6.10.5 Evaluation of Package Arrays under Normal Conditions of Transport

6.10.5.1 NCT Array Configuration

6.10.5.1.1 MURR Fuel Element Models

The NCT array model is a 9x9x1 array of the NCT single package model. Although an 8x8x1 array is of sufficient size to justify a CSI = 4.0, the larger 9x9x1 array is utilized simply for modeling convenience. Void is always present between the insulation and the outer tube, as this region is water-tight. The entire array is reflected with 12-in of full-density water.

The FHEs are pushed to the center of the array and rotated to minimize the distance between the fuel elements, see Figure 6.10-10. The modeled lateral shifting of the FHE inside of the tube is computed assuming the maximum inner diameter of the inner tube (5.814-in, see Section 6.3.1, *Model Configuration*) and minimum outer radius of the FHE (2.8-0.2 = 2.6-in, from the packaging general arrangement drawings), or 0.307-in. The fuel element is also modeled at the lateral "top" of the FHE to minimize the distance between the fuel elements.

Six calculational series are developed, as described below. Results are summarized in Table 6.10-10.

Series 1 (Cases XD1 through XD12): In Series 1, the water density is fixed at 1.0 g/cm^3 between the fuel plates, and the water density inside and outside the FHE is modeled at the same density, which is allowed to vary between 0 and 1.0 g/cm^3. This moderation condition simulates the partial moderation effect of assuming the plastic bag that surrounds the fuel element retains water. The neoprene (without chlorine) from the FHEs is modeled in an approximate manner. The modeled channel width is 0.088-in. Also, the FHE is modeled with the minimum wall thickness.

As a point of interest, an additional case (Case XD12) is developed in which the fuel elements are centered in the cavity and not rotated, using the moderation assumptions of the most reactive case (Case XD7). The reactivity drops by 18.5 mk, which essentially represents the additional conservatism of pushing the fuel elements to the center of the array.

Series 2 (Cases XE1 through XE11): Series 2 is the same as Series 1, although the FHE neoprene is not modeled. The results in Table 6.10-10 indicate that the maximum reactivity occurs when chlorine-free neoprene is modeled (compare Cases XD7 and XE7), although the difference is within statistical fluctuation.

Series 3 (Cases XF1 through XF10): In Series 3, the water density inside the FHE is fixed at 1.0 g/cm^3, while the water density outside the FHE is allowed to vary between 0 and 1.0 g/cm^3. This moderation condition simulates the partial moderation effect of assuming the FHE retains water. The maximum reactivity increases slightly compared to Series 1.

Series 4 (Cases XG1 through XG11): Series 4 is the same as Series 3, although the FHE is modeled with the maximum wall thickness. The reactivity increases slightly, although the difference is within statistical fluctuation.

Series 5 (Cases XH1 through XH11): Series 5 is the same as Series 3, although the density within the fuel plates is modeled at a reduced density of 0.9 g/cm^3. The reactivity drops sharply as the water density between the plates is reduced.

Series 6 (Cases XI1 through XI11) is the same as Series 4, except the channel width is increased from 0.088-in to 0.092-in. The reactivity increases with increasing channel width, consistent with the single package models. Reactivity is at a maximum for Case XI5, with $k_s = 0.85643$. In this case, the fuel elements are pushed to the center of the array, full-density water is modeled between the plates and inside the FHE, 0.4 g/cm^3 water is modeled outside the FHE, chlorine-free neoprene is included, the FHE is modeled with maximum wall thickness, and the channel width is modeled at 0.092-in. The maximum result is below the USL of 0.9209.

6.10.5.1.2 MIT Fuel Element Models

The NCT array model is a 9x9x1 array of the NCT single package model. Although an 8x8x1 array is of sufficient size to justify a CSI = 4.0, the larger 9x9x1 array is utilized simply for modeling convenience. Void is always present between the insulation and the outer tube, as this region is water-tight. The entire array is reflected with 12-in of full-density water.

The FHEs are pushed to the center of the array and rotated to minimize the distance between the fuel elements, see Figure 6.10-10. The modeled lateral shifting of the FHE inside of the tube is computed assuming the maximum inner diameter of the inner tube (5.814-in, see Section 6.3.1, *Model Configuration*) and minimum outer radius of the FHE (2.8-0.2 = 2.6-in, from the packaging general arrangement drawings), or 0.307-in.

In addition to the lateral shifting of the FHE within the tube, the MIT fuel element is free to move laterally within the FHE. To simplify the model geometry, rather than modeling each fuel element shifted within each FHE, the fuel elements are modeled in the center of the FHE, and the FHE is shifted toward the center of the array an additional 0.13-in (the approximate as-modeled distance between the fuel element and neoprene).

Six calculational series are developed, as described below. Results are summarized in Table 6.10-11.

Series 1 (Cases YD1 through YD12): In Series 1, the water density is fixed at 1.0 g/cm^3 between the fuel plates, and the water density inside and outside the FHE is modeled at the same density, which is allowed to vary between 0 and 1.0 g/cm^3. This moderation condition simulates the partial moderation effect of assuming the plastic bag that surrounds the fuel element retains water. The neoprene (without chlorine) from the FHE is modeled in an approximate manner. The modeled channel width is 0.094-in. Also, the FHE is modeled with the minimum wall thickness.

As a point of interest, an additional case (Case YD12) is developed in which the fuel elements are centered in the cavity and not rotated, using the moderation assumptions of the most reactive case (Case YD7). The reactivity drops by 12.5 mk, which essentially represents the additional conservatism of pushing the fuel elements to the center of the array.

Series 2 (Cases YE1 through YE11): Series 2 is the same as Series 1, although the FHE neoprene is not modeled. Comparing Series 1 to Series 2, the reactivity is slightly higher when chlorine-free neoprene is modeled (compare Cases YD7 and YE7), although the difference is within statistical fluctuation.

Series 3 (Cases YF1 through YF10): In Series 3, the water density inside the FHE is fixed at 1.0 g/cm^3, while the water density outside the FHE is allowed to vary between 0 and 1.0 g/cm^3. This moderation condition simulates the partial moderation effect of assuming the FHE retains water. The maximum reactivity increases slightly compared to Series 1, although the effect is well within statistical fluctuation.

Series 4 (Cases YG1 through YG11): Series 4 is the same as Series 3, although the FHE is modeled with the maximum wall thickness. The reactivity decreases slightly, although the difference may be statistical fluctuation. Note that reactivity increased slightly with the thicker walled FHE in the MURR models.

Series 5 (Cases YH1 through YH11): Series 5 is the same as Series 3, although the density within the fuel plates is modeled at a reduced density of 0.9 g/cm^3. The reactivity drops sharply as the water density between the plates is reduced.

Series 6 (Cases YI1 through YI11): Series 6 is the same as Series 3, although the modeled channel width is increased from 0.094-in to 0.116-in. Reactivity is at a maximum for Case YI6, with $k_s = 0.65658$. In this case, the fuel elements are pushed to the center of the array, full-density water is modeled between the plates and inside the FHE, 0.5 g/cm^3 water is modeled outside the FHE, chlorine-free neoprene is included, the FHE is modeled with minimum wall thickness, and the modeled channel width is 0.116-in. The maximum result is far below the USL of 0.9209.

6.10.5.2 NCT Array Results

The results for the NCT array cases are provided in the following tables. The most reactive configuration in each series is listed in boldface.

Table 6.10-10 – MURR NCT Array Results

Case ID	Filename	Water Density Inside FHE (g/cm^3)	Water Density Outside FHE (g/cm^3)	Water Density Between Plates (g/cm^3)	k_{eff}	σ	k_s (k+2σ)
Series 1: Variable water density inside and outside FHE, with neoprene.							
XD1	NA_MURR2_NW000	0	0	1.0	0.76937	0.00121	0.77179
XD2	NA_MURR2_NW010	0.1	0.1	1.0	0.79729	0.00123	0.79975
XD3	NA_MURR2_NW020	0.2	0.2	1.0	0.81129	0.00129	0.81387
XD4	NA_MURR2_NW030	0.3	0.3	1.0	0.82519	0.00129	0.82777
XD5	NA_MURR2_NW040	0.4	0.4	1.0	0.83449	0.00130	0.83709
XD6	NA_MURR2_NW050	0.5	0.5	1.0	0.83502	0.00123	0.83748
XD7	**NA_MURR2_NW060**	**0.6**	**0.6**	**1.0**	**0.83801**	**0.00124**	**0.84049**
XD8	NA_MURR2_NW070	0.7	0.7	1.0	0.83447	0.00111	0.83669
XD9	NA_MURR2_NW080	0.8	0.8	1.0	0.83185	0.00119	0.83423
XD10	NA_MURR2_NW090	0.9	0.9	1.0	0.82537	0.00123	0.82783
XD11	NA_MURR2_NW100	1.0	1.0	1.0	0.81935	0.00120	0.82175
XD12	NA_MURR2_NW060C	0.6	0.6	1.0	0.81957	0.00123	0.82203
Series 2: Repeat of Series 1 without neoprene							
XE1	NA_MURR2_W000	0	0	1.0	0.75717	0.00117	0.75951
XE2	NA_MURR2_W010	0.1	0.1	1.0	0.78680	0.00103	0.78886
XE3	NA_MURR2_W020	0.2	0.2	1.0	0.80910	0.00116	0.81142
XE4	NA_MURR2_W030	0.3	0.3	1.0	0.82154	0.00114	0.82382
XE5	NA_MURR2_W040	0.4	0.4	1.0	0.83148	0.00129	0.83406
XE6	NA_MURR2_W050	0.5	0.5	1.0	0.83479	0.00111	0.83701
XE7	**NA_MURR2_W060**	**0.6**	**0.6**	**1.0**	**0.83681**	**0.00115**	**0.83911**
XE8	NA_MURR2_W070	0.7	0.7	1.0	0.83504	0.00126	0.83756
XE9	NA_MURR2_W080	0.8	0.8	1.0	0.83138	0.00116	0.83370
XE10	NA_MURR2_W090	0.9	0.9	1.0	0.82487	0.00122	0.82731
XE11	NA_MURR2_W100	1.0	1.0	1.0	0.81734	0.00128	0.81990
Series 3: Variable water density outside FHE, with neoprene.							
XF1	NA_MURR2_FNW000	1.0	0	1.0	0.83204	0.00135	0.83474
XF2	NA_MURR2_FNW010	1.0	0.1	1.0	0.83421	0.00118	0.83657
XF3	NA_MURR2_FNW020	1.0	0.2	1.0	0.84008	0.00131	0.84270
XF4	**NA_MURR2_FNW030**	**1.0**	**0.3**	**1.0**	**0.84082**	**0.00132**	**0.84346**
XF5	NA_MURR2_FNW040	1.0	0.4	1.0	0.84055	0.00120	0.84295
XF6	NA_MURR2_FNW050	1.0	0.5	1.0	0.83832	0.00116	0.84064
XF7	NA_MURR2_FNW060	1.0	0.6	1.0	0.83730	0.00118	0.83966
XF8	NA_MURR2_FNW070	1.0	0.7	1.0	0.83373	0.00130	0.83633
XF9	NA_MURR2_FNW080	1.0	0.8	1.0	0.83100	0.00124	0.83348
XF10	NA_MURR2_FNW090	1.0	0.9	1.0	0.82544	0.00129	0.82802
XD11	NA_MURR2_NW100	1.0	1.0	1.0	0.81935	0.00120	0.82175

(continued)

Table 6.10-10 – MURR NCT Array Results (concluded)

Case ID	Filename	Water Density Inside FHE (g/cm^3)	Water Density Outside FHE (g/cm^3)	Water Density Between Plates (g/cm^3)	k_{eff}	σ	k_s $(k+2\sigma)$
Series 4: Same as Series 3 but with maximum thickness FHE.							
XG1	NA_MURR2_TFNW000	1.0	0	1.0	0.83659	0.00121	0.83901
XG2	NA_MURR2_TFNW010	1.0	0.1	1.0	0.83959	0.00114	0.84187
XG3	NA_MURR2_TFNW020	1.0	0.2	1.0	0.84116	0.00126	0.84368
XG4	NA_MURR2_TFNW030	1.0	0.3	1.0	0.84029	0.00128	0.84285
XG5	**NA_MURR2_TFNW040**	**1.0**	**0.4**	**1.0**	**0.84340**	**0.00128**	**0.84596**
XG6	NA_MURR2_TFNW050	1.0	0.5	1.0	0.83927	0.00116	0.84159
XG7	NA_MURR2_TFNW060	1.0	0.6	1.0	0.83816	0.00117	0.84050
XG8	NA_MURR2_TFNW070	1.0	0.7	1.0	0.83704	0.00131	0.83966
XG9	NA_MURR2_TFNW080	1.0	0.8	1.0	0.83199	0.00118	0.83435
XG10	NA_MURR2_TFNW090	1.0	0.9	1.0	0.82930	0.00116	0.83162
XG11	NA_MURR2_TFNW100	1.0	1.0	1.0	0.82461	0.00129	0.82719
Series 5: Same as Series 3 with 0.9 g/cm^3 water between fuel plates.							
XH1	NA_MURR2_M90FNW000	1.0	0	0.9	0.80160	0.00132	0.80424
XH2	NA_MURR2_M90FNW010	1.0	0.1	0.9	0.80747	0.00120	0.80987
XH3	NA_MURR2_M90FNW020	1.0	0.2	0.9	0.81288	0.00127	0.81542
XH4	**NA_MURR2_M90FNW030**	**1.0**	**0.3**	**0.9**	**0.81512**	**0.00127**	**0.81766**
XH5	NA_MURR2_M90FNW040	1.0	0.4	0.9	0.81504	0.00120	0.81744
XH6	NA_MURR2_M90FNW050	1.0	0.5	0.9	0.81382	0.00112	0.81606
XH7	NA_MURR2_M90FNW060	1.0	0.6	0.9	0.81369	0.00121	0.81611
XH8	NA_MURR2_M90FNW070	1.0	0.7	0.9	0.81165	0.00129	0.81423
XH9	NA_MURR2_M90FNW080	1.0	0.8	0.9	0.80950	0.00122	0.81194
XH10	NA_MURR2_M90FNW090	1.0	0.9	0.9	0.80311	0.00124	0.80559
XH11	NA_MURR2_M90FNW100	1.0	1.0	0.9	0.79735	0.00117	0.79969
Series 6: Same as Series 4 but with a modeled channel width of 0.092-in.							
XI1	NA_MURR2_TFNW000C	1.0	0	1.0	0.84994	0.00110	0.85214
XI2	NA_MURR2_TFNW010C	1.0	0.1	1.0	0.85141	0.00120	0.85381
XI3	NA_MURR2_TFNW020C	1.0	0.2	1.0	0.85273	0.00124	0.85521
XI4	NA_MURR2_TFNW030C	1.0	0.3	1.0	0.85209	0.00124	0.85457
XI5	**NA_MURR2_TFNW040C**	**1.0**	**0.4**	**1.0**	**0.85405**	**0.00119**	**0.85643**
XI6	NA_MURR2_TFNW050C	1.0	0.5	1.0	0.84925	0.00127	0.85179
XI7	NA_MURR2_TFNW060C	1.0	0.6	1.0	0.84912	0.00124	0.85160
XI8	NA_MURR2_TFNW070C	1.0	0.7	1.0	0.84584	0.00115	0.84814
XI9	NA_MURR2_TFNW080C	1.0	0.8	1.0	0.84296	0.00127	0.84550
XI10	NA_MURR2_TFNW090C	1.0	0.9	1.0	0.83957	0.00115	0.84187
XI11	NA_MURR2_TFNW100C	1.0	1.0	1.0	0.83490	0.00123	0.83736

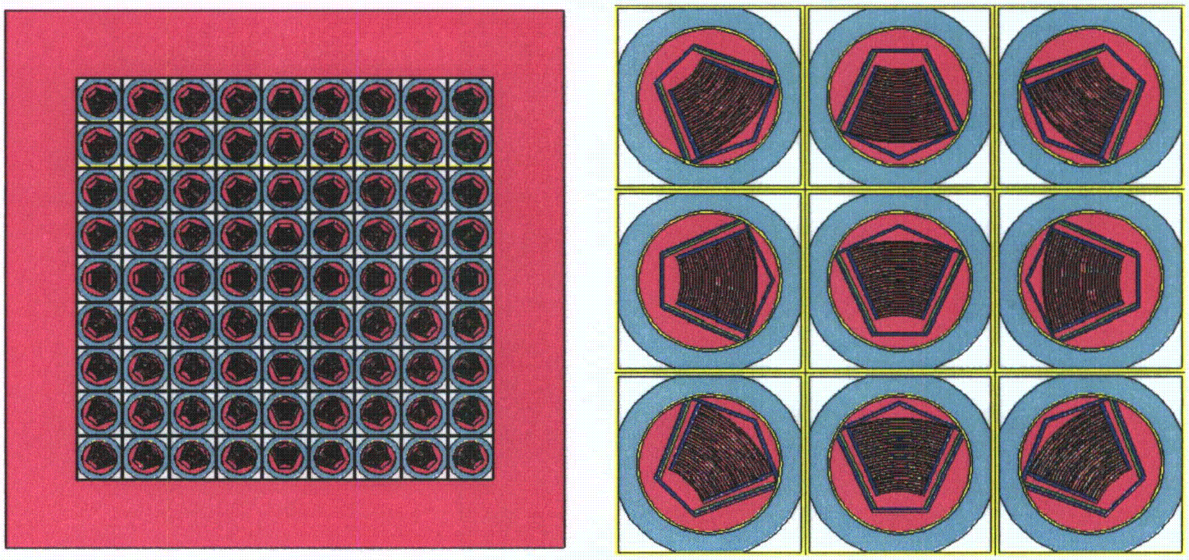
Table 6.10-11 – MIT NCT Array Results

Case ID	Filename	Water Density Inside FHE (g/cm^3)	Water Density Outside FHE (g/cm^3)	Water Density Between Plates (g/cm^3)	k_{eff}	σ	k_s (k+2σ)
Series 1: Variable water density and outside FHE, with neoprene							
YD1	NA_MIT_NW000	0	0	1.0	0.48041	0.00096	0.48233
YD2	NA_MIT_NW010	0.1	0.1	1.0	0.52918	0.00105	0.53128
YD3	NA_MIT_NW020	0.2	0.2	1.0	0.56301	0.00103	0.56507
YD4	NA_MIT_NW030	0.3	0.3	1.0	0.59062	0.00105	0.59272
YD5	NA_MIT_NW040	0.4	0.4	1.0	0.60722	0.00122	0.60966
YD6	NA_MIT_NW050	0.5	0.5	1.0	0.61575	0.00118	0.61811
YD7	**NA_MIT_NW060**	**0.6**	**0.6**	**1.0**	**0.61989**	**0.00114**	**0.62217**
YD8	NA_MIT_NW070	0.7	0.7	1.0	0.61723	0.00110	0.61943
YD9	NA_MIT_NW080	0.8	0.8	1.0	0.61618	0.00116	0.61850
YD10	NA_MIT_NW090	0.9	0.9	1.0	0.61352	0.00112	0.61576
YD11	NA_MIT_NW100	1.0	1.0	1.0	0.60885	0.00112	0.61109
YD12	NA_MIT_CNW060	0.6	0.6	1.0	0.60764	0.00103	0.60970
Series 2: Repeat of Series 1 without neoprene							
YE1	NA_MIT_W000	0	0	1.0	0.46154	0.00093	0.46340
YE2	NA_MIT_W010	0.1	0.1	1.0	0.51291	0.00095	0.51481
YE3	NA_MIT_W020	0.2	0.2	1.0	0.55394	0.00103	0.55600
YE4	NA_MIT_W030	0.3	0.3	1.0	0.58160	0.00113	0.58386
YE5	NA_MIT_W040	0.4	0.4	1.0	0.60184	0.00111	0.60406
YE6	NA_MIT_W050	0.5	0.5	1.0	0.61163	0.00119	0.61401
YE7	**NA_MIT_W060**	**0.6**	**0.6**	**1.0**	**0.61746**	**0.00117**	**0.61980**
YE8	NA_MIT_W070	0.7	0.7	1.0	0.61518	0.00116	0.61750
YE9	NA_MIT_W080	0.8	0.8	1.0	0.61215	0.00106	0.61427
YE10	NA_MIT_W090	0.9	0.9	1.0	0.61082	0.00111	0.61304
YE11	NA_MIT_W100	1.0	1.0	1.0	0.60324	0.00110	0.60544
Series 3: Variable water density outside FHE, with neoprene.							
YF1	NA_MIT_FNW000	1.0	0	1.0	0.55417	0.00118	0.55653
YF2	NA_MIT_FNW010	1.0	0.1	1.0	0.57731	0.00104	0.57939
YF3	NA_MIT_FNW020	1.0	0.2	1.0	0.59825	0.00117	0.60059
YF4	NA_MIT_FNW030	1.0	0.3	1.0	0.60830	0.00119	0.61068
YF5	NA_MIT_FNW040	1.0	0.4	1.0	0.61581	0.00116	0.61813
YF6	NA_MIT_FNW050	1.0	0.5	1.0	0.61968	0.00107	0.62182
YF7	**NA_MIT_FNW060**	**1.0**	**0.6**	**1.0**	**0.62059**	**0.00113**	**0.62285**
YF8	NA_MIT_FNW070	1.0	0.7	1.0	0.62035	0.00110	0.62255
YF9	NA_MIT_FNW080	1.0	0.8	1.0	0.61650	0.00110	0.61870
YF10	NA_MIT_FNW090	1.0	0.9	1.0	0.61120	0.00105	0.61330
YD11	NA_MIT_NW100	1.0	1.0	1.0	0.60885	0.00112	0.61109

(continued)

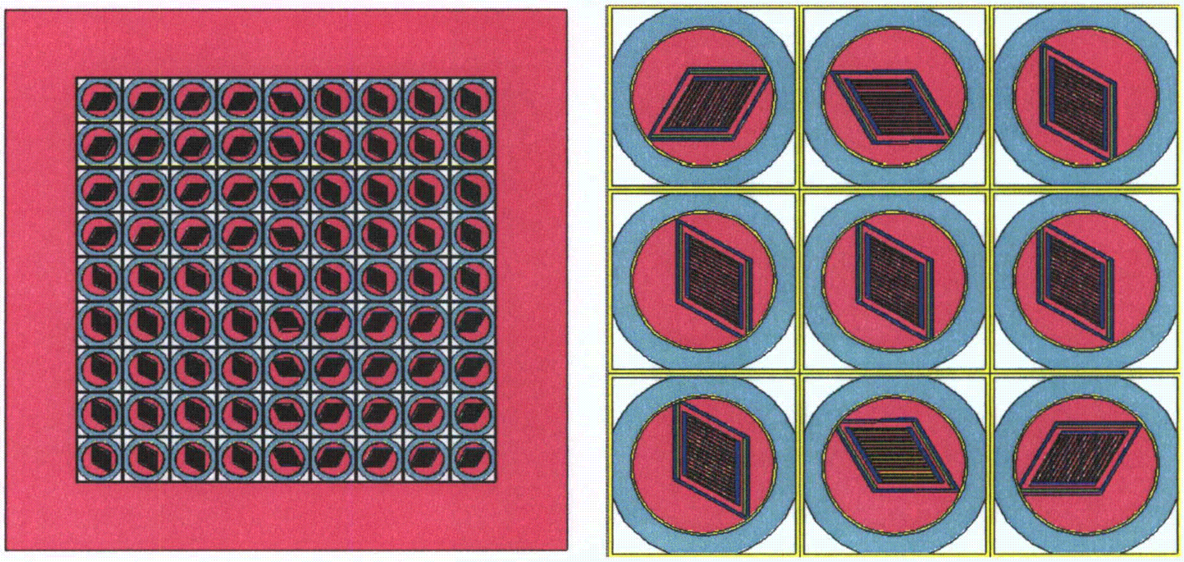
Table 6.10-11 – MIT NCT Array Results (concluded)

Case ID	Filename	Water Density Inside FHE (g/cm^3)	Water Density Outside FHE (g/cm^3)	Water Density Between Plates (g/cm^3)	k_{eff}	σ	k_s ($k+2\sigma$)
Series 4: Same as Series 3 but with maximum thickness FHE.							
YG1	NA_MIT_TFNW000	1.0	0	1.0	0.55951	0.00106	0.56163
YG2	NA_MIT_TFNW010	1.0	0.1	1.0	0.58058	0.00105	0.58268
YG3	NA_MIT_TFNW020	1.0	0.2	1.0	0.59653	0.00105	0.59863
YG4	NA_MIT_TFNW030	1.0	0.3	1.0	0.60581	0.00118	0.60817
YG5	NA_MIT_TFNW040	1.0	0.4	1.0	0.61242	0.00110	0.61462
YG6	NA_MIT_TFNW050	1.0	0.5	1.0	0.61318	0.00104	0.61526
YG7	NA_MIT_TFNW060	1.0	0.6	1.0	0.61463	0.00120	0.61703
YG8	**NA_MIT_TFNW070**	**1.0**	**0.7**	**1.0**	**0.61501**	**0.00111**	**0.61723**
YG9	NA_MIT_TFNW080	1.0	0.8	1.0	0.61394	0.00114	0.61622
YG10	NA_MIT_TFNW090	1.0	0.9	1.0	0.60894	0.00113	0.61120
YG11	NA_MIT_TFNW100	1.0	1.0	1.0	0.60456	0.00120	0.60696
Series 5: Same as Series 3 with 0.9 g/cm^3 water between fuel plates.							
YH1	NA_MIT_M90FNW000	1.0	0	0.9	0.53177	0.00107	0.53391
YH2	NA_MIT_M90FNW010	1.0	0.1	0.9	0.55655	0.00108	0.55871
YH3	NA_MIT_M90FNW020	1.0	0.2	0.9	0.57776	0.00122	0.58020
YH4	NA_MIT_M90FNW030	1.0	0.3	0.9	0.59349	0.00102	0.59553
YH5	NA_MIT_M90FNW040	1.0	0.4	0.9	0.60205	0.00103	0.60411
YH6	NA_MIT_M90FNW050	1.0	0.5	0.9	0.60659	0.00102	0.60863
YH7	NA_MIT_M90FNW060	1.0	0.6	0.9	0.60651	0.00119	0.60889
YH8	**NA_MIT_M90FNW070**	**1.0**	**0.7**	**0.9**	**0.60753**	**0.00121**	**0.60995**
YH9	NA_MIT_M90FNW080	1.0	0.8	0.9	0.60615	0.00112	0.60839
YH10	NA_MIT_M90FNW090	1.0	0.9	0.9	0.60192	0.00100	0.60392
YH11	NA_MIT_M90FNW100	1.0	1.0	0.9	0.59396	0.00111	0.59618
Series 6: Same as Series 3 but with modeled channel width of 0.116-in.							
YI1	NA_MIT_FNW000C	1.0	0	1.0	0.60247	0.00113	0.60473
YI2	NA_MIT_FNW010C	1.0	0.1	1.0	0.62391	0.00116	0.62623
YI3	NA_MIT_FNW020C	1.0	0.2	1.0	0.63710	0.00115	0.63940
YI4	NA_MIT_FNW030C	1.0	0.3	1.0	0.64617	0.00129	0.64875
YI5	NA_MIT_FNW040C	1.0	0.4	1.0	0.65160	0.00119	0.65398
YI6	**NA_MIT_FNW050C**	**1.0**	**0.5**	**1.0**	**0.65414**	**0.00122**	**0.65658**
YI7	NA_MIT_FNW060C	1.0	0.6	1.0	0.65181	0.00119	0.65419
YI8	NA_MIT_FNW070C	1.0	0.7	1.0	0.65016	0.00109	0.65234
YI9	NA_MIT_FNW080C	1.0	0.8	1.0	0.64541	0.00118	0.64777
YI10	NA_MIT_FNW090C	1.0	0.9	1.0	0.64029	0.00106	0.64241
YI11	NA_MIT_FNW100C	1.0	1.0	1.0	0.63436	0.00114	0.63664



MURR Full view

MURR Close-up



MIT Full view

MIT Close-up

Figure 6.10-10 – MURR/MIT NCT Array Geometry

6.10.6 Package Arrays under Hypothetical Accident Conditions

6.10.6.1 HAC Array Condition

The HAC array model is a 5x5x1 array of packages. The primary difference comparing NCT to HAC is the modeled fuel damage, and separation of the FHE halves. Consistent with the HAC single package models, the two FHE halves are allowed to separate to the maximum possible extent, and the fuel element pitch is allowed to increase to the maximum possible value until constrained by the FHE. It is established in the HAC single package analysis that the reactivity is maximized with the maximum pitch, so all HAC array calculations utilize the maximum pitch.

The moderation conditions for the HAC array cases are largely the same as the NCT array moderation conditions, with the exception of the insulation region. In the HAC models, this region may be filled with variable density water. From the NCT array calculations, it was determined that the neoprene has a statistically insignificant effect on the reactivity, although the results showed a negligible increase. Therefore, neoprene is included in all HAC array models. Also, it has also been established in the HAC single package and NCT array cases that reducing the water density between the fuel plates reduces the reactivity. Therefore, the water between the fuel plates is always modeled at full density.

Although it is not feasible in actual practice to push the FHEs to the center of the array if the two FHE halves are already pushed apart, both the MURR and MIT models are shifted by 0.307-in towards the center of the array, as determined in Section 6.10.5.1, *NCT Array Configuration.* Note in Figure 6.10-11 that the FHEs for both MURR and MIT are "sliced off" in the corners because such a translation is not possible without interference, and the aluminum corners of the MIT element are also "sliced off" slightly for the same reason.

6.10.6.1.1 MURR Fuel Element Models

Five calculational series are developed, as described below. Results are summarized in Table 6.10-12.

Series 1 (Cases XJ1 through XJ11): In Series 1, the water density inside and outside the FHE is modeled at the same density, which is allowed to vary between 0 and 1.0 g/cm^3. This moderation condition simulates the partial moderation effect of assuming the plastic bag that surrounds the fuel element retains water. The region between the circular and square tubes is modeled as insulation/void, and the FHE is modeled with the minimum wall thickness.

Series 2 (Cases XK1 through XK11): In Series 2, the water density inside the FHE is fixed at 1.0 g/cm^3, while the water density outside the FHE is allowed to vary between 0 and 1.0 g/cm^3. This moderation condition simulates the partial moderation effect of assuming the FHE retains water. The region between the circular and square tubes is modeled as insulation/void, and the FHE is modeled with a minimum wall thickness. The maximum reactivity increases slightly compared to Series 1, although the effect is well within statistical fluctuation.

An additional case (Case XK11) is developed in which the insulation is replaced with void for the most reactive Series 2 case (Case XK10). Comparing Cases XK10 and XK11, it is slightly more reactive to model the insulation, which is consistent with the trend in the ATR fuel analysis.

Series 3 (Cases XL1 through XL11): In Series 3, the outer insulation/void region is replaced with variable density water. There are now three regions that contain water: (1) between the circular and square tubes, (2) between FHE and circular tube, and (3) between fuel element and FHE. In this series, each of these regions is modeled with the same water density, which is allowed to vary between 0 and 1.0 g/cm^3. Reactivity is significantly lower in Series 3 compared with either Series 1 or 2.

Series 4 (Cases XM1 through XM10): In Series 4, full-density water is modeled inside the FHE, while variable density water between 0 and 1.0 g/cm^3 is modeled outside the FHE and between the inner and outer tubes. This series is less reactive than either Series 1 or 2.

Series 5 (Cases XN1 through XN11): Series 5 is a repeat of Series 2 except using a thick-walled FHE. The reactivity increases slightly when the thick-walled FHE is used.

Series 1, 2 and 5 result in similar reactivities within the statistical uncertainty of the method. Case XN9 is the most reactive MURR case, with $k_s = 0.85881$. In this case, the fuel elements are pushed to the center of the array, full-density water is modeled between the plates and inside the FHE, 0.8 g/cm^3 water is modeled outside the FHE, insulation/void is modeled between the inner and outer tubes, chlorine-free neoprene is included, and the FHE is modeled with maximum wall thickness. The maximum result is below the USL of 0.9209.

6.10.6.1.2 MIT Fuel Element Models

Five calculational series are developed, as described below. Results are summarized in Table 6.10-13.

Series 1 (Cases YJ1 through YJ11): In Series 1, the water density inside and outside the FHE is modeled at the same density, which is allowed to vary between 0 and 1.0 g/cm^3. This moderation condition simulates the partial moderation effect of assuming the plastic bag that surrounds the fuel element retains water. The region between the circular and square tubes is modeled as insulation/void, and the FHE is modeled with the minimum wall thickness.

Series 2 (Cases YK1 through YK11): In Series 2, the water density inside the FHE is fixed at 1.0 g/cm^3, while the water density outside the FHE is allowed to vary between 0 and 1.0 g/cm^3. This moderation condition simulates the partial moderation effect of assuming the FHE retains water. The region between the circular and square tubes is modeled as insulation/void, and the FHE is modeled with a minimum wall thickness. The maximum reactivity increases slightly compared to Series 1, although the effect is well within statistical fluctuation.

