Chapter 6

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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 or TalBor neutron absorber sheets which are held in place by steel cladding. The neutron absorber sheets have a minimum 0.02 g ^{10}B/cm^2 loading. 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 neutron absorber 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 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 or TalBor neutron absorber material; (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 absorbers; 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 neutron absorber 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 neutron absorber sheets from the outside of the tubes. The remainder of the tubes have neutron absorber 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 neutron absorber 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 neutron absorber 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 or TalBor neutron absorber; (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 absorbers; and (8) moderator assumed in the gap between the pellet and fuel rod clad.

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 neutron absorber 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	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}

6.3.3.2 Cask Material

The cask material densities for normal operating conditions are:

Material	Element	Density (atom/barn-cm) (directly loaded)	Density (atom/barn-cm) (canistered)
TalBor or Boral Core	^{10}B	7.098×10^{-3} (75% of Specified Minimum)	7.098×10^{-3} (75% of Specified Minimum)
	^{11}B	3.925×10^{-2}	3.925×10^{-2}
	C	1.220×10^{-2}	1.220×10^{-2}
	Al	3.358×10^{-2}	3.358×10^{-2}
Aluminum	Al	6.031×10^{-2}	6.031×10^{-2}
Stainless Steel, Type 304	Cr	1.743×10^{-2}	1.743×10^{-2}
	Fe	5.936×10^{-2}	5.936×10^{-2}
	Ni	7.721×10^{-3}	7.721×10^{-3}
	Mn	1.736×10^{-3}	1.736×10^{-3}
Lead	Pb	3.297×10^{-2}	3.297×10^{-2}
NS-4-FR	H	5.854×10^{-2}	5.841×10^{-2}
	O	2.609×10^{-2}	2.607×10^{-2}
	C	2.264×10^{-2}	2.265×10^{-2}
	N	1.394×10^{-3}	1.401×10^{-3}
	Al	7.763×10^{-3}	7.781×10^{-3}
	^{11}B	3.422×10^{-4}	3.565×10^{-4}
	^{10}B	8.553×10^{-5}	9.798×10^{-5}

6.3.3.3 Water Reflector Densities

The material densities for the water reflector outside the cask under normal operating conditions are:

Material	Element	Density (atom/barn-cm) (directly loaded)
H_2O	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 neutron absorber sheet ^{10}B content 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	$\Delta k/\sigma$
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.

In particular, the H/U (moderator to fuel) ratio of the AFA and AFA modified fuels at 4.5 wt. % ^{235}U are below that of the Westinghouse 17x17 OFA assembly at 4.2 wt.% ^{235}U. Section 6.4.2.3 and 6.4.2.4 demonstrate that the Westinghouse fuel assembly is under-moderated. The AFA fuel assembly, with a lower H/U ratio, is therefore also under-moderated and does not require any additional moderator density studies. Increase in reactivity for the AFA modified assembly is associated with an increased fuel fissile material mass, compared to the Westinghouse standard and OFA 17x17 assemblies, in conjunction with an improved H/U ratio compared to the

Westinghouse 17x17 standard assembly (but below that of the OFA assembly). The fissile material change has no impact on the relative flux trap behavior (i.e., tube movement) and will not impact the fuel assembly movement reactivity behavior (note that the fuel assembly is similar in size, < 0.09 inches wider, to the Westinghouse 17x17 assemblies). As shown in Section 6.4.2.2 the most reactive configuration concentrates fissile material in the center of the cask. The small change in fuel geometry (a slightly wider fuel assembly) has no impact on this behavior in that the fuel is still concentrated in the cask center and only the spacing between the center and the outer fuel assembly rings is slightly reduced (producing a higher reactivity system). Section 6.4.2.5 contains the criticality evaluation of AFAM fuel type at the most reactive system configuration.

