEL-PELLET GAP; 100% FUEL GEOMETRY OFFSET; 0 ENRIC

                               FREQUENCY FOR GENERATIONS  604 TO  803
0.8689 TO 0.8733     *
0.8733 TO 0.8776
0.8776 TO 0.8820     *
0.8820 TO 0.8864     *
0.8864 TO 0.8907     ****
0.8907 TO 0.8951     *
0.8951 TO 0.8995     ***
0.8995 TO 0.9038     *******
0.9038 TO 0.9082     ******
0.9082 TO 0.9125     ***********
0.9125 TO 0.9169     **************
0.9169 TO 0.9213     ****************
0.9213 TO 0.9256     **************
0.9256 TO 0.9300     **************
0.9300 TO 0.9344     ************
0.9344 TO 0.9387     *********
0.9387 TO 0.9431     *****************
0.9431 TO 0.9475     ************
0.9475 TO 0.9518     ************
0.9518 TO 0.9562     ***********
0.9562 TO 0.9605     **********
0.9605 TO 0.9649     *****
0.9649 TO 0.9693     *******
0.9693 TO 0.9736     ***
0.9736 TO 0.9780     **
0.9780 TO 0.9824     *****
0.9824 TO 0.9867     *
0.9867 TO 0.9911
0.9911 TO 0.9955     *
0.9955 TO 0.9998
0.9998 TO 1.0042
1.0042 TO 1.0086
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7.0 OPERATING PROCEDURES

This chapter provides an outline of the operating procedures and tests that are performed to ensure proper function of the NAC-STC during transport operations. The operating procedures provided in this chapter are the minimum generic requirements for loading, unloading, preparation for transport and for inspection, and testing of the cask. Bolt torque values are provided in Table 7-1. Each licensee and cask user will develop, prepare and approve site specific procedures, based on the approved detailed operating procedures provided by NAC, to assure that cask handling and shipping activities are performed in accordance with the package Certificate of Compliance and the applicable Nuclear Regulatory Commission and Department of Transportation regulations governing the packaging and transport of radioactive materials.

These procedures assume that the unloaded NAC-STC arrives at a site already configured for use at the site. If this is not the case, then additional operations would be specified in the site specific procedures to configure the cask for the intended use.

The operating procedures in this chapter have been written assuming direct loading or unloading of fuel in the basket in the NAC-STC in a spent fuel pool, or dry loading and unloading of a sealed canister in the reactor cask receiving area, fuel building or other suitable location identified by the user. With minor modifications, site specific procedures can be written to accommodate the dry direct loading or unloading of fuel from the cask in a hot cell.

Procedures are also provided for the preparation for shipment of an NAC-STC cask that has been loaded and stored at an Independent Spent Fuel Storage Installation (ISFSI) in accordance with the ISFSI license and the 10 CFR 72 requirements.

It is the responsibility of the cask user to prepare site specific handling procedures in accordance with the Certificate of Compliance, these generic procedures, and the licensee's Quality Assurance program. The site specific procedures will normally incorporate signoff blocks to document activities as they are performed. Oversight organizations, such as Quality Assurance or Quality Control, may participate in certain package handling operations. User approved operating procedures, including signoffs, ensure that critical steps are not overlooked, that the packaging is handled in accordance with its Certificate of Compliance and Safety Analysis Report, and that records are maintained as required by 10 CFR 71.91 and/or IAEA Safety Series No. ST-1, paragraphs 209 and 210.

The user will verify by fuel accounting, historical data, and inspection records, that the fuel assemblies to be loaded are in compliance with the content conditions of the Certificate of Compliance. In the directly loaded configuration, fuel assemblies or fuel rods with known or suspected cladding defects that exceed pin holes and hairline cracks are not to be loaded into the NAC-STC. In the canistered configuration, failed fuel will be separately containerized and sealed in the canister prior to transport.

The user shall verify that the NAC-STC transport cask has the correct o-ring configuration for the intended use. The transport cask may be configured with either metallic o-rings or with non-metallic EPDM or Viton o-rings. The o-rings may not be used interchangeably, since each o-ring type requires a different o-ring groove configuration. Consequently, the inner lid, vent and drain port coverplates and outer lid are machined with a square o-ring groove to accept metallic o-rings or are machined with a truncated triangular (dove-tail) groove to accept the non-metallic EPDM or Viton o-rings. The lid and port coverplates cannot be used interchangeably with two types of o-rings.

EPDM or Viton o-rings may be used only when directly loading spent fuel for transport without interim storage. Metallic o-rings must be used when directly loading spent fuel for an extended period of storage and may be used when directly loading spent fuel for transport without interim storage. Metallic o-rings must also be used when loading canistered fuel or GTCC waste for transport. The metallic and non-metallic o-rings have different limits of allowable leak rate as specified in the procedures.

Table 7-1 Torque Table

Component	No. Used	Fastener[1]	Torque Value[2]
Outer Lid Bolt	36	1-8 UNC Socket Head Cap Screw	550 ± 50 ft.-lb (746 ± 68 N-m)
Inner Lid Bolt	42	1 1/2 - 8 UN – 2A Socket Head Cap Screw	2,540 ± 200 ft-lb (3,443 ± 271 N-m)
Port Cover Bolt	6	3/8 - 16 UNC Socket Head Cap Screw	140 ± 10 in-lb (16 ± 1 N-m)
Coverplate Bolt	8	1/2 - 13 UNC Socket Head Cap Screw	300 ± 20 in-lb (34 ± 2 N-m)
Test Plug	1	Part No. 423-803-13	30 ± 3 ft-lb (41 ± 4 N-m)
Test Plug	2	Part No. 423-806-3	70 ± 5 in-lb (8 ± 0.6 N-m)
Test Plug	2	Part No. 423-807-8	70 ± 5 in-lb (8 ± 0.6 N-m)
Impact Limiter Retaining Rods	32	Part No. 423-811-7	75 ± 5 ft-lb (102 ± 7 N-m)
Impact Limiter Nut	32	1 - 8 UNC – 2B Heavy Hex Nut	35 ± 2 ft-lb (47 ± 3 N-m)
Impact Limiter Jam Nut	32	1 - 8 UN - 2B Heavy Hex Nut	75 ± 5 ft-lb (102 ± 7 N-m)

1. All threaded fasteners shall be lightly lubricated using Nuclear Grade Pure Nickel NEVER-SEEZ® or equivalent.
2. Torque values for fasteners not shown in this table are provided on the appropriate License Drawing.

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7.1 Outline of Procedures for Receipt and Loading the Cask

The following receipt and loading procedures are based on an acceptable cask receipt inspection for first time loading with spent fuel. For casks previously loaded and transported, the receiving inspections will require performance of radiation and removable contamination surveys of the empty cask and vehicle in accordance with 10 CFR 71, and 49 CFR 173 in the U.S. Similar requirements are contained in IAEA Safety Series No. ST-1.

7.1.1 Receiving Inspection

1. Perform radiation and removable contamination surveys in accordance with 49 CFR 173.441 and 173.443 requirements.
2. Move the transport vehicle with the cask to the cask receiving area.
3. Secure the transport vehicle. Remove the personnel barrier hold down bolts from both sides of the personnel barrier. Using the lifting sling, lift the personnel barrier off of the cask and store it in a designated area.
4. Visually inspect the NAC-STC while secured to the transport vehicle in the horizontal orientation for any signs of damage.
5. Attach slings to the top impact limiter lifting points, remove impact limiter lock wires, impact limiter jam nuts, impact limiter nuts and retaining rods. Remove impact limiter and store upright. Repeat operation for the bottom impact limiter.
6. Release the tiedown assembly from the front support by removing the front tiedown bolts and lock washers.
7. Attach a sling to the tiedown assembly lifting eyes and remove the tiedown assembly from the transport vehicle.
8. Attach the cask lifting yoke to a crane hook with the appropriate load rating. Engage the two yoke arms with the lifting trunnions at the top (front) end of the cask. Rotate/lift the cask to the vertical orientation and raise the cask off of the blocks of the rear support structure of the transport vehicle. Place the cask in the vertical orientation in a decontamination area or other suitable location identified by the user. Disengage the cask lifting yoke from the lifting trunnions.

7.1.2 Preparation of Cask for Loading

The loading procedures are based on the assumption that the cask is being prepared for first time fuel loading following fabrication, or that the scheduled annual maintenance required by the

Certificate of Compliance has been successfully completed within the previous 12 months. If the cask has been used previously, at the start of this procedure, it is assumed to have been externally decontaminated, empty of fuel contents, and sitting in the decontamination area, or in another location convenient for preparing the cask.

There are two (2) loading options for the NAC-STC. Each requires different preparation steps. The first is direct loading of fuel assemblies into a fuel basket installed in the cask, which is typically performed under water in the spent fuel pool cask loading area. The second is dry loading of a welded transportable storage canister that is already loaded with spent fuel assemblies, Reconfigured Fuel Assemblies, or with containers of Greater Than Class C (GTCC) waste, which is performed in the cask receiving area, or another convenient location established by the user, using a transfer cask system. The generic cask preparations for loading procedures for both wet direct fuel loading and dry canistered fuel loading options are presented below.

The NAC-STC may be closed with either metallic o-rings or non-metallic EPDM or Viton o-rings in the containment boundary and outer lid. Metallic o-rings are required when directly loading spent fuel for an extended period of storage and when loading canistered fuel or GTCC waste (for transport). Metallic or non-metallic o-rings may be used when directly loading spent fuel for transport without interim storage. O-rings may not be used interchangeably, as the inner lid and port cover o-ring grooves are different for each o-ring type. The lid and o-ring configurations to be used must be confirmed and the associated leak test requirements identified.

7.1.2.1 Preparation for Direct Fuel Loading (Uncanistered)

This procedure presents the steps necessary to prepare the cask for under water direct loading of fuel into a basket contained in the NAC-STC cask. This procedure may be modified to accommodate the dry direct loading of fuel in a hot cell.

1. Install appropriate work platforms/scaffolding to allow access to the top of the cask.
2. Detorque in reverse torquing sequence and remove the outer lid bolts. Install the two outer lid alignment pins.
3. Install lifting eyes in the outer lid lifting holes and attach the outer lid lifting sling to the outer lid and overhead crane. Remove the outer lid and place it aside in a temporary storage area. When setting the outer lid down, protect the o-ring and the o-ring groove of the lid from damage. Remove the outer lid alignment pins. Decontaminate the surface of the inner lid and top forging as required. At a convenient time, if a metallic

o-ring is used, remove and replace the metallic o-ring in the outer lid. If an EPDM or Viton o-ring is used, inspect the o-ring and replace as necessary.

4. Detorque drain and vent coverplate bolts and remove the drain port and the vent port coverplates from the inner lid. Store in temporary storage area.
5. Connect demineralized water supply to drain port quick-disconnect. Connect vent hose to vent port quick disconnect. Fill cask using demineralized water supply until water discharges from the vent hose. Ensure that the vent hose discharges into an appropriate rad waste handling system, as the cask interior may contain residual contamination.
6. Detorque and remove two inner lid bolts and install the two inner lid alignment pins at locations marked on the inner lid.
7. Detorque and remove the remaining inner lid bolts. Clean and visually inspect the outer lid bolts, inner lid bolts, and coverplate bolts for damage or excessive wear.
8. Detorque and remove the bolts and the interlid port and pressure port covers from the top forging. Store and protect all removed parts.
9. Attach the lifting yoke to a crane hook with the appropriate load rating and engage the yoke arms with the lifting trunnions.
10. Attach the lifting eyes to the inner lid. Install the inner lid lifting sling to the eyes in the inner lid and to the lifting eyes on the strongbacks of the lifting yoke.
11. Move the cask to the pool over the cask loading area. As the cask is lowered onto the cask loading area in the pool, spray the external surface of the cask with clear demineralized water to minimize external decontamination efforts.
12. After the cask is resting on the floor of the pool, disconnect the lifting yoke from the lifting trunnions and slowly raise the yoke to remove the inner lid.
13. Remove the lifting yoke and inner lid from the pool. Spray the yoke and lid, as they come out of the water to remove contamination.
14. Store the inner lid in a temporary storage area; remove and store the yoke and inner lid lifting sling in the storage area. When setting the inner lid down, ensure that the o-rings and o-ring grooves of the lid are protected from damage. Decontaminate inner lid, as necessary. At a convenient time, if metallic o-rings are used, remove and replace the metallic o-rings in the inner lid and in the vent and drain port coverplates. If EPDM or Viton o-rings are used, inspect the o-rings and replace as necessary.
15. Visually examine the internal cavity, fuel basket and drain line to ensure that: (a) no damage has occurred during transit; (b) no foreign materials are present that would inhibit cavity draining; and (c) all required components are in place.

7.1.2.2 Preparation for Canistered Fuel Loading

This procedure presents the steps required for loading canistered fuel or canistered GTCC waste into the NAC-STC. A canister of fuel or of GTCC waste is loaded dry into the cask, using a transfer cask and attendant support hardware, including the bottom spacer. The operation of the transfer cask is described in NAC approved site specific procedures. Loading of canistered fuel or canistered GTCC waste into the NAC-STC is done in the cask receiving area, or other suitable location specified by the user. The NAC-STC is assumed to be positioned in the area designated for dry canister loading and configured with metallic o-rings.

1. Install appropriate work platforms/scaffolding to allow access to the top of the cask.
2. Detorque in reverse torquing sequence and remove the outer lid bolts. Install the two outer lid alignment pins.
3. Install lifting eyes in the outer lid lifting holes and attach the outer lid lifting device to the outer lid and overhead crane. Remove the outer lid and place it aside in a temporary storage area. When storing the outer lid, protect the o-ring and the o-ring groove of the lid from damage. Remove the outer lid alignment pins. Decontaminate the surface of the inner lid and top forging as required.
4. Detorque the vent and drain coverplate bolts and remove the drain port coverplate and the vent port coverplate from the inner lid. Store the coverplates and bolts in a designated temporary storage area.
5. Detorque and remove two inner lid bolts and install the two inner lid alignment pins at locations marked on the inner lid.
6. Attach the inner lid lifting eyebolts and the inner lid lifting slings to the inner lid.
7. Detorque and remove the remaining inner lid bolts. Clean and visually inspect the outer lid bolts, inner lid bolts, and coverplate bolts for damage or excessive wear. Record inspection results on cask loading report. Replace damaged bolts with approved spare parts.
8. Detorque and remove the bolts and covers from the interlid port and the pressure port in the top forging. Store and protect all removed parts.
9. Lower auxiliary hook to above inner lid and engage lid lifting sling to auxiliary crane hook.
10. Slowly lift and remove the inner lid. The inner lid alignment pins will guide the inner lid until it clears the top forging.

11. Store the inner lid in a temporary storage area. When storing the inner lid, ensure that the o-rings and o-ring grooves of the lid are protected from damage. Decontaminate inner lid, as necessary.
12. Visually examine the internal cavity to ensure that the cavity is free of damage and foreign materials.
13. Install the bottom spacer. Attach the spacer lift fixture to the spacer. Using the auxiliary crane, lower the spacer into the cask cavity, and remove the lift fixture.
14. Install the adapter ring and torque the three captive bolts to 270 ± 20 ft.-lb.
15. Install the transfer adapter plate on the adapter ring.
16. Bolt the transfer adapter plate to the cask using 4 socket head bolts. Torque the 4 socket head bolts to 270 ± 20 ft.-lb.

7.1.3 Loading the NAC-STC Cask

There are two (2) loading options for the NAC-STC. Each requires different steps. The first is direct loading of fuel assemblies into a fuel basket installed in the cask. This loading is typically performed under water in the spent fuel pool cask loading area. The second is dry loading into the cask of a sealed transportable storage canister that already contains spent fuel assemblies or containers of GTCC waste. Dry loading of the canister into the cask is performed in the cask receiving area, or other convenient location established by the user, using a transfer cask. The generic procedures for fuel loading for these options are presented below. In both cases, it is assumed that the fuel assemblies to be directly loaded, or those contained within the sealed canister, have been selected to conform to the limiting conditions of the NAC-STC and canister. Direct loading of spent fuel for extended storage requires the use of metallic o-rings. Either metallic o-rings or non-metallic EPDM or Viton o-rings may be used in direct loading for transport without interim storage. Metallic o-rings must be used for loading canistered fuel or GTCC waste (for transport).