An additional case (Case YK11) is developed in which the insulation is replaced with void for the most reactive Series 2 case (Case YK9). Comparing Cases YK9 and YK11, it is slightly more reactive to model the insulation, which is consistent with the trend in the ATR fuel analysis.

Series 3 (Cases YL1 through YL11): In Series 3, the outer insulation/void region is replaced with variable density water. There are now three regions that contain water: (1) between the circular and square tubes, (2) between FHE and circular tube, and (3) between fuel element and FHE. In this series, each of these regions is modeled with the same water density, which is allowed to vary between 0 and 1.0 g/cm^3. Reactivity is significantly lower in Series 3 compared with either Series 1 or 2.

Series 4 (Cases YM1 through YM10): In Series 4, full-density water is modeled inside the FHE, while variable density water between 0 and 1.0 g/cm^3 is modeled outside the FHE and between the inner and outer tubes. This series is less reactive than either Series 1 or 2.

Series 5 (Cases YN1 through YN11): Series 5 is a repeat of Series 2 except using a thick-walled FHE. The reactivity decreases slightly when the thick-walled FHE is used, although the decrease is within statistical fluctuation.

Series 1, 2 and 5 result in similar reactivities within the statistical uncertainty of the method. Case YK9 is the most reactive MIT case, with $k_s = 0.67309$. In this case, the fuel elements are pushed to the center of the array, full-density water is modeled between the plates and inside the FHE, 0.8 g/cm^3 water is modeled outside the FHE, insulation/void is modeled between the inner and outer tubes, chlorine-free neoprene is included, and the FHE is modeled with minimum wall thickness. The maximum result is below the USL of 0.9209.

6.10.6.2 HAC Array Results

Following are the tabulated results for the HAC array cases. The most reactive configuration in each series is listed in boldface.

Table 6.10-12 – MURR HAC Array Results

Case ID	Filename	Water Density Between Tubes (g/cm^3)	Water Density Inside FHE (g/cm^3)	Water Density Outside FHE (g/cm^3)	k_{eff}	σ	k_s ($k+2\sigma$)
Series 1: Insulation modeled, full-density water between plates, variable density water as indicated.							
XJ1	HA_MURR2_NW000	0	0	0	0.76355	0.00115	0.76585
XJ2	HA_MURR2_NW010	0	0.1	0.1	0.78430	0.00122	0.78674
XJ3	HA_MURR2_NW020	0	0.2	0.2	0.80290	0.00111	0.80512
XJ4	HA_MURR2_NW030	0	0.3	0.3	0.81874	0.00124	0.82122
XJ5	HA_MURR2_NW040	0	0.4	0.4	0.83311	0.00127	0.83565
XJ6	HA_MURR2_NW050	0	0.5	0.5	0.84140	0.00122	0.84384
XJ7	HA_MURR2_NW060	0	0.6	0.6	0.84544	0.00124	0.84792
XJ8	HA_MURR2_NW070	0	0.7	0.7	0.85035	0.00118	0.85271
XJ9	HA_MURR2_NW080	0	0.8	0.8	0.84998	0.00127	0.85252
XJ10	**HA_MURR2_NW090**	**0**	**0.9**	**0.9**	**0.85379**	**0.00128**	**0.85635**
XJ11	HA_MURR2_NW100	0	1.0	1.0	0.84975	0.00120	0.85215
Series 2: Insulation modeled, full-density water between plates and inside FHE, variable density water as indicated.							
XK1	HA_MURR2_FNW000	0	1.0	0	0.83610	0.00115	0.83840
XK2	HA_MURR2_FNW010	0	1.0	0.1	0.84001	0.00125	0.84251
XK3	HA_MURR2_FNW020	0	1.0	0.2	0.84152	0.00115	0.84382
XK4	HA_MURR2_FNW030	0	1.0	0.3	0.84875	0.00130	0.85135
XK5	HA_MURR2_FNW040	0	1.0	0.4	0.84946	0.00127	0.85200
XK6	HA_MURR2_FNW050	0	1.0	0.5	0.84850	0.00119	0.85088
XK7	HA_MURR2_FNW060	0	1.0	0.6	0.85141	0.00118	0.85377
XK8	HA_MURR2_FNW070	0	1.0	0.7	0.85076	0.00117	0.85310
XK9	HA_MURR2_FNW080	0	1.0	0.8	0.85054	0.00127	0.85308
XK10	**HA_MURR2_FNW090**	**0**	**1.0**	**0.9**	**0.85391**	**0.00125**	**0.85641**
XJ11	HA_MURR2_NW100	0	1.0	1.0	0.84975	0.0012	0.85215
XK11	HA_MURR2_FNW090X	0	1.0	0.9	0.84922	0.00132	0.85186
Series 3: Insulation not modeled, variable density water as indicated.							
XL1	HA_MURR2_ANW000	0	0	0	0.75710	0.00115	0.75940
XL2	HA_MURR2_ANW010	0.1	0.1	0.1	0.78773	0.00117	0.79007
XL3	**HA_MURR2_ANW020**	**0.2**	**0.2**	**0.2**	**0.78883**	**0.00124**	**0.79131**
XL4	HA_MURR2_ANW030	0.3	0.3	0.3	0.77894	0.00115	0.78124
XL5	HA_MURR2_ANW040	0.4	0.4	0.4	0.75950	0.00114	0.76178
XL6	HA_MURR2_ANW050	0.5	0.5	0.5	0.74010	0.00119	0.74248
XL7	HA_MURR2_ANW060	0.6	0.6	0.6	0.72381	0.00113	0.72607
XL8	HA_MURR2_ANW070	0.7	0.7	0.7	0.70323	0.00130	0.70583
XL9	HA_MURR2_ANW080	0.8	0.8	0.8	0.69154	0.00108	0.69370
XL10	HA_MURR2_ANW090	0.9	0.9	0.9	0.67881	0.00115	0.68111
XL11	HA_MURR2_ANW100	1.0	1.0	1.0	0.67207	0.00113	0.67433

(continued)

Table 6.10-12 – MURR HAC Array Results (concluded)

Case ID	Filename	Water Density Between Tubes (g/cm^3)	Water Density Inside FHE (g/cm^3)	Water Density Outside FHE (g/cm^3)	k_{eff}	σ	k_s ($k+2\sigma$)
Series 4: Insulation not modeled, variable density water as indicated.							
XM1	**HA_MURR2_IFNW000**	**0**	**1.0**	**0**	**0.83196**	**0.00121**	**0.83438**
XM2	HA_MURR2_IFNW010	0.1	1.0	0.1	0.82347	0.00123	0.82593
XM3	HA_MURR2_IFNW020	0.2	1.0	0.2	0.80575	0.00127	0.80829
XM4	HA_MURR2_IFNW030	0.3	1.0	0.3	0.78652	0.00109	0.78870
XM5	HA_MURR2_IFNW040	0.4	1.0	0.4	0.76597	0.00108	0.76813
XM6	HA_MURR2_IFNW050	0.5	1.0	0.5	0.74360	0.00124	0.74608
XM7	HA_MURR2_IFNW060	0.6	1.0	0.6	0.72740	0.00119	0.72978
XM8	HA_MURR2_IFNW070	0.7	1.0	0.7	0.70952	0.00112	0.71176
XM9	HA_MURR2_IFNW080	0.8	1.0	0.8	0.69669	0.00115	0.69899
XM10	HA_MURR2_IFNW090	0.9	1.0	0.9	0.68144	0.00119	0.68382
XL11	HA_MURR2_ANW100	1.0	1.0	1.0	0.67207	0.00113	0.67433
Series 5: Repeat of Series 2 with thick-walled FHE.							
XN1	HA_MURR2_TFNW000	0	1.0	0	0.83999	0.00136	0.84271
XN2	HA_MURR2_TFNW010	0	1.0	0.1	0.84169	0.00120	0.84409
XN3	HA_MURR2_TFNW020	0	1.0	0.2	0.84521	0.00115	0.84751
XN4	HA_MURR2_TFNW030	0	1.0	0.3	0.84875	0.00131	0.85137
XN5	HA_MURR2_TFNW040	0	1.0	0.4	0.84997	0.00117	0.85231
XN6	HA_MURR2_TFNW050	0	1.0	0.5	0.85368	0.00128	0.85624
XN7	HA_MURR2_TFNW060	0	1.0	0.6	0.85219	0.00115	0.85449
XN8	HA_MURR2_TFNW070	0	1.0	0.7	0.85204	0.00121	0.85446
XN9	**HA_MURR2_TFNW080**	**0**	**1.0**	**0.8**	**0.85621**	**0.00130**	**0.85881**
XN10	HA_MURR2_TFNW090	0	1.0	0.9	0.85319	0.00126	0.85571
XN11	HA_MURR2_TFNW100	0	1.0	1.0	0.85277	0.00121	0.85519

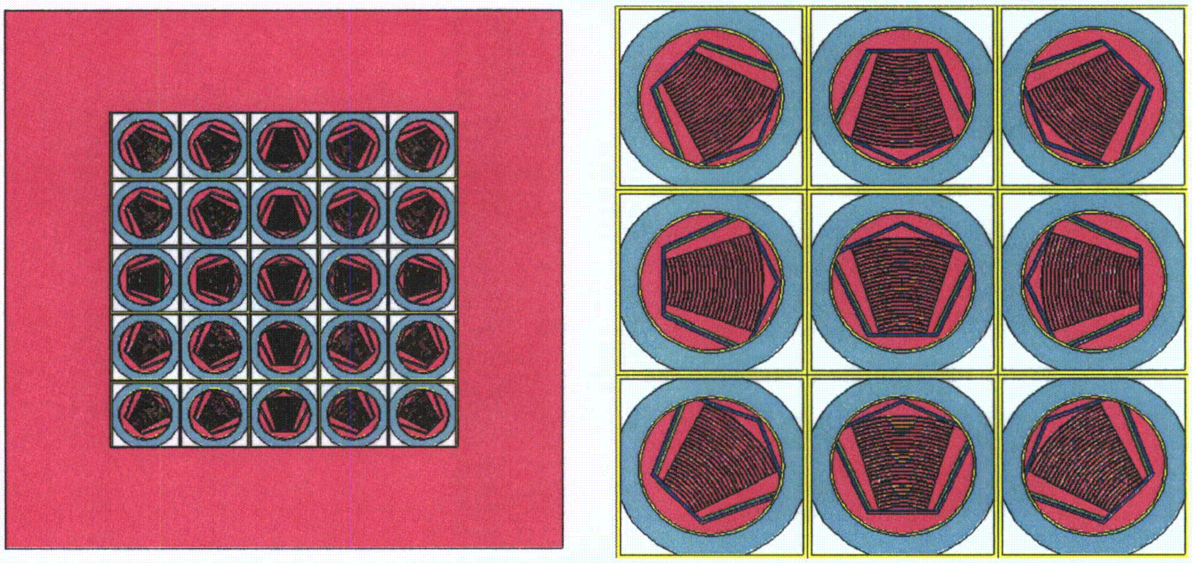
Table 6.10-13 – MIT HAC Array Results

Case ID	Filename	Water Density Between Tubes (g/cm^3)	Water Density Inside FHE (g/cm^3)	Water Density Outside FHE (g/cm^3)	k_{eff}	σ	k_s $(k+2\sigma)$
Series 1: Insulation modeled, full-density water between plates, variable density water as indicated.							
YJ1	HA_MIT_NW000	0	0	0	0.53667	0.00092	0.53851
YJ2	HA_MIT_NW010	0	0.1	0.1	0.56904	0.00111	0.57126
YJ3	HA_MIT_NW020	0	0.2	0.2	0.59837	0.00116	0.60069
YJ4	HA_MIT_NW030	0	0.3	0.3	0.62139	0.00122	0.62383
YJ5	HA_MIT_NW040	0	0.4	0.4	0.63737	0.00108	0.63953
YJ6	HA_MIT_NW050	0	0.5	0.5	0.65014	0.00109	0.65232
YJ7	HA_MIT_NW060	0	0.6	0.6	0.65850	0.00122	0.66094
YJ8	HA_MIT_NW070	0	0.7	0.7	0.66668	0.00115	0.66898
YJ9	**HA_MIT_NW080**	**0**	**0.8**	**0.8**	**0.67043**	**0.00121**	**0.67285**
YJ10	HA_MIT_NW090	0	0.9	0.9	0.67026	0.00112	0.67250
YJ11	HA_MIT_NW100	0	1.0	1.0	0.67058	0.00104	0.67266
Series 2: Insulation modeled, full-density water between plates and inside FHE, variable density water as indicated.							
YK1	HA_MIT_FNW000	0	1.0	0	0.60486	0.00110	0.60706
YK2	HA_MIT_FNW010	0	1.0	0.1	0.62101	0.00117	0.62335
YK3	HA_MIT_FNW020	0	1.0	0.2	0.63436	0.00121	0.63678
YK4	HA_MIT_FNW030	0	1.0	0.3	0.64759	0.00106	0.64971
YK5	HA_MIT_FNW040	0	1.0	0.4	0.65646	0.00117	0.65880
YK6	HA_MIT_FNW050	0	1.0	0.5	0.66078	0.00117	0.66312
YK7	HA_MIT_FNW060	0	1.0	0.6	0.66656	0.00107	0.66870
YK8	HA_MIT_FNW070	0	1.0	0.7	0.67022	0.00114	0.67250
YK9	**HA_MIT_FNW080**	**0**	**1.0**	**0.8**	**0.67105**	**0.00102**	**0.67309**
YK10	HA_MIT_FNW090	0	1.0	0.9	0.66898	0.00113	0.67124
YJ11	HA_MIT_NW100	0	1.0	1.0	0.67058	0.00104	0.67266
YK11	HA_MIT_FNW080X	0	1.0	0.9	0.66684	0.00110	0.66904
Series 3: Insulation not modeled, variable density water as indicated.							
YL1	HA_MIT_ANW000	0	0	0	0.53173	0.00103	0.53379
YL2	HA_MIT_ANW010	0.1	0.1	0.1	0.58121	0.00100	0.58321
YL3	HA_MIT_ANW020	0.2	0.2	0.2	0.59902	0.00119	0.60140
YL4	**HA_MIT_ANW030**	**0.3**	**0.3**	**0.3**	**0.60054**	**0.00105**	**0.60264**
YL5	HA_MIT_ANW040	0.4	0.4	0.4	0.59003	0.00116	0.59235
YL6	HA_MIT_ANW050	0.5	0.5	0.5	0.57811	0.00109	0.58029
YL7	HA_MIT_ANW060	0.6	0.6	0.6	0.56624	0.00114	0.56852
YL8	HA_MIT_ANW070	0.7	0.7	0.7	0.55438	0.00107	0.55652
YL9	HA_MIT_ANW080	0.8	0.8	0.8	0.54409	0.00114	0.54637
YL10	HA_MIT_ANW090	0.9	0.9	0.9	0.53935	0.00105	0.54145
YL11	HA_MIT_ANW100	1.0	1.0	1.0	0.53078	0.00104	0.53286

(continued)

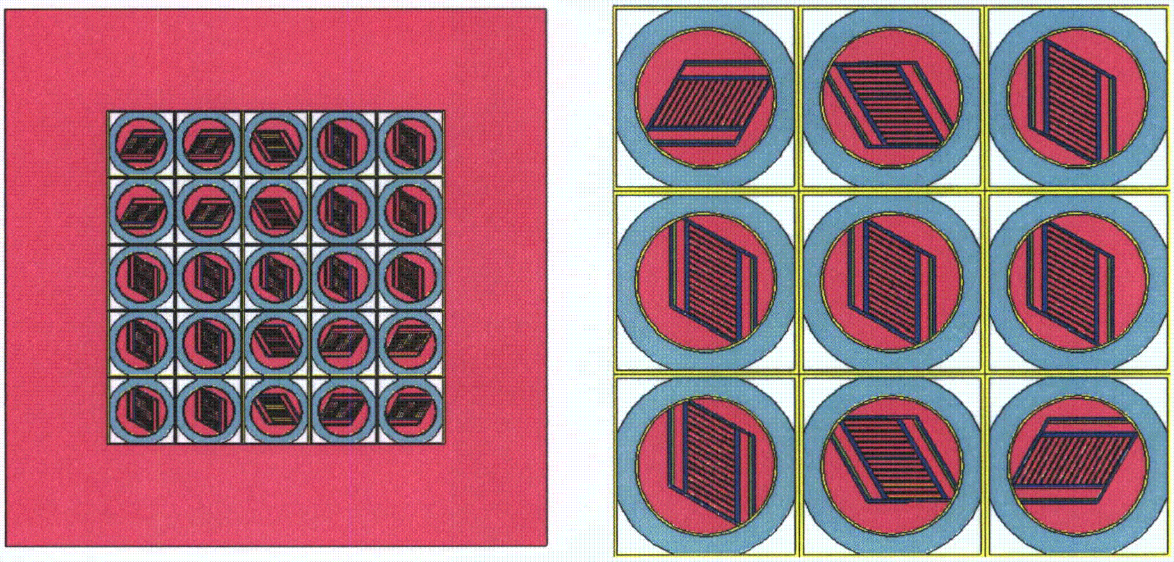
Table 6.10-13 – MIT HAC Array Results (concluded)

Case ID	Filename	Water Density Between Tubes (g/cm^3)	Water Density Inside FHE (g/cm^3)	Water Density Outside FHE (g/cm^3)	k_{eff}	σ	k_s (k+2σ)
Series 4: Insulation not modeled, variable density water as indicated.							
YM1	HA_MIT_IFNW000	0	1.0	0	0.59996	0.00108	0.60212
YM2	**HA_MIT_IFNW010**	**0.1**	**1.0**	**0.1**	**0.61992**	**0.00112**	**0.62216**
YM3	HA_MIT_IFNW020	0.2	1.0	0.2	0.61899	0.00117	0.62133
YM4	HA_MIT_IFNW030	0.3	1.0	0.3	0.61130	0.00107	0.61344
YM5	HA_MIT_IFNW040	0.4	1.0	0.4	0.59725	0.00106	0.59937
YM6	HA_MIT_IFNW050	0.5	1.0	0.5	0.58253	0.00113	0.58479
YM7	HA_MIT_IFNW060	0.6	1.0	0.6	0.56935	0.00115	0.57165
YM8	HA_MIT_IFNW070	0.7	1.0	0.7	0.56002	0.00118	0.56238
YM9	HA_MIT_IFNW080	0.8	1.0	0.8	0.54870	0.00112	0.55094
YM10	HA_MIT_IFNW090	0.9	1.0	0.9	0.54119	0.00095	0.54309
YL11	HA_MIT_ANW100	1.0	1.0	1.0	0.53078	0.00104	0.53286
Series 5: Repeat of Series 2 with thick-walled FHE.							
YN1	HA_MIT_TFNW000	0	1.0	0	0.61405	0.00116	0.61637
YN2	HA_MIT_TFNW010	0	1.0	0.1	0.62418	0.00114	0.62646
YN3	HA_MIT_TFNW020	0	1.0	0.2	0.63652	0.00110	0.63872
YN4	HA_MIT_TFNW030	0	1.0	0.3	0.64631	0.00101	0.64833
YN5	HA_MIT_TFNW040	0	1.0	0.4	0.65197	0.00108	0.65413
YN6	HA_MIT_TFNW050	0	1.0	0.5	0.65994	0.00114	0.66222
YN7	HA_MIT_TFNW060	0	1.0	0.6	0.66467	0.00118	0.66703
YN8	HA_MIT_TFNW070	0	1.0	0.7	0.66785	0.00120	0.67025
YN9	HA_MIT_TFNW080	0	1.0	0.8	0.66872	0.00123	0.67118
YN10	**HA_MIT_TFNW090**	**0**	**1.0**	**0.9**	**0.66920**	**0.00111**	**0.67142**
YN11	HA_MIT_TFNW100	0	1.0	1.0	0.66847	0.00122	0.67091



MURR Full view

MURR Close-up



MIT Full view

MIT Close-up

Figure 6.10-11 – MURR/MIT HAC Array Geometry

6.10.7 Fissile Material Packages for Air Transport

This section is not applicable.

6.10.8 Benchmark Evaluations

MURR and MIT fuel are both high-enriched aluminum plate-type fuel, similar to ATR fuel. Therefore, the benchmarking evaluation performed for the ATR fuel in Section 6.8, *Benchmark Evaluations*, is applicable to the current analysis, and the USL is 0.9209. The Monte Carlo computer program MCNP5 v1.30 was utilized in the benchmark analysis. MCNP has been used extensively in criticality evaluations for several decades and is considered a standard in the industry.

Five parameters were selected for the benchmark evaluation: (1) energy of the average neutron lethargy causing fission (EALF), (2) U-235 number density, (3) channel width, (4) H/U-235 atom ratio, and (5) pitch. The range of applicability of these parameters for the benchmarks utilized is summarized in Table 6.8-2. In the following sections, the range of applicability of the benchmarks is compared with the MURR and MIT criticality analysis.

6.10.8.1 Energy of the Average neutron Lethargy causing Fission (EALF)

Range of Applicability, MURR models: All of the single package models and most of the NCT and HAC array models fall within the range of the applicability. The EALF of the most reactive MURR fuel element model (Case XN9) has an EALF of 9.26E-08 MeV, which is within the range of applicability. Models with significantly more void spaces or low water densities sometimes exceed the range of applicability (maximum EALF = 2.03E-07 MeV for Case XE1), although these cases are not the most reactive. Therefore, the EALF of the most reactive models is acceptably within the range of applicability of the benchmarks.

Range of Applicability, MIT models: All of the single package models and most of the NCT and HAC array models fall within the range of the applicability. The EALF of the most reactive MIT fuel element model (Case YK9) has an EALF of 8.70E-08 MeV, which is within the range of applicability. Models with significantly more void spaces or low water densities sometimes exceed the range of applicability (maximum EALF = 3.30E-07 MeV for Case YE1), although these cases are not the most reactive. Therefore, the EALF of the most reactive models is acceptably within the range of applicability of the benchmarks.

6.10.8.2 U-235 Number Density

The U-235 number density is 3.61E-03 atom/b-cm in the MURR models and 3.68E-03 atom/b-cm in the MIT models. These number densities are within the range of applicability.

6.10.8.3 Channel Width

The maximum modeled NCT channel width is 0.092-in in the MURR models and 0.116-in in the MIT models. In the HAC models, in which the pitch is allowed to expand, the maximum channel width is 0.125-in in the MURR models and 0.176-in in the MIT models. All of these values exceed the maximum channel width of 0.078-in of the benchmark experiments. However, this parameter was artificially maximized in order to maximize model reactivity. As the channel width is directly related to system moderation, the acceptability of the EALF indicator demonstrates that MCNP is performing acceptably for thermal conditions. Therefore, this parameter is considered to be acceptable.

6.10.8.4 H/U-235 Atom Ratio

The H/U-235 atom ratio is used as the fourth trending parameter for the benchmark cases. The H/U-235 atom ratio is defined here as the ratio of hydrogen atoms to U-235 atoms in a unit cell. This parameter is computed by the following equation:

NH*C/(NU235*M)

where,

NH is the hydrogen number density

C is the channel width

NU235 is the U-235 number density

M is the fuel meat width

Range of Applicability, MURR models: The H/U-235 atom ratio may be computed as:

NCT: 6.687E-02*0.088/(3.6147E-03*0.02) = 81.4

NCT: 6.687E-02*0.092/(3.6147E-03*0.02) = 85.1

HAC: 6.687E-02*0.125/(3.6147E-03*0.02) = 115.6

Therefore, H/U-235 of the MURR cases is acceptably within the range of applicability of the benchmarks.

Range of Applicability, MIT models: The H/U-235 atom ratio may be computed as:

NCT: 6.687E-02*0.094/(3.6835E-03*0.03) = 56.9

NCT: 6.687E-02*0.116/(3.6835E-03*0.03) = 70.2

HAC: 6.687E-02*0.176/(3.6835E-03*0.03) = 106.5

The minimum H/U-235 atom ratio of the benchmark models is 65.1. Therefore, this parameter is slightly outside the range of the benchmark experiments for the 0.094-in channel width NCT cases, although this parameter is in range for the more reactive 0.116-in channel width NCT cases. Therefore, this parameter is considered to be acceptable for the NCT cases. For the HAC cases, which bound the NCT cases, this parameter is acceptably within the range of applicability of the benchmarks.

6.10.8.5 Pitch

The NCT pitch is fixed at 0.13-in in the MURR models and 0.16-in in the MIT models. In the HAC models, in which the pitch is allowed to expand, the maximum pitch is 0.167-in in the MURR models and 0.24-in in the MIT models. The maximum pitch of the benchmark models is 0.128-in, so the pitch in the models exceeds the range of the benchmarks, particularly for the

HAC cases. However, this parameter was artificially maximized in order to maximize model reactivity. As the pitch is directly related to system moderation, the acceptability of the EALF indicator demonstrates that MCNP is performing acceptably for thermal conditions. Therefore, this parameter is considered to be acceptable.

6.10.9 Sample Input Files

A sample input file is provided for the most reactive MURR and MIT cases.