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

Analysis	k_{eff}	σ	Δk_{eff}	$\Delta k_{eff}/\sigma$
Nominal Basket	0.90143	0.00090	----	----
Geometric Tolerances				
Min Disk Thickness	0.89900	0.00087	-0.00243	-2.793
Max Disk Thickness	0.90073	0.00087	-0.00070	-0.805

Based on reactivity 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 neutron absorber 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 neutron absorber 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 keff 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 keff 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 (neutron absorber 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 neutron absorber sheets were removed. Adjusting for the 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	Yes	75%	0.91291	0.00086	0.92698
270 cm	1.0	1.0	Yes	75%	0.91137	0.00085	0.92543
300 cm	1.0	1.0	Yes	75%	0.91086	0.00087	0.92493
250 cm	0.8	0.8	Yes	75%	0.84595	0.00083	0.86001
270 cm	0.8	0.8	Yes	75%	0.84564	0.00083	0.85970
300 cm	0.8	0.8	Yes	75%	0.84631	0.00083	0.86037
250 cm	0.6	0.6	Yes	75%	0.76900	0.00114	0.78319
270 cm	0.6	0.6	Yes	75%	0.76642	0.00110	0.78059
300 cm	0.6	0.6	Yes	75%	0.76671	0.00117	0.78092
250 cm	0.4	0.4	Yes	75%	0.67331	0.00106	0.68746
270 cm	0.4	0.4	Yes	75%	0.67276	0.00104	0.68691
300 cm	0.4	0.4	Yes	75%	0.67441	0.00110	0.68858
250 cm	0.2	0.2	Yes	75%	0.55708	0.00121	0.57131
270 cm	0.2	0.2	Yes	75%	0.55593	0.00120	0.57015
300 cm	0.2	0.2	Yes	75%	0.55529	0.00110	0.56946
250 cm	0.1	0.1	Yes	75%	0.49153	0.00123	0.50577
270 cm	0.1	0.1	Yes	75%	0.49294	0.00130	0.50722
300 cm	0.1	0.1	Yes	75%	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	75%	0.40726	0.00084	0.42132
270 cm	0.0001	1.0	Yes	75%	0.40776	0.00106	0.42191
300 cm	0.0001	1.0	Yes	75%	0.40638	0.00086	0.42045
250 cm	0.0001	0.8	Yes	75%	0.40775	0.00096	0.42186
270 cm	0.0001	0.8	Yes	75%	0.40756	0.00092	0.42165
300 cm	0.0001	0.8	Yes	75%	0.40704	0.00100	0.42117
250 cm	0.0001	0.6	Yes	75%	0.40862	0.00085	0.42268
270 cm	0.0001	0.6	Yes	75%	0.40788	0.00085	0.42194
300 cm	0.0001	0.6	Yes	75%	0.40823	0.00081	0.42228
250 cm	0.0001	0.4	Yes	75%	0.40805	0.00091	0.42214
270 cm	0.0001	0.4	Yes	75%	0.40706	0.00080	0.42111
300 cm	0.0001	0.4	Yes	75%	0.40580	0.00091	0.41989
250 cm	0.0001	0.2	Yes	75%	0.40931	0.00092	0.42340
270 cm	0.0001	0.2	Yes	75%	0.40933	0.00098	0.42345
300 cm	0.0001	0.2	Yes	75%	0.40683	0.00082	0.42088
250 cm	0.0001	0.1	Yes	75%	0.40663	0.00085	0.42069
270 cm	0.0001	0.1	Yes	75%	0.40955	0.00094	0.42365
300 cm	0.0001	0.1	Yes	75%	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	75%	0.91902	0.00085	0.93308
270 cm	1.0	1.0	No	75%	0.91787	0.00086	0.93194
300 cm	1.0	1.0	No	75%	0.91799	0.00087	0.93206
250 cm	0.8	0.8	No	75%	0.85275	0.00084	0.86681
270 cm	0.8	0.8	No	75%	0.85247	0.00085	0.86653
300 cm	0.8	0.8	No	75%	0.85157	0.00087	0.86564
250 cm	0.6	0.6	No	75%	0.77755	0.00084	0.79161
270 cm	0.6	0.6	No	75%	0.77531	0.00084	0.78937
300 cm	0.6	0.6	No	75%	0.77623	0.00083	0.79029
250 cm	0.4	0.4	No	75%	0.67887	0.00075	0.69290
270 cm	0.4	0.4	No	75%	0.67727	0.00105	0.69142
300 cm	0.4	0.4	No	75%	0.68166	0.00099	0.69578
250 cm	0.2	0.2	No	75%	0.56011	0.00059	0.57409
270 cm	0.2	0.2	No	75%	0.55940	0.00118	0.57361
300 cm	0.2	0.2	No	75%	0.56053	0.00119	0.57475
250 cm	0.1	0.1	No	75%	0.49514	0.00044	0.50908
270 cm	0.1	0.1	No	75%	0.49439	0.00135	0.50870
300 cm	0.1	0.1	No	75%	0.49446	0.00122	0.50870