7.1.3.1 Direct Loading of Fuel (Uncanistered)

The NAC-STC may be closed with either metallic or non-metallic o-rings in the containment boundary and outer lid. Metallic o-rings are required: 1) when directly loading spent fuel for an extended period of storage; and 2) when loading canistered fuel or GTCC waste (for transport). Metallic o-rings or non-metallic EPDM or Viton o-rings may be used when directly loading spent fuel for transport without interim storage. However, the metallic and non-metallic o-rings may not be used interchangeably, as the o-ring grooves are different for each o-ring type. As specified in the appropriate steps of this procedure, the two types of o-rings have different allowable leak rates, so the lid and o-ring configurations to be used must be confirmed and the associated leak test requirements identified.

1. Using approved fuel identification and handling procedures and fuel handling equipment, engage the fuel handling tool to the top of the fuel assembly, lift it from the storage rack location, transfer it to above the cask, and carefully lower it into the designated location in the fuel basket. Be careful not to contact any of the sealing surfaces on the top forging, or to come in contact with the inner lid guide pins during fuel assembly movement.

   Note: Each fuel assembly shall contain the standard number of fuel rods for an assembly of that type. For fuel assemblies with missing fuel rods, missing rods shall be replaced with dummy rods of equivalent water displacement prior to loading into cask for transport.
2. Record in the cask loading report the fuel identification number and basket position where the fuel assembly was placed.
3. Repeat steps 1 and 2 until the basket is fully loaded or until all desired fuel assemblies have been loaded. If the cask is going to be partially loaded, the fuel assemblies should be loaded, if possible, in a fully symmetric pattern to ensure that the center of gravity of the cask remains aligned as close as possible to the longitudinal axis of the cask.
4. Attach the inner lid lifting sling to an auxiliary crane hook, lift the inner lid, remove the inner lid o-rings, and clean inner lid o-ring groove surfaces. If metallic o-rings are used, replace the metallic o-rings on the inner lid. For EPDM or Viton o-rings, inspect the o-rings and replace as necessary. Carefully inspect the new o-rings for damage prior to installation. Secure the metallic o-rings in the groove by the use of the o-ring clips and screws. Similarly, replace the metallic o-rings in the vent and drain port coverplates or inspect and replace as necessary the EPDM or Viton o-rings.
5. After replacing the inner lid o-rings, lift the inner lid and place it on the cask using the inner lid alignment pins to assist in proper lid seating and orientation. Visually verify proper lid position.
6. Disconnect the lid lifting device from the auxiliary crane hook and remove crane hook from area.
7. Attach the lifting yoke to the crane hook, lower the lifting yoke into the lifting position over the cask lifting trunnions, and engage the lifting arms to the lifting trunnions. Slowly lift the cask out of the pool until the top of the cask is slightly above the pool water level.

Note: As an alternative method, the cask and inner lid may be handled simultaneously. In the event that this method is chosen, instead of performing steps 5, 6 and 7, attach the lifting yoke to a crane hook and the inner lid lifting eyes to the lift yoke. Lower the lid and engage to the cask using the lid alignment pins. Engage lifting arms to lifting trunnions. Slowly lift the cask out of the pool until the top of the cask is slightly above the pool water level.

8. Attach a drain line to the quick disconnect in the interlid port (located in the top forging) and allow the water to drain from the interlid region. Once drained, disconnect the drain line.
9. Install at least 10 inner lid bolts equally spaced on the bolt circle to hand tight.
10. Continue raising the cask from the pool while spraying the external cask surfaces with clean water to minimize surface contamination levels.
11. Move the cask to the cask decontamination area, lower the cask to the floor and disengage the lift yoke (or lift beam and inner lid lifting slings if the alternate method of handling the inner lid was used). Remove the lift yoke and crane from the area.
12. Connect a vent line to the vent port quick disconnect. Direct the free end of the vent line to a radioactive waste handling system capable of handling liquids and gas.
13. Remove the inner lid alignment pins and install the remaining inner lid bolts and torque all of the bolts to the torque value specified in Table 7-1. The bolt torquing sequence is shown on the inner lid.
14. Connect a drain line to the drain port quick disconnect (located in the inner lid). Remove the vent line from the vent port quick disconnect.
15. Drain the cask cavity by connecting an air, nitrogen or helium supply to the vent port quick disconnect (located in the inner lid). Purge the water from the cask by pressurizing to 60 to 75 psig and hold until all water is removed (observed when no water is coming from the drain line). Turn the air, nitrogen, or helium supply off and disconnect the air, nitrogen or helium supply line from the vent port. Then, disconnect the drain line from the drain port quick disconnect.
16. Install the drain port coverplate. Torque the bolts to the value indicated in Table 7-1.
17. Connect a vacuum pump to the cask cavity via the vent port quick disconnect in the inner lid. Evacuate the cask cavity until a pressure of 3 mbar (absolute) is reached. Continue pumping for a minimum of 1 hour after reaching 3 mbar (absolute). Valve off vacuum pump from system and using a calibrated vacuum gauge (minimum gauge readability of 2.5 mbar), observe for a pressure rise. If a pressure rise (ΔP) of more than 12 mbar in ten minutes is observed, continue pumping until the pressure does not rise

more than 12 mbar in ten minutes. Repeat dryness test until cavity dryness has been verified ($\Delta P < 12$ mbar in 10 minutes). Record test results in the cask loading report.

18. Without allowing air to re-enter the cask cavity, turn off and disconnect the vacuum pump. Connect a supply of helium (99.9% minimum purity) to the vent port quick disconnect and backfill the cask cavity to 1 atmosphere absolute helium pressure.

19. Connect the leak detector vacuum pump to the inner lid interseal test port and evacuate the air between the metallic o-rings. Hold a vacuum on the interseal region. Using the helium leak detector, verify that any detectable leak rate for metallic o-rings is $\leq 2 \times 10^{-7}$ cm^3/sec (helium). The sensitivity of the detector shall be $\leq 1 \times 10^{-7}$ cm^3/sec (helium). For EPDM and Viton o-rings, verify that any detectable leak rate is $\leq 4.1 \times 10^{-5}$ cm^3/sec (helium). The sensitivity of the detector shall be $\leq 2.0 \times 10^{-5}$ cm^3/sec.

20. Install the test port plug for the inner lid interseal test port using a new metallic o-ring and torque the plug to the value specified in Table 7-1.

21. Connect the leak detector vacuum pump to the vent port coverplate interseal test port. Evacuate the interseal volume until a pressure of 3 mbar is reached. Using the helium leak detector, verify that any detectable leak rate for metallic o-rings is $\leq 2 \times 10^{-7}$ cm^3/sec (helium). The sensitivity of the detector shall be $\leq 1 \times 10^{-7}$ cm^3/sec (helium). For EPDM and Viton o-rings, verify that any detectable leak rate is $\leq 4.1 \times 10^{-5}$ cm^3/sec (helium). The sensitivity of the detector shall be $\leq 2.0 \times 10^{-5}$ cm^3/sec.

22. Install the test port plug for the vent port coverplate using a new metallic o-ring and torque the plug to the value specified in Table 7-1.

23. Repeat Steps 21 and 22 for the drain port coverplate.

24. Drain residual water from the pressure port, ensuring that the pressure port is clear to also allow water to drain from the interlid region.

25. Remove the outer lid o-ring. Clean the outer lid o-ring seating surface and groove and install a new metallic o-ring, or inspect and reinstall the non-metallic (EPDM or Viton) o-ring. Install the outer lid alignment pins.

26. Attach the outer lid lifting device to the outer lid and overhead crane. Install the outer lid using the alignment pins to assist in proper seating. Remove the outer lid alignment pins. Install the outer lid bolts and torque to the value specified in Table 7-1. The bolt torquing sequence is shown on the outer lid.

27. Attach a supply of air or helium to the interlid port quick-disconnect. Backfill the interlid volume to 15 psig air or helium and hold for 10 minutes. No loss of pressure is permitted. Disconnect air or helium supply.

28. Install the interlid port cover using new o-rings if necessary. Torque the interlid port cover bolts to the value specified in Table 7-1.
29. Remove the o-ring test plug from the interlid port cover and, using the o-ring test fixture, pressurize the o-ring annulus to 15 psig with air or helium. Isolate the annulus and hold for 10 minutes. No loss of pressure is permitted.
30. Remove the air or helium supply and vent the annulus pressure. Replace the o-ring on the interlid port cover test plug, install the test plug and torque it to the value specified in Table 7-1.
31. Perform final external decontamination and perform survey to verify acceptable level of removable contamination to ensure compliance with 49 CFR 173.443. Perform final radiation survey. Record the survey results in the cask loading report.
32. Perform final visual inspection to verify assembly of the NAC-STC in accordance with the Certificate of Compliance. Verify that the loading procedure and checklist are appropriately completed and signed off.

7.1.3.2 Loading Canistered Fuel or GTCC Waste

Canistered fuel or canistered GTCC waste is loaded into the NAC-STC using a transfer cask. This procedure assumes that the canister has been previously loaded, drained, vacuum dried, backfilled with helium and welded closed. The canister may have been retrieved from dry storage, or it may have been loaded and sealed immediately prior to loading in the NAC-STC. This procedure assumes the sealed canister conforms to the design basis of the NAC-STC and that the canister is already in the transfer cask. The NAC-STC is assumed to be positioned in the area designated for dry canister loading, that the bottom spacer is installed in the cask cavity, and that the adapter plate and transfer cask alignment pins have been installed (refer to Section 7.1.2.2). Metallic o-rings must be used when loading the NAC-STC cask with canistered fuel or GTCC waste.

1. Attach the transfer cask yoke to the cask handling crane hook.
2. Engage the transfer cask yoke to the trunnion of the transfer cask.
3. Raise the transfer cask over the NAC-STC cask and lower it until it rests on the transfer cask adapter plate. Remove and store the transfer cask lifting yoke.
4. Attach the hydraulic system to the transfer cask doors.
5. Attach the two canister 3-legged lifting sling sets to the lifting rings in the canister lid. Attach the opposite end of the slings to the crane hook.

6. Raise the canister just enough to take the canister weight off of the transfer cask bottom doors.
7. Open the transfer cask shield doors.
8. Lower the canister into the NAC-STC cask. Exercise caution to avoid contact with the interior cavity wall.
9. Disconnect and remove the canister lifting sling.
10. Close the transfer cask bottom doors and install the door locking pins.
11. Retrieve the transfer cask lifting yoke and engage the transfer cask trunnions. Lift the transfer cask from the adapter plate. Store the transfer cask and transfer cask lifting yoke in the designated locations.
12. Install the Yankee-MPC canister top spacer.
13. Retrieve the adapter plate lifting sling and attach it to the adapter plate.
14. Remove the four (4) bolts attaching the adapter plate to the NAC-STC. Remove the adapter plate and store it in the designated location. Remove the adapter ring and bolts. Install the inner lid alignment pins.
15. Remove the inner lid o-rings and clean inner lid o-ring groove surfaces. Replace the metallic o-rings on the inner lid, carefully inspecting the new o-rings for damage prior to installation. Secure the o-rings in the groove using the o-ring clips and screws.
16. Attach the inner lid lifting slings to an auxiliary crane hook, lift the inner lid and place it on the cask using the inner lid alignment pins to assist in proper lid seating and orientation. Visually verify proper lid position.
17. Disconnect the lid lifting device from the crane hook and remove it from the inner lid.
18. Install at least 10 inner lid bolts equally spaced on the bolt circle to hand tight. Remove the inner lid alignment pins.
19. Install the remaining inner lid bolts and torque all of the bolts to the torque value specified in Table 7-1. The bolt torquing sequence will be specified in the detailed operating procedure.
20. Install the drain port coverplate using new metallic o-rings. Torque the bolts to the value specified in Table 7-1.
21. Connect the vacuum pump to the cask vent port and evacuate the cask cavity to a stable vacuum pressure of 3 mbar. Without allowing air to re-enter the cask, backfill the cavity with helium (99.9% minimum purity) to 0 psig. Disconnect the helium supply.
22. Remove the metallic o-rings in the vent port coverplate and clean and inspect the o-ring groove. Install new metallic o-rings in the vent port coverplate and install the coverplate. Torque the coverplate bolts to the value specified in Table 7-1.

23. Connect the leak detector vacuum pump to the inner lid interseal test port and evacuate the air between the metallic o-rings. Hold a vacuum on the interseal region. Using the helium leak detector, verify that the detectable leak rate is $\leq 2.0 \times 10^{-7}$ cm^3/sec (helium), using a detector sensitivity of at least $\leq 1.0 \times 10^{-7}$ cm^3/sec (helium).
24. Install the test port plug for the inner lid interseal test port using a new metallic o-ring and torque the plugs to the value specified in Table 7-1.
25. Connect the leak detector vacuum pump to the vent port coverplate interseal test port. Evacuate the interseal volume until a pressure of 3 mbar is reached. Using the helium leak detector, verify that any detectable leak rate is $\leq 2 \times 10^{-7}$ cm^3/sec (helium). The sensitivity of the detector shall be $\leq 1 \times 10^{-7}$ cm^3/sec (helium).
26. Install the test port plug for the vent port coverplate using a new metallic o-ring and torque the plug to the value specified in Table 7-1.
27. Repeat Steps 25 and 26 for the drain port coverplate test port.
28. Remove the outer lid metallic o-ring. Clean the outer lid o-ring seating surface and groove. Install a new outer lid o-ring. Install the outer lid alignment pins.
29. Attach the outer lid lifting device to the outer lid and overhead crane. Install the outer lid using the alignment pins to assist in proper seating. Remove the outer lid alignment pins. Install the outer lid bolts and torque to the value specified in Table 7-1. The bolt torquing sequence is shown on the outer lid.
30. Attach a supply of air or helium to the interlid port quick-disconnect. Backfill the interlid volume to 15 psig air or helium and hold for 10 minutes. No loss of pressure is permitted. Disconnect air or helium supply.
31. Install the transport interlid port cover in the interlid port using new o-rings. Torque the interlid port cover bolts to the value specified in Table 7-1.
32. Remove the o-ring test plug from the interlid port cover and, using the o-ring test fixture, pressurize the o-ring annulus to 15 psig with air or helium. Isolate the annulus and hold for 10 minutes. No loss of pressure drop is permitted.
33. Vent the annulus pressure, remove the air or helium supply, replace the o-ring on the interlid port cover test plug and install the test plug. Torque the plug to the value specified in Table 7-1.
34. Perform final external decontamination and perform survey to verify acceptable level of removable contamination to ensure compliance with 49 CFR 173.443. Perform final radiation survey. Record the survey results in the cask loading report.
35. Perform final visual inspection to verify assembly of the NAC-STC in accordance with the Certificate of Compliance. Verify that the loading procedure and checklist are appropriately completed and signed off.

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7.2 Preparation for Transport

Perform the procedures of either Section 7.2.1 or 7.2.2, whichever is appropriate. Section 7.2.1 addresses preparation for transport without interim storage after loading the cask either with directly loaded fuel or with a previously loaded canister. Section 7.2.2 addresses transport following long-term storage. Transport following long-term storage requires the verification of containment by leak testing the containment boundary formed by the outer o-rings of the inner lid and port covers, the o-ring test ports and the o-ring of the outer lid.