MURR Case XN9 (HA_MURR2_TFNW080)

```
MURR
999     0      -320:321:-322:323:-324:325               imp:n=0
900     0      310 -311 312 -313 24 -25     fill=3      imp:n=1
901     2 -1.0 (311:-310:313:-312:-24:25) 320 -321 322 -323 324 -325  imp:n=1
c
c       Universe 1: MURR Fuel Element (infinitely long)
c
10       10 5.4439E-02 52 -53 -16 -15                       u=1 imp:n=1 $
plate 1
11       3 -2.7        (-52:53:16:15) 51 -54 -7 -8          u=1 imp:n=1
12       10 5.4439E-02 401 -402 -406 -407                   u=1 imp:n=1 $
plate 2
13       3 -2.7        (-401:402:406:407) 400 -403 -404 -405 u=1 imp:n=1
14       10 5.4439E-02 411 -412 -416 -417                   u=1 imp:n=1 $
plate 3
15       3 -2.7        (-411:412:416:417) 410 -413 -414 -415 u=1 imp:n=1
16       10 5.4439E-02 421 -422 -426 -427                   u=1 imp:n=1 $
plate 4
17       3 -2.7        (-421:422:426:427) 420 -423 -424 -425 u=1 imp:n=1
18       10 5.4439E-02 431 -432 -436 -437                   u=1 imp:n=1 $
plate 5
19       3 -2.7        (-431:432:436:437) 430 -433 -434 -435 u=1 imp:n=1
20       10 5.4439E-02 441 -442 -446 -447                   u=1 imp:n=1 $
plate 6
21       3 -2.7        (-441:442:446:447) 440 -443 -444 -445 u=1 imp:n=1
22       10 5.4439E-02 451 -452 -456 -457                   u=1 imp:n=1 $
plate 7
23       3 -2.7        (-451:452:456:457) 450 -453 -454 -455 u=1 imp:n=1
24       10 5.4439E-02 461 -462 -466 -467                   u=1 imp:n=1 $
plate 8
25       3 -2.7        (-461:462:466:467) 460 -463 -464 -465 u=1 imp:n=1
26       10 5.4439E-02 471 -472 -476 -477                   u=1 imp:n=1 $
plate 9
27       3 -2.7        (-471:472:476:477) 470 -473 -474 -475 u=1 imp:n=1
28       10 5.4439E-02 481 -482 -486 -487                   u=1 imp:n=1 $
plate 10
29       3 -2.7        (-481:482:486:487) 480 -483 -484 -485 u=1 imp:n=1
30       10 5.4439E-02 491 -492 -496 -497                   u=1 imp:n=1 $
plate 11
31       3 -2.7        (-491:492:496:497) 490 -493 -494 -495 u=1 imp:n=1
32       10 5.4439E-02 501 -502 -506 -507                   u=1 imp:n=1 $
plate 12
33       3 -2.7        (-501:502:506:507) 500 -503 -504 -505 u=1 imp:n=1
34       10 5.4439E-02 511 -512 -516 -517                   u=1 imp:n=1 $
plate 13
35       3 -2.7        (-511:512:516:517) 510 -513 -514 -515 u=1 imp:n=1
```

```
36       10 5.4439E-02 521 -522 -526 -527                    u=1 imp:n=1 $
plate 14
37       3 -2.7        (-521:522:526:527) 520 -523 -524 -525 u=1 imp:n=1
38       10 5.4439E-02 531 -532 -536 -537                    u=1 imp:n=1 $
plate 15
39       3 -2.7        (-531:532:536:537) 530 -533 -534 -535 u=1 imp:n=1
40       10 5.4439E-02 541 -542 -546 -547                    u=1 imp:n=1 $
plate 16
41       3 -2.7        (-541:542:546:547) 540 -543 -544 -545 u=1 imp:n=1
42       10 5.4439E-02 551 -552 -556 -557                    u=1 imp:n=1 $
plate 17
43       3 -2.7        (-551:552:556:557) 550 -553 -554 -555 u=1 imp:n=1
44       10 5.4439E-02 561 -562 -566 -567                    u=1 imp:n=1 $
plate 18
45       3 -2.7        (-561:562:566:567) 560 -563 -564 -565 u=1 imp:n=1
46       10 5.4439E-02 571 -572 -576 -577                    u=1 imp:n=1 $
plate 19
47       3 -2.7        (-571:572:576:577) 570 -573 -574 -575 u=1 imp:n=1
48       10 5.4439E-02 581 -582 -586 -587                    u=1 imp:n=1 $
plate 20
49       3 -2.7        (-581:582:586:587) 580 -583 -584 -585 u=1 imp:n=1
50       10 5.4439E-02 591 -592 -596 -597                    u=1 imp:n=1 $
plate 21
51       3 -2.7        (-591:592:596:597) 590 -593 -594 -595 u=1 imp:n=1
52       10 5.4439E-02 601 -602 -606 -607                    u=1 imp:n=1 $
plate 22
53       3 -2.7        (-601:602:606:607) 600 -603 -604 -605 u=1 imp:n=1
54       10 5.4439E-02 611 -612 -616 -617                    u=1 imp:n=1 $
plate 23
55       3 -2.7        (-611:612:616:617) 610 -613 -614 -615 u=1 imp:n=1
56       10 5.4439E-02 621 -622 -626 -627                    u=1 imp:n=1 $
plate 24
57       3 -2.7        (-621:622:626:627) 620 -623 -624 -625 u=1 imp:n=1
150      2 -1.0   (-51:54:7:8)        (-400:403:404:405) (-410:413:414:415)
                  (-420:423:424:425) (-430:433:434:435) (-440:443:444:445)
                  (-450:453:454:455) (-460:463:464:465) (-470:473:474:475)
                  (-480:483:484:485) (-490:493:494:495) (-500:503:504:505)
                  (-510:513:514:515) (-520:523:524:525) (-530:533:534:535)
                  (-540:543:544:545) (-550:553:554:555) (-560:563:564:565)
                  (-570:573:574:575) (-580:583:584:585) (-590:593:594:595)
                  (-600:603:604:605) (-610:613:614:615) (-620:623:624:625)
                  u=1 imp:n=1
c
c       Universe 19: MURR with FHE
c
200      0         -232 -233 212 213 214 -234 fill=1(1) u=19 imp:n=1
201      5 -0.737  230 -210 212 214              u=19 imp:n=1 $ right
neoprene
202      5 -0.737  231 -211 213 214              u=19 imp:n=1 $ left neoprene
203      2 -1.0    213 212 234                   u=19 imp:n=1 $ top water
outside bag
204      2 -1.0    -230 232 214 212              u=19 imp:n=1 $ side water
outside bag
205      2 -1.0    -231 233 214 213              u=19 imp:n=1 $ side water
outside bag
206      3 -2.7    (210:211:-212:-213:-214) -220 -221 222 223 224 u=19 imp:n=1
$ FHE
207      2 -0.8     220:221:-222:-223:-224       u=19 imp:n=1 $ water
c
c       Universe 20: MURR with pipe (center)
```

```
c
210     0           -200 fill=19                u=20 imp:n=1
211     4 -7.94     200 -201                    u=20 imp:n=1 $ pipe
212     6 -0.096    201 -203 250 -251 252 -253  u=20 imp:n=1 $ insulation
213     0           203 250 -251 252 -253       u=20 imp:n=1 $ insulation to
tube
214     4 -7.94     -250:251:-252:253           u=20 imp:n=1 $ tube to inf
c
c       Universe 21: MURR with pipe (down)
c
220     0           -200 fill=19(2)             u=21 imp:n=1
221     4 -7.94     200 -201                    u=21 imp:n=1 $ pipe
222     6 -0.096    201 -203 250 -251 252 -253  u=21 imp:n=1 $ insulation
223     0           203 250 -251 252 -253       u=21 imp:n=1 $ insulation to
tube
224     4 -7.94     -250:251:-252:253           u=21 imp:n=1 $ tube to inf
c
c       Universe 22: MURR with pipe (up)
c
230     0           -200 fill=19(3)             u=22 imp:n=1
231     4 -7.94     200 -201                    u=22 imp:n=1 $ pipe
232     6 -0.096    201 -203 250 -251 252 -253  u=22 imp:n=1 $ insulation
233     0           203 250 -251 252 -253       u=22 imp:n=1 $ insulation to
tube
234     4 -7.94     -250:251:-252:253           u=22 imp:n=1 $ tube to inf
c
c       Universe 23: MURR with pipe (right)
c
240     0           -200 fill=19(4)             u=23 imp:n=1
241     4 -7.94     200 -201                    u=23 imp:n=1 $ pipe
242     6 -0.096    201 -203 250 -251 252 -253  u=23 imp:n=1 $ insulation
243     0           203 250 -251 252 -253       u=23 imp:n=1 $ insulation to
tube
244     4 -7.94     -250:251:-252:253           u=23 imp:n=1 $ tube to inf
c
c       Universe 24: MURR with pipe (left)
c
250     0           -200 fill=19(5)             u=24 imp:n=1
251     4 -7.94     200 -201                    u=24 imp:n=1 $ pipe
252     6 -0.096    201 -203 250 -251 252 -253  u=24 imp:n=1 $ insulation
253     0           203 250 -251 252 -253       u=24 imp:n=1 $ insulation to
tube
254     4 -7.94     -250:251:-252:253           u=24 imp:n=1 $ tube to inf
c
c       Universe 25: MURR with pipe (up right)
c
260     0           -200 fill=19(6)             u=25 imp:n=1
261     4 -7.94     200 -201                    u=25 imp:n=1 $ pipe
262     6 -0.096    201 -203 250 -251 252 -253  u=25 imp:n=1 $ insulation
263     0           203 250 -251 252 -253       u=25 imp:n=1 $ insulation to
tube
264     4 -7.94     -250:251:-252:253           u=25 imp:n=1 $ tube to inf
c
c       Universe 26: MURR with pipe (up left)
c
270     0           -200 fill=19(7)             u=26 imp:n=1
271     4 -7.94     200 -201                    u=26 imp:n=1 $ pipe
272     6 -0.096    201 -203 250 -251 252 -253  u=26 imp:n=1 $ insulation
273     0           203 250 -251 252 -253       u=26 imp:n=1 $ insulation to
tube
```

```
274     4 -7.94     -250:251:-252:253           u=26 imp:n=1 $ tube to inf
c
c       Universe 27: MURR with pipe (down right)
c
280     0           -200 fill=19(8)             u=27 imp:n=1
281     4 -7.94     200 -201                    u=27 imp:n=1 $ pipe
282     6 -0.096    201 -203 250 -251 252 -253  u=27 imp:n=1 $ insulation
283     0           203 250 -251 252 -253       u=27 imp:n=1 $ insulation to
tube
284     4 -7.94     -250:251:-252:253           u=27 imp:n=1 $ tube to inf
c
c       Universe 28: MURR with pipe (down left)
c
290     0           -200 fill=19(9)             u=28 imp:n=1
291     4 -7.94     200 -201                    u=28 imp:n=1 $ pipe
292     6 -0.096    201 -203 250 -251 252 -253  u=28 imp:n=1 $ insulation
293     0           203 250 -251 252 -253       u=28 imp:n=1 $ insulation to
tube
294     4 -7.94     -250:251:-252:253           u=28 imp:n=1 $ tube to inf
c
c       Universe 3: Array of Packages
c
300   0    -300 301 -302 303 imp:n=1 u=3 lat=1 fill=-2:2 -2:2 0:0
             25 25 22 26 26
             25 25 22 26 26
             23 23 20 24 24
             27 27 21 28 28
             27 27 21 28 28

c 5       p  2.4142136 -1 0 -0.13275   $ right Al outer
c 6       p -2.4142136 -1 0 -0.13275   $ left Al outer
7       p  2.4142136 -1 0 -1.09516   $ right Al inner
8       p -2.4142136 -1 0 -1.09516   $ left Al inner
c 9       cz 6.858                     $ Al boundary
c 10      cz 14.884                    $ Al boundary
c
15      p  2.4142136 -1 0 -1.39997   $ plate meat boundary
16      p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
24      pz -30.48                    $ bottom of fuel
25      pz  30.48                    $ top of fuel (24")
c
51      cz 7.0460 $ fuel plate 1
52      cz 7.0739
53      cz 7.1247
54      cz 7.1526
c
400 22    cz 7.3762 $ fuel plate 2
401 22    cz 7.4041
402 22    cz 7.4549
403 22    cz 7.4828
404 22    p  2.4142136 -1 0 -1.09516   $ right Al inner
405 22    p -2.4142136 -1 0 -1.09516   $ left Al inner
406 22    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
407 22    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
410 23  cz 7.7064 $ fuel plate 3
411 23  cz 7.7343
412 23  cz 7.7851
413 23  cz 7.8130
```

```
414 23    p  2.4142136 -1 0 -1.09516   $ right Al inner
415 23    p -2.4142136 -1 0 -1.09516   $ left Al inner
416 23    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
417 23    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
420 24  cz 8.0366 $ fuel plate 4
421 24  cz 8.0645
422 24  cz 8.1153
423 24  cz 8.1432
424 24    p  2.4142136 -1 0 -1.09516   $ right Al inner
425 24    p -2.4142136 -1 0 -1.09516   $ left Al inner
426 24    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
427 24    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
430 25  cz 8.3668 $ fuel plate 5
431 25  cz 8.3947
432 25  cz 8.4455
433 25  cz 8.4734
434 25    p  2.4142136 -1 0 -1.09516   $ right Al inner
435 25    p -2.4142136 -1 0 -1.09516   $ left Al inner
436 25    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
437 25    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
440 26  cz 8.6970 $ fuel plate 6
441 26  cz 8.7249
442 26  cz 8.7757
443 26  cz 8.8036
444 26    p  2.4142136 -1 0 -1.09516   $ right Al inner
445 26    p -2.4142136 -1 0 -1.09516   $ left Al inner
446 26    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
447 26    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
450 27  cz 9.0272 $ fuel plate 7
451 27  cz 9.0551
452 27  cz 9.1059
453 27  cz 9.1338
454 27    p  2.4142136 -1 0 -1.09516   $ right Al inner
455 27    p -2.4142136 -1 0 -1.09516   $ left Al inner
456 27    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
457 27    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
460 28  cz 9.3574 $ fuel plate 8
461 28  cz 9.3853
462 28  cz 9.4361
463 28  cz 9.4640
464 28    p  2.4142136 -1 0 -1.09516   $ right Al inner
465 28    p -2.4142136 -1 0 -1.09516   $ left Al inner
466 28    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
467 28    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
470 29  cz 9.6876 $ fuel plate 9
471 29  cz 9.7155
472 29  cz 9.7663
473 29  cz 9.7942
474 29    p  2.4142136 -1 0 -1.09516   $ right Al inner
475 29    p -2.4142136 -1 0 -1.09516   $ left Al inner
476 29    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
477 29    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
480 30  cz 10.0178 $ fuel plate 10
```

```
481 30  cz 10.0457
482 30  cz 10.0965
483 30  cz 10.1244
484 30    p  2.4142136 -1 0 -1.09516   $ right Al inner
485 30    p -2.4142136 -1 0 -1.09516   $ left Al inner
486 30    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
487 30    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
490 31  cz 10.3480 $ fuel plate 11
491 31  cz 10.3759
492 31  cz 10.4267
493 31  cz 10.4546
494 31    p  2.4142136 -1 0 -1.09516   $ right Al inner
495 31    p -2.4142136 -1 0 -1.09516   $ left Al inner
496 31    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
497 31    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
500 32  cz 10.6782 $ fuel plate 12
501 32  cz 10.7061
502 32  cz 10.7569
503 32  cz 10.7848
504 32    p  2.4142136 -1 0 -1.09516   $ right Al inner
505 32    p -2.4142136 -1 0 -1.09516   $ left Al inner
506 32    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
507 32    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
510 33  cz 11.0084 $ fuel plate 13
511 33  cz 11.0363
512 33  cz 11.0871
513 33  cz 11.1150
514 33    p  2.4142136 -1 0 -1.09516   $ right Al inner
515 33    p -2.4142136 -1 0 -1.09516   $ left Al inner
516 33    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
517 33    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
520 34  cz 11.3386 $ fuel plate 14
521 34  cz 11.3665
522 34  cz 11.4173
523 34  cz 11.4452
524 34    p  2.4142136 -1 0 -1.09516   $ right Al inner
525 34    p -2.4142136 -1 0 -1.09516   $ left Al inner
526 34    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
527 34    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
530 35  cz 11.6688 $ fuel plate 15
531 35  cz 11.6967
532 35  cz 11.7475
533 35  cz 11.7754
534 35    p  2.4142136 -1 0 -1.09516   $ right Al inner
535 35    p -2.4142136 -1 0 -1.09516   $ left Al inner
536 35    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
537 35    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
540 36  cz 11.9990 $ fuel plate 16
541 36  cz 12.0269
542 36  cz 12.0777
543 36  cz 12.1056
544 36    p  2.4142136 -1 0 -1.09516   $ right Al inner
545 36    p -2.4142136 -1 0 -1.09516   $ left Al inner
546 36    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
```

```
547 36    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
550 37  cz 12.3292 $ fuel plate 17
551 37  cz 12.3571
552 37  cz 12.4079
553 37  cz 12.4358
554 37    p  2.4142136 -1 0 -1.09516   $ right Al inner
555 37    p -2.4142136 -1 0 -1.09516   $ left Al inner
556 37    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
557 37    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
560 38  cz 12.6594 $ fuel plate 18
561 38  cz 12.6873
562 38  cz 12.7381
563 38  cz 12.7660
564 38    p  2.4142136 -1 0 -1.09516   $ right Al inner
565 38    p -2.4142136 -1 0 -1.09516   $ left Al inner
566 38    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
567 38    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
570 39  cz 12.9896 $ fuel plate 19
571 39  cz 13.0175
572 39  cz 13.0683
573 39  cz 13.0962
574 39    p  2.4142136 -1 0 -1.09516   $ right Al inner
575 39    p -2.4142136 -1 0 -1.09516   $ left Al inner
576 39    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
577 39    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
580 40  cz 13.3198 $ fuel plate 20
581 40  cz 13.3477
582 40  cz 13.3985
583 40  cz 13.4264
584 40    p  2.4142136 -1 0 -1.09516   $ right Al inner
585 40    p -2.4142136 -1 0 -1.09516   $ left Al inner
586 40    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
587 40    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
590 41  cz 13.6500 $ fuel plate 21
591 41  cz 13.6779
592 41  cz 13.7287
593 41  cz 13.7566
594 41    p  2.4142136 -1 0 -1.09516   $ right Al inner
595 41    p -2.4142136 -1 0 -1.09516   $ left Al inner
596 41    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
597 41    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
600 42  cz 13.9802 $ fuel plate 22
601 42  cz 14.0081
602 42  cz 14.0589
603 42  cz 14.0868
604 42    p  2.4142136 -1 0 -1.09516   $ right Al inner
605 42    p -2.4142136 -1 0 -1.09516   $ left Al inner
606 42    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
607 42    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
610 43  cz 14.3104 $ fuel plate 23
611 43  cz 14.3383
612 43  cz 14.3891
613 43  cz 14.4170
```

```
614 43    p  2.4142136 -1 0 -1.09516   $ right Al inner
615 43    p -2.4142136 -1 0 -1.09516   $ left Al inner
616 43    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
617 43    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
620 44  cz 14.6406 $ fuel plate 24
621 44  cz 14.6685
622 44  cz 14.7193
623 44  cz 14.7472
624 44    p  2.4142136 -1 0 -1.09516   $ right Al inner
625 44    p -2.4142136 -1 0 -1.09516   $ left Al inner
626 44    p  2.4142136 -1 0 -1.39997   $ plate meat boundary
627 44    p -2.4142136 -1 0 -1.39997   $ plate meat boundary
c
200      cz 7.3838 $ IR pipe
201      cz 7.6581 $ OR pipe
c 202      cz 38.1   $ 12" water
203      cz 10.1981 $ 1" insulation
c
210 50     p  2.194300 -1 0 11.6987 $ right lower inner
211 51     p -2.194300 -1 0 11.6987 $ left lower inner
212 50     p -0.455726 -1 0 -5.7501 $ right upper inner
213 51     p  0.455726 -1 0 -5.7501 $ left upper inner
214        py -5.6175               $ bottom inner
220 50     p  2.194300 -1 0 13.2300 $ right lower outer
221 51     p -2.194300 -1 0 13.2300 $ left lower outer
222 50     p -0.455726 -1 0 -6.4479 $ right upper outer
223 51     p  0.455726 -1 0 -6.4479 $ left upper outer
224        py -6.2525               $ bottom outer
230 50     p  2.194300 -1 0 10.9331 $ right neoprene
231 51     p -2.194300 -1 0 10.9331 $ left neoprene
232        p  3.1993   -1 0 13.2244 $ right plastic bag
233        p -3.1993   -1 0 13.2244 $ left plastic bag
234        c/z 0 -10.065 14.8       $ top of plastic bag
c
250      px  -9.6032 $ square tube
251      px   9.6032
252      py  -9.6032
253      py   9.6032
c
300      px  10.033 $ lattice surfaces/sq. tube
301      px -10.033
302      py  10.033
303      py -10.033
310      px -50.165 $ 5x5 bounds
311      px  50.165
312      py -50.165
313      py  50.165
320      px -80.645 $ outer bounds
321      px  80.645
322      py -80.645
323      py  80.645
324      pz -60.96
325      pz  60.96

m2      1001.62c  2          $ water
        8016.62c  1
mt2     lwtr.60t
m3      13027.62c 1          $ Al
m4      6000.66c   -0.08     $ SS-304
```

```
        14000.60c  -1.0
        15031.66c  -0.045
        24000.50c  -19.0
        25055.62c  -2.0
        26000.55c  -68.375
        28000.50c  -9.5
m5      1001.62c  -0.056920  $ neoprene (no Cl)
        6000.66c  -0.542646
c        17000.66c -0.400434
m6      13027.62c  -26.5     $ insulation material
        14000.60c  -23.4
        8016.62c   -50.2
m10     92234.69c 2.3171E-05
        92235.69c 3.6147E-03
        92236.69c 1.3402E-05
        92238.69c 1.9174E-04
        13027.62c 5.0596E-02
c           total 5.4439E-02
c
*tr1     0 -12.25 0                       $ base to center
*tr2     0 -0.7798 0  180 90 90 90 180 90  $ down
*tr3     0  0.7798 0                       $ up
*tr4     0.7798 0 0  90 180 90 0 90 90     $ right
*tr5    -0.7798 0 0  90 0 90 180 90 90     $ left
*tr6     0.5514   0.5514  0  45 135 90 45 45 90     $ up/right
*tr7    -0.5514   0.5514  0  45 45 90 135 45 90     $ up/left
*tr8     0.5514  -0.5514  0  135 135 90 45 135 90   $ down/right
*tr9    -0.5514  -0.5514  0  135 45 90 135 135 90   $ down/left
tr22 0 0.095 0 $ plate 2
tr23 0 0.190 0 $ plate 3
tr24 0 0.285 0 $ plate 4
tr25 0 0.380 0 $ plate 5
tr26 0 0.475 0 $ plate 6
tr27 0 0.570 0 $ plate 7
tr28 0 0.665 0 $ plate 8
tr29 0 0.760 0 $ plate 9
tr30 0 0.855 0 $ plate 10
tr31 0 0.950 0 $ plate 11
tr32 0 1.045 0 $ plate 12
tr33 0 1.140 0 $ plate 13
tr34 0 1.235 0 $ plate 14
tr35 0 1.330 0 $ plate 15
tr36 0 1.425 0 $ plate 16
tr37 0 1.520 0 $ plate 17
tr38 0 1.615 0 $ plate 18
tr39 0 1.710 0 $ plate 19
tr40 0 1.805 0 $ plate 20
tr41 0 1.900 0 $ plate 21
tr42 0 1.995 0 $ plate 22
tr43 0 2.090 0 $ plate 23
tr44 0 2.185 0 $ plate 24
tr50   0.7798 0 0  $ shift FHE right
tr51  -0.7798 0 0  $ shift FHE left
c
mode   n
kcode  2500 1.0 50 250
sdef    x=d1 y=d2 z=d3
si1     -50 50
sp1     0 1
si2     -50 50
```

```
sp2     0 1
si3     -31 31
sp3     0 1
```

MIT Case YK9 (HA_MIT_FNW080)

```
MIT
999     0      -320:321:-322:323:-324:325                imp:n=0
900     0      310 -311 312 -313 24 -25     fill=3       imp:n=1
901     2 -1.0 (311:-310:313:-312:-24:25) 320 -321 322 -323 324 -325  imp:n=1
c
c       Universe 1: MIT Fuel Element (infinitely long)
c
10      3 -2.7        10 -11 50 -124            u=1 imp:n=1 $ right Al piece
11      3 -2.7        13 -12 50 -124            u=1 imp:n=1 $ left Al piece
c 12      2 -1.0        12 -10 18 -50             u=1 imp:n=1
20      10 5.4398E-02 40 -41 70 -90             u=1 imp:n=1 $ plate 1
21      3 -2.7        12 -10 50 -110 #20        u=1 imp:n=1
22      2 -1.0        12 -10 110 -51            u=1 imp:n=1
30      10 5.4398E-02 40 -41 71 -91             u=1 imp:n=1 $ plate 2
31      3 -2.7        12 -10 51 -111 #30        u=1 imp:n=1
32      2 -1.0        12 -10 111 -52            u=1 imp:n=1
40      10 5.4398E-02 40 -41 72 -92             u=1 imp:n=1 $ plate 3
41      3 -2.7        12 -10 52 -112 #40        u=1 imp:n=1
42      2 -1.0        12 -10 112 -53            u=1 imp:n=1
50      10 5.4398E-02 40 -41 73 -93             u=1 imp:n=1 $ plate 4
51      3 -2.7        12 -10 53 -113 #50        u=1 imp:n=1
52      2 -1.0        12 -10 113 -54            u=1 imp:n=1
60      10 5.4398E-02 40 -41 74 -94             u=1 imp:n=1 $ plate 5
61      3 -2.7        12 -10 54 -114 #60        u=1 imp:n=1
62      2 -1.0        12 -10 114 -55            u=1 imp:n=1
70      10 5.4398E-02 40 -41 75 -95             u=1 imp:n=1 $ plate 6
71      3 -2.7        12 -10 55 -115 #70        u=1 imp:n=1
72      2 -1.0        12 -10 115 -56            u=1 imp:n=1
80      10 5.4398E-02 40 -41 76 -96             u=1 imp:n=1 $ plate 7
81      3 -2.7        12 -10 56 -116 #80        u=1 imp:n=1
82      2 -1.0        12 -10 116 -57            u=1 imp:n=1
90      10 5.4398E-02 40 -41 77 -97             u=1 imp:n=1 $ plate 8
91      3 -2.7        12 -10 57 -117 #90        u=1 imp:n=1
92      2 -1.0        12 -10 117 -58            u=1 imp:n=1
100      10 5.4398E-02 40 -41 78 -98             u=1 imp:n=1 $ plate 9
101      3 -2.7        12 -10 58 -118 #100       u=1 imp:n=1
102      2 -1.0        12 -10 118 -59            u=1 imp:n=1
110      10 5.4398E-02 40 -41 79 -99             u=1 imp:n=1 $ plate 10
111      3 -2.7        12 -10 59 -119 #110       u=1 imp:n=1
112      2 -1.0        12 -10 119 -60            u=1 imp:n=1
120      10 5.4398E-02 40 -41 80 -100            u=1 imp:n=1 $ plate 11
121      3 -2.7        12 -10 60 -120 #120       u=1 imp:n=1
122      2 -1.0        12 -10 120 -61            u=1 imp:n=1
130      10 5.4398E-02 40 -41 81 -101            u=1 imp:n=1 $ plate 12
131      3 -2.7        12 -10 61 -121 #130       u=1 imp:n=1
132      2 -1.0        12 -10 121 -62            u=1 imp:n=1
140      10 5.4398E-02 40 -41 82 -102            u=1 imp:n=1 $ plate 13
141      3 -2.7        12 -10 62 -122 #140       u=1 imp:n=1
142      2 -1.0        12 -10 122 -63            u=1 imp:n=1
150      10 5.4398E-02 40 -41 83 -103            u=1 imp:n=1 $ plate 14
151      3 -2.7        12 -10 63 -123 #150       u=1 imp:n=1
152      2 -1.0        12 -10 123 -64            u=1 imp:n=1
160      10 5.4398E-02 40 -41 84 -104            u=1 imp:n=1 $ plate 15
```

```
161      3 -2.7        12 -10 64 -124 #160        u=1 imp:n=1
c 162      2 -1.0        12 -10 124 -19             u=1 imp:n=1
170      2 -1.0        -13:11:-50:124             u=1 imp:n=1 $ water between
fuel and enclosure
c
c       Universe 19: MIT with FHE
c
201      0             30 38 -32 -39 fill=1                 u=19 imp:n=1
202      5 -0.737      -33 39 -32 30                        u=19 imp:n=1 $ right
neo
203      5 -0.737      31 -38 -32 30                        u=19 imp:n=1 $ left neo
204      3 -2.7        (-30:-31:32:33) 34 35 -36 -37        u=19 imp:n=1 $
enclosure
205      2 -0.8        -34:-35:36:37                        u=19 imp:n=1 $ water
outside FHE
c
c       Universe 20: FHE in tube (center)
c
210      2 -0.9      -200            fill=19                u=20 imp:n=1 $ inside
pipe
211      4 -7.94       200 -201                             u=20 imp:n=1 $ pipe
212      6 -0.096      201 -203 250 -251 252 -253           u=20 imp:n=1 $
insulation
213      0             203 250 -251 252 -253                u=20 imp:n=1 $ pipe to
tube
214      4 -7.94       -250:251:-252:253                    u=20 imp:n=1 $ tube to
inf
c
c       Universe 21: FHE in tube (down)
c
220      2 -0.9      -200            fill=19(2)             u=21 imp:n=1 $ inside
pipe
221      4 -7.94       200 -201                             u=21 imp:n=1 $ pipe
222      6 -0.096      201 -203 250 -251 252 -253           u=21 imp:n=1 $
insulation
223      0             203 250 -251 252 -253                u=21 imp:n=1 $ pipe to
tube
224      4 -7.94       -250:251:-252:253                    u=21 imp:n=1 $ tube to
inf
c
c       Universe 22: FHE in tube (up)
c
230      2 -0.9      -200            fill=19(3)             u=22 imp:n=1 $ inside
pipe
231      4 -7.94       200 -201                             u=22 imp:n=1 $ pipe
232      6 -0.096      201 -203 250 -251 252 -253           u=22 imp:n=1 $
insulation
233      0             203 250 -251 252 -253                u=22 imp:n=1 $ pipe to
tube
234      4 -7.94       -250:251:-252:253                    u=22 imp:n=1 $ tube to
inf
c
c       Universe 23: FHE in tube (right)
c
240      2 -0.9      -200            fill=19(4)             u=23 imp:n=1 $ inside
pipe
241      4 -7.94       200 -201                             u=23 imp:n=1 $ pipe
242      6 -0.096      201 -203 250 -251 252 -253           u=23 imp:n=1 $
insulation
```

```
243     0           203 250 -251 252 -253              u=23 imp:n=1 $ pipe to
tube
244     4 -7.94     -250:251:-252:253                  u=23 imp:n=1 $ tube to
inf
c
c       Universe 24: FHE in tube (left)
c
250     2 -0.9     -200           fill=19(5)           u=24 imp:n=1 $ inside
pipe
251     4 -7.94     200 -201                           u=24 imp:n=1 $ pipe
252     6 -0.096    201 -203 250 -251 252 -253         u=24 imp:n=1 $
insulation
253     0           203 250 -251 252 -253              u=24 imp:n=1 $ pipe to
tube
254     4 -7.94     -250:251:-252:253                  u=24 imp:n=1 $ tube to
inf
c
c       Universe 25: FHE in tube (up/right)
c
260     2 -0.9     -200           fill=19(6)           u=25 imp:n=1 $ inside
pipe
261     4 -7.94     200 -201                           u=25 imp:n=1 $ pipe
262     6 -0.096    201 -203 250 -251 252 -253         u=25 imp:n=1 $
insulation
263     0           203 250 -251 252 -253              u=25 imp:n=1 $ pipe to
tube
264     4 -7.94     -250:251:-252:253                  u=25 imp:n=1 $ tube to
inf
c
c       Universe 26: FHE in tube (up/left)
c
270     2 -0.9     -200           fill=19(7)           u=26 imp:n=1 $ inside
pipe
271     4 -7.94     200 -201                           u=26 imp:n=1 $ pipe
272     6 -0.096    201 -203 250 -251 252 -253         u=26 imp:n=1 $
insulation
273     0           203 250 -251 252 -253              u=26 imp:n=1 $ pipe to
tube
274     4 -7.94     -250:251:-252:253                  u=26 imp:n=1 $ tube to
inf
c
c       Universe 27: FHE in tube (down/right)
c
280     2 -0.9     -200           fill=19(8)           u=27 imp:n=1 $ inside
pipe
281     4 -7.94     200 -201                           u=27 imp:n=1 $ pipe
282     6 -0.096    201 -203 250 -251 252 -253         u=27 imp:n=1 $
insulation
283     0           203 250 -251 252 -253              u=27 imp:n=1 $ pipe to
tube
284     4 -7.94     -250:251:-252:253                  u=27 imp:n=1 $ tube to
inf
c
c       Universe 28: FHE in tube (down/left)
c
290     2 -0.9     -200           fill=19(9)           u=28 imp:n=1 $ inside
pipe
291     4 -7.94     200 -201                           u=28 imp:n=1 $ pipe
292     6 -0.096    201 -203 250 -251 252 -253         u=28 imp:n=1 $
insulation
```

```
293     0           203 250 -251 252 -253              u=28 imp:n=1 $ pipe to
tube
294     4 -7.94     -250:251:-252:253                  u=28 imp:n=1 $ tube to
inf
c
c       Universe 3: Array of Packages
c
300   0    -300 301 -302 303 imp:n=1 u=3 lat=1 fill=-2:2 -2:2 0:0
             25 25 22 26 26
             25 25 22 26 26
             23 23 20 24 24
             27 27 21 28 28
             27 27 21 28 28

10      px  2.5451    $ Al side
11      px  3.0226    $ Al side
12      px -2.5451    $ Al side
13      px -3.0226    $ Al side
18  10  py -3.02768   $ Al bottom
19  10  py 3.02768    $ Al top
20  10  py -3.34518   $ neoprene
21  10  py  3.34518   $ neoprene
c
24      pz -28.41625  $ bottom of fuel
25      pz  28.41625  $ top of fuel (22.375")
30 20   p -1.71429 -1 0 -7.3152 $ inner FHE
31 21   p  1.71429 -1 0 -7.3152 $ inner FHE
32 21   p -1.71429 -1 0  7.3152 $ inner FHE
33 20   p  1.71429 -1 0  7.3152 $ inner FHE
34 20   p -1.71429 -1 0 -7.9697 $ outer FHE
35 21   p  1.71429 -1 0 -7.9697 $ outer FHE
36 21   p -1.71429 -1 0  7.9697 $ outer FHE
37 20   p  1.71429 -1 0  7.9697 $ outer FHE
38 21   p  1.71429 -1 0 -6.6859 $ left neo
39 20   p  1.71429 -1 0  6.6859 $ right neo
c
40      px -2.3878 $ meat width (w/2*cos(30))
41      px  2.3878 $ meat width
c
50 10   py -4.34848
51 10   py -3.73888
52 10   py -3.12928
53 10   py -2.51968
54 10   py -1.91008
55 10   py -1.30048
56 10   py -0.69088
57 10   py -0.08128
58 10   py 0.52832
59 10   py 1.13792
60 10   py 1.74752
61 10   py 2.35712
62 10   py 2.96672
63 10   py 3.57632
64 10   py 4.18592
c
70 10   py -4.30530
71 10   py -3.69570
72 10   py -3.08610
73 10   py -2.47650
74 10   py -1.86690
```

```
75 10   py -1.25730
76 10   py -0.64770
77 10   py -0.03810
78 10   py 0.57150
79 10   py 1.18110
80 10   py 1.79070
81 10   py 2.40030
82 10   py 3.00990
83 10   py 3.61950
84 10   py 4.22910
c
90 10   py -4.22910
91 10   py -3.61950
92 10   py -3.00990
93 10   py -2.40030
94 10   py -1.79070
95 10   py -1.18110
96 10   py -0.57150
97 10   py 0.03810
98 10   py 0.64770
99 10   py 1.25730
100 10   py 1.86690
101 10   py 2.47650
102 10   py 3.08610
103 10   py 3.69570
104 10   py 4.30530
c
110 10   py -4.18592
111 10   py -3.57632
112 10   py -2.96672
113 10   py -2.35712
114 10   py -1.74752
115 10   py -1.13792
116 10   py -0.52832
117 10   py 0.08128
118 10   py 0.69088
119 10   py 1.30048
120 10   py 1.91008
121 10   py 2.51968
122 10   py 3.12928
123 10   py 3.73888
124 10   py 4.34848
c
199      cz 6.9012 $ Al
200      cz 7.3838 $ IR pipe
201      cz 7.6581 $ OR pipe
203      cz 10.1981 $ 1" insulation
c
250      px  -9.6032 $ square tube
251      px   9.6032
252      py  -9.6032
253      py   9.6032
c
300      px  10.033 $ lattice surfaces/sq. tube
301      px -10.033
302      py  10.033
303      py -10.033
310      px -50.165 $ 5x5 bounds
311      px  50.165
312      py -50.165
```

```
313      py  50.165
320      px -80.645 $ outer bounds
321      px  80.645
322      py -80.645
323      py  80.645
324      pz -58.8963
325      pz  58.8963

m2      1001.62c  2          $ water
        8016.62c  1
mt2     lwtr.60t
m3      13027.62c 1          $ Al
m4      6000.66c   -0.08     $ SS-304
        14000.60c  -1.0
        15031.66c  -0.045
        24000.50c  -19.0
        25055.62c  -2.0
        26000.55c  -68.375
        28000.50c  -9.5
m5      1001.62c  -0.056920  $ neoprene (no Cl)
        6000.66c  -0.542646
c        17000.66c -0.400434
m6      13027.62c  -26.5     $ insulation material
        14000.60c  -23.4
        8016.62c   -50.2
m10     92234.69c 2.3613E-05 $ fuel
        92235.69c 3.6835E-03
        92236.69c 1.3657E-05
        92238.69c 1.9539E-04
        13027.62c 5.0481E-02
c           total 5.4398E-02
c
*tr2     0 -0.7798 0  30 60 90 120 30 90   $ down
*tr3     0  0.7798 0  30 60 90 120 30 90   $ up
*tr4     0.7798 0 0                        $ right
*tr5    -0.7798 0 0                        $ left
*tr6     0.5514    0.5514  0                      $ up/right
*tr7    -0.5514    0.5514  0  90 0 90 180 90 90   $ up/left
*tr8     0.5514   -0.5514  0  90 0 90 180 90 90   $ down/right
*tr9    -0.5514   -0.5514  0                      $ down/left
*tr10    0 0 0  30 120 90 60 30 90 $ rotate fuel surfaces 30 deg CCW
*tr20    -0.7798 0 0  30.2 59.8 90 120.2 30.2 90 j j j -1 $ rotate right FHE
30.2 deg CCW
*tr21     0.7798 0 0  30.2 59.8 90 120.2 30.2 90 j j j -1 $ rotate left FHE
30.2 deg CCW
c
mode   n
kcode  2500 1.0 50 250
sdef    x=d1 y=d2 z=d3
si1     -50 50
sp1     0 1
si2     -50 50
sp2     0 1
si3     -31 31
sp3     0 1
```

6.11 Appendix C: Criticality Analysis for Small Quantity Payloads

The ATR FFSC may be utilized to transport fuel with a small U-235 fissile loading (≤ 400 g U-235). This fuel may be enriched up to 94% U-235. The intent is to bound in a generic manner several classes of research and development fuel types, as the geometry and fissile loading of such fuels is subject to change. These fuel types include AFIP elements, U-Mo foils, and design demonstration elements (DDEs). In addition, some standard fuel elements, such as RINSC, classify for transport as a small quantity payload, as well as individual plates used to fabricate MURR and MIT fuel. The following analysis demonstrates that the ATR FFSC with small quantity payload fuel complies with the requirements of 10 CFR 71.55 and 71.59. Based on a 3x4 array of undamaged packages and a 2x2 array of damaged packages, the Criticality Safety Index (CSI), per 10 CFR 71.59, is 25.0.

6.11.1 Description of Criticality Design

6.11.1.1 Design Features Important for Criticality

No special design features are required to maintain criticality safety. No poisons are utilized in the package. The separation provided by the packaging (outer flat-to-flat dimension of 7.9-in), along with the limit on the number of packages per shipment, is sufficient to maintain criticality safety.

