TABLE 2-3
SUMMARY OF STRUCTURAL RESULTS
FOR THE OPTIONAL TEMPORARY SHIELD TUBES[a]
(All stresses in ksi)

	1-in.-Thick	2-in.-Thick	Allowable
	End Drop		
Sidewall	32.0	31.3	40
Lid	0.5	0.5	60
Bottom plate	0.6	0.6	60
Bolts	0	0	40
Welds	0	0	40
	Side Drop		
Sidewall	1.8	0.8	60
Ends	0	0	40
Locating pins	30.4[b]	30.4[b]	40
Bolts	10.8[b]	10.8[b]	40
Welds	0.6	0.6	40

[a]End and side drops bound corner drop results.

[b]Since the shield tubes are supported uniformly on all sides, these stresses are actually zero during a side drop. However, for conservatism, they have been assumed to carry the side drop deceleration.

2.8 APPENDIX

2.8.1 Low Temperature Uranium Bar Drop Tests

2.8.1.1 Discussion. In an effort to obtain a preliminary indication of the ductility properties of uranium at subzero temperatures, a series of drop test was scheduled and conducted at National Lead Company's Albany branch. Samples of unalloyed depleted uranium were tested along with various samples of low alloys to serve as a basis for comparison.

Various diameters of as cast depleted uranium round bar were used; however, each round bar was cut to length such that the length to diameter ratio was 8 to 1 - this being approximately the same as the L/D ratio of the depleted uranium in Model FSV-1 Configurations A, B, C and D.

Most drops were conducted from a height of 29 feet, 3 inches onto essentially unyielding surfaces of either steel or concrete. Two samples, also from a height of 29 feet 3 inches, were dropped on a sharp edged fulcrum. Temperature at the top of drop of all samples ranged between -55°F to -60°F.

Results of these preliminary drop test indicated that the unalloyed depleted uranium exhibited good ductility properties at low temperatures. Furthermore, it wasn't until the third 29 feet 3 inches drop of a test specimen that ductility failure occurred. A 1-3/16" diam by 9-1/2 inch long unalloyed depleted uranium round bar was dropped on a concrete impact surface with no visible failure resulting. The same test specimen was then dropped from the same height of 29 feet 3 inches and at the same temperature of -60°F on a steel plate. This time a slight bend in the bar was noted. On the third test, the specimen was dropped on the sharp edge of a steel angle. Along with a greater bend in the bar, it was noted that a small crack developed opposite the side of impact.

2.8.1.2 Results

Test No.	Specimen Drop No.	Material (As-Cast)	Diameter (in.)	Attitude at Impact	Impacting Surface	Test Results
1	1	U-2% Mo	1-1/4	Horizontal	Concrete	No failure
2	1	Unalloyed	1-3/16	Horizontal	Concrete	No failure
3	1	Unalloyed	1-3/16	Horizontal	Concrete	No failure
4	1	U-1% Mo, 1% Nb	0.6	Horizontal	Concrete	No failure
5	1	U-1% Mo, 1% W	0.6	45° Corner Drop	Concrete	No failure
6	1	U-1% Nb, 1% W	0.6	45° Corner Drop	Concrete	No failure
7	1	U-1% Ta, 1% W	0.6	Horizontal	Concrete	No failure
8	1	Unalloyed	0.6	Horizontal	Concrete	No failure
9	1	Unalloyed	0.6	Horizontal	Concrete	No failure
10	2	Unalloyed	1-3/16	Horizontal	Stl Plate	Slight Bend
11	2	Unalloyed	1-3/16	Horizontal	Stl Plate	Slight Bend
12	2	U-2% Mo	1-1/4	Horizontal	Stl Plate	No failure
13	2	U-1% Mo, 1% W	0.6	Horizontal	Stl Plate	No failure
14	2	Unalloyed	0.6	Horizontal	Stl Plate	Slight Bend
15	3	Unalloyed	1-3/16	Horizontal	90° Corner	Bent & Cracked
16	3	Unalloyed	1-3/16	Slight Angle Corner Drop	90° Corner	Bent