7.2.1 Preparation for Transport (without Interim Storage)

1. Engage the lift beam to the cask lifting trunnions and move the cask to the cask loading area.
2. Load the cask onto the transport vehicle by gently lowering the rotation trunnion recesses into the rear support. Rotate the cask to horizontal by moving the overhead crane in the direction of the front support. Maintain the crane cables vertical over the lifting trunnions.
3. Using a lifting sling, place the tiedown assembly over the cask upper forging between the top neutron shield plate and front trunnions. Install the front tiedown bolts and lock washers to each side of the front support. Torque each of the tiedown bolts to the specified value.
4. Complete a Health Physics removable contamination survey of the cask to ensure compliance with 49 CFR 173.443.
5. Using the designated lifting slings and a crane of appropriate capacity, install the top impact limiter. Install the impact limiter retaining rods into each hole and torque to the value specified in Table 7-1. Install the impact limiter attachment nuts and torque to the value specified in Table 7-1. Install the impact limiter jam nuts and torque to the value specified in Table 7-1. Install the impact limiter lock wires. Repeat the operation for the bottom impact limiter installation.
6. Install security seals through holes provided in the upper impact limiter and one of the lifting trunnions; and through holes provided in all three bolts in the interlid port cover and the pressure port cover. Record the security seal identification numbers in the cask loading report.
7. Apply labels to the package in accordance with 49 CFR 172.200.
8. Install the personnel barrier/enclosure and torque all attachment bolts to the prescribed torque value. Install padlocks on all personnel barrier/enclosure accesses.

9. Complete a Health Physics radiation survey to ensure compliance with 49 CFR 173.441.
10. Complete a Health Physics removable contamination survey of the transport vehicle to ensure compliance with 49 CFR 173.443.
11. Complete the shipping documents in accordance with 49 CFR Subchapter C.
12. Apply placards to the transport vehicle in accordance with 49 CFR 172.500. Provide special instructions for Exclusive Use Shipment to the carrier.

7.2.2 Preparation for Transport (after Long-Term Storage)

This procedure applies to the transport of directly loaded fuel that has been in storage in the NAC-STC. Canistered fuel or canistered GTCC waste may not be loaded in the NAC-STC for storage. Canistered fuel or GTCC waste is loaded into the NAC-STC only for transport without interim storage in accordance with Section 7.2.1.

Prior to placing the cask in long term storage, the cask cavity is backfilled with 1.0 atmosphere (absolute) of helium (99.9% minimum purity) as the normal coolant for the spent fuel and to provide an inert atmosphere to prevent possible oxidation of the fuel. The inner lid interseal volume between the two inner lid metallic o-rings and the interlid region between the inner and outer lid are both backfilled to 15 psig with helium (99.9% minimum purity). The interlid volume is pressurized to 100 psig and then monitored for pressure loss by a pressure transducer installed in the cask upper forging, and closed by a specially equipped port cover filled with a pressure feed-through tube (License Drawing No. 423-807). This overpressure system ensures that in the off-normal event of any leakage of the inner lid o-rings, the leakage path will be clean helium into the cavity. If during the storage period, no significant pressure loss is observed in the pressure monitoring volume or system (normally recorded at a minimum of once every 24 hours during storage), it can be concluded that at the end of the storage period, the cask cavity remains backfilled with helium gas.

Prior to preparing the cask for transport, the pressure transducer wiring has been disconnected.

1. Move cask from extended storage location to a designated work area.
2. Evacuate a sample bottle using a vacuum pump. Isolate the sample bottle and connect it to the interlid port quick disconnect and fill it with interlid region atmosphere.
   Note: The interlid pressure may be as high as 100 psig. Use caution in collecting the gas sample.
3. Isolate the sample bottle and disconnect it from the interlid port quick disconnect.

4. Bring the sample bottle to the appropriate facility at the station and analyze the contents of the sample bottle.
5. If krypton-85 is present in the sample bottle, additional radiological precautions may be imposed by Health Physics personnel prior to proceeding with the removal of the outer lid. A determination shall also be made as to whether replacement of the inner lid seals is required. If the initial gas is acceptable, proceed with normal operations.
6. Attach valved venting hose to interlid port quick disconnect and open valve to vent interlid region.
7. Remove the outer lid bolts and install the outer lid alignment pins and outer lid lifting eye bolts.
8. Attach the outer lid lifting device to the outer lid lifting eye bolts and overhead crane. Remove the outer lid and place it aside in a temporary storage area. Protect the o-ring and o-ring groove of the lid from damage. Remove the outer lid alignment pins.
9. Verify the torque of the inner lid bolts and vent and drain port coverplate bolts by torquing the bolts in accordance with the bolt torque sequence to the values specified in Table 7-1.
10. Remove the drain port coverplate port plug. Connect the leak detector vacuum pump to the drain port coverplate test port and evacuate the helium between the metallic o-rings to a pressure of 3 mbar (absolute). Without allowing air to re-enter the interseal region, backfill the drain port coverplate interseal region with helium (99.9% minimum purity) to a pressure of 0 psig (1 atmosphere) (absolute).
11. Install the drain port coverplate test plug using a new o-ring and torque to the value specified in Table 7-1.
12. Repeat steps 10 and 11 for the vent port coverplate test plug.
13. Remove the inner lid interseal test port plug and connect a vacuum pump to the inner lid interseal test port quick-disconnect. Evacuate the inner lid interseal volume until a pressure of 3 mbar (absolute) is reached.
14. Without allowing air to re-enter the interseal volume, backfill the interseal volume with helium (99.9% minimum purity) to 0 psig. Disconnect helium supply.
15. Install the inner lid interseal test port plug with a new metallic o-ring and torque the plug to the value specified in Table 7-1.
16. Clean the outer lid o-ring seating surface and groove surface. Install a new metallic o-ring in the outer lid. Reinstall the outer lid alignment pins.

17. Attach the outer lid lifting device to the outer lid lifting eye bolts and the overhead crane. Install the outer lid and visually verify proper seating. Remove the alignment pins and lifting eye bolts, and install the outer lid bolts and torque to the value specified in Table 7-1. The bolt torquing sequence is shown on the outer lid.
18. Leak test the outer o-rings of the vent and drain port coverplates, the outer o-ring of the inner lid, the interseal test ports and the outer lid o-ring by connecting a vacuum pump and a helium mass spectrometer leak detector connected to the interlid port quick-disconnect. Evacuate the interlid region to a vacuum of 3 mbar or less.
19. Using the helium leak detector, verify that the leak rate is $\leq 2 \times 10^{-7}$ cm^3/sec (helium) using a leak test sensitivity of $\leq 1 \times 10^{-7}$ cm^3/sec.
20. Upon completion of the leak test, backfill the interlid region with helium (99.9% minimum purity) to 0 psig and disconnect the helium supply.
21. Install the transport interlid port cover using new o-rings and torque the port cover bolts to the value specified in Table 7-1.
22. Attach the test fixture to the interlid port interseal test hole and perform a functional leak test on the interlid port cover o-rings by applying a 15 psig pressure to the interseal region. Isolate and hold for 10 minutes. If no pressure drop is observed, the interlid port seals are acceptable. Record the leak test results in the cask loading report. Upon completion of the test, equalize interseal region pressure with ambient and disconnect the test fixture.
23. Load the cask on the transport vehicle.
24. Using a lifting sling, place the tiedown assembly over the cask upper forging between the top neutron shield plate and front trunnions. Install the front tiedown bolts and lock washers to each side of the front support. Torque each of the tiedown bolts to the specified value.
25. Complete a Health Physics removable contamination survey to ensure compliance with 49 CFR 173.443.
26. Using the designated lifting slings and a crane of appropriate capacity, install the top impact limiter. Install the impact limiter retaining rods into each hole and torque to the value specified in Table 7-1. Install the impact limiter attachment nuts and torque to the value specified in Table 7-1. Install the impact limiter jam nuts and torque to the value specified in Table 7-1. Install the impact limiter lock wires. Repeat the operation for the bottom impact limiter installation.

27. Install security seals through holes provided in the upper impact limiter and one of the lifting trunnions; and through holes provided in all three bolts in the interlid port cover and the pressure port cover.
28. Apply labels to the package in accordance with 49 CFR 172.200.
29. Install personnel barrier/enclosure and torque all attachment bolts to the prescribed torque value. Install padlocks on all personnel barrier/enclosure accesses.
30. Complete a Health Physics radiation survey to ensure compliance with 49 CFR 173.441 requirements.
31. Complete the shipping documents in accordance with 49 CFR Subchapter C.
32. Apply placards to transport vehicle in accordance with 49 CFR 172.500. Provide special instructions for Exclusive Use Shipment to the carrier.

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7.3 Outline of Procedures for Unloading the Cask

This section outlines the steps to be followed for unloading the cask following transport of either directly loaded fuel, canistered fuel or canistered GTCC waste.

7.3.1 Receiving Inspection

1. Perform radiation and removable contamination surveys in accordance with 49 CFR 173.441 and 173.443 requirements.
2. Remove the personnel barrier/enclosure and complete radiation and removable contamination surveys at the cask surfaces.
3. Visually inspect the NAC-STC while secured to the transport vehicle in the horizontal orientation for any signs of damage. Record any damage in the cask unloading report.
4. Secure the transport vehicle. Attach slings to the top impact limiter lifting points, remove impact limiter lock wires, jam nuts, attachment nuts and retaining rods, and remove the impact limiter. Store the impact limiter upright. Repeat the operation to remove the bottom impact limiter. Complete radiation and removable contamination surveys for exposed cask surfaces.
5. Release the tiedown assembly from the front support by removing the front tiedown bolts and lock washers.
6. Attach a sling to the tiedown assembly lifting eyes and remove the tiedown assembly from the transport vehicle.
7. Attach the cask lifting yoke to a crane hook with the appropriate load rating. Engage the two yoke arms with the lifting trunnions at the top end of the cask. Rotate/lift the cask to the vertical orientation and raise the cask off of the pillow blocks attached to the rear support structure of the transport vehicle. Place the cask in the vertical orientation in a decontamination area or other location identified by the user.
8. Wash any road dust and dirt off of the cask and decontaminate cask exterior, as required by contamination survey results.

7.3.2 Preparation of NAC-STC Cask for Unloading

The NAC-STC may contain fuel directly loaded into a basket within the cask, or a sealed transportable storage canister containing fuel or GTCC waste containers. Unloading of fuel from the directly loaded cask basket typically takes place under water in the spent fuel pool cask loading area. This procedure assumes that the cask is vertical in the reactor cask decontamination area, and that access is available to the top end of the NAC-STC. Canister unloading would be performed dry using a transfer cask. Canister unloading would take place in the reactor cask receiving area, or other location identified by the user. This procedure also assumes that the cask is vertical in the work area and that access to the top of the cask is available.

7.3.2.1 Preparation for Unloading the NAC-STC Cask (Directly Loaded Fuel Configuration)

1. Verify that excessive pressure does not exist in the interlid region by removing the interlid port cover and attaching a pressure test fixture to the interlid port quick disconnect that will allow the monitoring of the cask interlid region for any pressure buildup that may have occurred during transport. If a positive pressure exists, connect a vent/drain line to the interlid quick disconnect and vent the pressure to the off-gas system.
2. Remove the outer lid bolts and install the outer lid alignment pins and outer lid lifting eye bolts.
3. Attach the outer lid lifting device to the outer lid lifting eye bolts and the overhead crane. Remove the outer lid and place it aside in a temporary storage area. Protect the o-ring and the o-ring groove of the lid from damage.
4. Remove the port coverplates from the drain and vent ports in the inner lid with caution. Attach a pressure test fixture to the vent port that will allow the monitoring of the cask cavity for any pressure buildup that may have occurred during transport. If a positive pressure exists, vent the pressure to the off-gas system.
5. Connect a demineralized water supply line to the drain port quick disconnect and a drain line to the vent port quick disconnect. Route the drain line to a radioactive waste treatment system or the spent fuel pool.
6. To facilitate cooldown and to minimize thermal effects to the cask and its contents, slowly (8 gpm for 10 minutes, followed by up to 20 gpm for remainder) fill the cask cavity with clean demineralized water (cavity is full when water flows out of the vent port drain line). Circulate water through the cask until the water leaving the vent port drain line is within 50°F of the average spent fuel pool water temperature.
7. Disconnect the fill line from the drain port quick disconnect in the inner lid. (Note: Leave a short drain line attached to the vent port quick disconnect for continuous venting).

8. Loosen and remove all but four of the inner lid bolts. Leave the four remaining inner lid bolts hand tight. Install the inner lid alignment pins at locations marked on the inner lid and the lid lifting eyebolts.
9. Remove the interlid port cover from the top forging. Disengage the vent line from the vent port quick disconnect.
10. Attach the lifting yoke to a crane hook and engage the yoke arms with the lifting trunnions. Lift the cask and move it over to the cask loading area in the pool.

    Note: If the alternate method of handling the cask and the lid simultaneously is to be used, connect the inner lid lifting slings to the lid lifting eyebolts and to the lifting yoke prior to cask movement.
11. Spray the external surface of the cask with clear demineralized water to minimize external decontamination efforts. Slowly lower the cask into the pool. Just prior to submerging the top forging of the cask, complete the unthreading of the four remaining inner lid bolts and remove.

    Note: Use caution when removing these bolts as pressure may rise slightly in the cask during the time since completion of Step 9.
12. Continue lowering the cask until it rests in the cask loading area on the pool floor.
13. Disconnect the lifting yoke from the lifting trunnions and move the yoke so that it will not interfere with fuel movements.
14. Using the inner lid lifting device attached to an auxiliary crane hook, remove the inner lid from the cask.

    Note: If the alternate method of handling the cask is being used, slowly raise the lift yoke and the inner lid using the lid alignment pins to guide movement. Move the lift yoke and the inner lid out of the area so that it will not interfere with fuel movements.
15. Place the inner lid aside ensuring that the o-rings and o-ring grooves are protected from damage. Decontaminate, as necessary, and clean all sealing surfaces.

7.3.2.2 Preparation for Unloading the NAC-STC Cask (Canistered Configuration)

1. Verify that excessive pressure does not exist in the interlid region by removing the interlid port cover and attaching a pressure test fixture to the interlid port quick-disconnect that will allow the monitoring of the cask interlid region for any pressure buildup that may have occurred during transport. If a positive pressure exists, connect a

vent/drain line to the interlid quick-disconnect and vent the pressure to the off-gas system.

2. Remove the outer lid bolts and install the outer lid alignment pins and outer lid lifting eye bolts.
3. Attach the outer lid lifting device to the outer lid lifting eye bolts and the overhead crane. Remove the outer lid and place it aside in a temporary storage area. Protect the o-ring and the o-ring groove of the lid from damage.
4. Remove the port coverplates from the drain and vent ports in the inner lid with caution. Attach a pressure test fixture to the vent port that will allow the monitoring of the cask cavity for any pressure buildup that may have occurred during transport. If a positive pressure exists, vent the pressure to the off-gas system.
5. Loosen and remove all but four of the inner lid bolts. Leave the four remaining inner lid bolts hand tight. Install the inner lid alignment pins at locations marked on the inner lid and the lid lifting eyebolts.
6. Remove the interlid port cover from the top forging. Disengage the vent line from the vent port quick-disconnect.
7. Install the transfer cask adapter ring and torque the three captive bolts.
8. Install the transfer cask adapter plate.
9. Using the inner lid lifting device attached to an auxiliary crane hook, remove the inner lid from the cask.

   Note: If the alternate method of handling the cask is being used, slowly raise the lift yoke and the inner lid using the lid alignment pins to guide movement. Move the lift yoke and the inner lid out of the area so that it will not interfere with fuel movements.
10. Place the inner lid aside ensuring that the o-rings and o-ring grooves are protected from damage. Decontaminate, as necessary, and clean all sealing surfaces.
11. If present, remove the top spacer.
12. Install the transfer cask on the top of the NAC-STC. Operate and lock open the transfer cask bottom doors.

7.3.3 Unloading the NAC-STC Cask

The NAC-STC may contain either fuel directly loaded in the cask basket, or a welded transportable storage canister. The procedures for unloading the fuel or canister are presented below.

7.3.3.1 Unloading Directly Loaded (Uncanistered) Fuel

1. Using approved fuel identification and handling procedures, withdraw one fuel assembly from the basket and deposit it in the proper storage rack location. Be careful not to contact any of the sealing surfaces on the top forging.
2. Record and document the fuel movement from the cask to the fuel rack.
3. Repeat steps 1 and 2 until all fuel assemblies have been removed from the cask.
4. Attach the inner lid lifting slings to a crane hook, lift the inner lid and place it on the cask using the alignment pins to assist in proper seating. Visually verify proper lid position.
5. Disconnect the lid lifting device from the inner lid.
6. Attach the lifting yoke to the crane hook, lower to lifting position and engage lifting arms to lifting trunnions. Slowly lift the cask out of the pool until the top of the cask is slightly above the pool water level.