Chapter 7

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 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 Viton o-rings. The lid and port coverplates cannot be used interchangeably with two types of o-rings.

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.

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 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 a 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 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 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 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 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 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 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 Viton o-rings[1], 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 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 Viton o-rings[1], 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[1].
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 (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.

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[1] The inner o-ring of the lid, inner o-ring of the vent port cover plate and inner o-ring of the vent port cover plate are part of the containment boundary. The combined measured leak rate from all three Viton o-rings must be less than or equal to $\leq 4.1 \times 10^{-5}$ cm^3/sec (helium) in accordance with 10 CFR 71.51.

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. Complete a Health Physics radiation survey of the entire package to ensure compliance with 49 CFR 173.441.
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 of the entire package 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 of the entire package 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.

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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7.4 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 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 Viton o-rings.

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 cumulative 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 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 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 cumulative leakage rate for all metallic o-rings defined as the containment boundary 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 cumulative leakage rate for all Viton o-rings defined as the containment boundary 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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8.1.2.3 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 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 x 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 all three o-rings will not exceed a cumulative total of 2 x 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 x 10^{-7} cm^3/sec (helium) or better.

A leak rate past any seal or closure that exceeds 2.0 x 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 x 10^{-7} cm^3/sec (helium).

Viton O-Ring Testing

The final fabrication verification leak testing of the containment boundary closures using 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 x 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 Viton o-rings in the inner lid and the vent and drain port coverplates will be tested to ensure that the leak past all three o-rings will not exceed a cumulative total of 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 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. 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 x 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 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

Two alternate neutron poison materials, BORAL and TalBor, have been qualified by NAC for use 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 manufacturing process consists of several steps: the first step is 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. The mixture of powders is placed in an aluminum box with walls approximately one inch thick. The top lid is welded in place. This "ingot" is heated for several hours and then is hot-rolled to produce the sheet of design thickness. The rolling process densifies and bonds the powder mixture. The aluminum box walls become the cladding for the Al-B_4C core.

TalBor is manufactured by Talon Composites. (TalBor was formerly called Boralyn, and was produced by Alyn Corporation. Alyn Corporation went out of business and Talon Composites acquired the major production equipment and the patent rights for Boralyn. TalBor is identical to Boralyn). TalBor is manufactured by Talon Composites, Inc., using a Quality Assurance program that has been determined by NAC to be compliant with the applicable requirements of 10 CFR 50, Appendix, B. TalBor is a metal matrix composite (MMC). The aluminum and B_4C powders are mixed to the specified ^{10}B areal density and the powder mixture is vacuum sintered and hot pressed to achieve a fully dense billet. The billet is extruded, then cut and rolled to the design thickness.

After manufacturing, test samples from each batch of 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 or TalBor sheet from which the sample was taken and that batch of 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 a known standard, 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 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.