6.11.1.2 Summary Table of Criticality Evaluation

The upper subcritical limit (USL) for ensuring that the ATR FFSC (single package or package array) is acceptably subcritical, as determined in Section 6.11.8, *Benchmark Evaluations*, is:

$$\text{USL} = 0.9209$$

The package is considered to be acceptably subcritical if the computed k_{safe} (k_s), which is defined as $k_{effective}$ (k_{eff}) plus twice the statistical uncertainty (σ), is less than or equal to the USL, or:

$$k_s = k_{eff} + 2\sigma \leq \text{USL}$$

The USL is determined on the basis of a benchmark analysis and incorporates the combined effects of code computational bias, the uncertainty in the bias based on both benchmark-model and computational uncertainties, and an administrative margin. The results of the benchmark analysis indicate that the USL is adequate to ensure subcriticality of the package.

The packaging design is shown to meet the requirements of 10 CFR 71.55(b). Moderation by water in the most reactive credible extent is utilized in both the normal conditions of transport (NCT) and hypothetical accident conditions of transport (HAC) analyses. In the single package NCT models, full-density water fills the accessible cavity, while in the single package HAC models, full-density water fills all cavities. In all single package models, 12-in of water reflection is utilized.

A 3x4x1 array of 10 packages (2 empty locations) is utilized for the NCT array, while a 2x2x1 array of 4 packages is utilized in the HAC array. In the HAC array cases, partial moderation is considered to maximize array interaction effects. In all array models, 12-in of water reflection is utilized external to the array.

The maximum results of the criticality calculations are summarized in Table 6.11-1. The maximum calculated k_s is 0.8943, which occurs for the optimally moderated NCT array case. The NCT array is more reactive than the HAC array because the NCT array is larger, and moderation is allowed in both conditions. In this case, the fuel mixture is modeled with a height of 32.5 cm, and void is modeled between the insulation and outer tube.

6.11.1.3 Criticality Safety Index

The criticality safety index is defined in 10 CFR 71.59 as 50/N, where 5N packages are used in the NCT array configuration, and 2N packages are used in the HAC array configuration. A 2x2 array (2N = 4, or N = 2) is utilized for the HAC array calculations, while a 3x4 array of 10 packages (5N = 10, or N = 2) is utilized for the NCT array calculations. Therefore, the criticality safety index is 50/N = 50/2 = 25.0. With a CSI = 25.0, a maximum of four packages is allowed per exclusive use shipment.

Table 6.11-1 – Summary of Small Quantity Payloads Criticality Evaluation

Normal Conditions of Transport (NCT)	
Case	k_s
Single Unit Maximum	0.6478
Array Maximum	0.8943
Hypothetical Accident Conditions (HAC)	
Case	k_s
Single Unit Maximum	0.7244
Array Maximum	0.8222
USL = 0.9209	

6.11.2 Fissile Material Contents

The fissile material content is up to 400 g U-235 enriched up to 94% as a general payload material. Because HEU is modeled in the analysis, the results also apply to medium enriched uranium (MEU) and low enriched uranium (LEU) fuels. The analysis also applies to any generic fuel with U-235 as the fissile isotope. The objective is to bound research and development fuels with designs that are subject to change. The full list of anticipated contents bounded by this analysis is summarized in Section 1.2.2.4, *Small Quantity Payload.*

In general, for enrichments greater than 5% U-235, a system is more reactive using a homogenized mixture rather than an explicit heterogeneous representation[11]. Therefore, to simplify the modeling approach, the fuel is modeled as a homogenized mixture of uranium and

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[11] JJ Duderstadt and LJ Hamilton, *Nuclear Reactor Analysis*, p. 405, John Wiley & Sons, Inc., 1976.

water. Note that the homogenized representation is simply a conservative representation, and it is not implied that the actual fuel would behave in this manner. The fuel, even in accident conditions, would remain largely intact.

This fuel mixture is assumed to conform to the cylindrical geometry constraint of the inner circular tube of the ATR FFSC. The fuel element structural materials (i.e., aluminum, silicon, etc.) are conservatively ignored, as well as the fuel handling enclosure (FHE) that supports the fuel element (either the RINSC FHE for RINSC fuel, or the small payload FHE for the remaining fuels). Modeling the structural materials would increase parasitic neutron absorption, as well as enlarge the size of the fissile volume to achieve the same hydrogen/U-235 ratio, and both effects would decrease the reactivity. Dunnage or shoring used in the FHEs, which may include aluminum or neoprene, is not limited. A polyethylene limit of 100 g is justified in the analysis.

The isotopic distribution of HEU fuel used in the analysis is listed in Table 6.11-2. The U-235 enrichment is conservatively modeled at 94%, which bounds the approximately 20% enrichment of LEU fuel, and 40-80% enrichment of MEU fuel. The remaining uranium isotopic values are representative and are consistent with the values used in the ATR criticality analysis (see Section 6.2, *Fissile Material Contents*). The fuel is modeled as homogenized mixture of uranium and water. Optimum reactivity is achieved by varying the height of the fissile mixture. A useful index of moderation for homogeneous systems is the hydrogen to U-235 ratio, abbreviated as H/U-235. This parameter is adjusted by varying the height of the fissile mixture. Increasing the height of the fissile mixture increases H/U-235.

The number densities of the homogenized mixture are computed in the following manner. A U-235 mass of 400 g is modeled, which bounds the masses of the small quantity payload items. The weight percent of U-235 is 94.0%. Therefore, the total mass of uranium M_U for 400 g U-235 is 400/0.94 = 425.5 g U. The theoretical density of uranium is 19.0 g/cm^3, so the solid-volume V_U of 425.5 g U is 425.5/19.0 = 22.4 cm^3. The homogenized volume V is $\pi R^2 H$, where R is the inner radius of the ATR FFSC circular tube (7.3838 cm) and H is the height of the fissile mixture. The gram density of uranium in the mixture is then M_U/V, and if water of density 1.0 g/cm^3 fills the remaining volume, the water density in the mixture is $(V- V_U)/V$. The number densities of uranium and water may then be computed from the mixture densities. An example set of fuel mixture number densities for a height of 40 cm is provided in Table 6.11-3.

The ATR FFSC may contain hydrogenous materials. Fuel elements may be transported in a polyethylene (CH_2) bag with a mass of approximately 3 oz, or 85 g. Neoprene (C_4H_5Cl) is also used as a padding material in the fuel holders. A representative neoprene mass for the ATR FFSC is 1500 g. Homogenized mixtures are also developed that include either 100 g polyethylene or 1500 g neoprene using the same method described above. For these computations, the density of polyethylene is 0.92 g/cm^3, and the density of neoprene is 1.23 g/cm^3. Example fuel mixture number densities including either polyethylene or neoprene are provided in Table 6.11-3.

Table 6.11-2 – Uranium Isotopics

Isotope	Modeled HEU Isotopics (Wt. %)
U-234	0.60
U-235	94.0
U-236	0.35
U-238	5.05

Table 6.11-3 – Example Fissile Mixture Number Densities for Height = 40 cm

Isotope	Fuel/Water Number Densities (atom/b-cm)	Fuel/Water Number Densities (atom/b-cm) with 100 g of Polyethylene	Fuel/Water Number Densities (atom/b-cm) with 1500 g of Neoprene
U-234	9.5888E-07	9.5888E-07	9.5888E-07
U-235	1.4958E-04	1.4958E-04	1.4958E-04
U-236	5.5459E-07	5.5459E-07	5.5459E-07
U-238	7.9346E-06	7.9346E-06	7.9346E-06
H	6.6636E-02	6.6828E-02	6.2182E-02
O	3.3318E-02	3.2788E-02	2.7368E-02
C	-	6.2664E-04	5.9567E-03
Cl	-	-	1.4892E-03
Total	1.0011E-01	1.0040E-01	9.7155E-02

6.11.3 General Considerations

6.11.3.1 Model Configuration

The packaging is modeled essentially the same as described in Section 6.3.1, *Model Configuration*. Refer to that section for details of the packaging model. The package length is modeled as 48-in long to be consistent with the original criticality models using ATR fuel (which has an active length of 48-in), although this length is somewhat arbitrary and is conservatively shorter than the actual inner cavity length of 67.88-in. The package is reflected with 12-in of full-density water.

In the NCT single package models, the inner tube, insulation, and outer tube are modeled explicitly, as shown in Figure 6.11-1 and Figure 6.11-2. Although negligible water ingress is expected during NCT, the inner cavity of the package is assumed to be flooded with water because the package lid does not contain a seal. However, the region between the insulation and the outer tube will remain dry because water cannot enter this region. The fuel is transported in a Fuel Handling Enclosure (FHE), which is conservatively ignored because the fuel is homogenized with water. Modeling the FHE would decrease the reactivity significantly if it is assumed that the fuel is homogenized within the constraint of the FHE. If it is assumed that the homogenized mixture could flow out of the FHE, modeling the FHE would still be less reactive than ignoring it because it would displace fissile material and increase the size of the fissile cylinder.

Although the FHE is not modeled, hydrogenous neoprene cushioning material along the sides of the enclosure is included in the fissile mixture in the NCT array models to demonstrate the poisoning effect of neoprene. The mass of neoprene is estimated from the RSINC FHE drawing. The width of the neoprene is approximately 2*1.7 = 3.4-in, the length is approximately 40.2-in, the thickness is 1/8-in, and the inner cavity has four sides. Therefore, the volume of neoprene is approximately 3.4*40.2*1/8*4 = 68.3 in^3 = 1120 cm^3. With a density of 1.23 g/cm^3, the mass of neoprene is approximately 1377 g, which is rounded up to 1500 g.

The fuel elements may be transported in a polyethylene bag with an approximate mass of 3 oz, or 85 g. A polyethylene mass of 100 g is conservatively homogenized with the fuel/water mixture when indicated.

The HAC single package model is essentially the same as the NCT single package model. Damage in the drop tests was shown to be negligible and concentrated at the ends of the package [See Section 2.12.1, *Certification Tests on CTU-1*]. As the ends of the package are not modeled, this end damage does not affect the modeling. The various side drops resulted in only minor localized damage to the outer tube, and no observable bulk deformation of the package. Therefore, the minor damage observed will not impact the reactivity. The insulation is replaced with full-density water, and the region between the insulation and outer tube is also filled with full-density water (see Figure 6.11-3). The treatment of the FHE is the same as the NCT single package model.

In the NCT array models, a 3x4x1 array is utilized, although two array positions are empty, for a total of 10 packages. The geometry of a package in the NCT array is the same as the NCT single package models. In the HAC array models, a 2x2x1 array is utilized. The HAC array models are essentially the same as the NCT array models, except additional cases are developed to determine the reactivity effect of allowing variable density water in the region between the inner and outer tubes. Cases are also developed with and without the insulation. The FHE is conservatively ignored for the reasons stated in the previous paragraphs. Because the NCT and HAC models are very similar and the NCT models utilize a larger array, the NCT array models are more reactive than the HAC array models.

The detailed moderation assumptions for these cases are discussed more fully in Section 6.11.5, *Evaluation of Package Arrays under Normal Conditions of Transport*, and Section 6.11.6, *Package Arrays under Hypothetical Accident Conditions*.

6.11.3.2 Material Properties

An example fissile material composition is provided in Table 6.11-3. The material properties of the packaging materials are provided in Section 6.3.2, *Material Properties*.

6.11.3.3 Computer Codes and Cross-Section Libraries

The computer codes and cross-section libraries utilized are provided in Section 6.3.3, *Computer Codes and Cross-Section Libraries*.

6.11.3.4 Demonstration of Maximum Reactivity

A number of conservative assumptions are utilized to obtain the maximum reactivity:

- The fuel is modeled as a homogeneous mixture of uranium and water, which is a significantly more reactive configuration than modeling the fuel explicitly. Fuel element structural materials are ignored.
- 400 g of U-235 is modeled, which bounds the U-235 loading of the proposed contents.
- The U-235 enrichment is modeled as 94%, which bounds the enrichment of the proposed contents.

The fissile mixture is assumed to fill the inner tube of the ATR FFSC, and moderation is varied by running cases with different fissile mixture heights. No credit is taken for fuel handling enclosures that would maintain the fuel in a more favorable geometry. Note that the homogenized representation is simply a conservative representation, and it is not implied that the actual fuel would behave in this manner. The fuel, even in accident conditions, would remain largely intact.

In the NCT cases, water fills only the inner tube, because water would not enter the region between the inner circular tube and outer square tube. In the HAC cases, water is allowed in the region between the inner circular tube and outer square tube. Also, insulation may be replaced with water in the HAC cases. All single package cases are reflected with 12-in of water.

For the NCT array, 10 packages are modeled in a 3x4x1 array (with 2 empty locations), while in the HAC array, a smaller 2x2x1 array is utilized. Because negligible damage was observed in the drop tests, the package dimensions are the same between the NCT and HAC models. Dimensions of the packaging are selected to maximize reactivity, and 12-in of close-water reflection is utilized.

The NCT array analysis is rather straightforward, because the only variable is the height of the fissile mixture. In the HAC array analysis, variables include the height of the fissile mixture, the presence or absence of insulation, and the water density of the region between the circular and square tubes. These parameters are varied to find the most reactive HAC condition.

Because fuel elements may be transported in polyethylene bags, 100 g of polyethylene is included in the fissile mixture. Polyethylene has a small, but positive, effect on the reactivity. While the FHEs are not modeled, hydrogenous neoprene used as a cushioning material is attached to the FHE. If 1500 g of neoprene is included in the fissile mixture, the reactivity drops significantly due to the poisoning effect of chlorine in the neoprene. Therefore, it is conservative to ignore neoprene in the models, and the mass of neoprene in the ATR FFSC is not limited.

The NCT array is more reactive than the HAC array, primarily because the NCT array is significantly larger, and both cases use a homogenized fuel assumption. The most reactive NCT array case (Case HC16) has a fissile mixture height of 32.5 cm and results in a $k_s = 0.89427$, which is below the USL of 0.9209. The most reactive HAC array case (Case HD34) results in a $k_s = 0.82217$.

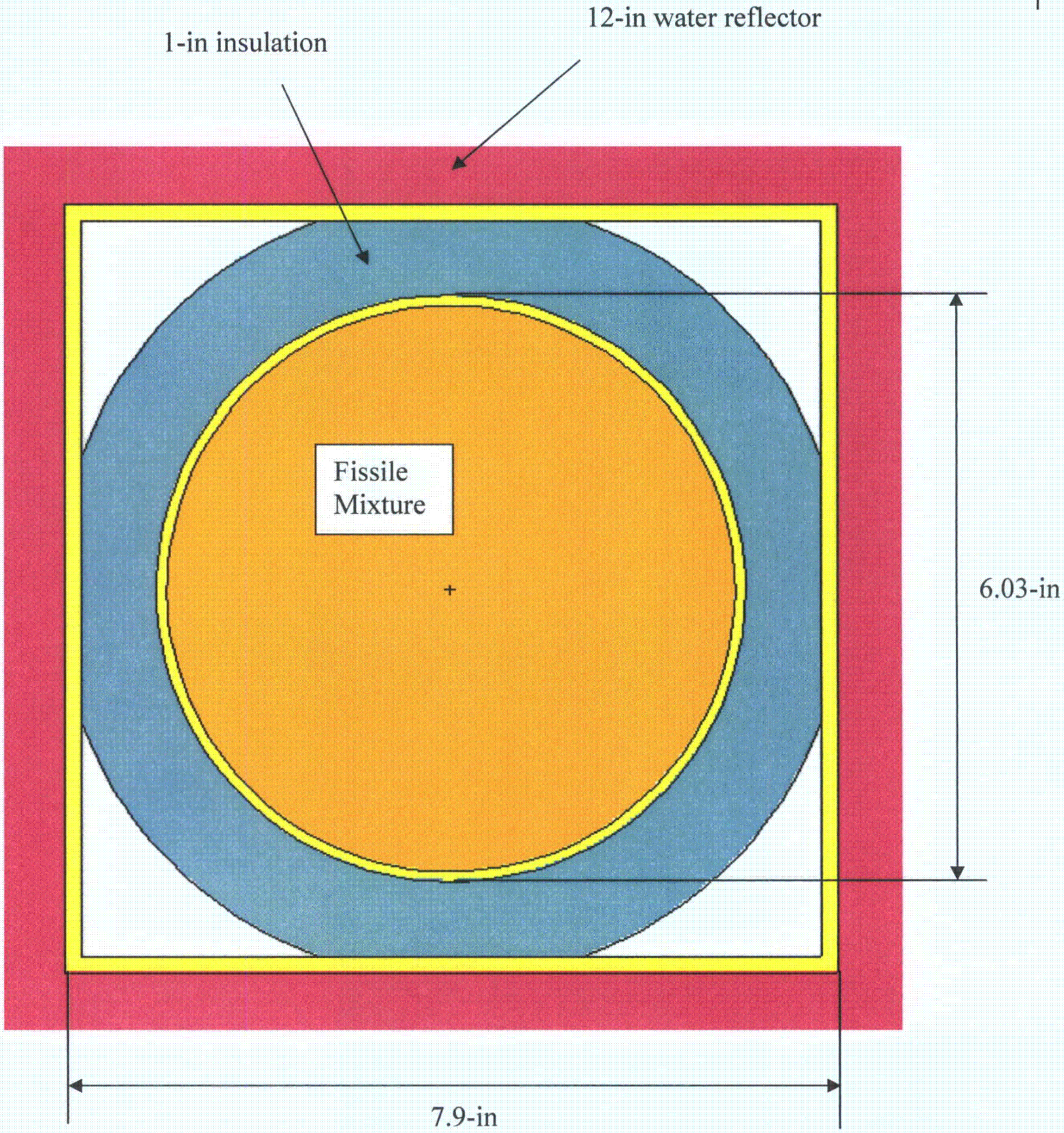


Figure 6.11-1 – NCT Single Package Model (planar view)

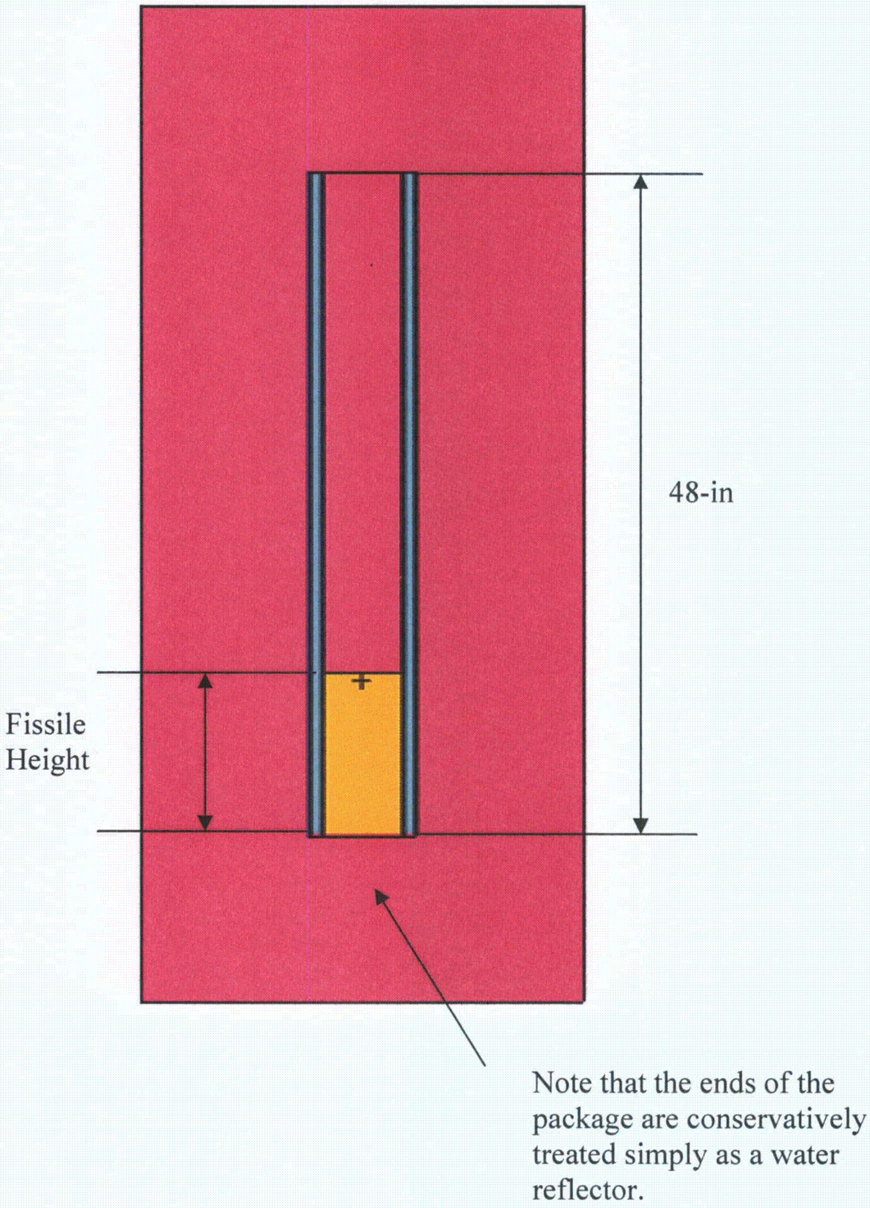


Figure 6.11-2 – NCT Single Package Model (axial view)

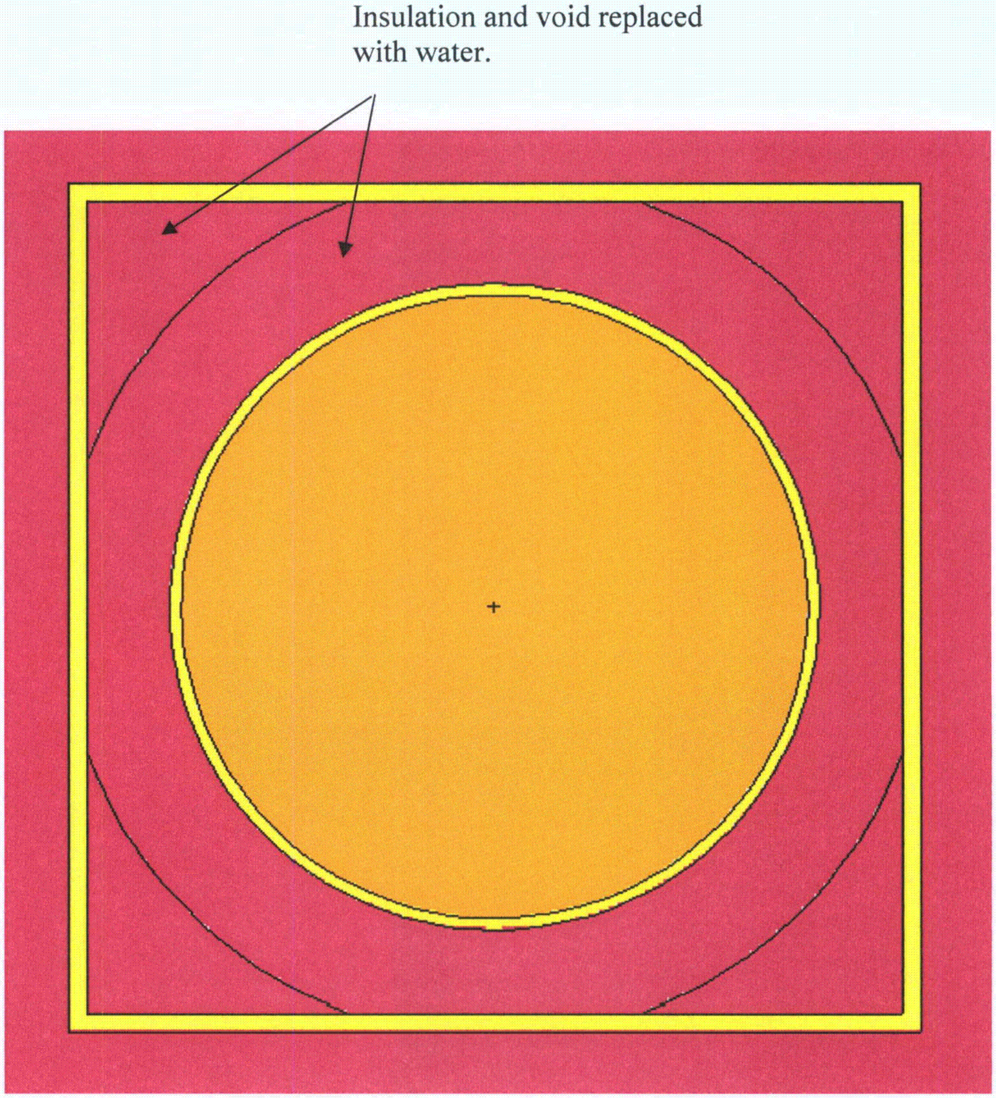


Figure 6.11-3 – HAC Single Package Model (planar view)

6.11.4 Single Package Evaluation

6.11.4.1 Single Package Configuration

6.11.4.1.1 NCT Single Package Configuration

The geometry of the NCT single package configuration is discussed in Section 6.11.3.1, *Model Configuration*. The fissile material is homogenized with water for a variety of fissile mixture heights. The water above the fissile mixture is modeled at full-density to maximize reflection. The package is reflected with 12-in of water.

Results are provided in Table 6.11-4. Cases HA1 through HA10 are without polyethylene, and Cases HA11 through HA20 include 100 g of polyethylene. The cases with polyethylene are slightly more reactive, although the effect is small. Maximum reactivity is achieved for Case HA13, with a fissile mixture height of 25.0 cm. The reactivity of this case is low, with k_s = 0.64775. This result is below the USL of 0.9209.

6.11.4.1.2 HAC Singe Package Configuration

The geometry of the HAC single package configuration is discussed in Section 6.11.3.1, *Model Configuration*. The fissile material is homogenized with water for a variety of fissile mixture heights. The water above the fissile mixture is modeled at full-density to maximize reflection. The insulation is replaced with full-density water, and full-density water is also modeled between the inner and outer tubes. The package is reflected with 12-in of water.

Results are provided in Table 6.11-5. Cases HB1 through HB10 are without polyethylene, and Cases HB11 through HB20 include 100 g of polyethylene. The cases with polyethylene are slightly more reactive, although the effect is small. Maximum reactivity is achieved for Case HB15, with a fissile mixture height of 27.5 cm. The reactivity of this case is low, with k_s = 0.72441. This result is below the USL of 0.9209.

6.11.4.2 Single Package Results

Following are the tabulated results for the single package cases. The most reactive configurations are listed in boldface.

Table 6.11-4 – NCT Single Package Results

Case ID	Filename	Fissile Mixture Height (cm)	k_{eff}	σ	k_s $(k+2\sigma)$
No Polyethylene					
HA1	NS_HEU_H15	15.0	0.61609	0.00130	0.61869
HA2	NS_HEU_H20	20.0	0.63614	0.00115	0.63844
HA3	NS_HEU_H25	25.0	0.64046	0.00116	0.64278
HA4	**NS_HEU_H275**	**27.5**	**0.64251**	**0.00114**	**0.64479**
HA5	NS_HEU_H30	30.0	0.64189	0.00116	0.64421
HA6	NS_HEU_H325	32.5	0.63773	0.00111	0.63995
HA7	NS_HEU_H35	35.0	0.62944	0.00106	0.63156
HA8	NS_HEU_H40	40.0	0.62060	0.00105	0.62270
HA9	NS_HEU_H45	45.0	0.60913	0.00110	0.61133
HA10	NS_HEU_H50	50.0	0.59328	0.00104	0.59536
With 100 g Polyethylene					
HA11	NS_HEUP_H15	15.0	0.62298	0.00128	0.62554
HA12	NS_HEUP_H20	20.0	0.64179	0.00112	0.64403
HA13	**NS_HEUP_H25**	**25.0**	**0.64531**	**0.00122**	**0.64775**
HA14	NS_HEUP_H275	27.5	0.64503	0.00114	0.64731
HA15	NS_HEUP_H30	30.0	0.64193	0.00113	0.64419
HA16	NS_HEUP_H325	32.5	0.63741	0.00116	0.63973
HA17	NS_HEUP_H35	35.0	0.63154	0.00113	0.63380
HA18	NS_HEUP_H40	40.0	0.62058	0.00108	0.62274
HA19	NS_HEUP_H45	45.0	0.60798	0.00109	0.61016
HA20	NS_HEUP_H50	50.0	0.59553	0.00101	0.59755

Table 6.11-5 – HAC Single Package Results

Case ID	Filename	Fissile Mixture Height (cm)	k_{eff}	σ	k_s ($k+2\sigma$)
No Polyethylene					
HB1	HS_HEU_H15	15.0	0.69170	0.00124	0.69418
HB2	HS_HEU_H20	20.0	0.71519	0.00122	0.71763
HB3	HS_HEU_H225	22.5	0.72038	0.00131	0.72300
HB4	**HS_HEU_H25**	**25.0**	**0.72067**	**0.00126**	**0.72319**
HB5	HS_HEU_H275	27.5	0.71817	0.00114	0.72045
HB6	HS_HEU_H30	30.0	0.71422	0.00120	0.71662
HB7	HS_HEU_H325	32.5	0.70809	0.00116	0.71041
HB8	HS_HEU_H35	35.0	0.70653	0.00121	0.70895
HB9	HS_HEU_H40	40.0	0.69450	0.00111	0.69672
HB10	HS_HEU_H45	45.0	0.67855	0.00120	0.68095
With 100 g Polyethylene					
HB11	HS_HEUP_H15	15.0	0.69905	0.00128	0.70161
HB12	HS_HEUP_H20	20.0	0.71848	0.00128	0.72104
HB13	HS_HEUP_H225	22.5	0.72122	0.00125	0.72372
HB14	HS_HEUP_H25	25.0	0.72136	0.00120	0.72376
HB15	**HS_HEUP_H275**	**27.5**	**0.72189**	**0.00126**	**0.72441**
HB16	HS_HEUP_H30	30.0	0.71679	0.00130	0.71939
HB17	HS_HEUP_H325	32.5	0.71212	0.00123	0.71458
HB18	HS_HEUP_H35	35.0	0.70759	0.00119	0.70997
HB19	HS_HEUP_H40	40.0	0.69424	0.00111	0.69646
HB20	HS_HEUP_H45	45.0	0.67857	0.00112	0.68081

6.11.5 Evaluation of Package Arrays under Normal Conditions of Transport

6.11.5.1 NCT Array Configuration

The NCT array model is a 3x4x1 array with two empty locations, for a total of 10 packages. The array configuration utilized is the most reactive 10 package configuration, with 9 packages in a 3x3 configuration, and one package at the center of a side, see Figure 6.11-4. Axial stacking configurations, such as 2x3x2 with two empty locations, would lower the reactivity and are not investigated. The geometry of the individual packages is the same as the NCT single package model. The entire array is reflected with 12-in of full-density water. Moderation is varied by adjusting the height of the fissile mixture. The region above the fissile mixture is filled with full density water to maximize reflection.

The results are summarized in Table 6.11-6. Cases HC1 through HC10 are without polyethylene or neoprene, Cases HC11 through HC20 include 100 g of polyethylene, and Cases HC21 through HC27 include 1500 g neoprene. The cases with polyethylene are slightly more reactive, although the effect is small. Adding neoprene has a very strong negative effect on the reactivity, which is expected due to the poisoning effect of chlorine. Therefore, the mass of neoprene in the ATR FFSC is not limited. The most reactive condition is Case HC16, with a fissile height of 32.5 cm. For this case, $k_s = 0.89427$, which is below the USL of 0.9209.

6.11.5.2 NCT Array Results

The results for the NCT array cases are provided in the following table. The most reactive configurations are listed in boldface.