   Note: As an alternative method, the cask and inner lid may be handled simultaneously. In the event that this method is chosen, instead of performing steps 4, 5 and 6, attach the lifting yoke to a crane hook and the inner lid to the lift yoke. Lower the lid and engage to the cask using the lid alignment pins. Engage lifting arms to lifting trunnions. Slowly lift the cask out of the pool until the top of the cask is slightly above the pool water level.
7. Install at least 10 inner lid bolts equally spaced on the bolt circle to hand tight. Remove the inner lid alignment pins.
8. Attach a drain line to the quick disconnect in the interlid port (located in the top forging) and allow the water to drain from the interlid region. Once drained, disconnect the drain line.
9. Move the NAC-STC cask to the cask decontamination area and disengage the lift yoke or lift beam and inner lid lifting slings if the alternate method of handling the inner lid was used. Remove the inner lid lifting eye bolts.
10. Move the cask lifting equipment away from the cask work area.
11. Install the remaining inner lid bolts and torque all of the inner lid bolts to the value specified in Table 7-1 in accordance with the torquing sequence as detailed in the NAC-STC Operations Manual.
12. Disconnect the drain line from the quick disconnect in the interlid port.
13. Connect a drain line to the drain port quick disconnect and a regulated air fill line to the vent port quick disconnect.

14. Purge the water from the cask by pressurizing to 60 to 75 psig and hold until all water is removed (observed when no water is coming from the drain line).
15. Remove the lines from the drain and the vent port quick disconnect.
16. Install the port coverplates over the vent and drain ports in the inner lid. Torque the coverplate bolts to the value specified in Table 7-1.
17. Decontaminate the surfaces of the inner lid and the inner surfaces of the top forging.
18. Install the outer lid alignment pins. Using the outer lid lifting device, install the outer lid using the alignment pins to assist in proper seating. Remove the lid lifting device, lid lifting eyebolts, and the outer lid alignment pins.
19. Install the outer lid bolts and torque them to the value specified in Table 7-1.
20. Install the interlid port cover and torque the bolts to the value specified in Table 7-1.

7.3.3.2 Unloading Canistered Fuel or Canistered GTCC Waste

Canistered fuel or GTCC waste is unloaded from the NAC-STC using a transfer cask. The transfer cask could be used to transfer the loaded canister to a work station where the canister could be opened, or to transfer it to another storage or disposal overpack.

1. Install the lift rings in the canister lid.
   Note: The canister lid may be thermally hot.
2. Attach the canister lifting sling to the lifting rings in the canister lid. Position the sling so that the free end of the sling can be engaged by the cask handling crane hook.
3. Install the transfer cask adapter plate.
4. Attach the transfer cask lifting yoke to the cask handling crane hook. Engage the yoke to the lifting trunnions of the transfer cask.
5. Lift the transfer cask and move it over the NAC-STC cask. Lower the transfer cask to engage the transfer cask adapter plate. Once the transfer cask is fully seated, remove the transfer cask lifting yoke and store it in the designated location.
6. Install the transfer cask bottom door hydraulic operating system and open the transfer cask bottom doors.
7. Lower the cask handling crane hook through the transfer cask and engage the canister lifting sling.
8. Raise the canister into the transfer cask just far enough to allow the transfer cask bottom doors to close. Use caution to ensure that the cavity walls of the NAC-STC and the transfer cask are not contacted.

9. Close the bottom doors and install the door locking pins.
10. Carefully lower the canister until it rests on the transfer cask bottom doors. Disengage the canister lifting sling from the crane hook.
11. Retrieve the transfer cask lifting yoke and attach it to the transfer cask trunnions. Lift the transfer cask from the NAC-STC cask and move it to its intended destination.
12. Attach the adapter plate lifting fixture.
13. Remove the four (4) bolts securing the adapter plate to the NAC-STC and using the auxiliary crane, lift the adapter plate from the top of the cask. Move the adapter plate to the designated storage location.
14. Install the inner lid alignment pins.
15. Attach the inner lid lifting fixture to the inner lid and engage the lifting fixture to the auxiliary crane. Install the inner lid in the NAC-STC using the alignment pins to assist in proper seating.
16. Disconnect the lifting fixture and remove the guide pins.
17. Install and torque the inner lid bolts.
18. Install the port coverplates over the vent and drain ports in the inner lid. Torque the coverplate bolts to the values specified in Table 7-1.
19. Decontaminate the surfaces of the inner lid and the inner surfaces of the top forging.
20. Install the outer lid alignment pins. Using the outer lid lifting device, install the outer lid using the alignment pins to assist in proper seating. Remove the lid lifting device, lid lifting eyebolts, and the outer lid alignment pins.
21. Install the outer lid bolts and torque them to the value specified in Table 7-1.
22. Install the interlid port cover and torque the bolts to the value specified in Table 7-1.

7.3.4 Preparation of Empty Cask for Transport

1. Decontaminate all surfaces of the cask to acceptable release limits as defined in 49 CFR 173.
2. Attach the lifting yoke to a crane hook and engage the yoke arms with the lifting trunnions. Lift the cask onto the transport vehicle and lower to the horizontal position.
3. Using a lifting sling, place the tiedown assembly over the cask upper forging between the top neutron shield plate and front trunnions. Install the front tiedown bolts and lock washers to each side of the front support. Torque each of the tiedown bolts to the value specified in Table 7-1.

4. Initiate Health Physics radiation and removable contamination surveys to ensure compliance with 49 CFR 173.441 and 49 CFR 173.443.
5. Using the designated lifting slings and a crane of appropriate capacity, install the top impact limiter. Install the impact limiter retaining rods into each hole and torque to the value specified in Table 7-1. Install the impact limiter attachment nuts and torque to the value specified in Table 7-1. Install the impact limiter jam nuts and torque to the value specified in Table 7-1. Install the impact limiter lock wires. Repeat the operation for the bottom impact limiter installation.
6. Apply labels to the package in accordance with 49 CFR 172.200.
7. Install the personnel barrier/enclosure and torque all attachment bolts to the prescribed torque value. Install padlocks on all personnel barrier/enclosure accesses.
8. Complete the Health Physics radiation and removable contamination surveys to ensure compliance with 49 CFR 173 requirements.
9. Complete the shipping documents.
10. Apply placards, if required, to the transport vehicle in accordance with 49 CFR 172.500.

7.4 Leak Test Requirements and Procedures

This section provides the leak testing procedures used to perform the Containment System Verification Leak Tests for the NAC-STC containment boundary o-ring seals. These tests are required following cask loading operations for transport without interim storage and after long-term storage in preparation for transport. Detailed procedures, describing the equipment and the leak test system used to perform the leak tests, are developed for use at the licensee's facilities. The containment boundary conditions, required leak tests and leak test acceptance criteria are provided in Table 4.1-1.

The transport cask may be configured with either metallic o-rings or with non-metallic EPDM or Viton o-rings. The two types of o-rings may not be used interchangeably, since each o-ring type requires a different o-ring groove configuration. Consequently, the inner lid, vent and drain port coverplates and outer lid are machined with a square o-ring groove to accept metallic o-rings or are machined with a truncated triangular (dove-tail) groove to accept EPDM or Viton o-rings.

EPDM or Viton o-rings may be used only when directly loading spent fuel for transport without interim storage. Metallic o-rings must be used when directly loading spent fuel for an extended period of storage and may be used when directly loading spent fuel for transport without interim storage. Metallic o-rings must be used when loading canistered fuel or GTCC waste (for transport). The metallic and non-metallic o-rings have different allowable leak rates, as specified in the procedures.

7.4.1 Containment System Verification Leak Test Procedures

As described in Chapter 4, the NAC-STC primary containment boundary is designed and tested to assure that there is no leakage under any of the normal conditions of transport or accident conditions that exceeds that permitted in accordance with 10 CFR 71.51. This is verified prior to transport by the performance of leak tests on the containment boundary to ensure that the leak rate is less than 2×10^{-7} cm^3/sec (helium) for metallic o-rings, and is less then 4.1×10^{-5} cm^3/sec (helium) for EPDM or Viton o-rings. As described in Section 4.1, the containment boundary is defined differently for transport after long-term storage than for loading for transport without interim storage. As described in this section, leak tests are performed in accordance with the requirements of ANSI N14.5-1997.

The leak test requirements and acceptance criteria performed after long-term storage in preparation for transport and following cask loading operations for transport without interim storage are described in Sections 7.4.2 and 7.4.3, respectively. The generic procedures used to perform leak testing are incorporated in the NAC-STC loading procedures in Section 7.2. Detailed procedures, describing the equipment and the leak test system used to perform the leak tests, are developed for use at the licensee's facilities. As noted in Section 7.1, the transportable storage canister will have been loaded, closed and sealed prior to loading into the NAC-STC. The canister is a separate inner container for the transport of damaged fuel.

Section 7.4.4 provides the procedural guidance on corrective actions to be taken in the event a leak test does not meet the acceptance criteria.

7.4.2 Leak Testing for Transport After Long-Term Storage

This section summarizes the leak test method used to demonstrate continued containment of PWR spent fuel prior to transport following an extended period of storage. The containment boundary is defined as Containment Condition A in Section 4.1 and requires the use of metallic o-rings in the containment boundary. In addition to the steel inner lid and port coverplates, the containment boundary is specified as the outer o-rings of the inner lid and of the vent and drain port coverplates and the o-ring test ports, which are inside of the containment boundary formed by the outer o-rings. As specified in the generic loading procedure, the outer lid must be removed to test the inner lid and the vent and drain port coverplates.

To conduct the leak test, the inner seal regions (annulus between the o-rings) of the inner lid and the vent and drain port coverplates are evacuated to 3 millibars, or less, and backfilled to 0 psig with 99.9 % pure helium, and the o-ring test port plugs are reinstalled. The outer lid is reinstalled using a new o-ring. The interlid region (between the inner and outer lids) is evacuated to a vacuum of 3 millibars, or less. After the vacuum condition is reached, a helium leak detector is used to measure the interlid region for helium leakage past the inner lid outer o-ring or the inner lid interseal test port o-ring. The allowable leak rate for this test is $\leq 2 \times 10^{-7}$ cm^3/sec (helium) with a minimum test sensitivity of $\leq 1 \times 10^{-7}$ cm^3/sec (helium). This test method conforms to A5.4 of Appendix A of ANSI N14.5-1997. If helium leakage is detected exceeding the criteria, corrective action is taken as described in Section 7.4.4.

The outer lid and pressure port are tested using a pressure drop method to confirm the installation of the outer lid and pressure port o-rings. The interlid region is pressurized using the interlid port to 15 psig with air and the pressure is held for 10 minutes. No loss of pressure is permitted during the test period. Following the test, the interlid region pressure is reduced to 0 psig. The interlid port cover is installed and the annulus between the o-rings of the port cover is tested using the same method. This test confirms the installation of the interlid port cover o-rings and conforms to test method A.5.1 of Appendix A of ANSI N14.5-1997.

7.4.3 Leak Testing for Transport without Interim Storage

This section summarizes the leak tests required to demonstrate cask containment of directly loaded PWR spent fuel, or of a sealed transportable storage canister, for transport without interim storage after loading. The containment boundary is defined as Containment Condition B in Section 4.1. In addition to the steel inner lid and port coverplates, the containment boundary is specified as the inner o-rings of the inner lid and of the vent and drain port coverplates. The inner lid and vent and drain port coverplate o-rings are tested using the evacuated envelope method (Test description A5.4 of Appendix A of ANSI N14.5-1997) with a vacuum in the annulus between the o-rings. The containment boundary o-rings for fuel directly loaded for transport without interim storage may be either metallic or non-metallic (EPDM or Viton). The containment boundary o-rings for canistered fuel or GTCC waste must be metallic o-rings. The leak detector is used to detect helium in the annulus between the o-rings. The allowable leakage rate for metallic o-rings is $\leq 2 \times 10^{-7}$ cm^3/sec (helium) with a minimum test sensitivity of $\leq 1 \times 10^{-7}$ cm^3/sec (helium). The allowable leakage rate for EPDM or Viton o-rings is $\leq 4.1 \times 10^{-5}$ cm^3/sec (helium) with a minimum test sensitivity of $\leq 2.0 \times 10^{-5}$ cm^3/sec (helium). This series of helium leak tests confirms that the allowable leak rates are satisfied for the o-rings used in the containment boundary for Containment Condition B. Section 7.4.4 provides the procedural guidance on corrective actions to be taken in the event a leak test does not meet the acceptance criteria.

The outer lid and pressure port are tested using a pressure drop method to confirm the installation of the outer lid and pressure port o-rings. The interlid region is pressurized using the interlid port to 15 psig with air and the pressure is held for 10 minutes. No loss of pressure is permitted during the test period. Following the test, the interlid region pressure is reduced to 0 psig. The interlid port cover is installed and the annulus between the o-rings of the port cover is tested using the same method. This test confirms the installation of the interlid port cover o-rings.

These components form an additional barrier against the release of radioactive material, but are not a containment boundary.

7.4.4 Corrective Action

If a specific component containing an o-ring fails to meet the leakage test acceptance criteria established for a leak test, the component is removed and the o-ring removed. The o-ring groove is cleaned and visually inspected to ensure proper cleanliness and surface condition. A new o-ring is installed. The removed component is re-installed and the bolts torqued to the appropriate torque value. The component is then retested in accordance with the applicable test procedure.

For the replacement of the inner lid o-ring either immediately after loading or after extended storage, in the directly loaded configuration, it will be necessary to replace the cask in the spent fuel pool to remove the inner lid and allow access for inner lid o-ring replacement. For placement of the cask in the fuel pool following extended storage, the procedures for cask unloading (Section 7.3.3) are utilized to prepare and cool down the cask prior to placement in the pool. At cask storage facilities having appropriate dry transfer or hot cell facilities, the inner lid o-ring can be replaced without placement of the cask in a fuel pool for shielding purposes. Prior to removal of the inner lid, a gas sample should be taken at the vent port to verify the condition in the cavity environment. If there are indications that fuel has failed during the storage period, care should be exercised in both flooding the cask and in removing the inner lid.

In the canistered configuration, the NAC-STC inner lid metallic o-rings may be replaced without returning to the pool since the canister confines the spent fuel or GTCC waste. Radiation shielding is provided by the canister shield and structural lids.

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8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

This chapter describes the acceptance tests and maintenance program to be used for the NAC-STC to assure compliance with 10 CFR 71 and IAEA Safety Series No. 6 acceptance and maintenance criteria. Also included is a general description of the fabrication of the NAC-STC cask and the transportable storage canister with additional information on the lead pouring requirements and procedures.

Where required, specific procedures for inspection, special processes, and testing will be developed to support the entire manufacturing process with a Quality Assurance (QA) program that has been approved in accordance with 10 CFR 71 Subpart H and IAEA Safety Series No. ST-1.

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8.1 Fabrication Requirements and Acceptance Tests

This section identifies the fabrication, inspection and acceptance requirements, tests, and acceptance criteria established for the NAC-STC to verify, prior to acceptance and packaging marking per 10 CFR 71.85(c), that the packaging has been fabricated, assembled, tested, inspected and accepted in accordance with the applicable NAC-STC License Drawings (Section 1.3.2) and the other requirements of this application.

8.1.1 Weld Procedures, Examination, and Acceptance

The primary containment components of the package and the canister shell will be fabricated in accordance with the ASME Boiler and Pressure Vessel Code (ASME Code), Section III, Division I, Subsection NB requirements. The noncontainment components of the packaging, except the fuel basket assembly and the neutron shield vessel and fins, will be fabricated in accordance with ASME Code, Section VIII, Division 1 requirements. The fuel basket assembly components for either the directly loaded fuel basket or the canister fuel basket will be fabricated in accordance with ASME Code, Section III, Subsection NG. The fabrication of the neutron shield shell and fins, and the heat transfer disks and the GTCC basket will be in accordance with ASME Code, Section III, Subsection NF. The fabrication and welding requirements for the NAC-STC cask, and the transportable storage canister, are shown on the NAC-STC License Drawings. Fabrication of the transportable storage canister is described in Section 8.1.8.