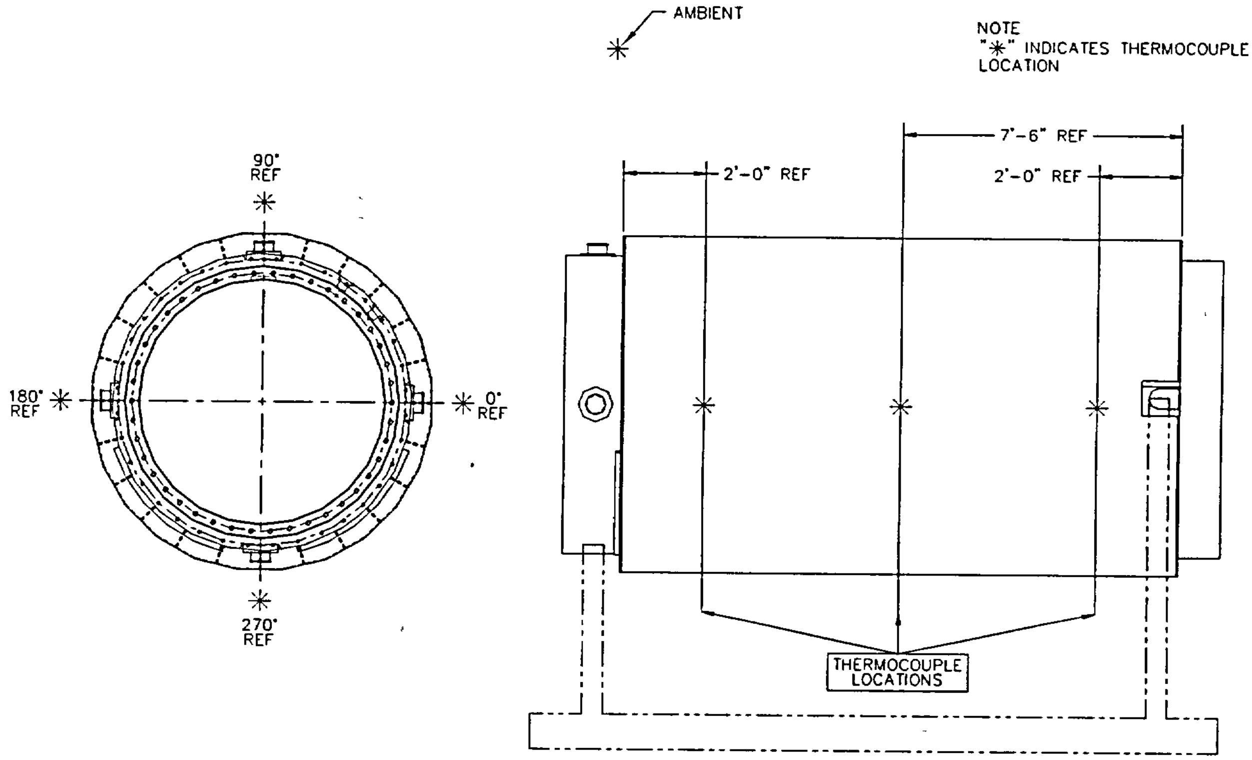
The finished surfaces of all canister welds are visually examined in accordance with ASME Code Section V, Article 9, to verify that the components are assembled in accordance with the License Drawings and that the components are free of nicks, gouges, and other damage. The acceptance criteria for the 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. Viton o-rings shall be inspected prior to each use and replaced as necessary. 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 (total) permissible leak rate for all containment boundary metallic o-rings shall be less than or equal to 2.0×10^{-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 Viton o-rings, the maximum (total) permissible leak rate for all containment boundary o-rings shall be less than or equal to 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. Viton O-rings shall be replaced annually and as required, based on leak testing results and inspection during 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	Prior to each Shipment
Liquid Penetrant Inspection of Surfaces and Accessible Welds	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
Viton O-Ring Replacement	Annually or more often, 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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