Table 6.11-6 – NCT Array Results

Case ID	Filename	Fissile Mixture Height (cm)	k_{eff}	σ	k_s $(k+2\sigma)$
No Polyethylene or Neoprene					
HC1	NA_HEU_H15	15.0	0.81375	0.00130	0.81635
HC2	NA_HEU_H20	20.0	0.86031	0.00130	0.86291
HC3	NA_HEU_H25	25.0	0.88140	0.00120	0.88380
HC4	NA_HEU_H275	27.5	0.88591	0.00129	0.88849
HC5	**NA_HEU_H30**	**30.0**	**0.89141**	**0.00120**	**0.89381**
HC6	NA_HEU_H325	32.5	0.89089	0.00123	0.89335
HC7	NA_HEU_H35	35.0	0.89028	0.00114	0.89256
HC8	NA_HEU_H40	40.0	0.88126	0.00116	0.88358
HC9	NA_HEU_H45	45.0	0.87387	0.00116	0.87619
HC10	NA_HEU_H50	50.0	0.85981	0.00104	0.86189
With 100 g Polyethylene					
HC11	NA_HEUP_H15	15.0	0.81856	0.00130	0.82116
HC12	NA_HEUP_H20	20.0	0.86138	0.00129	0.86396
HC13	NA_HEUP_H25	25.0	0.88386	0.00119	0.88624
HC14	NA_HEUP_H275	27.5	0.88818	0.00113	0.89044
HC15	NA_HEUP_H30	30.0	0.88873	0.00122	0.89117
HC16	**NA_HEUP_H325**	**32.5**	**0.89207**	**0.00110**	**0.89427**
HC17	NA_HEUP_H35	35.0	0.88988	0.00113	0.89214
HC18	NA_HEUP_H40	40.0	0.88439	0.00110	0.88659
HC19	NA_HEUP_H45	45.0	0.87352	0.00106	0.87564
HC20	NA_HEUP_H50	50.0	0.86011	0.00110	0.86231
With 1500 g Neoprene					
HC21	NA_HEUN_H30	30.0	0.62595	0.00096	0.62787
HC22	NA_HEUN_H35	35.0	0.63410	0.00092	0.63594
HC23	NA_HEUN_H40	40.0	0.63992	0.00099	0.64190
HC24	**NA_HEUN_H45**	**45.0**	**0.64188**	**0.00091**	**0.64370**
HC25	NA_HEUN_H50	50.0	0.63611	0.00086	0.63783
HC26	NA_HEUN_H55	55.0	0.63358	0.00079	0.63516
HC27	NA_HEUN_H60	60.0	0.62747	0.00087	0.62921

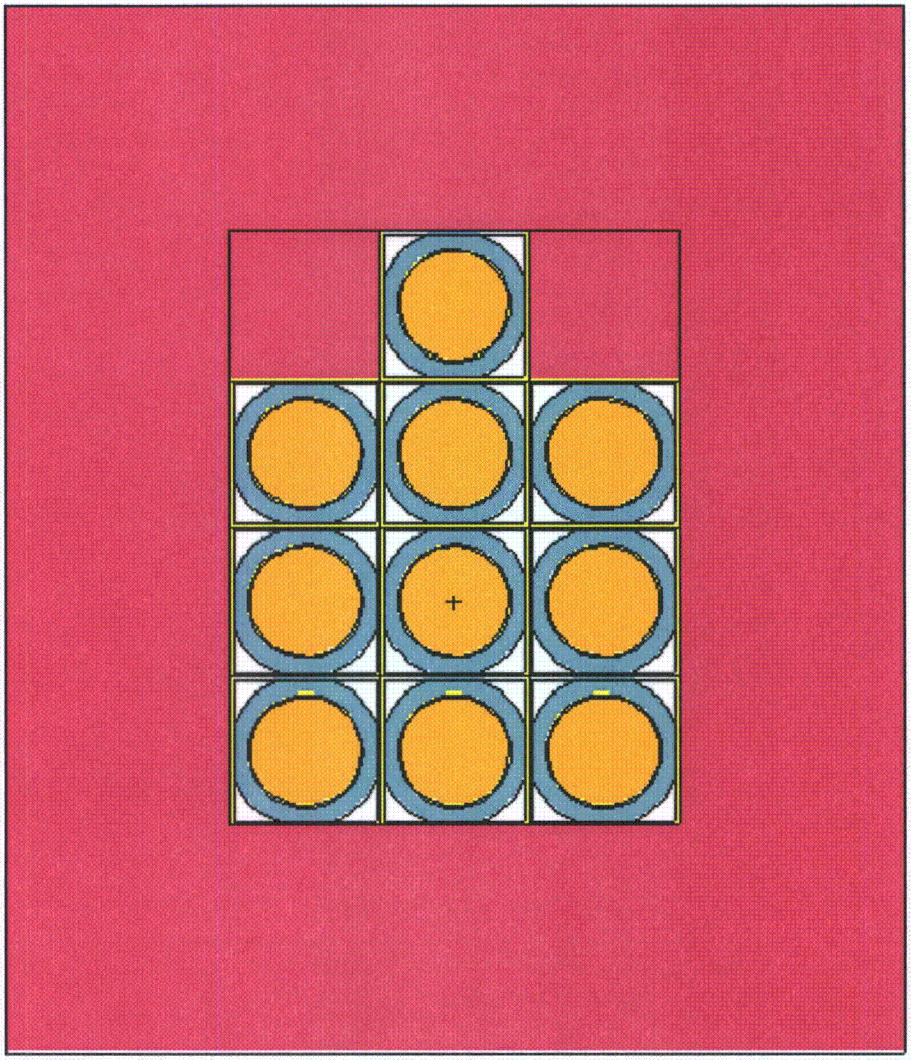


Figure 6.11-4 – NCT Array Geometry

6.11.6 Package Arrays under Hypothetical Accident Conditions

6.11.6.1 HAC Array Configuration

The HAC array model is a 2x2x1 array of the HAC single package model, as shown in Figure 6.11-5. Results are provided in Table 6.11-7. Because it has been demonstrated in the NCT single package, HAC single package, and NCT array cases that adding 100 g of polyethylene to the fissile mixture slightly increases the reactivity, all HAC array cases include 100 g of polyethylene.

In Cases HD1 through HD10, the region between the inner circular tube and outer square tube is filled with full-density water. Therefore, the insulation is replaced with water. The fissile mixture height is varied to find the optimum moderation, and the region above the fissile mixture is filled with full-density water. Of these 10 cases, Case HD4 is the most reactive, with a fissile mixture height of 25.0 cm.

In Cases HD11 through HD15, the most reactive fissile mixture height of 25.0 cm is modeled. The insulation is modeled explicitly, and a range of water densities are modeled between the insulation and outer square tube. These cases are less reactive than Case HD4, indicating that it is conservative to ignore the insulation in the HAC array models.

In Cases HD16 through HD25, Case HD4 is modified for a range of water densities between the inner circular tube and outer square tube. Case HD22 is the most reactive, with $k_s = 0.81981$ and a water density between tubes of 0.6 g/cm^3. This case is slightly more reactive than Case HD4, for which $k_s = 0.81502$. However, the reactivity gain by using a reduced water density between the tubes is small.

The most reactive fissile mixture height may change based on the water density between the tubes. For this reason, a limited number of additional cases are run for fissile mixture heights of 22.5 cm, 27.5 cm, and 30.0 cm. In Cases HD26 through HD31, the fissile mixture height is 22.5 cm and the water density is varied between 0.3 and 0.8 g/cm^3. Cases HD32 through HD37 are similar except the fissile mixture height is 27.5 cm, and in Cases HD38 through HD43 the fissile mixture height is 30.0 cm. The most reactive case is Case HD34, which is slightly more reactive than Case HD22.

Therefore, Case HD34 is the most reactive, with $k_s = 0.82217$. This case has a fissile mixture height of 27.5 cm, the insulation has been replaced with water, and the water density between the inner circular tube and outer square tube is 0.5 g/cm^3. This case is below the USL of 0.9209. Note that the most reactive HAC array case is less reactive than the most reactive NCT array case (Case HC16) because the NCT array uses 10 packages, while the HAC array uses only 4 packages.

6.11.6.2 HAC Array Results

Following are the tabulated results for the HAC array cases. The most reactive configurations are listed in boldface.

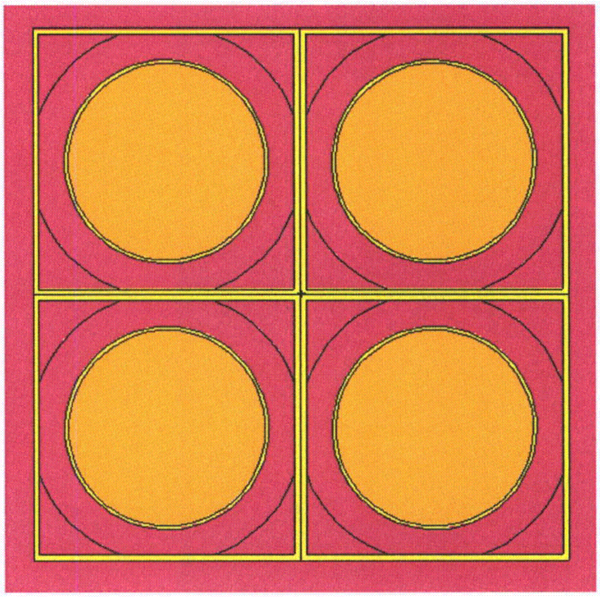
Table 6.11-7 – HAC Array Results

Case ID	Filename	Fissile Mixture Height (cm)	Water Density Between Tubes (g/cm^3)	Insulation	k_{eff}	σ	k_s (k+2σ)
HD1	HA_HEUP_H15	15.0	1.0	No	0.77954	0.00115	0.78184
HD2	HA_HEUP_H20	20.0	1.0	No	0.80655	0.00123	0.80901
HD3	HA_HEUP_H225	22.5	1.0	No	0.80899	0.00130	0.81159
HD4	**HA_HEUP_H25**	**25.0**	**1.0**	**No**	**0.81254**	**0.00124**	**0.81502**
HD5	HA_HEUP_H275	27.5	1.0	No	0.81232	0.00124	0.81480
HD6	HA_HEUP_H30	30.0	1.0	No	0.80789	0.00116	0.81021
HD7	HA_HEUP_H325	32.5	1.0	No	0.80247	0.00114	0.80475
HD8	HA_HEUP_H35	35.0	1.0	No	0.79682	0.00119	0.79920
HD9	HA_HEUP_H40	40.0	1.0	No	0.78144	0.00114	0.78372
HD10	HA_HEUP_H45	45.0	1.0	No	0.76909	0.00110	0.77129
HD11	HA_HEUP_H25_IW000	25.0	0	Yes	0.79417	0.00131	0.79679
HD12	HA_HEUP_H25_IW025	25.0	0.25	Yes	0.79759	0.00128	0.80015
HD13	HA_HEUP_H25_IW050	25.0	0.50	Yes	0.80131	0.00121	0.80373
HD14	HA_HEUP_H25_IW075	25.0	0.75	Yes	0.80017	0.00121	0.80259
HD15	HA_HEUP_H25_IW100	25.0	1.0	Yes	0.80331	0.00118	0.80567
HD16	HA_HEUP_H25_W000	25.0	0	No	0.79115	0.00126	0.79367
HD17	HA_HEUP_H25_W010	25.0	0.1	No	0.79794	0.00117	0.80028
HD18	HA_HEUP_H25_W020	25.0	0.2	No	0.80884	0.00133	0.81150
HD19	HA_HEUP_H25_W030	25.0	0.3	No	0.81008	0.00123	0.81254
HD20	HA_HEUP_H25_W040	25.0	0.4	No	0.81535	0.00116	0.81767
HD21	HA_HEUP_H25_W050	25.0	0.5	No	0.81666	0.00129	0.81924
HD22	**HA_HEUP_H25_W060**	**25.0**	**0.6**	**No**	**0.81733**	**0.00124**	**0.81981**
HD23	HA_HEUP_H25_W070	25.0	0.7	No	0.81576	0.00130	0.81836
HD24	HA_HEUP_H25_W080	25.0	0.8	No	0.81435	0.00121	0.81677
HD25	HA_HEUP_H25_W090	25.0	0.9	No	0.81266	0.00130	0.81526
HD26	HA_HEUP_H225_W030	22.5	0.3	No	0.80656	0.00134	0.80924
HD27	HA_HEUP_H225_W040	22.5	0.4	No	0.80968	0.00135	0.81238
HD28	HA_HEUP_H225_W050	22.5	0.5	No	0.81297	0.00126	0.81549
HD29	HA_HEUP_H225_W060	22.5	0.6	No	0.81408	0.00113	0.81634
HD30	HA_HEUP_H225_W070	22.5	0.7	No	0.81343	0.00114	0.81571
HD31	HA_HEUP_H225_W080	22.5	0.8	No	0.81282	0.00123	0.81528
HD32	HA_HEUP_H275_W030	27.5	0.3	No	0.81386	0.00118	0.81622
HD33	HA_HEUP_H275_W040	27.5	0.4	No	0.81679	0.00123	0.81925
HD34	**HA_HEUP_H275_W050**	**27.5**	**0.5**	**No**	**0.81993**	**0.00112**	**0.82217**
HD35	HA_HEUP_H275_W060	27.5	0.6	No	0.81757	0.00123	0.82003
HD36	HA_HEUP_H275_W070	27.5	0.7	No	0.81559	0.00114	0.81787
HD37	HA_HEUP_H275_W080	27.5	0.8	No	0.81315	0.00125	0.81565

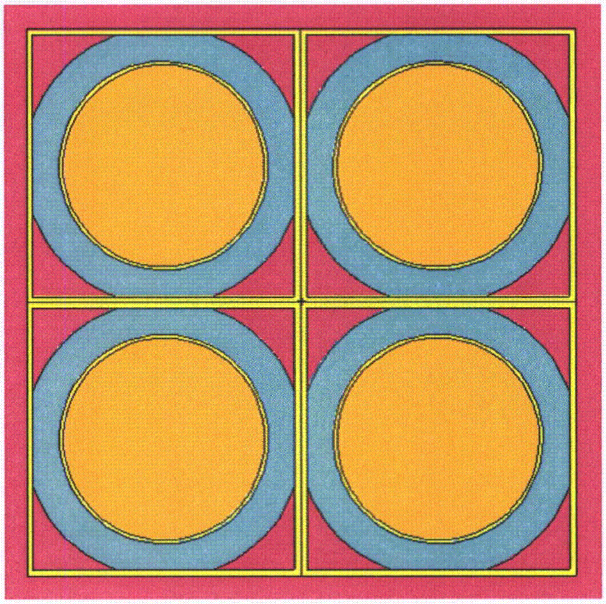
(continued)

Table 6.11-7 – HAC Array Results (concluded)

Case ID	Filename	Fissile Mixture Height (cm)	Water Density Between Tubes (g/cm^3)	Insulation	k_{eff}	σ	k_s ($k+2\sigma$)
HD38	HA_HEUP_H30_W030	30.0	0.3	No	0.81016	0.00115	0.81246
HD39	HA_HEUP_H30_W040	30.0	0.4	No	0.81437	0.00121	0.81679
HD40	HA_HEUP_H30_W050	30.0	0.5	No	0.81585	0.00121	0.81827
HD41	HA_HEUP_H30_W060	30.0	0.6	No	0.81631	0.00113	0.81857
HD42	HA_HEUP_H30_W070	30.0	0.7	No	0.81257	0.00108	0.81473
HD43	HA_HEUP_H30_W080	30.0	0.8	No	0.81328	0.00113	0.81554



Without insulation



With insulation

Figure 6.11-5 – HAC Array Geometry

6.11.7 Fissile Material Packages for Air Transport

This section is not applicable.

6.11.8 Benchmark Evaluations

The Monte Carlo computer program MCNP5 v1.30[12] is utilized for this benchmark analysis. MCNP has been used extensively in criticality evaluations for several decades and is considered a standard in the industry.

The uranium isotopes utilize preliminary ENDF/B-VII cross section data that are considered by Los Alamos National Laboratory to be more accurate than ENDF/B-VI cross sections. ENDF/B-V cross sections are utilized for chromium, nickel, and iron because natural composition ENDF/B-VI cross sections are not available for these elements. The remaining isotopes utilize ENDF/B-VI cross sections. All cross sections utilized are at room temperature. A listing of the cross section libraries used in the ATR FFSC analysis is provided in Table 6.3-4. These cross sections are consistent with the cross sections utilized in the benchmarks.

The ORNL USLSTATS code[13] is used to establish a USL for the analysis. USLSTATS provides a simple means of evaluating and combining the statistical error of the calculation, code biases, and benchmark uncertainties. The USLSTATS calculation uses the combined uncertainties and data to provide a linear trend and an overall uncertainty. Computed multiplication factors, k_{eff}, for the package are deemed to be adequately subcritical if the computed value of k_s is less than or equal to the USL as follows:

$$k_s = k_{eff} + 2\sigma \leq USL$$

The USL includes the combined effects of code bias, uncertainty in the benchmark experiments, uncertainty in the computational evaluation of the benchmark experiments, and an administrative margin. This methodology has accepted precedence in establishing criticality safety limits for transportation packages complying with 10 CFR 71.

6.11.8.1 Applicability of Benchmark Experiments

The critical experiment benchmarks are selected from the *International Handbook of Evaluated Criticality Safety Benchmark Experiments*[14] based upon their similarity to the ATR FFSC and contents. The important selection parameters are high enriched uranium solutions with a thermal spectrum and no strong absorbers such as boron. Ten benchmarks are available that meet this criteria. Because this is a small benchmark set, to supplement these benchmark cases, an additional 45 benchmarks are used for high enriched uranium solutions with boron or cadmium,

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[12] MCNP5, "*MCNP – A General Monte Carlo N-Particle Transport Code, Version 5; Volume II: User's Guide,*" LA-CP-03-0245, Los Alamos National Laboratory, April, 2003.

[13] USLSTATS, "*USLSTATS: A Utility To Calculate Upper Subcritical Limits For Criticality Safety Applications,*" Version 1.4.2, Oak Ridge National Laboratory, April 23, 2003.

[14] OECD Nuclear Energy Agency, *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, NEA/NSC/DOC(95)03, September, 2006.

as well as 42 low enriched (10%) solutions without poisons. The titles for all utilized experiments are listed in Table 6.11-8.

6.11.8.2 Bias Determination

The USL is calculated by application of the USLSTATS computer program. USLSTATS receives as input the k_{eff} as calculated by MCNP, the total 1-σ uncertainty (combined benchmark and MCNP uncertainties), and a trending parameter. Two trending parameters have been selected: (1) Energy of the Average neutron Lethargy causing Fission (EALF), and (2) the ratio of the hydrogen to U-235 number density (H/U-235).

The uncertainty value, σ_{total}, assigned to each case is a combination of the benchmark uncertainty for each experiment, σ_{bench}, and the Monte Carlo uncertainty associated with the particular computational evaluation of the case, σ_{MCNP}, or:

$$\sigma_{total} = (\sigma_{bench}^2 + \sigma_{MCNP}^2)^{½}$$

These values are input into the USLSTATS program in addition to the following parameters, which are the values recommended by the USLSTATS user's manual:

- P, proportion of population falling above lower tolerance level = 0.995 (note that this parameter is required input but is not utilized in the calculation of USL Method 1)
- 1-γ, confidence on fit = 0.95
- α, confidence on proportion P = 0.95 (note that this parameter is required input but is not utilized in the calculation of USL Method 1)
- Δk_m, administrative margin used to ensure subcriticality = 0.05.

These data are followed by triplets of trending parameter value, computed k_{eff}, and uncertainty for each case. A confidence band analysis is performed on the data for each trending parameter using USL Method 1. The USL generated for each of the trending parameters utilized is provided in Table 6.11-9. All benchmark data used as input to USLSTATS are reported in Table 6.11-10.

Energy of the Average neutron Lethargy causing Fission (EALF)

The EALF is used as the first trending parameter for the benchmark cases. The EALF comparison provides a means to observe neutron spectral dependencies or trends. USLSTATS is run for all experiments, as well as the subset of experiments that do not contain poisons. The data for the subset of experiments without poisons are plotted in Figure 6.11-6, while the data for all experiments is plotted in Figure 6.11-7. Over the range of applicability, the minimum USL is 0.9344 for the subset of benchmarks that do not contain poisons, and is 0.9309 when all benchmarks are considered. In both cases the USL is trending downward for increasing EALF. Note that for the benchmarks that do not contain poison, the data tests not normal by a small margin (chi = 12.4231, upper bound = 9.49). This behavior is judged to be acceptable, both because the deviation from normal is not large, and the USL generated from this data is bounded by the USL with poison.

EALF for all ATR FFSC small quantity payload cases falls within the range of applicability. The EALF is 4.98E-08 MeV for the most reactive case (Case HC16).

H/U-235 Atom Ratio

The H/U-235 atom ratio is used as the second trending parameter for the benchmark cases. The data for the subset of experiments without poisons are plotted in Figure 6.11-8, while the data for all experiments is plotted in Figure 6.11-9. Over the range of applicability, the minimum USL is 0.9401 for the subset of benchmarks that do not contain poisons, and is 0.9359 when all benchmarks are considered. The USL is relatively constant over the range of applicability when no poisons are considered, and is trending downward for decreasing H/U-235 when all benchmarks are considered. Note that for the benchmarks that do not contain poison, the data tests not normal by a small margin (chi = 12.4231, upper bound = 9.49). This behavior is judged to be acceptable, both because the deviation from normal is not large, and the USL generated from this data is bounded by the USL with poison.

The H/U-235 atom ratio for all ATR FFSC small quantity payload cases falls within the range of applicability. The H/U-235 atom ratio is 363 for the most reactive case (Case HC16).

Recommended USL

For the H/U-235 trending parameter, the minimum USL is 0.9359, while for the EALF trending parameter, the USL is 0.9309. Therefore, a USL of 0.9309 could be justified. However, a benchmark analysis was also performed for high-enriched plate fuel for the original ATR FFSC criticality analysis (see Section 6.8, *Benchmark Evaluations*). In that section, a USL of 0.9209 is justified. Therefore, a USL of 0.9209 is conservatively selected as the USL for this analysis for consistency.

Table 6.11-8 – Benchmark Experiments Utilized

Series	Title
HEU-SOL-THERM-001	Minimally Reflected Cylinders of Highly Enriched Solutions of Uranyl Nitrate
HEU-SOL-THERM-027	Uranium (89% ^{235}U) Nitrate Solution with Central Boron Carbide or Cadmium Absorber Rod
HEU-SOL-THERM-028	Uranium (89% ^{235}U) Nitrate Solutions with Central Boron Carbide Absorber Rod
HEU-SOL-THERM-029	Uranium (89% ^{235}U) Nitrate Solution with Cluster of Seven Boron Carbide Absorber Rods
HEU-SOL-THERM-030	Uranium (89% ^{235}U) Nitrate Solution with Cluster of Several Boron Carbide Absorber Rods
HEU-SOL-THERM-036	Square-Pitched Lattices of Boron Carbide Absorber Rods In Uranium (89% ^{235}U) Nitrate Solutions
LEU-SOL-THERM-003	Full and Truncated Bare Spheres of 10% Enriched Uranyl Nitrate Water Solutions
LEU-SOL-THERM-004	Stacy: Water-Reflected 10%-Enriched Uranyl Nitrate Solution in a 60-cm-Diameter Cylindrical Tank
LEU-SOL-THERM-007	Stacy: Unreflected 10%-Enriched Uranyl Nitrate Solution in a 60-cm-Diameter Cylindrical Tank
LEU-SOL-THERM-016	Stacy: 28-cm-Thick Slabs of 10%-Enriched Uranyl Nitrate Solutions, Water-Reflected
LEU-SOL-THERM-017	Stacy: 28-cm-Thick Slabs of 10%-Enriched Uranyl Nitrate Solutions, Unreflected
LEU-SOL-THERM-020	Stacy: 80-cm-Diameter Cylindrical Tank of 10%-Enriched Uranyl Nitrate Solutions, Water-Reflected
LEU-SOL-THERM-021	Stacy: 80-cm-Diameter Cylindrical Tank of 10%-Enriched Uranyl Nitrate Solutions, Unreflected

Table 6.11-9 – USL Results

Trending Parameter (X)	Experiment Set	Minimum USL Over Range of Applicability	Range of Applicability
EALF (MeV)	No poison (1-10, 56-97)	0.9344	$3.43E-08 \leq x \leq 2.95E-07$
EALF (MeV)	All	0.9309	$3.43E-08 \leq x \leq 2.95E-07$
H/U-235	No poison (1-10, 56-97)	0.9401	$68.2 \leq x \leq 1437.5$
H/U-235	All	0.9359	$68.2 \leq x \leq 1437.5$

Table 6.11-10 – Benchmark Experiment Data

No	Case	k	σ_{mcnp}	σ_{bench}	σ_{total}	EALF (MeV)	H/U-235
1	HST001_C01	0.99661	0.00100	0.0060	0.0061	8.17E-08	181.8
2	HST001_C02	0.99185	0.00096	0.0072	0.0073	2.76E-07	70.6
3	HST001_C03	0.99921	0.00090	0.0035	0.0036	8.00E-08	185.7
4	HST001_C04	0.99586	0.00094	0.0053	0.0054	2.93E-07	68.2
5	HST001_C05	0.99785	0.00079	0.0049	0.0050	4.28E-08	499.4
6	HST001_C06	1.00159	0.00081	0.0046	0.0047	4.45E-08	458.8
7	HST001_C07	0.99693	0.00092	0.0040	0.0041	7.70E-08	193.3
8	HST001_C08	0.99696	0.00094	0.0038	0.0039	8.18E-08	181.8
9	HST001_C09	0.99087	0.00101	0.0054	0.0055	2.95E-07	68.2
10	HST001_C10	0.99005	0.00086	0.0054	0.0055	4.61E-08	427.4
11	HST027_C01	0.99609	0.00093	0.0046	0.0047	7.42E-08	203.6
12	HST027_C02	0.99522	0.00090	0.0043	0.0044	7.49E-08	203.6
13	HST027_C03	0.99626	0.00089	0.0037	0.0038	7.52E-08	203.6
14	HST027_C04	0.99780	0.00093	0.0037	0.0038	7.53E-08	203.6
15	HST027_C05	0.99563	0.00086	0.0044	0.0045	7.58E-08	203.6
16	HST027_C06	0.99028	0.00095	0.0043	0.0044	7.50E-08	203.6
17	HST027_C07	0.99604	0.00094	0.0038	0.0039	7.50E-08	203.6
18	HST027_C08	0.99772	0.00091	0.0035	0.0036	7.48E-08	203.6
19	HST027_C09	0.99517	0.00090	0.0039	0.0040	7.49E-08	203.6
20	HST028_C01	0.99350	0.00080	0.0023	0.0024	4.72E-08	374.6
21	HST028_C02	0.99332	0.00078	0.0034	0.0035	4.77E-08	374.6
22	HST028_C03	0.99596	0.00080	0.0026	0.0027	4.71E-08	374.6
23	HST028_C04	0.99814	0.00078	0.0028	0.0029	4.76E-08	374.6
24	HST028_C05	0.99070	0.00077	0.0031	0.0032	4.74E-08	374.6
25	HST028_C06	0.99492	0.00080	0.0023	0.0024	4.77E-08	374.6
26	HST028_C07	0.99497	0.00082	0.0038	0.0039	4.77E-08	374.6
27	HST028_C08	0.99433	0.00083	0.0027	0.0028	4.81E-08	374.6
28	HST028_C09	0.99179	0.00088	0.0049	0.0050	1.45E-07	91.5
29	HST028_C10	0.99032	0.00086	0.0053	0.0054	1.46E-07	91.5
30	HST028_C11	0.99179	0.00090	0.0051	0.0052	1.47E-07	91.5
31	HST028_C12	0.99009	0.00083	0.0046	0.0047	1.49E-07	91.5
32	HST028_C13	0.99102	0.00089	0.0058	0.0059	1.49E-07	91.5
33	HST028_C14	0.99180	0.00086	0.0046	0.0047	1.51E-07	91.5
34	HST028_C15	1.00006	0.00092	0.0064	0.0065	1.50E-07	91.5
35	HST028_C16	0.99561	0.00084	0.0052	0.0053	1.52E-07	91.5
36	HST028_C17	0.99144	0.00087	0.0066	0.0067	1.53E-07	91.5
37	HST028_C18	0.99322	0.00085	0.0060	0.0061	1.54E-07	91.5
38	HST029_C01	0.99468	0.00088	0.0066	0.0067	1.58E-07	91.5

(continued)

Table 6.11-10 – Benchmark Experiment Data

No	Case	k	σ_{mcnp}	σ_{bench}	σ_{total}	EALF (MeV)	H/U-235
39	HST029_C02	0.99722	0.00085	0.0058	0.0059	1.58E-07	91.5
40	HST029_C03	0.99112	0.00090	0.0068	0.0069	1.59E-07	91.5
41	HST029_C04	0.99158	0.00087	0.0074	0.0075	1.67E-07	91.5
42	HST029_C05	0.99602	0.00085	0.0067	0.0068	1.69E-07	91.5
43	HST029_C06	0.99484	0.00092	0.0065	0.0066	1.69E-07	91.5
44	HST029_C07	0.99381	0.00089	0.0063	0.0064	1.68E-07	91.5
45	HST030_C01	0.99405	0.00078	0.0039	0.0040	4.78E-08	374.6
46	HST030_C02	0.99786	0.00079	0.0032	0.0033	4.85E-08	374.6
47	HST030_C03	0.99465	0.00075	0.0031	0.0032	4.88E-08	374.6
48	HST030_C04	0.99533	0.00092	0.0064	0.0065	1.58E-07	91.1
49	HST030_C05	0.99334	0.00085	0.0058	0.0059	1.60E-07	91.1
50	HST030_C06	0.99430	0.00084	0.0059	0.0060	1.61E-07	91.1
51	HST030_C07	0.99458	0.00082	0.0064	0.0065	1.65E-07	91.1
52	HST036_C01	0.99355	0.00086	0.0045	0.0046	5.58E-08	302.5
53	HST036_C02	0.99779	0.00084	0.0039	0.0040	5.79E-08	302.5
54	HST036_C03	0.99834	0.00084	0.0044	0.0045	6.05E-08	302.5
55	HST036_C04	0.99971	0.00078	0.0062	0.0062	6.31E-08	302.5
56	LST003_C01	0.99621	0.00040	0.0039	0.0039	4.10E-08	770.3
57	LST003_C02	0.99383	0.00038	0.0042	0.0042	3.91E-08	877.6
58	LST003_C03	0.99926	0.00038	0.0042	0.0042	3.89E-08	897.0
59	LST003_C04	0.99292	0.00036	0.0042	0.0042	3.87E-08	913.2
60	LST003_C05	0.99641	0.00032	0.0048	0.0048	3.59E-08	1173.4
61	LST003_C06	0.99695	0.00030	0.0049	0.0049	3.57E-08	1213.1
62	LST003_C07	0.99535	0.00030	0.0049	0.0049	3.55E-08	1239.8
63	LST003_C08	0.99894	0.00027	0.0052	0.0052	3.45E-08	1411.6
64	LST003_C09	0.99697	0.00025	0.0052	0.0052	3.43E-08	1437.5
65	LST004_C01	1.00136	0.00067	0.0008	0.0010	4.17E-08	719.0
66	LST004_C29	1.00057	0.00065	0.0009	0.0011	4.08E-08	771.3
67	LST004_C33	0.99847	0.00059	0.0009	0.0011	3.96E-08	842.2
68	LST004_C34	1.00148	0.00061	0.0010	0.0012	3.88E-08	895.8
69	LST004_C46	1.00196	0.00052	0.0010	0.0011	3.82E-08	941.7
70	LST004_C51	0.99877	0.00056	0.0011	0.0012	3.78E-08	982.5
71	LST004_C54	1.00160	0.00052	0.0011	0.0012	3.73E-08	1017.5
72	LST007_C01	0.99414	0.00045	0.0009	0.0010	4.25E-08	709.2
73	LST007_C02	0.99734	0.00044	0.0009	0.0010	4.11E-08	770.0
74	LST007_C03	0.99472	0.00041	0.0010	0.0011	3.99E-08	842.2
75	LST007_C04	0.99791	0.00038	0.0011	0.0012	3.91E-08	896.0
76	LST007_C05	0.99628	0.00038	0.0011	0.0012	3.85E-08	942.2
77	LST016_C105	1.00345	0.00047	0.0013	0.0014	5.14E-08	468.7
78	LST016_C113	1.00438	0.00049	0.0013	0.0014	4.89E-08	514.2
79	LST016_C125	1.00368	0.00045	0.0014	0.0015	4.51E-08	608.4
80	LST016_C129	1.00225	0.00041	0.0014	0.0015	4.39E-08	650.2

(continued)

Table 6.11-10 – Benchmark Experiment Data (concluded)

No	Case	k	σ_{mcnp}	σ_{bench}	σ_{total}	EALF (MeV)	H/U-235
81	LST016_C131	1.00227	0.00044	0.0014	0.0015	4.26E-08	699.1
82	LST016_C140	1.00142	0.00041	0.0015	0.0016	4.17E-08	738.9
83	LST016_C196	1.00218	0.00041	0.0015	0.0016	4.11E-08	771.8
84	LST017_C104	1.00273	0.00050	0.0013	0.0014	5.15E-08	468.7
85	LST017_C122	1.00223	0.00049	0.0013	0.0014	4.94E-08	510.8
86	LST017_C123	1.00095	0.00045	0.0014	0.0015	4.52E-08	610.9
87	LST017_C126	1.00158	0.00044	0.0014	0.0015	4.39E-08	650.1
88	LST017_C130	1.00164	0.00046	0.0015	0.0016	4.27E-08	699.2
89	LST017_C147	1.00152	0.00042	0.0015	0.0016	4.20E-08	729.0
90	LST020_C01	0.99867	0.00038	0.0010	0.0011	3.78E-08	971.0
91	LST020_C02	0.99796	0.00034	0.0010	0.0011	3.69E-08	1053.9
92	LST020_C03	0.99807	0.00033	0.0012	0.0012	3.60E-08	1168.0
93	LST020_C04	0.99839	0.00031	0.0012	0.0012	3.54E-08	1239.3
94	LST021_C01	0.99672	0.00038	0.0009	0.0010	3.79E-08	971.0
95	LST021_C02	0.99767	0.00035	0.0010	0.0011	3.71E-08	1052.7
96	LST021_C03	0.99630	0.00034	0.0011	0.0012	3.61E-08	1168.0
97	LST021_C04	0.99786	0.00032	0.0012	0.0012	3.57E-08	1238.9