In the fabrication of the NAC-STC, the plates and forgings that comprise the cask body are joined by welding.. The welding procedure qualifications and the welding performance qualifications for the fabrication of the NAC-STC will be in accordance with Part QW-Welding, Section IX of the ASME Code. All exposed welds on the NAC-STC will be ground flush to the base metal or to a smooth fillet.

Fabricators of the NAC-STC will be experienced and qualified with nuclear component fabrication. Fabrication will be in full accordance with the applicable requirements of ASME Code Section III for the containment vessel, recognizing that design specification, design report, authorized inspection agency, and code stamping do not apply. The fabricator will establish a detailed written weld inspection plan, in accordance with an approved Quality Assurance program, of visual, dye penetrant, ultrasonic and radiographic weld examinations to be performed during fabrication and prior to acceptance of the cask. The weld inspection plan will identify the welds to be examined, the sequence of the examinations, the weld examination method used, and the criteria for acceptance of the weld in accordance with the applicable sections of the ASME Code.

The finished surfaces of all welds on the NAC-STC will be visually examined in accordance with ASME Code, Section V, Article 9, to verify that the components are assembled in accordance with the License Drawings and that the components are free of nicks, gouges, or other damage. The acceptance criteria for the visually examined welds will be in accordance with ASME Code, Section VIII, Division 1, UW-35 and UW-36.

The NAC-STC primary containment boundary welds shall be radiographic examined in accordance with ASME Code, Section V, Article 2. Acceptance criteria for radiographic examinations shall be in accordance with ASME Code Section III, Division I, Subsection NB, Article NB-5320. Unacceptable imperfections such as a crack, a zone of incomplete fusion or penetration, elongated indications with lengths greater than specified limits, and rounded indications in excess of the limits specified shall be cause for rejection of the weld. Repair of unacceptable weld metal defects in welds shall be in accordance with paragraph NB-4450, of the ASME Code, Section III. Repaired welds shall be reexamined in accordance with the original examination criteria.

The circumferential and longitudinal welds of the outer shell assembly, and the connection welds of the outer shell assembly to the upper forging shall be radiographic examined in accordance with the ASME Code, Section V, Article 2. Acceptance criteria for radiographic examination of the outer shell welds shall be in accordance with ASME Code, Section VIII, Division 1, UW-51. Repair of unacceptable defects shall be in accordance with UW-38. Repaired welds shall be re-examined in accordance with the original examination criteria.

The final NAC-STC cask closure welds of the bottom ring forging to the bottom forging and to the outer shell, and the closure weld of the bottom plate to the bottom ring forging shall be ultrasonic examined in accordance with ASME Code, Section V, Article 5. Acceptance criteria for the ultrasonic examination shall be in accordance with ASME Code, Section VIII, Division 1, UW -53 and Appendix 12. Repair of unacceptable defects shall be in accordance with UW-38. Repaired welds shall be re-examined in accordance with the original examination criteria.

Welds that are marked “PT Root and Final Pass” on the NAC-STC License Drawings (Section 1.3.2) will be liquid penetrant (PT) examined in accordance with ASME Code, Section V, Article 6. The liquid penetrant examination method is used to detect discontinuities, such as cracks, seams, laps, laminations and porosity that are open to the surface of nonporous metals. Acceptance criteria for liquid penetrant examined welds shall be in accordance with ASME Code Section III, Division I, Subsection NB, Article NB-5350. All other noncontainment welds that are marked “PT” on the NAC-STC License Drawings are liquid penetrant examined in accordance with ASME Code, Section V, Article 6. Acceptance criteria for these noncontainment welds shall be in accordance with ASME Code Section VIII, Division 1, Appendix 8, except for the fin to outer shell, and fin to neutron shield closure plate welds which will be examined and evaluated in accordance with ASME Code Section III, Subsection NF, Article NF-5350. Unacceptable indications shall be cause for rejection of the welds. Rejected welds shall be repaired in accordance with approved weld repair procedures prepared in accordance with the applicable provisions of the ASME Code, Section III, NB-4450, for containment welds, NF-4450 for fin to neutron shield shell and cask outer shell welds, and Section VIII, UW-38 for other non-containment welds. Repaired welds shall be re-examined in accordance with the original examination criteria.

All weld inspections shall be performed by qualified personnel in accordance with written procedures. Inspection personnel shall be qualified in accordance with SNT-TC-1A, “Personnel Qualification and Certification in Nondestructive Testing,” The American Society for Nondestructive Testing, Inc., edition as invoked by the applicable ASME Code.

8.1.2 Structural and Pressure Tests

8.1.2.1 Lifting Trunnion Load Testing

Each of the two pairs of the cask lifting trunnions shall be load tested in accordance with the requirements of ANSI N14.6 “Special Lifting Devices for Shipping Containers Weighing 10,000 pounds (4500 kg) or More for Nuclear Materials.” The load test will be performed for one pair and repeated for the other pair. The load test shall be performed in accordance with approved written procedures.

The lifting trunnion load test shall consist of applying a vertical load of 750,000 pounds, which is 300 percent of the maximum service load to diametrically opposite trunnion pairs.

The load will be applied in a vertical direction, equally distributed between the two trunnions and over the length of 2.25 inches of the trunnion/lifting yoke interface areas. The inner and outer lids will be bolted in place for the test. The test may be carried out by the use of calibrated hydraulic rams combined with a load spreading beam, or the cask lifting yoke, attached to the trunnion pair. The load will be held for a minimum of 10 minutes.

Following completion of the lifting trunnion load test, all accessible trunnion welds and load bearing surfaces shall be visually inspected for permanent deformation, galling or cracking. Inspections utilizing liquid penetrant examination shall be performed in accordance with the ASME Code, Section V, Article 6. Liquid penetrant acceptance standards shall be in accordance with Paragraph NF-5350 of the ASME Code, Section III, Division 1.

Any evidence of permanent deformation, cracking, galling of the load bearing surfaces or unacceptable dye penetrant results shall be cause for rejection of the trunnion or related welds.

8.1.2.2 Load Testing of the Rotation Trunnion Recesses

The rotation trunnion recesses at the lower end of the cask shall be load tested. The load test shall be performed in accordance with approved written procedures.

The load test for recesses shall consist of applying a vertical load of 375,000 pounds (170.1 MT) to the rotation trunnion recess pair, which is 150 percent of the maximum service load. The load will be applied in a vertical direction and equally distributed between the two rotation trunnion recesses by the use of hydraulic rams combined with a load spreading beam.

Following completion of the rotation trunnion recesses load test, all accessible trunnion recess welds and load bearing surfaces shall be visually inspected for permanent deformation, galling or cracking. Inspections utilizing liquid penetrant examination shall be performed in accordance with the "ASME Boiler and Pressure Vessel Code," Section V, Article 6. Liquid penetrant acceptance standards shall be as indicated in paragraph NF-5350 of the "ASME Boiler and Pressure Vessel Code," Section III, Division 1.

Any evidence of permanent deformation, cracking, galling of the load bearing surfaces or unacceptable dye penetrant results shall be cause for rejection of the rotation trunnion recesses or related welds.

8.1.2.3 Hydrostatic Testing

A hydrostatic test shall be performed on the NAC-STC cask containment boundary, prior to final acceptance of the cask, in accordance with the ASME Code, Section III, Division I, Article NB-6200. The hydrostatic test pressure shall be at least 76 psig, which is 150 percent of the Maximum Normal Operating Pressure. This test shall be performed in accordance with approved written procedures. All pressure retaining components, appurtenances, and completed systems shall be pressure tested.

The vent port will be used for the test connection. Only the vent port quick disconnect will be installed during the testing. The hydrostatic test will be performed with the inner lid and the drain port coverplate installed and torqued.

The hydrostatic test system components, although not part of the cask containment boundary, will be visually inspected prior to the start of the hydrostatic test. Leak from the valves or connections will be corrected prior to the start of the hydrostatic test.

The test pressure gauge installed on the cask will have an upper limit of approximately twice that of the test pressure. The hydrostatic test pressure shall be maintained for a minimum of 30 minutes, during which time a visual inspection is made to detect any evidence of leakage. Any evidence of leakage during the minimum hold period will be cause for rejection.

After completion of the hydrostatic test, the cask containment boundary will be dried and prepared for visual and/or dye penetrant inspections as appropriate. The components of the cask containment boundary shall be visually inspected. All accessible welds within the cavity shall be liquid penetrant inspected. Any evidence of cracking or permanent deformation is cause for rejection of the affected component.

8.1.2.4 Pneumatic Bubble Testing of the Neutron Shield Tank

A pneumatic bubble test of the neutron shield tank will be performed in accordance with Section V, Article 10, Appendix I, of the ASME Code following final closure welding of the bottom closure plates. The pneumatic test pressure shall be 12.5 + 1.5/-0 psig, which is 125 percent of the relief valve set pressure. The test shall be performed in accordance with approved written procedures.

During the test, the two relief valves on the neutron shield tank will be removed. One of the relief valves threaded connections will be used for connection of the air pressure line and test pressure gauge. The other relief valve connection will be plugged with a threaded plug.

Following introduction of pressurized air into the neutron shield, a 15-minute minimum soak time will be required. Following completion of the soak time, approved soap bubble solution will be applied to all fin to shell, shell to end plate, and end plate to outer shell welds. The acceptance criteria for the bubble test will be no air leak from any tested weld as indicated by continuous bubbling of the solution. If air leak is indicated, the weld shall be repaired in accordance with approved weld repair procedures and the pneumatic bubble test shall be repeated until no unacceptable air leak is observed.

8.1.3 Leak Tests

Leak tests shall be performed in accordance with Section 7.3 of ANSI N14.5-1997, containment System Fabrication Verification, on the NAC-STC cask containment boundary seals to verify proper fabrication of the cask. The leak tests shall be performed in accordance with approved written procedures. Leak tests shall be performed on the cask containment weldment, the inner lid o-rings, the inner lid interseal test port plug, the vent port coverplate o-rings and its interseal test plug, and the drain port coverplate metallic o-rings and its interseal test plug.

Following the hydrostatic testing of the containment weldment per Section 8.1.2.3, the containment cavity shall be drained and cleaned. A helium leak test of the containment weldment shall be performed in accordance with the requirements of ASME Code, Section V, Article 10. The containment weldment shall have an indicated leak rate of less than 2×10^{-7} cm^3/sec (helium), using a minimum test sensitivity of 1.0×10^{-7} cm^3/sec (helium). If a leak is detected, the affected weld shall be rejected. Rejected welds shall be repaired in accordance with the requirements of ASME Code Section III, Division I, Subsection NB, Article NB-4450. The repaired weld area shall be retested and reinspected in accordance with the above test requirements and acceptance standards.

The containment boundary may use either metallic o-rings or non-metallic EPDM or Viton o-rings. The two o-ring types require different o-ring groove designs and, therefore, may not be used interchangeably and must be used with the inner lid, vent and drain port coverplates and outer lid having the appropriate o-ring groove machined in the component. The two o-ring types also have different allowable leak rate criteria as described in Section 4.1. Consequently, different acceptance criteria are applied to the metallic and non-metallic o-ring configurations.

The detailed procedures for the NAC-STC cask leak testing are presented in Section 7.4.

Metallic O-Ring Testing

The final fabrication verification leak testing of the containment boundary closures using metallic o-rings consists of a series of leak tests using (minimum 99.9 percent pure) helium as a tracer gas and a helium leak detection system calibrated to a minimum sensitivity of 1×10^{-7} cm^3/sec (helium).

The test plug o-rings on the coverplate and the interseal test plug will be tested using the vacuum air pressure rise method. The metallic o-rings in the inner lid and the vent and drain port coverplates will be tested to ensure that the leak past a single o-ring will not exceed 2×10^{-7} cm^3/sec (helium). The tracer gas shall be introduced on the containment side of the o-ring in all cases. The test procedures and methods will be selected to ensure that the sensitivity of each leak test is 1×10^{-7} cm^3/sec (helium) or better.

A leak rate past any seal or closure that exceeds 2.0×10^{-7} cm^3/sec (helium) shall be cause for rejection of the item being tested. Seal replacement or other corrective actions will be taken to correct the leak. The item shall then be retested and inspected in accordance with the above test requirements and acceptance standards.

The outer lid metallic o-ring, the interlid port cover and the pressure port PTFE o-rings will be tested using an air or helium pressure drop test. The test shall demonstrate a leak rate not greater than 2×10^{-7} cm^3/sec (helium).

EPDM and Viton O-Ring Testing

The final fabrication verification leak testing of the containment boundary closures using EPDM or Viton o-rings consists of leak tests of the closure o-rings using (minimum 99.9 percent pure) helium as a tracer gas and a helium leak detection system calibrated to a minimum sensitivity of 4.1×10^{-5} cm^3/sec (helium).

The test plug o-rings on the coverplate and the interseal test plug will be tested using the vacuum air pressure rise method. The EPDM or Viton o-rings in the inner lid and the vent and drain port coverplates will be tested to ensure that the leak past a single o-ring will not exceed 4.1 x 10^{-5} cm^3/sec (helium). The tracer gas shall be introduced on the containment side of the o-ring in all cases. The test procedures and methods will be selected to ensure that the sensitivity of each leak test is 2.0 x 10^{-5} cm^3/sec (helium) or better.

A leak rate past any seal or closure that exceeds 4.1 x 10^{-5} cm^3/sec (helium) shall be cause for rejection of the item being tested. Seal replacement or other corrective actions will be taken to correct the leak. The item shall then be retested and inspected in accordance with the above test requirements and acceptance standards.

The outer lid metallic o-ring, the interlid port cover and the pressure port PTFE o-rings will be tested using an air or helium pressure drop test. The test shall demonstrate a leak rate not greater than 4.1 x 10^{-5} cm^3/sec (helium).

8.1.4 Component Tests

Tests performed on individual components are designed to ensure that the component meets the design requirements for correct and proper operation of the cask system.

Acceptance criteria are established based on the functions and design requirements of the component being tested.

8.1.4.1 Valves

There are no valves that are part of the NAC-STC containment boundary for transport. Quick-disconnect fittings are installed in the vent, drain and interseal test port openings in the inner lid to provide access to the cavity, and in the interlid port to provide access to the interlid region. These fittings serve as valves when the mating parts are connected, and are used to connect ancillary equipment to the cask cavity for filling, draining, drying, backfilling, gas sampling, and leak testing operations. Upon removal of the external fitting, the valve in the quick disconnect closes automatically. The design and selection of the quick disconnects is based on similar equipment and procedures used with other NRC-approved storage and transport casks. For transport, the quick disconnects are sealed inside the transport containment boundary using a bolted coverplate fitted with two o-ring seals. These o-rings are leak tested before each use.

There are no rupture disks on the NAC-STC.

Two self-actuating pressure relief valves are installed on the external shell of the neutron shield to provide for venting of vapor from the shielding material during transport thermal accident conditions. These valves have stainless steel bodies and an operating pressure range of zero to 200 psig with an adjustable cracking pressure within this range. The cracking pressure is set at 10 psig. These relief valves do not provide a safety function, but have been designed to minimize recovery efforts in the unlikely event of a neutron shield overpressure condition.

8.1.4.2 Gaskets

As described in Section 8.1.3, the containment boundary of the NAC-STC may use either metallic o-rings or non-metallic EPDM or Viton o-rings. The two o-ring types require different o-ring groove designs and, therefore, may not be used interchangeably and must be used with the inner lid, vent and drain port coverplates and outer lid having the appropriate o-ring groove machined in the component. Metallic o-rings must be used for direct loading of the NAC-STC with fuel for extended storage and for loading of a transportable storage canister (for transport). For direct loading of fuel for immediate transport, either metallic or non-metallic o-rings may be used.

The outer lid, inner lid, drain port coverplate, vent port coverplate, interlid port cover, pressure port cover, and interseal test plug gaskets are o-rings. For transport after an extended period of storage, the containment boundary is formed by the outer metallic o-ring of the inner lid, the outer metallic o-rings on the vent and drain port coverplates, and the interseal test plug metallic o-rings for the inner lid, the vent port coverplate and the drain port coverplate. The inner metallic o-rings of the inner lid, vent port coverplate and drain port coverplate, the metallic o-ring of the outer lid, and the PTFE o-rings of the interlid and pressure port covers provide a secondary closure to the cask contents. For immediate transport, the containment boundary is formed by the inner o-rings of the inner lid and vent and drain port coverplates. A second boundary is formed by the o-rings of the outer lid and interseal and pressure port covers.

The o-ring replacement schedule depends upon the o-ring material. The metallic o-ring(s) of any component shall be replaced prior to reinstallation of the component. EPDM and Viton o-rings are inspected prior to each use and replaced as necessary. The PTFE o-rings of the interlid and pressure ports will be visually inspected prior to each use, and replaced if necessary. The PTFE o-rings shall be replaced at least once every two years during cask transport operations, or prior to transport if they have been installed longer than two years (i.e., after extended storage).

The containment boundary o-rings shall be tested and maintained in accordance with the Maintenance Program Schedule of Table 8.2-1 and the leak test criteria of Section 8.2.2.

8.1.4.3 Miscellaneous

The removable transport impact limiters consist of redwood and balsa wood. License drawings and the supporting analyses specify the crush strengths of the redwood and balsa wood to be 6240 psi ± 620 psi and 1550 psi ± 150 psi respectively. For manufacturing purposes, verification of the impact limiter material is accomplished by verifying the densities of the wood. Three samples from each redwood board are to be tested for density, and the average density of the samples shall be 23.5 ± 3.5 pounds/cubic foot. Each 15-degree and 30-degree pie shaped section of the impact limiter shall have a density of 22.3 ± 1.2 pounds/cubic foot in accordance with the License Drawings. The moisture content for any single redwood board must be greater than 5 percent, but less than 15 percent. The average moisture content for a lot of redwood used in impact limiter construction must not be greater than 12 percent.

Following final closure welding of the transport impact limiter stainless steel shell, a leak test of the shell welds shall be performed to verify weld integrity. The test shall be performed by evacuating the impact limiter to 75 mbar and performing a 30-minute test to determine if there is any increase in the impact limiter pressure. Any detected leak shall not exceed 1×10^{-2} cm^3/sec. If a leak exceeding this value is detected, the cause of the leak shall be determined, and the weld repaired and retested.

8.1.5 Tests for Shielding Integrity

8.1.5.1 Gamma Shield Test

A gamma scan test shall be conducted by continuous scanning or probing over 100 percent of all accessible cask surfaces using a 3-inch detector and a ^{60}Co source. The source strength shall be of an intensity sufficient to produce a count rate that equals or exceeds three times the background count rate on the external surfaces of the cask. The count rate shall be maintained for greater than one minute prior to the start of scanning. The detector scan path spacing (cask exterior surface) will be a maximum of 2.5 inches and the scanning speed will be 4.5 feet per minute or less. The source scan path spacing (cask interior surface) will be on a 2-inch grid pattern (when using a 3-inch detector). Flat surfaces, such as the cask bottom and closure lids, will use a 2.5 inch spacing for both the detector and source scan paths (when using a 3-inch detector).

The acceptance criteria for the shield test will be that the shield effectiveness of the cask body and lids shall be equal to or greater than the shield effectiveness of a lead and steel mock-up. The steel thickness of the mock-up shall be equivalent to the minimum steel thickness specified on the License Drawings and the lead thickness shall be equivalent to the minimum lead thickness specified in the License Drawings less 3 percent. The shielding mock-up will be produced using the same fabrication techniques as those approved for the cask.

Measured count rates that exceed those established by the test mock-up shall cause the component to be rejected. The rejected areas/components shall be evaluated to determine the corrective action to be taken. Any repaired areas shall be retested prior to acceptance.

An additional gamma shield effectiveness test shall be performed on each cask following first fuel loading. The neutron and gamma shield effectiveness test procedures and acceptance criteria are described in Section 8.1.5.4.

8.1.5.2 Neutron Shielding Test

The neutron shielding of the NAC-STC is provided by a solid layer of NS-4-FR, which is a hard polymer material. A 5.5-inch layer of NS-4-FR is located in the annulus formed by the outer shell and the 0.236-inch (6 mm) thick neutron shield shell. The neutron shield is divided in sections by the copper/stainless steel fins. A 2-inch thick layer of NS-4-FR is also installed in the cask inner lid and cask bottom.

The installation of NS-4-FR material in the fabrication of the cask is a special process and, as such, procedures will be prepared and qualified to ensure that the mix ratios, mixing method, degassing, pouring, and curing of the material is properly performed. The NS-4-FR raw material is provided in the form of a 3-part mixing kit. The material content of the raw material is tested and certified at the time of kit preparation. The neutron shielding material is installed into the annulus between the outer shell and the neutron shield shell by pouring it with the cask in an inverted vertical position. Prior to installation, samples from each mix of the actual material being poured into the annulus are wet density tested to ensure that the material is properly mixed. Mixes that do not meet the wet density acceptance criteria are rejected. Procedures used for installation of the material are validated prior to use by destructive examination of a full scale mock-up of the neutron shield cavity. Qualification of the installation procedure verifies material homogenous properties and minimizes the potential deleterious voids.

8.1.5.3 Neutron Shielding Material Testing

The neutron shield properties of NS-4-FR are provided in Chapters 1 and 3. Each lot (mixed batch) of neutron shield material shall be tested to verify that the material composition (aluminum and hydrogen), boron concentration, and neutron shield density meet the requirements specified in Chapters 1 and 3 and the License Drawings. Testing shall be performed by qualified laboratories in accordance with written and approved procedures. Material composition, boron concentration, and density data for each lot of neutron shield material shall become part of the quality record documentation package.

Dimensional inspection of the cavities containing the neutron shielding material shall ensure that the required thickness specified in the License Drawings is incorporated into the cask.

The installation of the neutron shielding material shall be performed in accordance with written, approved, and qualified procedures. The procedures shall ensure that mix ratios and mixing methods are controlled in order to achieve proper material composition, boron concentration and distribution, and that pours are controlled in order to prevent gaps or unacceptable voids from occurring in the material. Procedures shall be qualified by the use of mock-ups to ensure that the NS-4-FR installation does not result in the creation of unacceptable voids. Samples of each lot of neutron shield material shall be maintained as part of the quality record documentation package.

8.1.5.4 Neutron and Gamma Shield Effectiveness Tests

Following first fuel loading, a neutron and gamma shield effectiveness test shall be performed for each cask prior to transport. The test shall be performed with the cask loaded with fuel, drained, vacuum dried and backfilled with helium. The purpose of the test is to document the effectiveness of the neutron and gamma shielding materials. The test shall be performed in accordance with detailed, approved written test procedures.

Calibrated neutron and gamma dose rate meters shall be used to measure the neutron and gamma dose rate at contact with the outer shell of the neutron shield and at 2.3 meters from the surface (equivalent to 2 meters from the sides of the railcar). Dose measurement points shall be established on the external surface of the shell at 30° intervals and at five points along the height of the shield (a total of 60 measuring points). In addition, neutron and gamma dose rate measurements shall be made of the trunnion areas above the neutron shield, at four points below the neutron shield, and at the edges and center of the cask top (outer lid) and cask bottom surfaces. Dose rates at the top and bottom of the cask shall be measured with the transport impact limiters installed. The dose rates measured at contact and at 2.3 meters shall be recorded on the test data sheet, along with the total power of the loaded fuel assemblies; date, time and location of test; identification and calibration of instrumentation; and identification of test engineer and operators.

To allow an evaluation of the measured dose rates to be completed, the burnup and cool time for the actual fuel assemblies loaded into the cask will be determined and recorded. From this fuel history data, the total actual neutron and gamma source terms will be estimated using ORIGEN or similar calculations.

If the measured dose rates exceed the applicable regulatory limits, the licensee shall notify the NRC. Appropriate corrective measures will be taken, including fuel unloading and correction of the shielding deficiency. Following corrective actions, the test will be reperformed to the original acceptance criteria prior to final acceptance.

8.1.6 Thermal Test

Prior to acceptance of the cask body at each fabrication facility, a first article thermal test using electric heaters shall be performed to confirm and verify that the fabricated and assembled cask possesses the heat rejection capabilities predicted by the thermal analyses. The thermal test shall be performed in accordance with approved written procedures. The thermal test demonstrates the ability of the cask body to reject heat to the environment as predicted by the thermal analysis.

The test is performed for the maximum heat load of 22.1 kW. This bounds any lower heat load.

8.1.6.1 Thermal Test Set-up

The thermal test shall be performed with the cask positioned horizontally on a test frame. The transport impact limiter or equivalent insulating material shall be installed on each end of the cask to simulate the transport configuration. The cask will be located in a covered enclosure in a still environment. A thermal test lid with connections for thermocouple leads and electric heater power cables shall be installed in place of the inner lid. The outer lid will not be installed for the test. The thermal test lid will be provided with an o-ring seal capable of containing the containment cavity helium atmosphere.

Electric heaters shall be installed in a suitable frame inserted into the cask cavity. The electric heaters will have an active length of between 120 and 150 inches and be capable of generating a total minimum heat load of 22.1 kW. The heaters shall not be in contact with the cask cavity wall. The power supplied to the heater will be recorded throughout the test duration.

Calibrated test thermocouples will be installed on the inner shell and outer neutron shield shell surfaces. The location of the test thermocouples shall coincide with regular intervals along the circumference and length of the cask body to provide direct correlation between inner shell and outer surface temperatures at a number of locations. The location and placement of thermocouples shall be specified in the thermal test plan and in the thermal analysis that supports the thermal test configuration. Approximate locations are shown in Figure 8.1-1.

The output of the test thermocouples will be recorded throughout the test by a strip chart recorder.

8.1.6.2 Test Procedure

With the cask assembled and instrumented, the cask cavity is evacuated and backfilled to 1.0 atmosphere absolute (14.7 psia) with helium. Power will be applied to the heaters to simulate the cask content heat load. After initiation of power to the heaters, the temperatures of all thermocouples and heater power levels will be monitored and recorded on data sheets. Power will be maintained to the electrical heaters until the cask has reached thermal equilibrium.

For the purpose of the test, thermal equilibrium is defined as being achieved when, for over two consecutive hours, the temperature recorded at a single set of inner shell and outer surface thermocouples does not vary by more than 2°F. Based upon the thermal heat-up evaluation, thermal equilibrium should be achieved in approximately five days.

After verification of thermal equilibrium, final temperature measurements will be recorded for all test thermocouples. The final power readings for the electric heaters will also be recorded. The strip chart will be marked to indicate the time of the final cask measurements. The printout of the strip chart recorder and the completed test data sheets will be incorporated into an approved final thermal test report. The test will be determined to be acceptable if the acceptance criteria of Section 8.1.6.3 are met.

If the acceptance criteria are not met, the cask will not be accepted until appropriate corrective actions are completed. Upon completion of corrective actions, the cask shall be retested to the original test requirements and acceptance criteria.

8.1.6.3 Acceptance Criteria

The purpose of the thermal test is to confirm that the heat rejection capability of the as-built cask is acceptable and that the measured temperatures are bounded by the temperatures calculated in the thermal analyses that define and support the test configurations.

Package heat dissipation acceptance testing assures that the maximum material temperatures do not exceed material allowables and that the measured temperature gradients are less than the thermal gradients calculated in the test configuration thermal analyses.

The thermal acceptance test shall be specified in the test plan and shall be based on the calculated values determined in the test configuration thermal analysis. At a minimum, the test acceptance criteria shall specify the maximum cask body surface temperature at any measured location (thermocouple location) and shall specify the maximum temperature gradient for the measured locations.

8.1.7 Neutron Absorber Tests

Neutron absorber material, BORAL, is used as a neutron poison in the fuel tubes. BORAL is manufactured by AAR Advanced Structures (AAR), under a Quality Assurance/Quality Control program in conformance with the requirements of 10 CFR 50, Appendix B. The computer-aided manufacturing process consists of several steps—the first being the mixing of the aluminum and boron-carbide powders that form the core of the finished material, with the amount of each powder a function of the desired ^{10}B areal density. The methods used to control the weight and blend of the powders are patented and proprietary processes of AAR.

After manufacturing, test samples from each batch of BORAL neutron absorber (poison) sheets shall be tested using wet chemistry techniques to verify the presence, proper distribution, and minimum weight percent of ^{10}B. The tests shall be performed in accordance with approved written procedures.

8.1.7.1 Neutron Absorber Material Sampling Plan

The neutron absorber sampling plan is selected to demonstrate a 95/95 statistical confidence level in the neutron absorber sheet material compliance with the specification. In addition to the specified sampling plan, each sheet of material is visually and dimensionally inspected using at least 6 measurements on each sheet. No rejected neutron absorber sheet is used. The sampling plan is supported by written and approved procedures.

The sampling plan requires that a coupon sample be taken from each of the first 100 sheets of absorber material. Thereafter, coupon samples are taken from 20 randomly selected sheets from each set of 100 sheets. This 1 in 5 sampling plan continues until there is a change in lot or batch of constituent materials of the sheet (i.e., boron carbide powder, aluminum powder, or aluminum extrusion) or a process change. The sheet samples are indelibly marked and recorded for identification. This identification is used to document neutron absorber test results, which become part of the quality record documentation package.

8.1.7.2 Wet Chemistry Test Performance

An approved facility with chemical analysis capability shall be selected to perform the wet chemistry tests. The tests will ensure the presence of boron and enable the calculation of the ^{10}B areal density.

The most common method of verifying the acceptability of neutron absorber material is the wet chemistry method—a chemical analysis where the aluminum is separated from a sample with known thickness and volume. The remaining boron-carbide material is weighed and the areal density of ^{10}B is computed. A statistical conclusion about the BORAL sheet from which the sample was taken and that batch of BORAL sheets may then be drawn based on the test results and the established manufacturing processes previously noted.

8.1.7.3 Neutron Absorption Test Performance

An approved facility with a neutron source and neutron detection capability shall be selected to perform the described tests, if the neutron absorption test method is used. The tests will assure that the neutron absorption capacity of the material tested is equal to, or higher than, the given reference value and will verify the uniformity of boron distribution. The principle of measurement of neutron absorption is that the presence of boron results in a reduction of neutron flux between the thermalized neutron source and the neutron detector—depending on the material thickness and boron content.

Typical test equipment will consist of thermal neutron source equipment, a neutron detector and a counting instrument. The test equipment is calibrated using BORAL standards, whose ^{10}B content has been checked and verified by an independent method such as chemical analysis. The highest permissible counting rate is determined from the neutron counting rates of the reference sheet(s), which should be ground to the minimum allowable plate thickness. This calibration process shall be repeated daily (every 24 hours) while tests are being performed.

8.1.7.4 Acceptance Criteria

The wet chemistry test results shall be considered acceptable if the ^{10}B areal density is determined to be equal to, or greater than, that specified on the fuel tube drawings. The neutron absorption test shall be considered acceptable if the neutron count determined for each test specimen is less than, or equal to, the highest permissible neutron count rate determined from the BORAL standard, which is based on the ^{10}B areal density specified on the fuel tube drawings. Any specimen not meeting the acceptance criteria for either test method shall be rejected and all of the sheets from that batch shall be similarly rejected.

8.1.8 Transportable Storage Canister

The transportable storage canister is constructed of Type 304L stainless steel, and is fabricated in two sections. Each section has a seam weld, and the sections are joined by a circumferential weld. In joining the two sections, the seam welds shall not be aligned within 45°

circumferentially. The welded cylinder is closed at the bottom by a circular plate welded to the shell wall. The top of the cylinder is closed by two field-installed circular plates, welded to the canister shell wall following fuel loading.

The transportable storage canister is a welded closed component. The canister serves as a secondary containment boundary for intact spent fuel and as the "separate inner container" required by 10 CFR 71.63(b) for failed fuel for transport. With its double lid configuration the canister provides the redundant sealing required by 10 CFR 72.236(e) and serves as the confinement boundary component of the NAC-MPC System during storage of spent fuel in the vertical concrete cask.