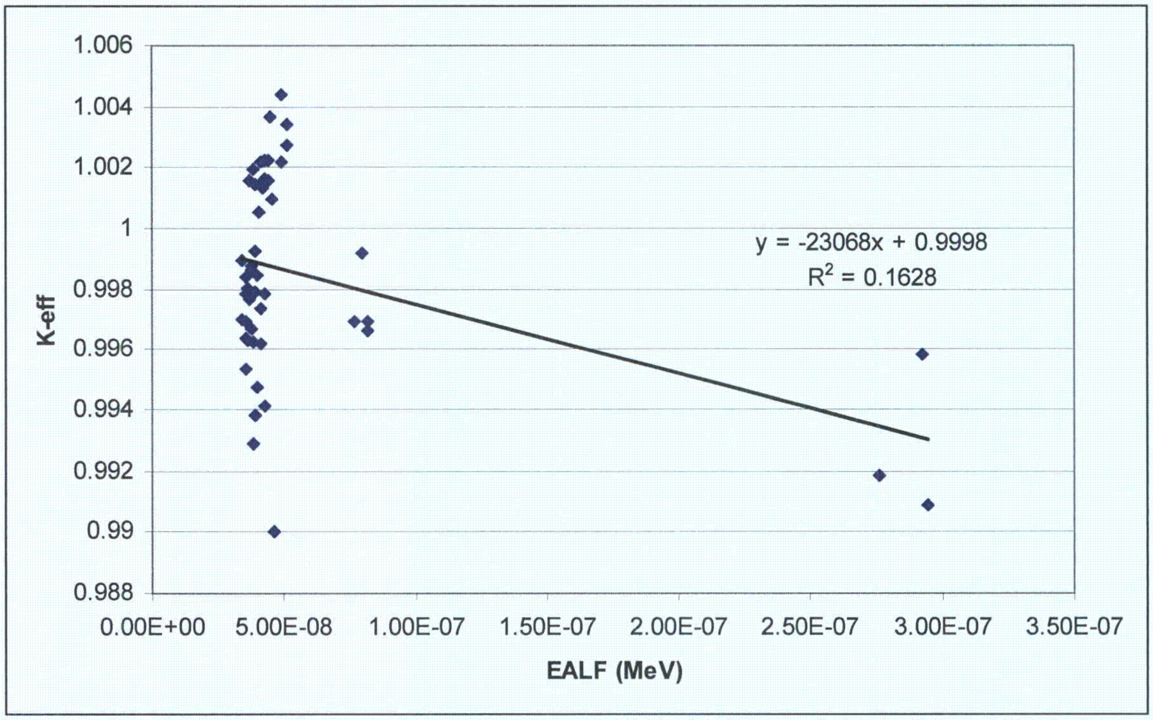

Figure 6.11-6 – Benchmark Data Trend for EALF (no poisons)

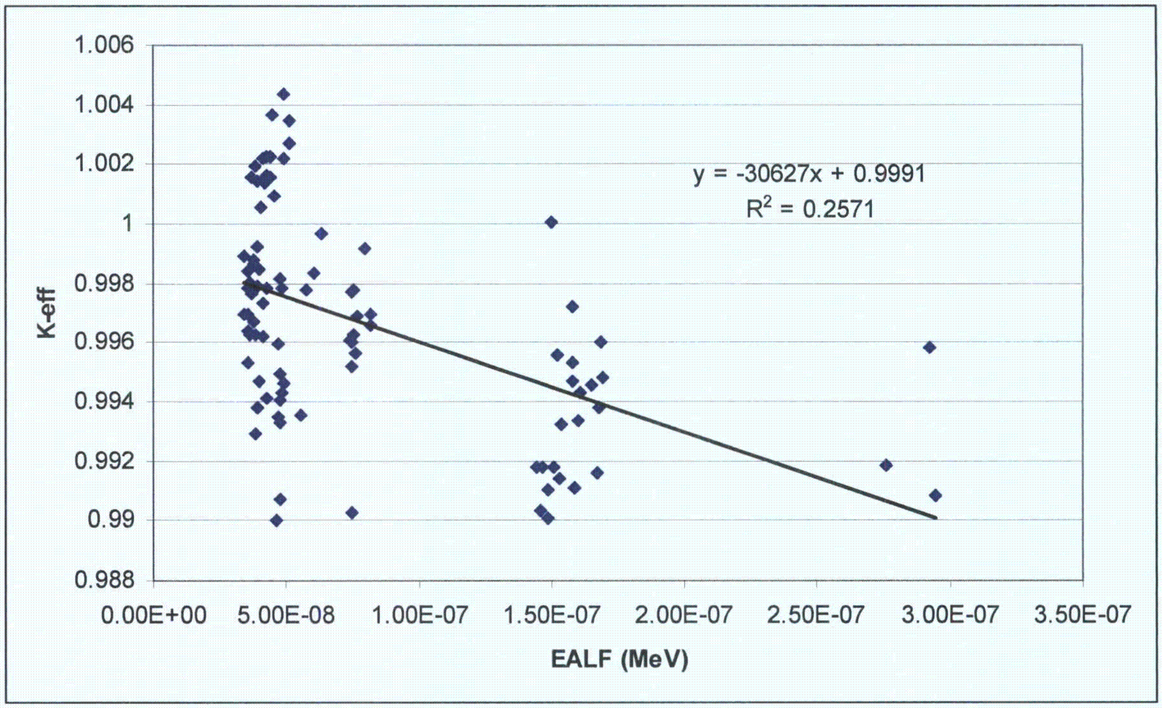

Figure 6.11-7 – Benchmark Data Trend for EALF (all)

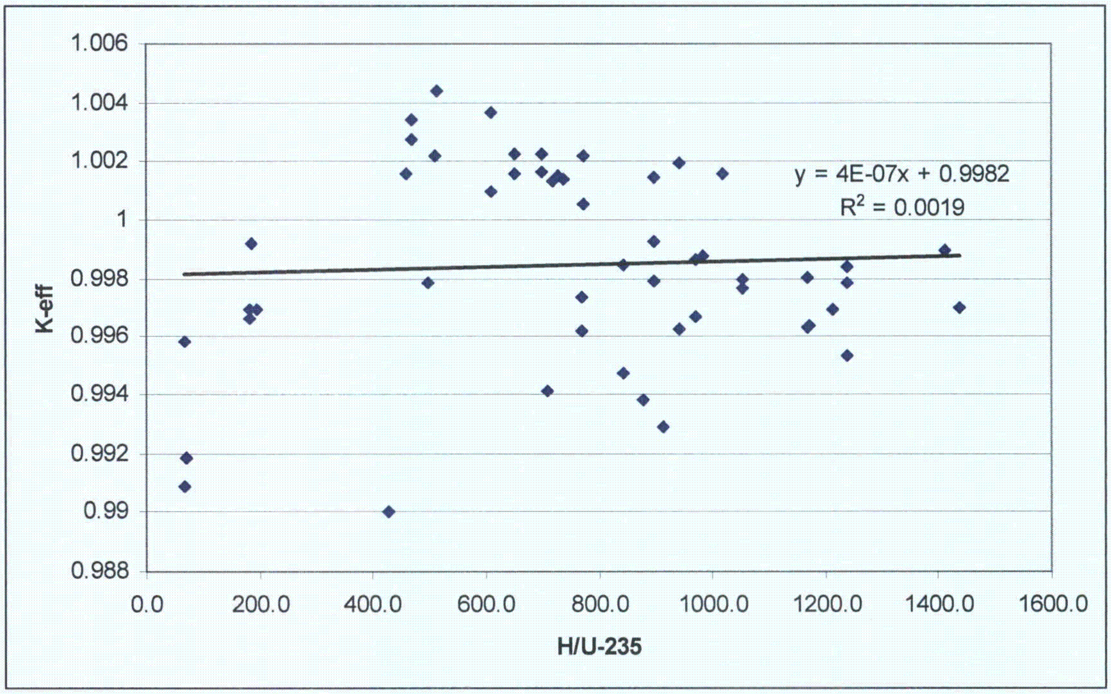

Figure 6.11-8 – Benchmark Data Trend for H/U-235 (no poisons)

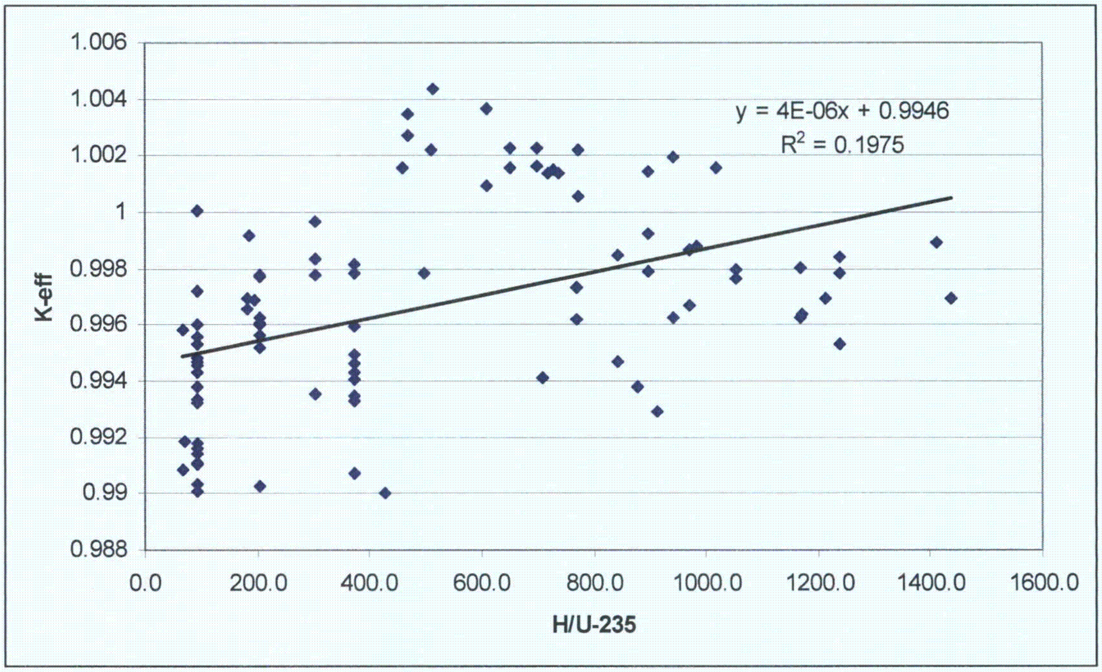

Figure 6.11-9 – Benchmark Data Trend for H/U-235 (all)

6.11.9 Sample Input Files

A sample input file (NA_HEUP_H325) is provided for the most reactive case (Case HC16).

```
ATR Package
999     0      -320:321:-322:323:-324:325                imp:n=0
900     0      310 -311 312 -313 24 -25     fill=3       imp:n=1
901     2 -1.0 (311:-310:313:-312:-24:25) 320 -321 322 -323 324 -325  imp:n=1
c
c       Universe 20: Fuel mixture with pipe
c
200     10 1.0043E-01 -26 -200                 u=20 imp:n=1 $ fuel mix
201     2 -1.0         26 -200                 u=20 imp:n=1 $ water above fuel
202     4 -7.94     200 -201                   u=20 imp:n=1 $ pipe
203     6 -0.096    201 -203 250 -251 252 -253 u=20 imp:n=1 $ insulation
204     0           203 250 -251 252 -253      u=20 imp:n=1 $ insulation to
tube
205     4 -7.94     -250:251:-252:253          u=20 imp:n=1 $ tube to inf
c
c       Universe 21: Water
c
210     2 -1.0      -204                       u=21 imp:n=1
c
c       Universe 3: Array of Packages
c
300   0    -300 301 -302 303 imp:n=1 u=3 lat=1 fill=-1:1 -1:2 0:0
             20 20 20
             20 20 20
             20 20 20
             21 20 21

24      pz  0              $ bottom of fuel
25      pz  121.92         $ top of cavity (48")
26      pz  32.5           $ top of fuel mix
c
200      cz 7.3838  $ IR pipe
201      cz 7.6581  $ OR pipe
203      cz 10.1981 $ 1" insulation
204      pz 1000    $ dummy
c
250      px  -9.6032 $ square tube
251      px   9.6032
252      py  -9.6032
253      py   9.6032
c
300      px  10.033 $ lattice surfaces/sq. tube
301      px -10.033
302      py  10.033
303      py -10.033
310      px -30.099 $ 3x4 bounds
311      px  30.099
312      py -30.099
313      py  50.165
320      px -60.579 $ outer bounds
321      px  60.579
322      py -60.579
323      py  80.645
324      pz -30.48
325      pz  152.4
```

```
m2      1001.62c  2          $ water
        8016.62c  1
mt2     lwtr.60t
m3      13027.62c 1          $ Al
m4      6000.66c   -0.08     $ SS-304
        14000.60c  -1.0
        15031.66c  -0.045
        24000.50c  -19.0
        25055.62c  -2.0
        26000.55c  -68.375
        28000.50c  -9.5
m5      1001.62c  -0.056920  $ neoprene
        6000.66c  -0.542646
c       17000.66c -0.400434
m6      13027.62c  -26.5     $ insulation material
        14000.60c  -23.4
        8016.62c   -50.2
m10    92234.69c 1.1802E-06 $ HEU fuel H=32.5 M235=400.0 100g Poly
       92235.69c 1.8410E-04
       92236.69c 6.8258E-07
       92238.69c 9.7657E-06
        1001.62c 6.6822E-02
        6000.66c 7.7125E-04
        8016.62c 3.2640E-02
c          Total 1.0043E-01
mt10    lwtr.60t
c
mode   n
kcode  2500 1.0 50 250
sdef    x=d1 y=d2  z=d3
si1     -30 30
sp1     0 1
si2     -30 50
sp2     0 1
si3     0 32.5
sp3     0 1
```

7.0 PACKAGE OPERATIONS

This section provides general instructions for loading and unloading operations of the ATR FFSC. Due to the low specific activity of neutron and gamma emitting radionuclides, dose rates from the contents of the package are minimal. As a result of the low dose rates, there are no special handling requirements for radiation protection.

Package loading and unloading operations shall be performed using detailed written procedures. The operating procedures developed by the user for the loading and unloading activities shall be performed in accordance with the procedural requirements identified in the following sections.

The closure handle must be rendered inoperable for lifting and tiedown during transport per 10 CFR §71.45. To satisfy this requirement either the closure handle may be removed or the cover installed. If the closure handle cover is utilized it may be stored with the closure assembly in the installed position. When stored with the closure assembly the cover must be removed prior to the package loading and unloading operations and may be reinstalled following installation of the closure. The installation of the closure handle cover is presented in Section 7.1.4, *Preparation for Transport.*

7.1 Package Loading

7.1.1 Preparation for Loading

Prior to loading the ATR FFSC, the packaging is inspected to ensure that it is in unimpaired physical condition. The packaging is inspected for:

- Damage to the closure locking mechanism including the spring. Inspect for missing hardware and verify the locking pins freely engage/disengage with the package body mating features.
- Damage to the closure lugs and interfacing body lugs. Inspect lugs for damage that precludes free engagement of the closure with the body.
- Deformation of the inner shell (payload cavity) that precludes free entry/removal of the payload.
- Deformed threads or other damage to the fasteners or body of the loose fuel plate basket.
- Damage to the spring plunger, or ball lock pins and end spacers, as applicable, or body of the fuel handling enclosure.

Acceptance criteria and detailed loading procedures derived from this section are specified in user written procedures. These user procedures are specific to the authorized content of the package and inspections ensure the packaging complies with Appendix 1.3.2, *Packaging General Arrangement Drawings.*

Defects that require repair shall be corrected prior to shipping in accordance with approved procedures consistent with the quality program in effect.

7.1.2 Loading of Contents - ATR Fuel Assembly

1. Remove the closure by depressing the spring-loaded pins and rotating the closure 45° to align the closure locking tabs with the mating cut-outs in the body. Remove the closure from the body.
2. Remove the fuel handling enclosure if present in the payload cavity.
3. Prior to loading, visually inspect the ATR fuel handling enclosure for damage, corrosion, and missing hardware to ensure compliance with Appendix 1.3.2, *Packaging General Arrangement Drawings*.
4. Open the ATR fuel handling enclosure lid and place a fuel element into the holder with the narrow end of the fuel element facing the bottom side of the fuel handling enclosure. As a property protection precaution, the fuel element may optionally be inserted into a plastic bag prior to placement in the fuel handling enclosure.
    a. To open the fuel handling enclosure, release the lid by pulling on the spring plunger located at each end and rotate the lid about the hinged side.
    b. To close the fuel handling enclosure, rotate the lid to the closed position, pull the spring plunger located at each end to allow the lid to fully close, align then release the spring plungers with the receiving holes, gently lift the lid to confirm no movement and that the spring plungers are in the locked position.
5. Insert the fuel handling enclosure into the package.
6. Depress the package closure spring-loaded pins, insert closure onto package body by aligning the closure locking tabs with the mating cut-outs in the body, and rotate the closure to the locked position. Release the spring-loaded pins so that they engage with the mating holes in the package body. Observe the pins to ensure they are in the locked position as illustrated in Figure 7.1-1. The closure is fully locked when both locking pins are compressing the sleeve between the locking pin handle and the closure body.

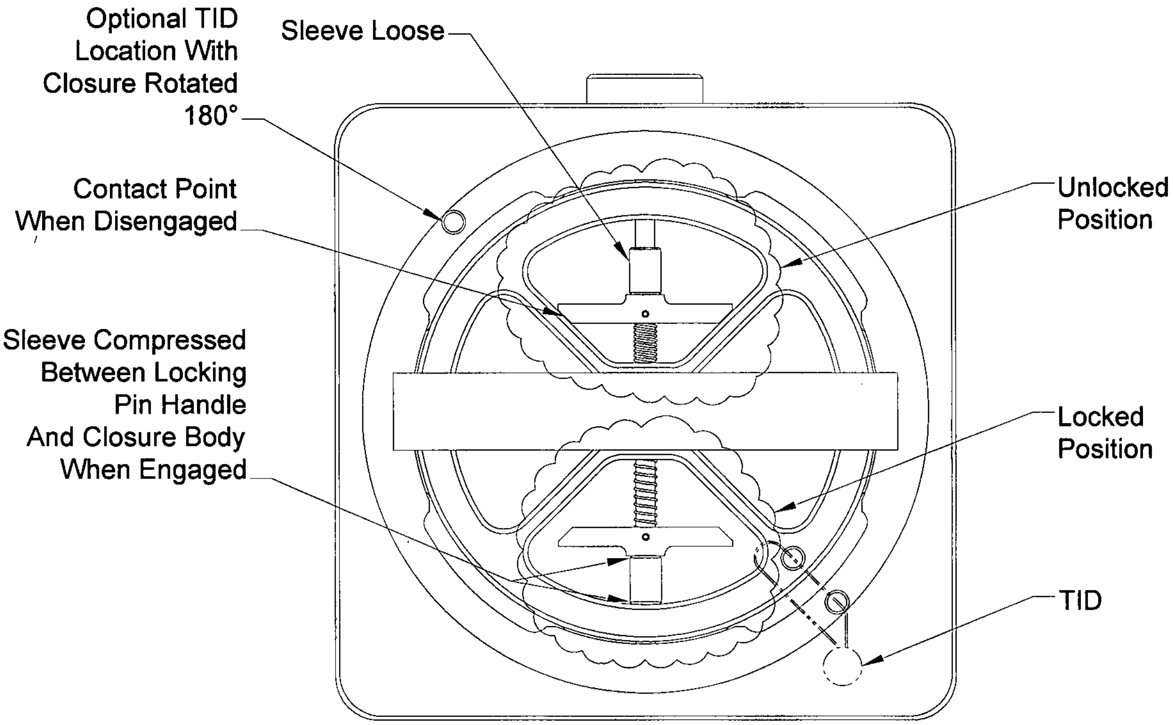

Figure 7.1-1 - Closure Locking Positions

7.1.3 Loading of Contents - Loose ATR Fuel Plates

1. Remove the closure by depressing the spring-loaded pins and rotating the closure 45° to align the closure locking tabs with the mating cut-outs in the body. Remove the closure from the body.
2. Remove the fuel plate basket if present in the payload cavity.
3. Prior to loading, visually inspect the loose fuel plate basket for damage, corrosion, and missing hardware/fastening devices to ensure compliance with Appendix 1.3.2, *Packaging General Arrangement Drawings*.
4. Open the loose fuel plate basket by removing the 8 wing nut fasteners securing each half of the basket.
5. Place the fuel plates into one half of the loose fuel plate basket
    a. Ensure the combined weight of the loose fuel plates and optional dunnage is 20 lbs or less. The loose fuel plates may only be ATR fuel plates.
    b. Ensure the combined fissile mass of the loose fuel plates does not exceed 600 g uranium-235.
    c. Flat and curved fuel plates may not be mixed in the same basket.
    d. As a property protection precaution, the fuel plates may optionally be inserted into a plastic bag prior to placement in the fuel plate basket.

   e. Dunnage plates may also be included with the loose fuel plates to reduce any gaps with the basket cavity as a property protection precaution. The dunnage plates may be any aluminum alloy and any size deemed appropriate.

6. Close the fuel plate basket and verify the basket fasteners are installed and finger tight.
   a. With one half of the basket loaded, carefully place the second half over the fuel plates and match the fastener holes.
   b. Insert the 8 spade head screws through the holes and secure with corresponding wing nut (washer optional).
   c. Tighten the 8 wing nut fasteners finger tight.
   d. Visually check the 4 hex head screws located in the center of the basket to verify that they have not loosened. In the event the screws appear to be loose, tighten the fasteners to drawing requirements.
7. Insert the loose fuel plate basket into the package.
8. Depress the package closure spring-loaded pins, insert closure onto package body by aligning the closure locking tabs with the mating cut-outs in the body, and rotate the closure to the locked position. Release the spring-loaded pins so that they engage with the mating holes in the package body. Observe the pins to ensure they are in the locked position as illustrated in Figure 7.1-1. The closure is fully locked when both locking pins are compressing the sleeve between the locking pin handle and the closure body.

7.1.4 Loading of Contents – MIT, MURR, or RINSC Fuel Assembly

The loading of MIT, MURR, and RINSC fuel elements is procedurally identical.

1. Remove the closure by depressing the spring-loaded pins and rotating the closure 45° to align the closure locking tabs with the mating cut-outs in the body. Remove the closure from the body.
2. Remove the fuel handling enclosure if present in the payload cavity.
3. Prior to loading, visually inspect the fuel handling enclosure for damage, corrosion, and missing hardware to ensure compliance with Appendix 1.3.2, *Packaging General Arrangement Drawings*.
4. Open (disassemble) the fuel handling enclosure and place a fuel element into one enclosure half. Ensure that the MIT, MURR, or RINSC fuel element is only used with the corresponding MIT, MURR, or RINSC fuel handling enclosure. As a property protection precaution, the fuel element may optionally be inserted into a plastic bag prior to placement in the fuel handling enclosure.
   a. To open the fuel handling enclosure, remove the two ball lock pins securing each end spacer. Slide each end spacer from the center enclosure halves allowing the enclosure halves to freely come apart.
   b. To close the fuel handling enclosure, with one enclosure half loaded, carefully place the second enclosure half over the fuel element and align the circular ends. Slide one end spacer over the circular end and insert the ball lock pin through the end

spacer and enclosure halve alignment holes. Ensure the ball lock pin is in the locked position by observing the pin and locking mechanism protruding from the back side. Repeat with the second end spacer and ensure it is locked in the same manner.

5. Insert the fuel handling enclosure into the package.
6. Depress the package closure spring-loaded pins, insert closure onto package body by aligning the closure locking tabs with the mating cut-outs in the body, and rotate the closure to the locked position. Release the spring-loaded pins so that they engage with the mating holes in the package body. Observe the pins to ensure they are in the locked position as illustrated in Figure 7.1-1. The closure is fully locked when both locking pins are compressing the sleeve between the locking pin handle and the closure body.

7.1.5 Loading of Contents – Small Quantity Payloads (except RINSC)

The loading of small quantity payloads is procedurally identical.

1. Remove the closure by depressing the spring-loaded pins and rotating the closure 45° to align the closure locking tabs with the mating cut-outs in the body. Remove the closure from the body.
2. Remove the fuel handling enclosure if present in the payload cavity.
3. Prior to loading, visually inspect the fuel handling enclosure for damage, corrosion, and missing hardware to ensure compliance with Appendix 1.3.2, *Packaging General Arrangement Drawings.*
4. Open (disassemble) the small quantity fuel handling enclosure and place the payload into one enclosure half. As a property protection precaution, the payload may optionally be inserted into a plastic bag prior to placement in the fuel handling enclosure. Optionally add dunnage in the form of aluminum sheets, plates, or shapes if desired, up to a maximum weight of the loaded small quantity fuel handling enclosure of 50 lbs. Miscellaneous steel or aluminum fasteners may be used with the optional dunnage. Neoprene rub strips, 1/8 inch thick, may also be used as a property protection precaution. Neoprene rub strips may be used between the SQFHE and the small quantity payloads and/or between the optional aluminum dunnage and the small quantity payloads. The 1/8 inch neoprene rub strips shall not be stacked in more than two layers between the small quantity payload and any interior face of the SQFHE.
    a. To open the fuel handling enclosure, remove the two ball lock pins securing each end spacer. Slide each end spacer from the center enclosure halves allowing the enclosure halves to freely come apart.
    b. To close the fuel handling enclosure, with one enclosure half loaded, carefully place the second enclosure half over the fuel element, loose fuel plates, or foils and align the circular ends. Slide one end spacer over the circular end and insert the ball lock pin through the end spacer and enclosure halve alignment holes. Ensure the ball lock pin is in the locked position by observing the pin and locking mechanism protruding from the back side. Repeat with the second end spacer and ensure it is locked in the same manner.
5. Insert the fuel handling enclosure into the package.

6. Depress the package closure spring-loaded pins, insert closure onto package body by aligning the closure locking tabs with the mating cut-outs in the body, and rotate the closure to the locked position. Release the spring-loaded pins so that they engage with the mating holes in the package body. Observe the pins to ensure they are in the locked position as illustrated in Figure 7.1-1. The closure is fully locked when both locking pins are compressing the sleeve between the locking pin handle and the closure body.

7.1.6 Preparation for Transport

1. Install the closure handle cover by aligning the cover against the handle and insert the fastener through the holes in the cover and behind the handle as illustrated in Figure 7.1-2. Once installed, the cover renders the handle inoperable for lifting or tiedown during transport. Option: In lieu of installing the cover, the closure handle may be removed as a method of rendering the handle inoperable for lifting or tiedown during transport.
2. Install the tamper indicating device between the posts on the package closure and body.
3. Perform a survey of the dose rates and levels of non-fixed (removable) radioactive contamination per 49CFR §173.441 and 49CFR §173.443, respectively. The contamination measurements shall be taken in the most appropriate locations to yield a representative assessment of the non-fixed contamination levels.
4. Complete the necessary shipping papers in accordance with Subpart C of 49 CFR §172.
5. Ensure that the package markings are in accordance with 10 CFR §71.85(c) and Subpart D of 49 CFR §172. Package labeling shall be in accordance with Subpart E of 49CFR §172. Package placarding, for either single package transport or the racked configuration, shall be in accordance with Subpart F of 49 CFR §172.
6. Transfer the package to the conveyance and secure the package(s).

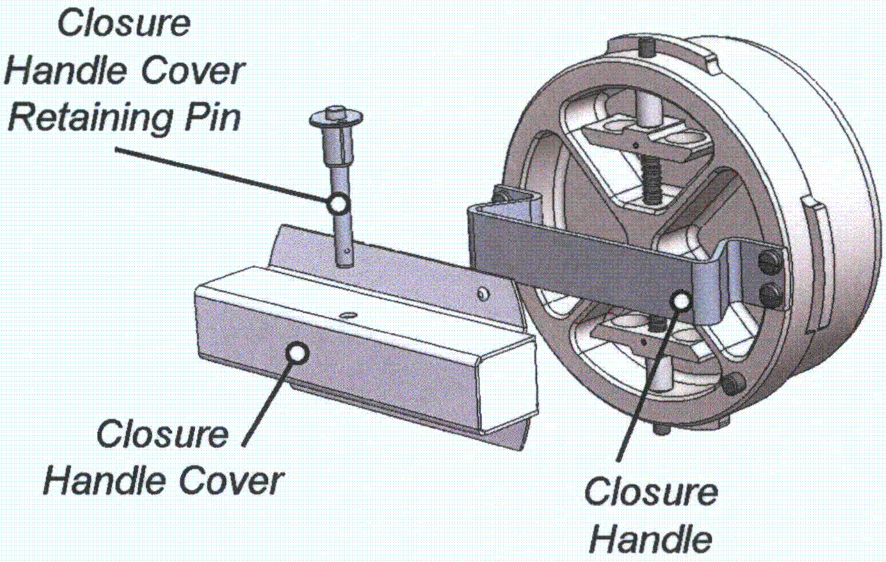

Figure 7.1-2 – Closure Handle Cover Installation

7.2 Package Unloading

7.2.1 Receipt of Package from Conveyance

Radiation and contamination surveys shall be performed upon receipt of the package and the package shall be inspected for damage as required by and in accordance with the user's personnel protection or ALARA program. In addition, the tamper indicating device (TID) shall be inspected. A missing TID or indication of damage to a TID is a Safeguards and Security concern. Disposition of such an incident is beyond the scope of this SAR.

7.2.2 Removal of Contents

1. Remove tamper indicating device.
2. Remove the package closure by depressing the spring-loaded pins and rotating the closure 45° to align the closure locking tabs with the mating cut-outs in the body. Remove the closure from the body.
3. Remove the payload container.
4. Open the payload container (fuel handling enclosure or loose fuel plate basket) and remove the contents.
    a. Open the ATR fuel handling enclosure by releasing the spring plunger located at each end and rotate the lid about the hinged side.
    b. Open the loose fuel plate basket by removing the 8 wing nut fasteners securing each half of the basket.

   c. Open the MIT, MURR, RINSC, or small quantity payload fuel handling enclosure by removing the two ball lock pins and sliding the end spacers from each end of the enclosure halves.

5. Close the fuel handling enclosure lid or loose fuel plate basket as appropriate. If required, return the empty payload container to the package.
   a. To close the ATR fuel handling enclosure, rotate the lid to the closed position, pull the spring plunger located at each end to allow the lid to fully close, align then release the spring plungers with the receiving holes, gently lift the lid to confirm no movement and that the spring plungers are in the locked position.
   b. To close the loose fuel plate basket, place each half of the basket together and align the fastener holes. Insert the 8 spade head screws through the holes and secure with corresponding wing nut (washer optional). Tighten each wing nut finger tight.
   c. To close the MIT, MURR, RINSC, or small quantity payload fuel handling enclosure, place each enclosure half together and align the circular ends. Slide one end spacer over the circular end and insert the ball lock pin through the end spacer and enclosure halve alignment holes. Ensure the ball lock pin is in the locked position by observing the pin and locking mechanism protruding from the back side. Repeat with the second end spacer and ensure it is locked in the same manner.
6. Depress the package closure spring-loaded pins, insert closure onto package body by aligning the closure locking tabs with the mating cut-outs in the body, and rotate the closure to the locked position. Release the spring-loaded pins so that they engage with the mating holes in the package body. Observe the pins to ensure they are in the locked position as illustrated in Figure 7.1-1. The closure is fully locked when both locking pins are compressing the sleeve between the locking pin handle and the closure body.

7.3 Preparation of Empty Package for Transport

Empty packages are prepared and transported per the guidelines of 49 CFR §173.428. The packaging is inspected to ensure that it is in an unimpaired condition and is securely closed.

Any labels previously applied in conformance with subpart E of 49CFR §172 are removed, obliterated, or covered and the “Empty” label prescribed in 49 CFR §172.450 is affixed to the packaging.

7.4 Other Operations

This section does not apply.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 Acceptance Tests

Per the requirements of 10 CFR §71.85, the inspections and tests to be performed prior to first use of the package are described in this section.

8.1.1 Visual Inspections and Measurements

All packaging dimensions, tolerances, general notes, materials of construction, and assembly shall be examined in accordance with the requirements delineated on the drawings in Appendix 1.3.2, *Packaging General Arrangement Drawings*. Source inspections and final release of the packaging will be performed, verifying the quality characteristics were inspected and that the packaging is acceptable. Any characteristic that is out of specification shall be reported and dispositioned in accordance with the quality assurance program in effect.

8.1.1.1 Compression Spring

The compression spring is a component of the closure locking system that maintains the locking pin in the closed position. The compression spring shall be procured to Stock Precision Engineered Components (SPEC) catalog number C0360-035-1120 specification, or equivalent, which includes the following:

- Material shall be approximately 0.035 inch diameter stainless steel wire.
- The nominal outside diameter of the spring shall be approximately 0.36 inches.
- The free length of the spring shall be approximately 1.12 inches.
- The solid height of the spring shall be approximately 0.33 inches.
- The spring shall have a 4.77 (-.1, +.5) lb load at a load length of approximately 0.55 inches.
- The spring rate shall be 8.33 (-.1, +.5) lbs/in.