The finished surfaces of all canister welds are visually examined in accordance with ASME Code Section V, Article 9, to verify that the components are assembled in accordance with the License Drawings and that the components are free of nicks, gouges, and other damage. The acceptance criteria for the visually examined welds is in accordance with ASME Code Section VIII, Division 1, UW-35 and UW-36.

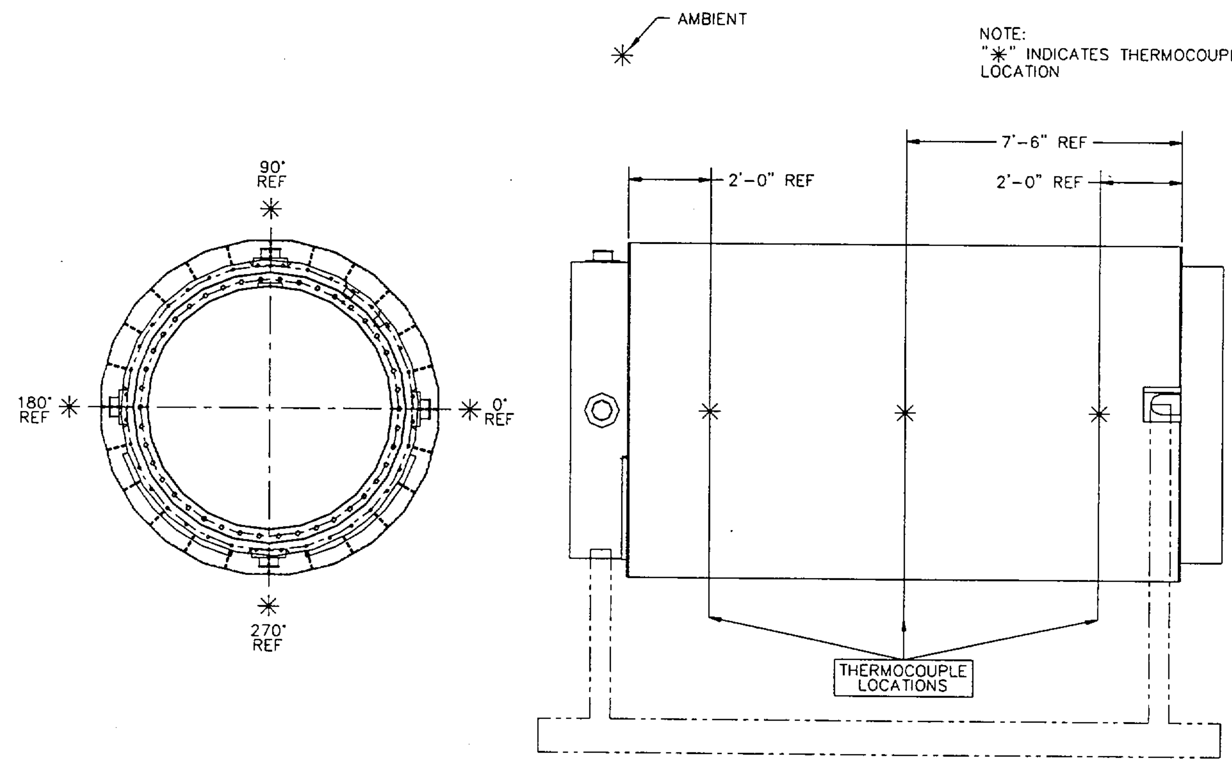
The seam and girth welds in the transportable storage canister shell are full-penetration welds that are radiographic examined in accordance with ASME Code Section V, Article 2. The acceptance criteria for the examined welds is that specified in ASME Code Section III, Subsection NB, Article NB-5320. The canister shell to bottom plate weld is a full-penetration double-bevel weld with an inside fillet weld that is ultrasonic examined in accordance with ASME Code Section V, Article 5, with acceptance criteria as specified in ASME Code Section III, Subsection NB, Article NB-5330. The final surfaces of the seam and girth welds in the canister and the canister shell to bottom plate weld are also liquid penetrant examined in accordance with ASME Code Section V, Article 6, with the acceptance criteria being that specified in ASME Code Section III, Subsection NB, Article NB-5350.

Field installed partial-penetration groove welds attach the shield (inner) lid to the canister shell and the vent port and the drain port coverplates to the shield lid, after the canister is loaded. The structural lid is attached to the canister shell by a partial penetration weld. The root and final surfaces of the shield lid weld are liquid penetrant examined in accordance with the ASME Code Section V, Article 6. Acceptance criteria are as specified in ASME Code Section III, Division 1, Subsection NB, Article NB-5330. The vent port and the drain port coverplate to shield lid welds are liquid penetrant examined, i.e., root and final surfaces, in accordance with ASME Code

Section V, Article 6. Acceptance criteria is specified in ASME Code Section III, Division 1, Subsection NB, Article NB-5350. The structural lid weld is either ultrasonic (UT) examined in accordance with the ASME Code, Section V, Article 5 with the final weld surface liquid penetrant examined in accordance with ASME Code, Section V, Article 6, or progressively liquid penetrant examined in accordance with the ASME Code, Section V, Article 6. Acceptance criteria is specified in ASME Code Section III, Division 1, Subsection NB, Article NB-5330 (ultrasonic) and Article NB-5350 (liquid penetrant). Following completion of the shield lid to canister shell weld and the drain port coverplate to shield lid welds, the canister is leak tested in accordance with ASME Code Section V, Article 10, Appendix IV, using a leak rate test sensitivity of 1 x 10^{-7} cm^3/sec (helium).

The fabricator of the transportable storage canister will establish a written weld inspection plan in accordance with an approved quality assurance program. The weld inspection plan will include visual, liquid penetrant, ultrasonic, and radiographic examination. In addition, the weld inspection plan will identify the welds to be examined, the sequence of the examinations, the type of examination method to be used, and the criteria for acceptance of the weld in accordance with the applicable sections of the ASME Code.

Figure 8.1-1 Thermal Test Arrangement



8.2 Maintenance Program

To ensure that the NAC-STC packaging is in compliance with the requirements of the regulations, the Certificate of Compliance, and this application, a cask Maintenance Program for the NAC-STC shall be established. The cask Maintenance Program shall specify the inspections, tests, and replacement of components to be performed, and the frequency and schedule for these activities. This chapter describes the overall requirements of the Maintenance Program and establishes the frequency and schedule for the maintenance activities. The detailed, written inspection, test, component replacement, and repair procedures shall be included in the NAC-STC Operations Manual. The NAC-STC Operations Manual will be issued to Users of the packaging and will be prepared and issued prior to first use of the cask in each configuration.

There are no maintenance requirements for the welded canister containing either fuel or GTCC waste.

8.2.1 Structural and Pressure Tests of the Cask

The four lifting trunnions and the two rotation trunnion recesses shall be visually inspected prior to each shipment. The visual inspections shall be performed in accordance with approved written procedures, and inspection results shall be evaluated against established acceptance criteria.

Evidence of cracking on the load bearing surfaces shall be cause for rejection of the affected trunnion until an approved repair has been completed, and the surfaces re-inspected and accepted. Such repairs shall be implemented and documented in accordance with an approved QA program.

The lifting trunnions are also inspected annually in accordance with Paragraph 6.3.1(b) of ANSI N14.6. All accessible trunnion welds and accessible welds that are part of the load path are visually inspected for permanent deformation, galling or cracking. Liquid penetrant examinations of welds and load-bearing surfaces are performed in accordance with the ASME Code, Section V, Article 6. Liquid penetrant acceptance standards are those of Paragraph NF-5350 of the ASME Code, Section III, Division 1.

During periods of nonuse of the transport cask, the inspection of the trunnions may be omitted, provided that the trunnions are inspected in accordance with this section prior to the next use.

8.2.2 Leak Tests

Leak tests are performed in accordance with the methodologies and requirements of ANSI N14.5-1997 using approved written procedures.

8.2.2.1 Containment Fabrication Verification Leak Test

The containment fabrication verification leak test is performed on each NAC-STC cask at the fabricator's facility in accordance with Section 8.1.3.

8.2.2.2 Containment Periodic Verification Leak Test

The periodic verification leak test shall be performed on each cask after the third use (prior to fourth cask loading sequence) and every twelve months thereafter to verify the containment capability and whenever a replaceable containment component is installed. Metallic o-rings used for the containment boundary seals shall be replaced during each cask loading operation and the seals leak tested in accordance with the containment system periodic verification leak test requirements. EPDM and Viton o-rings shall be inspected prior to each use and replaced as necessary. EPDM and Viton o-ring performance shall be demonstrated by leak testing prior to each shipment.

The periodic verification leak test shall be performed using approved written test procedures and in accordance with the test requirements and acceptance criteria established in Section 8.1.3 for the containment fabrication verification leak test.

During periods when the cask is not in use for transport, the periodic verification leak test need not be performed on an annual basis, but shall be reperformed prior to returning the cask to service and use as a transport package.

8.2.2.3 Acceptance Criteria

For the containment verification leak tests, the maximum permissible leak rate for metallic o-rings shall be 2.0 x 10^{-7} cm^3/sec (helium). The minimum test sensitivity for both the fabrication verification and verification leak tests shall be 1.0 x 10^{-7} cm^3/sec (helium). For EPDM and Viton o-rings, the maximum permissible leak rate shall be 4.1 x 10^{-5} cm^3/sec (helium). The minimum test sensitivity for both the fabrication verification and verification leak tests shall be 2.0 x 10^{-5} cm^3/sec (helium). Unacceptable leak test results shall be cause for rejection of the component tested. Corrective actions, including repair or replacement of the o-rings and/or closure component, shall be taken and documented as appropriate. The leak test shall be repeated and accepted prior to returning the cask to service.

8.2.3 Subsystems Maintenance

There are no subsystems maintenance requirements on the NAC-STC.

8.2.4 Valves, Rupture Disks and Gaskets on the Containment Vessel

There are no valves on the NAC-STC packaging providing a containment function. Four quick disconnects, one each on the vent, drain, inner lid interseal test and interlid ports, are provided for ease of cask operation.

The quick disconnect shall be inspected during each cask loading and unloading operation for proper performance and function. As necessary, the subject quick disconnect shall be replaced. The quick disconnects shall be replaced every two years during transport operations, and following fuel unloading after extended storage.

There are no rupture disks on the NAC-STC containment vessel.

All o-rings on the NAC-STC shall be visually inspected for damage during each cask operation. All metallic o-rings shall be replaced during each cask loading sequence. PTFE o-rings shall be replaced if damage is noted during the visual inspection and every two years during transport operations.

8.2.5 Shielding

The gamma and neutron shields of the NAC-STC packaging do not degrade with time or usage. The radiation surveys performed by licensees prior to transport and upon receipt of the loaded cask provide a continuing validation of the shield effectiveness of the NAC-STC.

8.2.6 Miscellaneous

The transport impact limiters shall be visually inspected prior to each shipment. The limiters shall be visually inspected for gross damage or cracking to the stainless steel shells in accordance with approved written procedures and established acceptance criteria. Impact limiters not meeting the established acceptance criteria shall be rejected until repairs are performed and the component reinspected and accepted.

The cask cavity shall be visually inspected prior to each fuel loading. Evidence of gross scoring of the cavity surface, or build-up of other foreign matter in the cask cavity that could block the cavity drainage paths shall be cause for rejection of the cask for use until approved maintenance and/or repair activities have been acceptably completed. The basket assembly for the directly loaded (uncanistered) or canistered configuration shall be visually inspected for deformation of the basket disks or tubes. Evidence of damage shall be cause for rejection of the basket until approved repair activities have been completed, and the basket has been re-inspected and approved for use.

The overall condition of the cask, including the fit and function of all removable components, shall be visually inspected and documented during each cask use. Components or cask conditions which are not in compliance with the Certificate of Compliance shall cause the cask to be rejected for transport use until repairs and/or replacement of the cask or component are performed, and the component reinspected and accepted.

The results of the visual inspections, leak tests, shielding and radiological contamination surveys; fuel identification information for the package contents; date, time, and location of the cask loading operations; and remarks regarding replaced components shall be included in the cask loading report for each loaded cask transport. The requirements of the cask loading report shall be detailed in the NAC-STC Operations Manual.

8.2.7 Maintenance Program Schedule

Table 8.2-1 presents the overall maintenance program schedule for the NAC-STC.

Table 8.2-1 Maintenance Program Schedule

Task	Frequency
Cavity Visual Inspection	Prior to Loading Fuel
Basket Visual Inspection	Prior to Fuel Loading
O-Ring Visual Inspection	Prior to Fuel Loading
Inner and Outer Lid and Port Coverplate Bolt Visual Inspection	Prior to installation during each use
Cask Visual and Proper Function Inspections	Prior to each Shipment
Lifting and Rotation Trunnion Visual Inspection Liquid Penetrant Inspection of Surfaces and Accessible Welds	 Prior to each Shipment Annually during use
Containment System Verification Leak Test of Inner Lid and Port Coverplate O-Rings	Prior to each Shipment
Transport Impact Limiter Visual Inspection	Prior to each Shipment
Quick-Disconnect Inspection for Proper Function	During each Cask Loading/Unloading Operation
Quick-Disconnect Replacement	Every two years during transport operations
Metallic O-Ring Replacement	Following removal of a component with a metallic o-ring
EPDM and Viton O-Ring Replacement	As required, based on inspection or leak test results
Inner and Outer Lid Bolt Replacement	Every 240 bolting cycles (every 20 years at 12 cycles per year)
PTFE O-Ring Replacement	Every two years during transport operations or as required by inspections.
Periodic Verification Leak Test	After 3rd use, annually thereafter, before use after extended storage, and following any containment system component replacement.

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8.3 Quick-Disconnect Valves

"Snap-Tite" quick disconnect nipples (quick disconnects) are used in the vent, drain, and inner lid interseal test ports to isolate the cavity, and in the interlid port to isolate the region between the inner and outer lids. No credit is taken for any containment function provided by these components. The drain line quick disconnect of the Transportable Storage Canister need not be valved.

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8.4 Cask Body Fabrication

8.4.1 General Fabrication Procedures

The NAC-STC cask body is a welded structure of stainless steel plates and forgings. Chemical Copper lead is poured in place between the inner and outer shells to serve as the main gamma shielding material. NS-4-FR is poured in place between the neutron shield shell and the outer shell. NS-4-FR is also form fit between the bottom inner forging and the bottom plate and in the inner lid. Welding on the NAC-STC shall be performed in accordance with the requirements of the ASME Code and the American Welding Society (AWS) Structural Welding Code - Steel (ANSI/AWS D.1-1) as specified on the License Drawings and in Section 8.1.1.

The general fabrication procedures for the NAC-STC are summarized herein to facilitate an understanding of the component configurations and the weld locations shown on the license drawings.

Each of the two inner shell rings (upper and lower) is rolled from Type XM-19 stainless steel plate and seam welded longitudinally. The outside diameter of each inner shell ring is machined to the defined transition section dimensions. The minimum length of each Type XM-19 shell ring shall be in accordance with the License Drawings. The central inner shell sections are each rolled from Type 304 stainless steel plate and seam welded longitudinally. The number and length of the individual inner shell sections to be used to obtain the required total inner shell length is optional. The inner shell sections are girth welded to each other and the inner shell rings are girth welded on each end of the inner shell. Longitudinal seam welds in adjacent inner shell sections shall be offset 180 degrees for girth-welded sections.

After initial rough machining and final weld preparation, the top forging and the bottom inner forging are individually welded to the opposite ends of the inner shell/inner shell ring weldment to form the cask cavity. The preparation, examination, and acceptance procedures for the welds are described in Section 8.1.1 and on the License Drawings. Following inspection and acceptance of the welds, the top forging and the outside diameter of the cask cavity weldment are final machined. Following final machining of both sides of the inner shell, an ultrasonic thickness test of the inner shell wall of the cask cavity shall be performed to confirm that the wall thickness of any location on the shell is not less than 1.46 inches (37.1 mm). A wall thickness at any location of less that 1.46 inches (37.1 mm) will be cause for rejection. Rejected areas of the shell wall can be repaired by weld overlay using approved written weld overlay procedures. Following repair, the repaired areas shall be examined in accordance with the original inspection requirements and acceptance criteria.