8.1.1.2 Roll Pin

The roll pin is a component of the closure locking system that maintains the locking pin in the closed position. The roll pin shall be procured to Stock Drive Products/Sterling Instrument (SDP/SI) catalog number A9Y35-0324 specification, or equivalent, which includes the following:

- Material shall be stainless steel.
- The free diameter of the roll pin shall be between 0.099 to 0.103 inches.
- The length of the roll pin shall be approximately 0.75 inches

8.1.1.3 Insulating Blanket

The ceramic fiber insulating blanket is a component of the body and closure assemblies used to reduce heat transfer during thermal events. The insulating blanket shall be procured to Unifrax Durablanket S 6 lb/ft^3 specification, or equivalent, which includes the following:

- The material shall be comprised of inorganic ceramic fibers.
- The nominal thickness shall be 0.5 (-0, +.2) inches.
- The nominal density shall be 6 (-15%, +30%) lb/ft^3.
- The specific heat shall be 0.25 Btu/lb$_m$-°F minimum.
- The thermal conductivity shall be 0.145 Btu/hr-ft-°F or less at 1200°F.

8.1.2 Weld Examinations

All welds shall be examined in accordance with the requirements delineated on the drawings in Appendix 1.3.2, *Packaging General Arrangement Drawings.* Visual examinations are performed in accordance with AWS D1.6[1], Section 6 for stainless steel, AWS D1.2[2], for aluminum, and penetrant examinations are performed under procedures written to ASTM E165-02, *Standard Test Method for Liquid Penetrant Examination.*

8.1.3 Structural and Pressure Tests

The packaging does not retain pressure and no pressure testing is required prior to use.

8.1.4 Leakage Tests

The packaging contains no seals or containment boundaries that require leakage rate testing.

8.1.5 Component and Material Tests

No component or material tests are required for this packaging.

8.1.6 Shielding Tests

The packaging does not contain any biological shielding. Shielding tests are not required.

8.1.7 Thermal Tests

The material thermal properties utilized in Chapter 3.0, *Thermal* are nominal. However, the thermal analyses in which these values are used are consistently conservative for the Normal

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[1] ANSI/AWS D1.6:1999, *Structural Welding Code – Stainless Steel*, American Welding Society (AWS).

[2] ANSI/AWS D1.2:2003, *Structural Welding Code – Aluminum*, American Welding Society.

Conditions of Transport (NCT) and Hypothetical Accident Condition (HAC). Therefore, specific acceptance tests for material thermal properties are not required or performed.

8.1.8 Miscellaneous Tests

No other acceptance tests are necessary for the packaging.

8.2 Maintenance Program

This section describes the maintenance program used to ensure continued performance of the packaging. The packaging is maintained consistent with a 10 CFR 71 subpart H QA program. Packagings that do not conform to the license drawings are removed from service until they are brought back into compliance. Repairs are performed in accordance with approved procedures and consistent with the quality assurance program in effect.

8.2.1 Structural and Pressure Tests

There are no structural or pressure tests that are necessary to ensure continued performance of the packaging.

8.2.2 Leakage Rate Tests

No leakage rate tests are necessary to ensure continued performance of the packaging.

8.2.3 Component and Material Tests

There is no predetermined replacement schedule for any packaging components and there are no items that would be expected to wear or become damaged during normal usage. The items identified in this section are routinely used during operations and shall be visually inspected prior to each use. Damaged components shall be repaired or replaced prior to further use.

8.2.3.1 Packaging Body and Closure

The closure assembly locking pin spring shall be visually inspected and replaced if it becomes damaged or otherwise fails to function properly (Drawing 60501-10, Item 20, of Appendix 1.3.2, *Packaging General Arrangement Drawings*).

The index lug screws and corresponding tap, or optional wire insert, shall be visually inspected for deformed or stripped threads prior to installation of the screws (Drawing 60501-10, Items 3 and 16).

8.2.3.2 ATR Fuel Handling Enclosure

The spring plunger shall be visually inspected and replaced if it becomes damaged or otherwise fails to function properly (Drawing 60501-30, Item 6, of Appendix 1.3.2, *Packaging General Arrangement Drawings*).

8.2.3.3 Loose Fuel Plate Basket

All threaded components shall be visually inspected as they are installed for deformed or stripped threads (Drawing 60501-20, Items 2, 3, 4, and 5 of Appendix 1.3.2, *Packaging General Arrangement Drawings*).

8.2.3.4 MIT Fuel Handling Enclosure

The ball lock pin shall be visually inspected and replaced if it becomes damaged or otherwise fails to function properly (Drawing 60501-40, Item 4, of Appendix 1.3.2, *Packaging General Arrangement Drawings*).

8.2.3.5 MURR Fuel Handling Enclosure

The ball lock pin shall be visually inspected and replaced if it becomes damaged or otherwise fails to function properly (Drawing 60501-50, Item 4, of Appendix 1.3.2, *Packaging General Arrangement Drawings*).

8.2.3.6 RINSC Fuel Handling Enclosure

The ball lock pin shall be visually inspected and replaced if it becomes damaged or otherwise fails to function properly (Drawing 60501-60, Item 5, of Appendix 1.3.2, *Packaging General Arrangement Drawings*).

8.2.3.7 Small Quantity Payload Fuel Handling Enclosure

The ball lock pin shall be visually inspected and replaced if it becomes damaged or otherwise fails to function properly (Drawing 60501-70, Item 4, of Appendix 1.3.2, *Packaging General Arrangement Drawings*).

8.2.4 Thermal Tests

No thermal tests are necessary to ensure continued performance of the packaging.

8.2.5 Miscellaneous Tests

No miscellaneous tests are required to ensure continued performance of the packaging.

9.0 QUALITY ASSURANCE

The Advanced Test Reactor Fresh Fuel Shipping Container (ATR FFSC) is anticipated to be used by both U.S. Department of Energy (DOE) and U.S. Nuclear Regulatory Commission (NRC) licensed users. 10 CFR §71.101, *Quality assurance requirements*, requires each licensee's quality assurance program to be approved by the Commission before any use of the package for shipments.

NRC licensed users shall follow their NRC approved quality assurance program and be identified by the Commission as an authorized user. For DOE and its subcontractors, this chapter defines the approved Quality Assurance (QA) requirements and methods of compliance applicable to the ATR FFSC package.

The ATR FFSC package described in this SAR is used to transport unirradiated single fuel elements. The QA requirements for packagings are described in Subpart H of 10 CFR Part 71 (10 CFR 71). Subpart H is an 18-criteria QA program based on ANSI/ASME NQA-1. Guidance for QA programs for packaging is provided by NRC Regulatory Guide 7.10[1]. The DOE QA requirements for the use of 10CFR71 certified packagings are described in DOE Order 460.1B[2].

The ATR FFSC packaging is designed and built for Idaho National Laboratory (INL). Procurement, design, fabrication, assembly, testing, maintenance, repair, modification, and use of the ATR FFSC package are all done under QA programs that meet all applicable NRC and DOE QA requirements.

The DOE Idaho Operations Office approved QA program is implemented for all Nuclear Safety activities. Compliance with NRC and DOT packaging and transportation requirements is mandated by DOE Order 460.1B.

This document establishes the programmatic requirements for site-wide implementation and serves as the basis for INL quality assurance program acceptability. It is designed such that implementation of the full scope of requirements as stated in DOE Orders 414.1C, *Quality Assurance* and 460.1B *Packaging and Transport Safety*, constitutes compliance to nuclear safety quality assurance criteria required by 10 CFR 830, Subpart A, *Nuclear Safety Management Quality Assurance Requirements*.

A detailed discussion of the QA program which governs ATR FFSC packaging operations is presented on the following pages to demonstrate compliance with 10 CFR 71, Subpart H.

9.1 Organization

9.1.1 ATR FFSC Project Organization

This section identifies the organizations involved and describes the responsibilities of and interactions between these organizations.

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[1] U.S. Nuclear Regulatory Commission, Regulatory Guide 7.10, *Establishing Quality Assurance Programs for Packaging Used in transport of Radioactive Material, Revision 2*, March 2005.

[2] U.S. Department of Energy Order 460.1B, *Packaging and Transportation Safety*, 4-4-03.

9.1.1.1 Idaho National Laboratory (INL)

INL Contractor Management has overall responsibility for successfully accomplishing activities. Management provides the necessary planning, organization, direction, control, resources, and support to achieve their defined objectives. Management is responsible for planning, performing, assessing, and improving the work.

INL Contractor Management is responsible for establishing and implementing policies, plans, and procedures that control the quality of work, consistent with requirements.

INL Contractor Management responsibilities include:

- Ensuring adequate technical and QA training is provided for personnel performing activities.
- Ensuring compliance with all applicable regulations, DOE orders and requirements, and applicable federal, state, and local laws.
- Ensuring personnel adhere to procedures for the generation, identification, control, and protection of QA records.
- Exercising authority and responsibility to STOP unsatisfactory work such that cost and schedule do not override environmental, safety, or health considerations.
- Developing, implementing, and maintaining plans, policies, and procedures that implement the Quality Assurance Program Description (QAPD).
- Identifying, investigating, reporting, and correcting quality problems.
- Achieving and maintaining quality in their respective areas. (Quality achievement is the responsibility of those performing the work. Quality achievement is verified by persons or organizations not directly responsible for performing the work.)
- Empowering employees by delegating authority and decision making to the lowest appropriate level in the organization.

9.1.1.2 Members of the INL Contractor Workforce (at all levels)

- Implement the organization's procedures to meet QA requirements.
- Comply with administrative and technical work control requirements.
- Identify and report issues to the responsible manager for resolution and continuous improvement for the work being performed.
- Seek, identify, and recommend work methods or procedural changes that would improve quality and efficiency.

9.1.1.3 INL Contractor Quality Assurance Management

The INL Contractor QA Management provides independent oversight of all quality related activities.

9.2 Quality Assurance Program

9.2.1 General

The INL Contractor's QA Program defines and establishes requirements for programs, projects, and activities.

The INL Contractor QA program is developed and maintained through an ongoing process that selectively applies QA criteria as appropriate to the function or work activity being performed. Applicable QA criteria consist of the following:

- Title 10 CFR Subpart 71, Packaging and Transportation of Radioactive Material
- Title 10 CFR 830.120, Quality Assurance Requirements
- ASME NQA-1-2000, Quality Assurance Requirements for Nuclear Facility Application
- DOE O 414.1C, Quality Assurance
- DOE O 461.1B, Packaging and Transport Safety
- DOE G 414.1-1A, Management Assessment and Independent Assessment

The INL Contractor QA Program is inclusive of applicable requirements from criteria noted above and addresses the following for this SAR:

- Organization
- Quality Assurance Program
- Implementation of the QA Program
- Personnel Qualification and Training
- Quality Improvement
- Documents
- Records
- Work Process
- Procurement
- Inspection and Testing
- Management Assessments
- Independent Assessment

The INL Contractor QA Director is responsible for ensuring implementation of requirements as defined within the QA program and requirements of this SAR, including design, procurement, fabrication, inspection, testing, maintenance, and modifications. Procurement documents are to reflect applicable requirements from 10 CFR 71, Subpart H, ASME NQA-1 and the QA program.

INL Contractor Quality Management assesses the adequacy and effectiveness of the QA program to ensure effective implementation inclusive of objective evidence and independent verification, where appropriate, to demonstrate that specific project and regulatory objectives are achieved.

All INL Contractor personnel and contractors are responsible for effective implementation of the QA program within the scope of their responsibilities. INL Contract packaging and quality engineers are responsible for inspection and testing and are to be qualified, as appropriate, through minimum education and/or experience, formal training, written examination and/or other demonstration of skill and proficiency. Objective evidence of qualifications and capabilities are to be maintained as required. As appropriate, the initial employee training should consist of the following:

- General employee indoctrination
- Program indoctrination
- QA program training
- Applicable NRC and DOT requirements.

Note: Only packaging engineers and Quality Engineers with training and/or experience in applicable NRC and DOT requirements and Safety Analysis Reports (SARs) can plan or determine the application of internal INL processes to ensure compliance with Chapter 9 and this SAR.

9.2.2 ATR FFSC-Specific Program

The ATR FFSC was designed and tested as described in Chapter 2, *Structural Evaluation,* of this SAR. QA requirements are invoked in the design, procurement, fabrication, assembly, testing, maintenance, and use of the packaging to ensure established standards are maintained. Items and activities to be controlled and documented are described in this chapter.

9.2.3 QA Levels

Materials and components of the ATR FFSC are designed, procured, fabricated, assembled, and tested using a graded approach under a 10 CFR 71, Subpart H equivalent QA Program and Regulatory Guide (RG) 7.10. Under that program, the categories critical to safety are established for all ATR FFSC packaging components. These defined quality categories consider the impact to safety if the component were to fail or perform outside design parameters.

9.2.3.1 Graded Quality Category A Items:

These items and services are critical to safe operation and include structures, components, and systems whose failure could directly result in a condition adversely affecting public health and safety. The failure of a single item could cause loss of primary containment leading to a release of radioactive material beyond regulatory requirements, loss of shielding beyond regulatory requirements, or unsafe geometry compromising criticality control.

9.2.3.2 Graded Quality Category B Items:

These items and services have a major impact on safety and include structures, components, and systems whose failure or malfunction could indirectly result in a condition adversely affecting public health and safety. The failure of a Category B item, in conjunction with the failure of an additional item, could result in an unsafe condition.

9.2.3.3 Graded Quality Category C Items:

These items and services have a minor impact on safety and include structures, components, and systems whose failure or malfunction would not significantly reduce the packaging effectiveness and would not be likely to create a situation adversely affecting public health and safety.

9.2.3.4 Application of Quality Categories

The design effort and requirements for a QA program are interrelated and are developed simultaneously. To ensure the development of a QA program in which the application of QA requirements is commensurate with their safety significance, engineering personnel perform a systematic analysis of each component, structure, and system to assess the consequences to the health and safety of the public and the environment that would result from malfunction or failure of such items. This engineering assessment is initiated during the design process and performed in accordance with approved procedures. Establishment of the engineering basis during the design process enables a uniform, consistent application of QA requirements during fabrication, use, and maintenance of packaging.

A logical sequence is established to identifying realistic QA requirements would involve (1) classifying each structure, system, and component (2) grouping items classified as important to safety into quality categories; and (3) specifying the applicable level of QA effort for each category.

The Design Authority (DA) identifies the critical characteristics when they identify design attributes necessary to preserve the safety support function. As necessary, the DA also ensures critical characteristics are included in this SAR by the identification of SSCs and their QA Category designations. Additionally, this SAR includes the safety function, design, and operational attributes necessary for reliable performance. The DA applies design criteria to the design, operation, and maintenance of each critical SSC including recommended codes and standards, as required by RG 7.10. QA requirements shall be applied as necessary to assure the SSCs can perform their function.

The package-specific safety documents identify systems, structures, and components (SSCs) that are important to the safety functions for transportation. As appropriate, the hazard analysis and accident scenarios in the safety basis documents help identify SSCs that must function in order to prevent or mitigate these events. These SSCs are then identified using the classification system found in the NRC QA Category system provided in NRC Regulatory Guide (RG) 7.10. The categories as defined in RG 7.10, and listed below, are analogous to Safety Class, Safety Significant, and General Service that are identified for facility SSCs.

Upon custodianship of the ATR FFSC packages by INL, functional classifications will be used for site operations and activities related to the ATR FFSC. The method of classification is documented as follows.

Quality Category A:

Critical impact on safety and associated functional requirements – items or components whose single failure or malfunction could directly result in an unacceptable condition of containment, shielding, or nuclear criticality control. This is functionally equivalent to “safety class” designation used for nuclear facility safety.

Quality Category B:

Impact on safety and associated functional requirement – components whose failure or malfunction in conjunction with one other independent failure or malfunction could result in an unacceptable condition of containment, shielding, or nuclear criticality control. This is functionally equivalent to “safety significant” designation used for nuclear facility safety.

Quality Category C:

> Minor impact on safety and associated functional requirements – components whose failure or malfunction would not result in an unacceptable condition of containment, shielding, or nuclear criticality control regardless of other single failures. This is functionally equivalent to designations given to components that do not meet "safety class or safety significant" criteria used for nuclear facility safety.

The tabulation of this classification process is provided in Tables 9.2-1 and 9.2-2.

Table 9.2-1 - QA Categories for Design and Procurement of ATR FFSC Subcomponents

Component	Subcomponent	Category
Body Assembly	Outer Square Tube	A
	Inner Round Tube	A
	Bottom End Plate	A
	Closure End Plate	A
	Stiffening Ribs	A
	Thermal Shield Sheet	B
	Insulation	B
	Tamper Indicating Device Dowel Pin	C
	Index Lug Screw	B
	Weld Wire	A
Closure Assembly	Outer Plate, Closure	A
	Inner Plate (Insulation Pocket)	B
	Closure Locking Hardware (Pin, Handle, Spring, etc.)	B
	Insulation	B
	Tamper Indicating Device Dowel Pin	C
	Weld Wire	A
Fuel Handling Enclosure	Aluminum Body Sheets	C
	Aluminum End Plates	C
	Fasteners and Hardware	C
Loose Fuel Plate Basket	Machined Aluminum Body	A
	Screws, Wing Nuts, and Hex Nuts	C

Table 9.2-2 - Level of Quality Assurance Effort per QA Element

10CFR71 Subpart H QA Element	Level of QA Effort	QA Category		
		A	B	C
1 (71.103)	**QA Organization (¶9.1)**			
	• Organizational structure and authorities defined	X	X	
	• Responsibilities defined	X	X	
	• Reporting levels established	X	X	
	• Management endorsement	X	X	
2 (71.105)	**QA Program (¶9.2)**			
	• Implementing procedures in place	X	X	
	• Trained personnel	X	X	
	• Activities controlled	X	X	
3 (71.107)	**Design (¶9.3)**			
	• Control of design process and inputs	X	X	X
	• Control of design input	X	X	X
	• Software validated and verified	X	X	
	• Design verification controlled	X	X	
	• Quality category assessment performed	X	X	
4 (71.109)	**Procurement Document Control (¶9.4)**			
	• Complete traceability	X	X	
	• Qualified suppliers list	X	X	
	• Commercial grade dedicated items acceptable	X	X	
	• Off-the-shelf item			X
5 (71.111)	**Instructions, Procedures, and Drawings (¶9.5)**			
	• Must be written and controlled	X	X	
	• Qualitative or quantitative acceptance criteria	X	X	
6 (71.113)	**Document Control (¶9.6)**			
	• Controlled issuance	X	X	
	• Controlled changes	X	X	
	• Procurement documents	X	X	X

10CFR71 Subpart H QA Element	Level of QA Effort	QA Category		
		A	B	C
7 (71.115)	**Control of Purchased Material, Equipment, and Services (¶9.7)**			
	• Source evaluation and selection plans	X	X	
	• Evidence of QA at supplier	X	X	
	• Inspections at supplier, as applicable	X	X	
	• Receiving inspection	X	X	
	• Objective proof that all specifications are met	X	X	
	• Audits/surveillances at supplier facility, as applicable	X	X	
	• Incoming inspection for damage only			X
8 (71.117)	**Identification and Control of Material, Parts, and Components (¶9.8)**			
	• Positive identification and traceability of each item	X	X	
	• Identification and traceable to heats, lots, or other groupings	X	X	
	• Identification to end use drawings, etc.			X
9 (71.119)	**Control of Special Processes (¶9.9)**			
	• All welding, heat treating, and nondestructive testing done by qualified personnel	X	X	
	• Qualification records and training of personnel	X	X	
	• No special processes			X
10 (71.131)	**Inspection (¶9.10)**			
	• Documented inspection to all specifications required	X	X	
	• Examination, measurement, or test of material or processed product to assure quality	X	X	
	• Process monitoring if quality requires it	X	X	
	• Inspectors must be independent of those performing operations	X	X	X
	• Qualified inspectors only	X	X	X
	• Receiving inspection	X	X	X
11 (71.123)	**Test Control (¶9.11)**			
	• Written test program	X	X	
	• Written test procedures for requirements in the package approval	X	X	
	• Documentation of all testing and evaluation	X	X	
	• Representative of buyer observes all supplier acceptance tests if specified in procurement documents	X		
	• No physical tests required			X

10CFR71 Subpart H QA Element	Level of QA Effort	QA Category		
		A	B	C
12 (71.125)	**Control of Measuring and Test Equipment (¶9.12)**			
	• Tools, gauges, and instruments to be in a formal calibration program	X	X	
	• Only qualified inspectors	X	X	
	• No test required			X
13 (71.127)	**Handling, Storage, and Shipping (¶9.13)**			
	• Written plans and procedures required	X	X	
	• Routine handling			X
14 (71.129)	**Inspection, Test, and Operating Status (¶9.14)**			
	• Individual items identified as to status or condition	X	X	
	• Stamps, tags, labels, etc., must clearly show status	X	X	X
	• Visual examination only			X
15 (71.131)	**Nonconforming Materials, Parts, or Components (¶9.15)**			
	• Written program to prevent inadvertent use	X	X	X
	• Nonconformance to be documented and closed	X	X	X
	• Disposal without records			X
16 (71.133)	**Corrective Action (¶9.16)**			
	• Objective evidence of closure for conditions adverse to quality	X	X	X
17 (71.135)	**QA Records (¶9.17)**			
	• Design and use records	X	X	
	• Results of reviews, inspections, test, audits, surveillance, and materials analysis	X	X	
	• Personnel qualifications	X	X	
	• Records of fabrication, acceptance, and maintenance retained throughout the life of package	X	X	X
	• Record of package use kept for three years after shipment	X	X	
	• All records managed by written plans for retention and disposal	X	X	
	• Procurement records	X	X	X
18 (71.137)	**Audits (¶9.18)**			
	• Written plan of periodic audits	X	X	
	• Lead auditor certified	X	X	

9.3 Package Design Control

As required by the INL Contractor's Quality Program, design processes shall be established and implemented to satisfy the requirements of the QAPD. These requirements are to be in accordance with:

- 10 CFR 830.122(f), *Criterion 6 – Performance/Design*[3]
- DOE Order 414C, CRD, Attachment 1, 2.b.(2), *Criterion 6 – Design.*

Requirements are implemented to ensure processes and procedures are in place to ensure design features of packaging systems are appropriately translated into specifications, drawings, procedures, and instructions. Design control measures are established for criticality, shielding, thermal, and structural analyses under both normal and accident condition analyses as defined in NRC regulations.

The INL Contractor is responsible for maintaining the package and this SAR. The design documents (e.g., drawings and specifications) are controlled by incorporation into this SAR, which will be reviewed and approved by the NRC.

The design of the ATR FFSC was performed under an NRC-approved QA Program as required by INL. Design inputs consist of an INL statement of work, applicable DOE orders, national standards, specifications, and drawings.

Procedures control design activities to ensure the following occur:

- Design activities are planned, controlled, and documented.
- Regulatory requirements, design requirements, and appropriate quality standards are correctly translated into specifications, drawings, and procedures.
- Competent engineering personnel, independent of design activities, perform design verification. Verification may include design reviews, alternate calculations, or qualification testing. Qualification tests are conducted in accordance with approved test programs or procedures.
- Design interface controls are established and adequate.
- Design, specification, and procedure changes are reviewed and approved in the same manner as the original issue. In a case where a proposed design change potentially affects licensed conditions, the Quality Assurance Program shall provide for ensuring that licensing considerations have been reviewed and are complied with or otherwise reconciled by amending the license.
- Design errors and deficiencies are documented, corrected and corrective action to prevent recurrence is taken.
- Design organization(s) and their responsibilities and authorities are delineated and controlled through written procedures.

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[3] DOE, Code of Federal Regulations, 10 CFR 830.122, *Quality Assurance Criteria*, U.S. Department of Energy, Washington, D.C., 2006.

Materials, parts, equipment, and processes essential to the function of items that are important to safety are selected and reviewed for suitability of application.

Computer programs used for design analysis or verification are controlled in accordance with approved procedures. These procedures provide for verification of the accuracy of computer results and for the assessment and resolution of reported computer program errors.

9.4 Procurement Document Control

As required by the INL Contractor Quality Program, procurement/acquisition processes and related document control activities are established and implemented to satisfy requirements of the QAPD. Requirements are to be in accordance with:

- 10 CFR 830.122(d), *Criterion 4 – Management/Documents and Records*
- 10 CFR 830.122(g), *Criterion 7 – Performance/Procurement*
- DOE Order 414C, CRD, Attachment 1, 2.a.(4), *Criterion 4 – Documents and Records*
- DOE Order 414C, CRD, Attachment 1, 2.b.(3), *Criterion 7 – Procurement*
- DOE Guide 414.1-3, *Suspect/Counterfeit Items.*

Processes and procedures are in place to ensure appropriate levels of quality are achieved in procurement of material, equipment, and services. Quality Level and Quality Category designations assigned by the Design Authority grade the application of QA requirements for procurements based on radiological material at risk, mission importance, safety of workers, public, environment, and equipment, and other differentiating criteria. Implementing procedures provide the logic process for determining Quality Levels used in procurement of equipment and subcontracting of services. Procedures ensure processes address document preparation and document control, and records management to meet regulatory requirements. Procurement records are kept in a manner that satisfies regulatory requirements.

INL Contractor procurement actions for packaging and spare parts shall be controlled. Contracts and Purchase Orders for packaging and spare parts shall require the selected vendor to implement and maintain an NRC approved 10CFR71, Subpart H QA Program.

Implementing procedures ensure procurement documents are prepared to clearly define applicable technical and quality assurance requirements including codes, standards, regulatory requirements and commitments, and contractual requirements. These documents serve as the principal documents for procurement of structures, systems and components, and related services for use in design, fabrication, maintenance and operation, inspection and testing of storage and/or transportation systems. Procedures ensure purchased material, components, equipment, and services adhere to applicable requirements. Furthermore:

- The assignment of quality requirements through procurement documents is administered and controlled.
- Procurement activities are performed in accordance with approved procedures delineating requirements for preparation, review, approval, and control of procurement documents. Revisions to procurement documents are reviewed and approved by the same cognizant groups as the original document.

- Quality requirements are included in quality-related purchase orders as applicable to the scope of the procurement referencing 10 CFR 71, Subpart H or other codes and standards, as appropriate.
- INL Contractor procurement documents will require suppliers to convey appropriate quality assurance program requirements to sub-tier suppliers.
- INL Contractor procurement documents will include provisions that suppliers either maintain or supply those QA records which provide evidence of conformance to the procurement documents. Additionally, procurement documents shall designate the supplier documents required for submittal to INL for review and/or approval.
- INL shall maintain the right of access to supplier facilities and performance of source surveillance and/or audit activities, as applicable. A statement to this effect is to be included in procurement documents.
- INL shall require the Supplier to warrant that all items furnished under the Contract are genuine (i.e., new, not refurbished, not counterfeit) and match the quality, test reports, markings and/or fitness for intended use as required by the Contract. Any materials furnished as part of the Contract which has been previously found to be suspect/counterfeit by the government or other duly recognized agency, shall not be used.

Procurement documents shall also address the applicability of the provisions of 10 CFR 21 for the Reporting of Defects and Noncompliances.

9.5 Instructions, Procedures, and Drawings

As required by the INL Contractor Quality Program, instructions, procedures, and drawing work processes and applicable quality improvement activities shall be established and implemented to satisfy the requirements of the QAPD. These requirements are to be in accordance with:

- 10 CFR 830.122(c*), Criterion 3 – Management/Quality Improvement*
- 10 CFR 830.122(e), *Criterion 5 – Performance/Work Processes*
- DOE Order 414C, CRD, Attachment 1, 2.a.(3), *Criterion 3 – Quality Improvement*
- DOE Order 414C, CRD, Attachment 1, 2.b.(1), *Criterion 5 – Work Processes.*

Requirements are implemented to ensure processes and procedures are in place that achieve quality objectives and ensure appropriate levels of quality and safety are applied to critical components of packaging and transportation systems utilizing a graded approach. The program shall ensure processes and procedures in place to identify and correct problems associated with transportation and packaging activities.

Implementing procedures shall be established to ensure that methods for complying with each of the applicable criteria of 10 CFR 71, Subpart H, as applicable, for activities affecting quality during design, fabrication, inspection, testing, use and maintenance are specified in instructions, procedures, and/or drawings. In addition:

- Instructions, procedures, and drawings shall be developed, reviewed, approved, utilized, and controlled in accordance with the requirements of approved procedures. These instructions, procedures, and drawings shall include appropriate quantitative and qualitative acceptance criteria.

- Changes to instructions, procedures and drawings, are developed, reviewed, approved, utilized and controlled using the same requirements and controls as applied to the original documents.
- Compliance with these approved instructions, procedures and drawings is mandatory for INL personnel while performing activities affecting quality.

Specific activities by INL regarding preparation of packaging for use, repair, rework, maintenance, loading contents, unloading contents, and transport, must be accomplished in accordance with written and approved instructions, procedures, specifications, and/or drawings. These documents must identify appropriate inspection and hold points and emphasize those characteristics that are important to safety and quality. Transportation package procedures are to be developed and reviewed by technical and quality staff and shall be approved by appropriate levels of management.

9.5.1 Preparation and Use

Activities concerning loading and shipping are performed in accordance with written operating procedures developed by the user and approved by the package custodian. Packaging first-time usage tests, sequential loading and unloading operations, technical constraints, acceptance limits, and references are specified in the procedures. A pre-planned and documented inspection will be conducted to ensure that each loaded package is ready for delivery to the carrier.

9.5.2 Operating Procedure Changes

Changes in operating procedures that affect the process must be approved at the same supervisory level as the initial issue.

9.5.3 Drawings

Controlled drawings are shown in Appendix 1.3.2, *Packaging General Arrangement Drawings*, of this SAR. Implementation of design revisions is discussed in SAR Section 9.3, *Package Design Control.*

9.6 Document Control

As required by the INL Contractor Quality Program, document control activities shall be established and implemented to satisfy the requirements of the QAPD. These requirements are to be in accordance with:

- 10 CFR 830.122(d), *Criterion 4 – Management/Documents and Records*
- DOE Order 414C, CRD, Attachment 1, 2.a.(4), *Criterion 4 – Documents and Records.*

Requirements are implemented to ensure processes and procedures are in place to address document, document control, and for the management of records. Records (engineering, test reports, user instructions, etc.) must be maintained in a manner that conforms to regulatory requirements.

Document control activities related to the design, procurement, fabrication, and testing of ATR FFSC components; and SAR preparation shall be controlled.

Implementing procedures shall be established to control the issuance of documents that prescribe activities affecting quality and to assure adequate review, approval, release, distribution, use of documents and their revisions. Controlled documents may include, but are not limited to:

- Design specifications
- Design and fabrication drawings
- Special process specifications and procedures
- QA Program Manuals/Plans, etc.
- Implementing procedures
- Test procedures
- Operational test procedures and data.

Requirements shall ensure changes to documents, which prescribe activities affecting quality, are reviewed and approved by the same organization that performed the initial review and approval, or by qualified responsible organizations. Documents that prescribe activities affecting quality are to be reviewed and approved for technical adequacy and inclusion of appropriate quality requirements prior to approval and issuance. Measures are taken to ensure that only current documents are available at the locations where activities affecting quality are performed prior to commencing the work.

Package users are responsible for establishment, development, review, approval, distribution, revision, and retention of their documents. Documents requiring control, the level of control, and the personnel responsibilities and training requirements are to be identified.

Packaging documents to be controlled include as a minimum:

- Operating procedures
- Maintenance procedures
- Inspection and test procedures
- Loading and unloading procedures
- Preparation for transport procedures
- Repair procedures
- Specifications
- Fabrication records
- Drawings of packaging and components
- SAR and occurring supplements.

Revisions are handled in a like manner as the original issue. Only the latest revisions must be available for use.

Documentation received from the supplier for each package must be filed by package serial number. These documents are to be retained in the user's facility.

9.7 Control Of Purchased Material, Equipment And Services

As required by the INL Contractor Quality Program, the control of purchased material, equipment and services and applicable quality improvement activities shall be established and implemented to satisfy the requirements of the QAPD. These requirements are to be in accordance with:

- 10 CFR 830.122(c), *Criterion 3 – Management/Quality Improvement*
- 10 CFR 830.122(g), *Criterion 7 – Performance/Procurement*
- 10 CFR 830.122(h), *Criterion 8 – Performance/Inspection and Acceptance Testing*
- DOE Order 414C, CRD, Attachment 1, 2.b.(3), *Criterion 3 – Quality Improvement*
- DOE Order 414C, CRD, Attachment 1, 2.b.(3), *Criterion 7 – Procurement*
- DOE Order 414C, CRD, Attachment 1, 2.b.(4), *Criterion 8 – Inspection and Acceptance Testing.*

Requirements are implemented to ensure processes and procedures are in place to ensure appropriate inspections and tests are applied prior to acceptance or use of the packaging or component, and to identify the status of packaging items, components, etc. Requirements shall ensure processes and procedures are in place such that appropriate levels of quality are achieved in the procurement of material, equipment, and services. Quality Level and Quality Category designations by the Design Authority are used to grade the application of QA requirements of procurements based on radiological material at risk, mission importance, safety of workers, public, environment, and equipment, and other differentiating criteria. Requirements shall ensure processes and procedures in place to identify and correct problems associated with transportation and packaging activities.