Following thickness testing, the cask cavity weldment, which is the NAC-STC primary containment boundary, shall be hydrostatically tested according to ASME Code, Section III, Subsection NB-6000, as described in Section 8.1.2.3. The cask cavity weldment is dried, the primary containment boundary welds are liquid penetrant examined in accordance with ASME Code, Section V, Article 6, and the welds are accepted in accordance with ASME Code, Section III, Subsection NB-5350. The cask cavity weldment is then helium leak tested to verify that the Containment System Fabrication Verification leak rate is satisfied, as described in Section 8.1.3.

Each of the outer shell sections is rolled from Type 304 stainless steel plate and seam welded longitudinally. The number and length of outer shell sections to be used to achieve the required total outer shell length is optional. The outer shell sections are girth welded to each other and the inside diameter of the "outer shell weldment" is final machined. Longitudinal seam welds in adjacent outer shell sections are offset 180 degrees for girth-welded sections. The outer shell weldment is welded to the cask cavity weldment at the top forging/outer shell interface to form the "body weldment". The preparation, examination, and acceptance procedures for the welds are described in Section 8.1.1 and on the License Drawings.

The body weldment is inverted (closure end down) in a pit or other sheltered location in preparation for lead pouring. A temporary dam extension and supports are welded to the open end of the outer shell to permit the full length of the lead shell to be poured and to maintain the outer shell position. "Backing bars" are tack-welded on the inside diameter of the outer shell overlapping the end of the weld prep and on the top surface of the bottom inner forging overlapping the outside diameter of the forging (adjacent to the outside diameter of the inner shell). The backing bars prevent the lead contamination of the welds when the outer shell/bottom outer forging weld and the bottom outer forging/bottom inner forging weld are performed after cask body cooldown following the lead pour. Lead pouring preparations, the pour itself, and the cooldown are performed in accordance with the lead pour requirements and procedures as described in Section 8.4.2.

Following cooldown, the cask may be moved to a location that is more suitable for the fabrication activities that are to follow. The temporary dam extension and supports at the open end of the outer shell are removed and the lead is machined to its final configuration, including facing off the backing bars to ensure that no lead remains on the weld side of the backing bars.

The bottom outer forging is welded to the outer shell and to the bottom inner forging with the backing bars preventing lead contamination of the welds. The weld examination and acceptance criteria are described in Section 8.1.1, and on the License Drawings. The NS-4-FR neutron shield material is installed in the bottom forging of the NAC-STC. The NS-4-FR is machined to obtain the specified 2-inch thickness and to provide a groove around the outside diameter. A backing bar is tack-welded on the inside diameter of the bottom outer forging in the groove in the NS-4-FR and flush with its surface. The bottom plate is positioned and welded to the bottom outer forging. The weld examination and acceptance criteria are described in Section 8.1.1 and on the License Drawings.

The outside diameter of the outer shell is then machined to the specified final dimensions. If required to achieve dimensional compliance with the License Drawings, additional localized machining of the inner shell will be performed. Remachined areas of the inner shell shall be re-examined by ultrasonic testing to confirm that the minimum thickness of 1.46 inches (37.1 mm) is maintained. Upon completion of final machining and prior to removal from the machine, the dimensional inspection of the inside diameter and cylindricity of the cavity shall be performed. Using inside micrometers, the inside diameter at 0, 45, 90 and 135 degree radial locations shall be measured. This measurement shall be repeated at a minimum of 6 axial locations through the bore of the inner shell. Using a dial indicator or the electronic measuring system on the machine, a "sweep" of the entire length of the bore at the same radial locations measured with the inside micrometers and also a "sweep" of the diameter at the same axial locations will be performed. The combination of these two inspections will demonstrate the actual diameter and cylindricity of the inner shell bore. Calibrated inspection equipment and approved written procedures will be used to perform the final dimensional inspections.

The Type 17-4 PH stainless steel lifting trunnions are welded to the top forging. The Type 17-4 PH stainless steel rotation trunnion recesses are welded to the outer shell at its juncture with the bottom outer forging. Both the lifting trunnion and rotation trunnion recess weld surfaces are prepared with a minimum 0.25-inch thick overlay of Inconel. The shear ring and the neutron shield upper end plate are welded to the top forging. The weld examination and acceptance criteria are described in Section 8.1.1, and on the License Drawings.

The explosively-bonded stainless steel/copper (SS/Cu) heat transfer fins extending through the neutron shield are welded (only the stainless steel is welded) to the upper end plate and to the outer shell. Following liquid penetrant examination of the fin to outer shell welds, the 24 neutron shield shell plates are prepared for installation and 1/8-inch thick expansion foam is applied to the interior surface using approved adhesive in accordance with the License Drawings. The neutron shield shell plates are individually positioned and welded to the stainless steel extended tip of the SS/Cu fins. These closure welds are then examined and accepted in accordance with the requirements of the License Drawings. The cask is then placed in the inverted position (closure end down). Following an installation procedure that has been approved by NAC and by the material supplier, the NS-4-FR neutron shield material is installed by pouring into each of the 24 regions between the fins in the NAC-STC neutron shield cavity. After the NS-4-FR has hardened, expansion foam (Section 4.5.5) is installed in the open end of the neutron shield. The inside and outside diametrical (curved) surfaces of the expansion foam are covered by a protective thermal insulation (FPC, see Section 4.5.4). The 24 sections of the neutron shield bottom end plate are each positioned and welded to the outer shell, the fins, the neutron shield shell, and to each other. All of the neutron shield and fin welds are liquid penetrant examined and accepted in accordance with the License Drawings. The neutron shield tank is leak tested using the pneumatic bubble method to verify shell integrity.

The Type 17-4 PH stainless steel outer lid forging and the Type 304 stainless steel inner lid forging are machined to the specified final dimensions. The NS-4-FR neutron shield material is installed in the top of the inner lid following an installation procedure that has been approved by NAC and by the material supplier. The exposed surface of the NS-4-FR is machined to obtain the specified 2-inch thickness and the coverplate is welded to the inner lid body. The weld examination and acceptance are in accordance with the requirements of the License Drawings. The top surface of the inner lid is then final machined.

The remaining fabrication details (including the installation of the drain line) are then completed.

Following machining of the structural steel support disks and the aluminum heat transfer disks, the components will be individually inspected for dimensional compliance to the License Drawings to ensure that each disk meets the stated tolerances. The diameter of each disk is measured using a calibrated external micrometer. The openings in each disk are inspected using a calibrated three coordinate measurement machine. The machining center may also be used for these inspections if previously qualified and calibrated. In the case of the diametral tolerances of the disks, the inspections are performed at 65±5°F (18±3°C) or else thermal expansion corrections will be addressed during the inspection process.

The separately fabricated and assembled fuel basket is then inserted into the cask body by carefully guiding the pre-assembled basket into the cask cavity. The acceptance tests described in Section 8.1 not previously completed during fabrication are performed and the completed NAC-STC is prepared for delivery.

8.4.2 Description of Lead Pour Procedures

This section describes the general requirements and the procedure that applies to the pouring of the lead in the annulus formed by the inner and outer shells of the NAC-STC cask body. The lead annulus provides the primary radial gamma shielding in the cask body and is subjected to a gamma scan test to verify its shielding integrity. The description that follows includes the pre-pour preparations, the pouring of the molten lead in the annulus between the inner and outer shells of the NAC-STC, and the post-pour controlled cooldown of the cask.

8.4.2.1 Preparation for Lead Pour

The following activities must be completed in preparation for pouring of the lead in the NAC-STC cask body:

1. Temporary stiffener bars/rings are installed both inside and outside of the body weldment at intermittent locations along the cask length. The stiffeners support the inner and outer shells during the lead pour and cooldown in order to maintain the specified dimensions of the lead annulus. The stiffeners are removed after the cooldown operation is completed.

2. A minimum of 12 pairs of thermocouples are used to monitor the heating and cooling cycle of the inner and outer shells. Each pair of thermocouples is positioned at approximately the same radial and axial location, one on the inside diameter of the inner shell and one on the outside diameter of the outer shell.

3. Electric heaters are installed in the cask cavity for use in heating the inner shell.

4. The body weldment (Section 8.4.1) of the NAC-STC is inverted and supported in a stable, vertical position in a "pit" or within a windbreak structure to provide a basically draft-free operations area.

5. An auxiliary dam extension and supports are welded to the open end of the outer shell. The extension and supports permit the full length of the lead shell to be poured in one operation while maintaining the annulus spacing at the open end of the outer shell.

6. A minimum of 20 gas heating/water cooling rings are installed around the outside of the body weldment for use in heating, and later in cooling, the outer shell. Gas torches are provided for heating the outside surface of the bottom inner forging.

7. The body weldment surfaces, especially the lead annulus, are checked for dimensional accuracy to ensure that the required spacing has been maintained and for cleanliness to ensure that no foreign materials are present.

8. The general arrangement of the equipment for the lead pour operation is shown in Figure 8.4-1.

8.4.2.2 Lead Pour Operations

The requirements and activities that must be completed during the pouring of the lead in the NAC-STC cask body are:

1. The lead material certification is checked to ensure that it conforms to the requirements of the American Society of Testing Materials (ASTM) B29, Chemical Copper Grade - 99.90 percent pure.

2. Approximately 60,000 pounds of lead is placed in appropriate size kettles and melted. During the lead pouring operations the temperature of the molten lead is maintained between 650°F (343°C) and 750°F (399°C).

3. At the same time that the lead is being melted, the NAC-STC body weldment is simultaneously heated using both the electric heaters on the interior and the gas

heating rings on the exterior. The body weldment will be heated in a steady and uniform manner at a rate not exceeding 125°F/hour (52°C/hour). Gas torches are used to heat the exterior of the bottom inner forging. The surface temperature of the body weldment is never permitted to exceed 800°F (427°C). The temperature of the entire body weldment is maintained between 640°F (338°C) and 740°F (393°C) throughout the lead pour operations.

4. The lead pour is initiated immediately after the temperatures of the lead and the body weldment are stabilized in the ranges previously specified. The actual pouring of the lead is completed without interruption and in as short a period of time as possible. During the lead pour the bottom end of the filler-tube is kept below the surface of the molten lead to preclude the formation of voids in the lead.

5. The lead is poured to a level that is sufficient to ensure that dross removal and contraction during solidification do not reduce the finished surface below the required level. A long steel rod inserted into the molten lead annulus is used to ensure that no solidification has begun anywhere in the volume of molten lead.

8.4.2.3 Cooldown Following Lead Pour

The procedures and requirements that must be completed during cooldown of the NAC-STC body weldment following completion of the lead pour are as follows:

1. Cooldown is initiated by turning off the electrical heater (interior) and the gas heating/water cooling ring (exterior) at the lowest end of the cask (in the as-poured position). The gas heating/water cooling ring is then used to facilitate and control cooling by spraying water on the exterior surface of the cask. As cooldown proceeds, the heaters and rings upward along the cask are successively turned off and the cooling water spray is turned on from each ring.

2. The cooldown process is temperature controlled to maintain approximately uniform solidification conditions across the thickness and around the circumference of the annulus.

3. The cooldown rate is held steady and uniform at a rate not to exceed 125°F/hour (52°C/hour) and the temperature differential between the inside shell and the outside shell is not allowed to exceed 100°F (38°C). Once the inner and outer shell temperatures have cooled to 150°F (66°C), it is no longer necessary to control the cooldown rate.

4. The solidification level in the lead annulus is checked with the aid of a long steel rod. The maximum difference in the elevation of the solidified lead between the inside surface of the outer shell and the outside surface of the inner shell is not permitted to exceed 2 inches (51 mm).

5. Dross is skimmed off the top of the lead while maintaining the molten head throughout the cooldown process.

8.4.2.4 Lead Pour Documentation

The following data is included in the Data Package for the Lead Pour Operation:

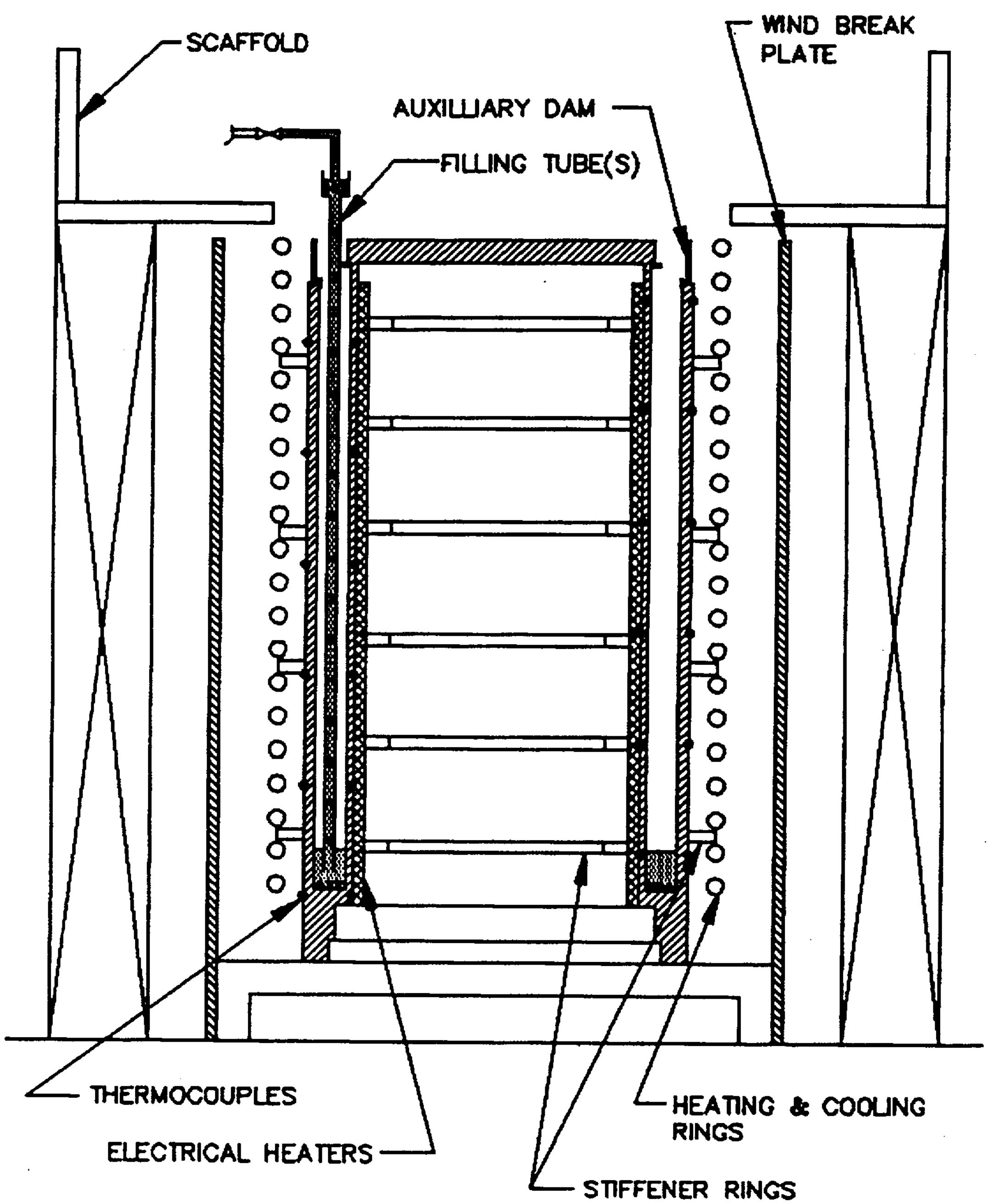
1. Certificate of Chemical Analysis of the lead.

2. Heating and cooling charts showing elapsed time and temperatures.

3. Location, time and temperature for readings taken with a handheld pyrometer or other temperature reading device.

4. Difference in solidification elevations when checking at the inside surface of the outer shell and the outside surface of the inner shell.

Figure 8.4-1 Arrangement of Lead Pour Equipment



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