Activities related to the control of purchased material, equipment and services shall be controlled. Control of purchased material, equipment, and services consist of the following elements:

- Implementing procedures shall be established to assure that purchased material, equipment and services conform to procurement documents.
- Procurement documents shall be reviewed and approved by authorized personnel for acceptability of proposed suppliers based on the quality requirements of the item/activity being purchased.
- As required, audits and/or surveys are conducted to determine supplier acceptability. These audits/surveys are based on one or all of the following criteria: the supplier's capability to comply with the requirements of 10 CFR 71, Subpart H that are applicable to the scope of work to be performed; a review of previous records to establish the past performance of the supplier; and/or a survey of the supplier's facilities and review of the

supplier's QA Program to assess adequacy and verify implementation of quality controls consistent with the requirements being invoked.

- Qualified personnel shall conduct audits and surveys. Audit/survey results are to be documented and retained as Quality Assurance Records. Suppliers are re-audited and/or re-evaluated at planned intervals to verify that they continue to comply with quality requirements and to assess the continued effectiveness of their QA Program. Additionally, interim periodic evaluations are to be performed of supplier quality activities to verify implementation of their QA Program.
- Suppliers are required to provide objective evidence that items or services provided meet the requirements specified in procurement documents. Items are properly identified to appropriate records that are available to permit verification of conformance with procurement documents. Any procurement requirements not met by suppliers shall be reported to INL Contractor Quality Management for assessment of the condition. These conditions are reviewed by technical and quality personnel to assure that they have not compromised the quality or service of the item.
- Periodic surveillance of supplier in-process activities is performed as necessary, to verify supplier compliance with the procurement documents. When deemed necessary, the need for surveillance is noted in approved quality or project planning documents. Surveillances are to be performed and documented in accordance with approved procedures. Personnel performing surveillance of supplier activities are to be trained and qualified in accordance with approved procedures.
- Quality planning for the performance of source surveillance, test, shipping and/or receiving inspection activities to verify compliance with approved design and licensing requirements, applicable 10 CFR 71 criteria, procurement document requirements, or contract specifications is to be performed in accordance with approved procedures.
- For commercial "off-the-shelf" items, where specific quality controls appropriate for nuclear applications cannot be imposed in a practical manner, additional quality verification shall be performed to the extent necessary to verify the acceptability and conformance of an item to procurement document requirements. When dedication of a commercial grade item is required for use in a quality-related application, such dedication shall be performed in accordance with approved procedures.

To ensure compliance with procurement requirements, control measures shall include verification of supplier capability and verification of item or service quality. Procurements of ATR FFSC components are required to be placed with pre-qualified and selected vendors. The vendor's QA Plan must address the requirements of 10 CFR 71, Subpart H and defined requirements. A graded approach is used based on the QA Levels established in Table 9.2-2.

The approach used to control the procurement of items and services must include the following:

- Source evaluation and selection
- Evaluation of objective evidence of quality furnished by the supplier
- Source inspection
- Audit
- Examination of items or services upon delivery or completion.

9.8 Identification And Control Of Material, Parts And Components

As required by the INL Contractor Quality Program, activities concerning the identification and control of material, parts, and components shall be established and implemented to satisfy the requirements of QAPD. These requirements are to be in accordance with:

- 10 CFR 830.122(e), *Criterion 5 – Performance/Work Processes*
- 10 CFR 830.122(g), *Criterion 7 – Performance/Procurement*
- 10 CFR 830.122(h), *Criterion 8 – Performance/Inspection and Acceptance Testing*
- DOE Order 414C, CRD, Attachment 1, 2.b.(1), *Criterion 5 – Work Processes*
- DOE Order 414C, CRD, Attachment 1, 2.b.(3), *Criterion 7 – Procurement*
- DOE Order 414C, CRD, Attachment 1, 2.b.(4), *Criterion 8 – Inspection and Acceptance Testing.*

Requirements are implemented to ensure processes and procedures are in place that achieve quality objectives and ensure appropriate levels of quality and safety are applied to critical components of packaging and transportation systems utilizing a graded approach. The program also ensures processes and procedures are in place such that appropriate inspections and tests are applied prior to acceptance or use of the packaging or component, and to identify the status of packaging items, and components. The program shall ensure processes and procedures are in place to ensure appropriate levels of quality are achieved in the procurement of material, equipment, and services.

Activities related to the identification and control of material, parts and components shall be controlled. The requirements for identification and control of material, parts, and components consist of the following elements:

- Implementing procedures are established to identify and control materials, parts, and components. These procedures assure identification of items by appropriate means during fabrication, installation, and use of the items and prevent the inadvertent use of incorrect or defective items.
- Requirements for identification are established during the preparation of procedures and specifications.
- Methods and location of identification are selected to not adversely affect the quality of the item(s) being identified.

- Items having limited shelf or operating life are controlled to prevent their inappropriate use.

Control and identification must be maintained either directly on the item or within documents traceable to the item to ensure that only correct and acceptable items are used. When physical identification is not practical, other appropriate means of control must be established such as bagging, physical separation, or procedural control. Each packaging unit shall be assigned a unique serial number after fabrication or purchase. All documentation associated with subsequent storage, use, maintenance, inspection, acceptance, etc., must refer to the assigned serial number. Verification of acceptance status is required prior to use. Items that are not acceptable must be controlled accordingly. Control of nonconforming items is addressed in Section 9.15, *Nonconforming Parts, Materials, or Components.*

Each ATR FFSC package will be conspicuously and durably marked with information identifying the package owner, model number, unique serial number, and package gross weight, in accordance with 10 CFR 71.85(c).

Replacement parts must be identified to ensure correct application. Minute items must be individually packaged with the package marked with the part identification and traceability information.

9.9 Control Of Special Processes

As required by the INL Contractor Quality Program, activities for the control of special processes shall be established and implemented to satisfy the requirements of the QAPD. These requirements are to be in accordance with:

- 10 CRF 830.122(b), *Criterion 2 – Management/Personnel Training and Qualifications*
- 10 CFR 830.122(e), *Criterion 5 – Performance/Work Processes*
- 10 CFR 830.122(g), *Criterion 7 – Performance/Procurement*
- DOE Order 414C, CRD, Attachment 1, 2.a.(2), *Criterion 2 - Personnel Training and Qualifications*
- DOE Order 414C, CRD, Attachment 1, 2.b.(1), *Criterion 5 – Work Processes*
- DOE Order 414C, CRD, Attachment 1, 2.b.(3), *Criterion 7 – Procurement.*

Requirements will be implemented to ensure only trained and qualified personnel perform transportation and packaging activities. The program shall ensure processes and procedures are in place that achieve quality objectives and ensure appropriate levels of quality and safety are applied to critical components of packaging and transportation systems utilizing a graded approach.

Activities related to the control of special processes shall be controlled. The requirements for control of special processes consist of the following elements:

- Implementing procedures shall be established to control special processes used in the fabrication and inspection of storage/transport systems. These processes may include welding, non-destructive examination, or other special processes as identified in procurement documents.

- Special processes are performed in accordance with approved procedures.
- Personnel who perform special processes shall be trained and qualified in accordance with applicable codes, standards, specifications, and/or other special requirements. Records of qualified procedures and personnel are to be maintained and kept current by the organization that performs the special processes.

Package users are responsible to ensure special processes for welding and nondestructive examination of the ATR FFSC during fabrication, use, and maintenance are controlled. Equipment used in conduct of special processes must be qualified in accordance with applicable codes, standards, and specifications. Special process operations must be performed by qualified personnel and accomplished in accordance with written process sheets or procedures with recorded evidence of verification when applicable. Qualification records of special process procedures, equipment, and personnel must be maintained.

Welders, weld procedures, and examination personnel are to be qualified in accordance with the appropriate articles of ASME BPVC, Section IX, "Welding and Brazing Qualifications";[4] and ASME BPVC, Section V, "Nondestructive Examination."[5]

Special processes for QA Level A and B items must be performed by qualified personnel in accordance with documented and approved procedures. Applicable special processes performed by an outside supplier such as welding, plating, anodizing, and heat treating, which are controlled by the suppliers' quality program, are reviewed and/or witnessed in accordance with procurement requirements.

9.10 Internal Inspection

As required by the INL Contractor Quality Program, internal inspection activities shall be established to satisfy the requirements of the QAPD. These requirements are to be in accordance with:

- 10 CRF 830.122(b), *Criterion 2 – Management/Personnel Training and Qualifications*
- 10 CFR 830.122(h), *Criterion 8 – Performance/Inspection and Acceptance Testing*
- DOE Order 414C, CRD, Attachment 1, 2.a.(2), *Criterion 2 - Personnel Training and Qualifications*
- DOE Order 414C, CRD, Attachment 1, 2.b.(4), *Criterion 8 – Inspection and Acceptance Testing.*

Requirements are implemented to ensure only trained and qualified personnel perform transportation and packaging activities. The program shall ensure processes and procedures are in place to ensure appropriate inspections and tests are applied prior to acceptance or use of the packaging or component, and to identify the status of packaging items, components, etc.

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[4] ASME, 2004, American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section IX, *Welding and Brazing Qualifications*, American Society of Mechanical Engineers, New York, NY

[5] ASME, 2004, American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section V, *Nondestructive Examination*, American Society of Mechanical Engineers, New York, NY

Activities related to internal inspection shall be controlled. The program requirements for control of internal inspection consist of the following elements:

- Implementing procedures shall be established to assure that inspection or surveillance is performed to verify that materials, parts, processes, or other activities affecting quality conform to documented instructions, procedures, specifications, drawings, and/or procurement documents.
- Personnel performing inspection and surveillance activities shall be trained and qualified in accordance with written approved procedures.
- Inspections and surveillances are to be performed by individuals other than those who performed or supervised the subject activities.
- Inspection or surveillance and process monitoring are both required where either one, by itself, will not provide assurance of quality.
- Modifications and/or repairs to and replacements of safety-related and important-to-safety structures, systems, and components are inspected in accordance with the original design and inspection requirements or acceptable alternatives.
- Mandatory hold points, inspection equipment requirements, acceptance criteria, personnel qualification requirements, performance characteristics, variable and/or attribute recording instructions, reference documents, and other requirements are considered and included, as applicable, during inspection and surveillance planning.

9.10.1 Inspections During Fabrication

Specific inspection criteria are incorporated into the drawings for the ATR FFSC packaging. Inspection requirements for fabrication are divided into two responsible areas that document that an accepted ATR FFSC package conforms to tested and certified design criteria. These two areas are:

- In-process inspections performed by the fabricator.
- Independent surveillance of fabrication activities performed by individuals acting on behalf of the purchaser.

The vendor (fabricator) is required to submit Manufacturing/Fabrication Plans prior to the start of fabrication for approval by the customer. These plans shall be used as a tool for establishing witness and hold points. A review for compliance with procurement documents is normally performed as part of the surveillance function at the vendor's facility. The plans shall define how fabrications and inspections are to be performed, processes to be engaged. Inspections must be documented and records delivered in individual data packages accompanying the package in accordance with the procurement specification.

Independent surveillance activities will be performed by qualified personnel selected with approval of the customer.

9.10.2 Inspections During Initial Acceptance and During Service Life

Independent inspections are performed upon receipt of the ATR FFSC packaging prior to first usage (implemented by package user procedures) and on an annual basis. Post-loading inspections are also performed prior to shipment. Inspection to be implemented by the package user (by qualified independent inspection personnel) must include the following:

- Acceptance – Ensure compliance with procurement documents. Per Chapter 8, *Acceptance Tests and Maintenance Program* of this SAR, perform (as applicable) first-time-usage inspections, and weld examinations.
- Operation – Verify proper assembly and verify that post-load leak testing (if applicable) is carried out as discussed in Chapter 7, *Package Operations*, of this SAR.
- Maintenance – Ensure adequate packaging maintenance to ensure that performance is not impaired as discussed in Chapter 8, *Acceptance Tests and Maintenance Program* of this SAR.
- Final – Verify proper contents, assembly, marking, shipping papers, and implementation of any special instructions.

9.11 Test Control

As required by the INL Contractor Quality Program, test control activities shall be established and implemented to satisfy the requirements of the QAPD. These requirements are to be in accordance with:

- 10 CFR 830.122(e), *Criterion 5 – Performance/Work Processes*
- DOE Order 414C, CRD, Attachment 1, 2.b.(1), *Criterion 5 – Work Processes.*

Requirements are implemented to ensure processes and procedures are in place that achieve quality objectives and ensure appropriate levels of quality and safety are applied to critical components of packaging and transportation systems utilizing a graded approach.

Activities related to test control shall be controlled. The requirements for test control consist of the following elements:

- Implementing procedures shall be established to assure that required proof, acceptance, and operational tests, as identified in design or procurement documents, are performed and appropriately controlled.
- Test personnel shall have appropriate training and shall be qualified for the level of testing which they are performing. Personnel shall be qualified in accordance with approved, written instructions, procedures, and/or checklists.
- Tests are performed by qualified personnel in accordance with approved, written instructions, procedures, and/or checklists. Test procedures are to contain or reference the following information, as applicable:
  - Acceptance criteria contained in the applicable test specifications, or design and procurement documents.
  - Instructions for performance of tests, including environmental conditions.

  - Test prerequisites such as test equipment, instrumentation requirements, personnel qualification requirements, fabrication, or operational status of the items to be tested.
  - Provisions for data recording and records retention.
- Test results are to be documented and evaluated to ensure that acceptance criteria have been satisfied.
- Tests to be conducted after modifications, repairs, or replacements of safety-related and important-to-safety structures, systems, or components are to be performed in accordance with the original design and testing requirements or acceptable alternatives.

Tests are required when it is necessary to demonstrate that an item or process will perform satisfactorily. Test procedures must specify the objectives of the tests, testing methods, required documentation, and acceptance criteria. Tests to be conducted by vendors at vendor facilities must be specified in procurement documents. Personnel conducting tests, test equipment, and procedures must be qualified and records attesting to qualification retained.

9.11.1 Acceptance and Periodic Tests

- The fabricator must supply QA documentation for the fabrication of each ATR FFSC packaging in accordance with applicable drawings, specifications, and/or other written requirements.
- The package user must ensure required ATR FFSC packaging inspections and tests are performed prior to first usage.
- Periodic testing, as applicable, will be performed to ensure the ATR FFSC packaging performance has not deteriorated with time and usage. The requirements for the periodic tests are given in the Chapter 8, *Acceptance Tests and Maintenance Program* of this SAR. The results of these tests are required to be documented and maintained with the specific packaging records by the package user.

9.11.2 Packaging Nonconformance

Packaging that does not meet the inspection criteria shall be marked or tagged as nonconforming, isolated, and documented in accordance with Section 9.15, *Nonconforming Parts, Materials, or Components*. The packaging must not be used for shipment until the nonconformance report has been properly dispositioned in accordance with Section 9.15.

9.12 Control Of Measuring And Test Equipment

As required by the INL Contractor Quality Program, activities pertaining to the control of measuring and test equipment shall be established and implemented to satisfy the requirements of the QAPD. These requirements are to be in accordance with:

- 10 CFR 830.122(h), *Criterion 8 – Performance/Inspection and Acceptance Testing*
- DOE Order 414C, CRD, Attachment 1, 2.b.(4), *Criterion 8 – Inspection and Acceptance Testing.*

Requirements are implemented to ensure processes and procedures are in place to ensure appropriate inspections and tests are applied prior to acceptance or use of the packaging or component, and to identify the status of packaging items, components, etc.

Activities pertaining to the control of measuring and test equipment shall be controlled. The requirements for control of measuring and test equipment shall consist of the following elements:

- Implementing procedures shall be established to assure that tools, gages, instruments and other measuring and testing devices (M&TE) used in activities affecting quality are properly controlled, calibrated and adjusted to maintain accuracy within required limits.
- M&TE are calibrated at scheduled intervals against certified standards having known valid relationships to national standards. If no national standards exist, the basis for calibration shall be documented. Calibration intervals are based on required accuracy, precision, purpose, amount of use, stability characteristics and other conditions that could affect the measurements.
- Calibrations are to be performed in accordance with approved written procedures. Inspection, measuring and test equipment are to be marked to indicate calibration status.
- M&TE are to be identified, labeled or tagged indicating the next required calibration due date, and traceable to calibration records.
- If M&TE is found to be out of calibration, an evaluation shall be performed and documented regarding the validity of inspections or tests performed and the acceptability of items inspected or tested since the previous acceptable calibration. The current status of M&TE is to be recorded and maintained. Any M&TE that is consistently found to be out of calibration shall be repaired or replaced.

Special calibration and control measures on rules, tape measures, levels and other such devices are not required where normal commercial practices provide adequate accuracy.

9.13 Handling, Storage, And Shipping Control

As required by the INL Contractor Quality Program, handling, storage, and shipping control activities shall be established and implemented to satisfy the requirements of the QAPD. These requirements are to be in accordance with:

- 10 CFR 830.122(e), *Criterion 5 – Performance/Work Processe*s
- DOE Order 414C, CRD, Attachment 1, 2.b.(1), *Criterion 5 – Work Processes.*

Requirements are implemented to ensure processes and procedures are in place that achieve quality objectives and ensure appropriate levels of quality and safety are applied to critical components of packaging and transportation systems utilizing a graded approach.

Activities pertaining to handling, storage, and shipping shall be controlled. The requirements for handling, storage, and shipping control consist of the following elements:

- Implementing procedures shall be established to assure that materials, parts, assemblies, spare parts, special tools, and equipment are handled, stored, packaged, and shipped in a manner to prevent damage, loss, loss of identity, or deterioration.

- When necessary, storage procedures address special requirements for environmental protection such as inert gas atmospheres, moisture control, temperature levels, etc.

Package users shall ensure that components associated with the ATR FFSC are controlled to prevent damage or loss, protected against damage or deterioration, and provide adequate safety of personnel involved in handling, storage, and shipment (outgoing and incoming) operations. Handling, storage, and shipping must be accomplished in accordance with written and approved instructions, procedures, specifications, and/or drawings. These documents must identify appropriate information regarding shelf life, environment, temperature, cleaning, handling, and preservation, as applicable, to meet design, regulatory, and/or DOE shipping requirements.

Preparation for loading, handling, and shipment will be done accordance with approved procedures to ensure that all requirements have been met prior to delivery to a carrier. A package ready for shipment must conform to its shipping paper.

Empty packages, following usage, must be checked and decontaminated if required. Each package must be inspected, reconditioned, or repaired, as appropriate, in accordance with approved written procedures before storing or loading. Empty ATR FFSC packagings are to be tagged with "EMPTY" labels and stored in designated protected areas in order to minimize environmental effects on the containers.

Routine maintenance on the ATR FFSC packaging may be performed as deemed necessary by package users and is limited to cleaning, rust removal, painting, light metal working to restore the original contours and replacement of damaged, worn, or malfunctioning components. Spare components will be placed in segregated storage to maintain proper identification and to avoid misuse.

9.14 Inspection, Test, And Operating Status

As required by the INL Contractor Quality Program, inspection, test, and operating status activities shall be established and implemented to satisfy the requirements of the QAPD. These requirements are to be in accordance with:

- 10 CFR 830.122(e), *Criterion 5 – Performance/Work Processes*
- 10 CFR 830.122(h), *Criterion 8 – Performance/Inspection and Acceptance Testing*
- DOE Order 414C, CRD, Attachment 1, 2.b.(1), *Criterion 5 – Work Processes*
- DOE Order 414C, CRD, Attachment 1, 2.b.(4), *Criterion 8 – Inspection and Acceptance Testing.*

Requirements are implemented to ensure processes and procedures are in place that achieve quality objectives and ensure appropriate levels of quality and safety are applied to critical components of packaging and transportation systems utilizing a graded approach. In addition, processes and procedures shall be in place to ensure appropriate inspections and tests are applied prior to acceptance or use of the packaging or component, and to identify the status of packaging items, components, etc.

Activities pertaining to inspection, test, and operating status activities shall be controlled. The requirements for inspection, test, and operating status consist of the following elements:

- Implementing procedures shall be established to assure that the inspection and test status of materials, items, structures, systems, and components throughout fabrication, installation, operation, and test are clearly indicated by suitable means, (e.g., tags, labels, cards, form sheets, check lists, etc.).
- Bypassing of required inspections, tests, or other critical operations is prevented through the use of approved instructions or procedures
- As appropriate, the operating status of nonconforming, inoperative or malfunctioning components of a storage/transport system is indicated to prevent inadvertent operation. The application and removal of status indicators is performed in accordance with approved instructions and procedures.
- Any nonconforming items are identified and controlled in accordance with Section 9.15, *Nonconforming Parts, Materials, or Components*, of this SAR.

Package users shall ensure that the status of inspection and test activities are identified on the item or in documents traceable to the item to ensure that proper inspections or tests have been performed and that those items that do not pass inspection are not used. The status of fabrication, inspection, test, assembly, and refurbishment activities must be identified in documents traceable to the package components.

Measures established in specifications, procedures, and other instructions shall ensure that the following objectives are met:

- QA personnel responsible for oversight of packaging inspections can readily ascertain the status of inspections, tests, and/or operating conditions.
- No controlled items are overlooked.
- Inadvertent use or installation of unqualified items is prevented.
- Documentation is complete.

9.15 Nonconforming Materials, Parts, or Components

As required by the INL Contractor Quality Program, control of nonconforming materials, parts, or components shall be established and implemented to satisfy the requirements of the QAPD. These requirements are to be in accordance with:

- 10 CFR 830.122(c), *Criterion 3 – Management/Quality Improvement*
- DOE Order 414C, CRD, Attachment 1, 2.b.(3), *Criterion 3 – Quality Improvement.*

Requirements are implemented to ensure that processes and procedures are in place to identify and correct problems associated with transportation and packaging activities.

Activities pertaining to the control of nonconforming materials, parts, or components shall be controlled. The requirements for nonconforming materials, parts, or components consist of the following elements:

- Implementing procedures shall be established to control materials, parts, and components that do not conform to requirements to prevent their inadvertent use during fabrication or during service.

- Nonconforming items include those items that do not meet specification or drawing requirements. Additionally, nonconforming items include items not fabricated or tested (1) in accordance with approved written procedures, (2) by qualified processes, or (3) by qualified personnel; where use of such procedures, processes, or personnel is required by the fabrication, test, inspection, or quality assurance requirements.
- Nonconforming items are identified and/or segregated to prevent their inadvertent use until properly dispositioned. The identification of nonconforming items is by marking, tagging, or other methods that do not adversely affect the end use of the item. The identification shall be legible and easily recognizable. When identification of each nonconforming item is not practical, the container, package, or segregated storage area, as appropriate, is identified.
- Nonconforming conditions are documented in NCRs and affected organizations are to be notified. The nonconformance report shall include a description of the nonconforming condition. Nonconforming items are dispositioned as use-as-is, reject, repair, or rework.
- Inspection or surveillance requirements for nonconforming items following rework, repair are detailed in the nonconformance reports and approved following completion of the disposition.
- Acceptability of rework or repair of nonconforming materials, parts, and components is verified by re-inspecting and/or re-testing the item to the original requirements or equivalent inspection/testing methods. Inspection, testing, rework, and repair methods are to be documented and controlled.
- The disposition of nonconforming items as use-as-is or repair shall include technical justification and independent verification to assure compliance with design, regulatory, and contractual requirements.
- Items dispositioned as rework or repair are reinspected and retested in accordance with the original inspection and test requirements or acceptable alternatives that comply with the specified acceptance criteria.
- When specified by contract requirements, nonconformances that result in a violation of client contract or specification requirements shall be submitted for client approval.
- Nonconformance reports are made part of the inspection records and are periodically reviewed to identify quality trends. Unsatisfactory quality trends are documented on a Corrective Action Report (CAR) as detailed in Section 9.16, *Corrective Action*, of this SAR. The results of these reviews are to be reported to management.
- Nonconformance reports relating to internal activities are issued to management of the affected organization. The appropriate Quality Assurance Manager shall approve the disposition and performs follow-up activities to assure proper closure.
- Compliance with the evaluation and reporting requirements of 10 CFR 21 related to defects and noncompliances are to be controlled by approved procedures.

9.16 Corrective Action

As required by the INL Contractor Quality Program, requirements for corrective action shall be established and implemented to satisfy the requirements of the QAPD. These requirements are to be in accordance with:

- 10 CFR 830.122(c), *Criterion 3 – Management/Quality Improvement*
- DOE Order 414C, CRD, Attachment 1, 2.b.(3), *Criterion 3 – Quality Improvement.*

Requirements are implemented to ensure that processes and procedures are in place to identify and correct problems associated with transportation and packaging activities.

Activities pertaining to corrective actions shall be controlled. The requirements for corrective action consist of the following elements:

- Implementing procedures shall be established to identify significant conditions adverse to quality. Significant and/or repetitive failures, malfunctions and deficiencies in material, components, equipment, and operations are to be promptly identified and documented on a Corrective Action Reports (CARs) and reported to appropriate management. The cause of the condition and corrective action necessary to prevent recurrence are identified, implemented, and followed up to verify corrective action is complete and effective.
- The INL Contractor Quality Assurance Director (DQA) is responsible for ensuring implementation of the corrective action program, including follow up and closeout actions. The DQA may delegate certain activities in the Corrective Action process to others.

9.17 Quality Assurance Records

As required by the INL Contractor Quality Program, activities associated with QA records shall be established and implemented to satisfy the requirements of the QAPD. These requirements are to be in accordance with:

- 10 CRF 830.122(b), *Criterion 2 – Management/Personnel Training and Qualifications*
- 10 CFR 830.122(d), *Criterion 4 – Management/Documents and Records*
- 10 CFR 830.122(e), *Criterion 5 – Performance/Work Processes*
- 10 CFR 830.122(h), *Criterion 8 – Performance/Inspection and Acceptance Testing*
- DOE Order 414C, CRD, Attachment 1, 2.a.(2), *Criterion 2 - Personnel Training and Qualifications*
- DOE Order 414C, CRD, Attachment 1, 2.a.(4), *Criterion 4 – Documents and Records*
- DOE Order 414C, CRD, Attachment 1, 2.b.(1), *Criterion 5 – Work Processes*
- DOE Order 414C, CRD, Attachment 1, 2.b.(4), *Criterion 8 – Inspection and Acceptance Testing.*

Requirements are implemented to ensure that only trained and qualified personnel perform transportation and packaging activities. The program shall ensure processes and procedures are in place to address document preparation, document control, and management of records. In addition, the program ensures processes and procedures are in place which achieves quality objectives and appropriate levels of quality and safety are applied to critical components of packaging and transportation systems utilizing a graded approach. Finally, the program ensures processes and procedures are in place to identify appropriate inspections and tests are applied prior to acceptance or use of the package or component, and to identify the status of packaging items, components, etc.

Quality assurance records shall be controlled. The requirements for quality assurance records consist of the following elements:

- Implementing procedures shall be established to assure control of quality records. The purpose of the Quality Assurance Records system is to assure that documented evidence relative to quality related activities is maintained and available for use by INL Contractor, its customers, and/or regulatory agencies, as applicable.
- Approved procedures identify the types of documents to be retained as QA records, as well as those to be retained by the originating organization. Lifetime and Non-Permanent records are retained by Records Management (RMA) or its customers, as appropriate. Records are identified, indexed, and stored in accessible locations.
- QA Records are maintained for periods specified to furnish evidence of activities affecting the quality of structures, systems, and components that are safety-related or important-to-safety. These records include records of design, procurement, fabrication, assembly, inspection, and testing.
- Maintenance records shall include the use of operating logs; results of reviews, inspections, tests, and audits; results from monitoring of work performance and material analyses; results of maintenance, modification, and repair activities; qualification of personnel, procedures, and equipment; records of calibration of measuring and test equipment; and related instructions, procedures, and drawings.
- Requirements for indexing, record retention period, storage method(s) and location(s), classification, preservation measures, disposition of nonpermanent records, and responsibility for safekeeping are specified in approved procedures. Record storage facilities are established to prevent destruction of records by fire, flood, theft, and deterioration due to environmental conditions (such as temperature, humidity, or vermin). As an alternative, two identical sets of records (dual storage) may be maintained at separate locations.
- INL shall retain required records for at least three (3) years beyond the date of last engagement of activities.

9.17.1 General

Sufficient records must be maintained by package users to furnish evidence of quality of items and of activities affecting quality. QA records that must be retained for the lifetime of the packaging include:

- Appropriate production-related records that are generated throughout the package manufacturing and fabrication process

- Records demonstrating evidence of operational capability; e.g., completed acceptance tests and inspections
- Records verifying repair, rework, and replacement
- Audit reports, and corrective actions
- Records that are used as a baseline for maintenance
- Records showing evidence of delivery of packages to a carrier and proof that all DOT requirements were satisfied.

9.17.2 Generating Records

Package user documents designated as QA records must be:

- Legible
- Completed to reflect the work accomplished and relevant results or conclusions
- Signed and dated or otherwise authenticated by authorized personnel.

QA records should be placed in a records storage area as soon as is feasible to avoid loss or damage. Individual package QA records must be generated and maintained for each package by the package serial number.

9.17.3 Receipt, Retrieval, and Disposition of Records

The RMA has overall responsibility for records management for the ATR FFSC. Package users are responsible for maintaining records while they are in process and for providing completed records to the RMA. A receipt control system shall be established, and records maintained in-house or at other locations are to be identifiable and retrievable and not disposed of until prescribed conditions are satisfied.

Records are to be available for inspection upon request.

Table 9.17-1 - Quality Assurance Records

Quality Assurance Record	Retention period
Design and Fabrication Drawings	LOP+
Test Reports	LOP+
Independent Design Review Comments	LOP+
Safety Analysis Report for Packaging	LOP+
Vendor Manufacturing and Inspection Plans	LOP+
Material Test Report of Certification of Materials	LOP+
Welding Specifications and Procedures	LOP+
Weld Procedure Qualification Record	LOP+
Welder or Welding Operator Qualification Tests	LOP+
Record of Qualification of Personnel Performing Radiographic and PT Reports	LOP+
Weld Radiographs	LOP+
Liquid Penetrant Reports	LOP+
Dimensional Inspection Report for All Features	LOP+
Visual and Dimensional Inspection upon Receipt of Packaging	LOP+
Package Loading Procedure	S+
Unloading Procedure	S+
Maintenance Procedures	LOP+
Repair Procedures	LOP+
Procurement Specifications	LOP+
Personnel Training and Qualification Documentation	LOP+
Maintenance Log	LOP+
Corrective Action Reports	LOP+
Nonconformance Reports (and resolutions)	LOP+
Incident Reports per 10 CFR 71.95	LOP+
Preliminary Determinations per 10 CFR 71.85	S+
Routine Determinations per 10 CFR 71.87	S+
Shipment Records per 10 CFR 71.91(a), (b), (c), (d)	S+
LOP+ Lifetime of packaging plus 3 years S+ Shipping date plus 3 years	

9.18 Audits

As required by the INL Contractor Quality Program, audit requirements shall be established and implemented to satisfy the requirements of the QAPD. These requirements are to be in accordance with:

- 10 CFR 830.122(i), *Criterion 9 – Assessment/Management Assessment*
- 10 CFR 830.122(j), *Criterion 10 – Assessment/Independent Assessment*
- DOE Order 414C, CRD, Attachment 1, 2.c.(1), *Criterion 9 – Management Assessment*
- DOE Order 414C, CRD, Attachment 1, 2.c.(2), *Criterion 10 – Independent Assessment.*

Requirements are implemented to ensure management assessments are performed on a regular basis. Management assessments are planned and conducted in accordance with written procedures. In addition, the program will be independently assessed periodically in accordance with procedures.

Activities pertaining to audits and assessments shall be controlled. The requirements for audits and assessments consist of the following elements:

- Implementing procedures shall be established to assure that periodic audits verify compliance with all aspects of the Quality Assurance Program and determine its effectiveness. Areas and activities to be audited, such as design, procurement, fabrication, inspection, and testing of storage/transportation systems, are to be identified as part of audit planning.
- INL audits supplier Quality Assurance Programs, procedures, and implementation activities to evaluate and verify that procedures and activities are adequate and comply with applicable requirements.
- Audits are planned and scheduled in a manner to provide coverage and coordination with ongoing Quality Assurance Program activities commensurate with the status and importance of the activities.
- Audits are performed by trained and qualified personnel not having direct responsibilities in the areas being audited and are conducted in accordance with written plans and checklists. Audit results are documented and reviewed by management having responsibility for the area audited. Corrective actions and schedules for implementation are established and recorded. Audit reports include an objective evaluation of the quality-related practices, procedures, and instructions for the areas or activities being audited and the effectiveness of implementation.
- Responsible management shall undertake corrective actions as a follow-up to audit reports when appropriate. The Quality Assurance Management (QAM) shall evaluate audit results for indications of adverse trends that could affect quality. When results of such assessments so indicate, appropriate corrective action will be implemented.

The QAM shall follow up on audit findings to assure that appropriate corrective actions have been implemented and directs the performance of re-audits when deemed necessary.