Test Conditions

Height of drop	29'3"
Temperature of specimens	-55°F to -60°F
Material Condition	As cast
Material Configuration	Round bars, L/D = 8:1

2.8.2 Low Temperature 1/8 Scale Uranium Shell Impact Tests

2.8.2.1 Purpose of Tests. Experimental knowledge is required of the effects of impact loads as used in casks with uranium shielding and having relatively large L/D ratios. The experimental test specimen was subjected to several puncture tests to determine the amount of deformation and to observe the surface condition of the uranium in the impacted areas.

2.8.2.2 Material Used. An as cast 0.2% - 0.3% molybdenum-uranium cylindrical shell, 1/8 the size of the actual shielding in the shipping cask, was used for this series of tests.

Comparative dimensions and weights:

	1/8 Scale Cylindrical Shell	Full Size Uranium Shielding
Outside diameter	3-1/4"	26"
Inside diameter	2-3/8"	19"
Length	24-3/8"	194"
Weight	64 lb	32,800 lb

2.8.2.3 Test Procedures. Tests were conducted using the indoor drop test facilities of NLC, Wilmington branch.

An iron-constantan thermocouple was attached to the outer surface of the uranium cylindrical shell. The thermocouple extension leads were connected to a calibrated pyrometer indicator.

The test specimen was then submerged in a solution of acetone and dry-ice until it reached a temperature of approximately -60°F. With the thermocouple still attached, the uranium was connected to a quick release mechanism which, in turn, was attached to an overhead crane. The entire assembly was moved over the impact area which consisted of a 3/4 inch wide carbon steel fulcrum 4 inch deep and 12 inch long welded to a 12 inch x 12 inch x 3/4 inch carbon steel base plate. This weldment was resting on a steel anvil pad supported by a concrete foundation. With the use of a scaled line and plumb bob, the test specimen was raised to a height of 40 inches over the fulcrum. Its long axis was positioned level and perpendicular to the long axis of the fulcrum so that the center of gravity of the shell would impact against the fulcrum.

When the pyrometer indicator measured a surface temperature of -40°F the solenoid on the release mechanism was actuated, pulled a release pin and allowed the test specimen to free fall on the fulcrum.

This same test was conducted at 60 inches, 80 inches, 100 inches and 120 inches. Measurements were taken after each test of the outside diameter, inside diameter, length and angle of bend.

2.8.2.4 Results. Results of all free fall fulcrum tests proved negative. The test specimen experienced no dimensional changes or deformations.

The 120 inches drop test had a rebound after impact of 31-1/4 inches above the fulcrum--the test specimen remained level during the rebound. Although no damage occurred to the uranium, the 3/4 inch fulcrum received an indentation approximately 1/4 inch deep.

2.8.3 Uranium Weld Joint Study

2.8.3.1 Discussion. Successful completion of side puncture tests on a uranium casting scale model has prompted a review of impact condition analyses and has also allowed consideration of a type of joint for the uranium sections which permits a greatly reduced depth of welding.

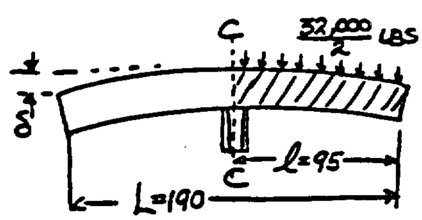
The previous calculations for side wall puncture assumed the onset of plastic hinge deformation at 30,000 psi, and required that 83% of the kinetic energy of the 40 in. drop had to be absorbed by this mechanism. The new drop tests proved that more than double this height of drop did not produce any measurable permanent set. Obviously, justification of this performance requires that the calculated instantaneous peak bending stresses be allowed to reach for higher values and still be elastic.

The effects of this new performance are now investigated in regard to accident conditions, and include the behavior of the redesigned joints under such loadings.

According to the tests, separately reported, a drop height of 120 in., with a rebound of 31-1/4 in., can be credited, conservatively, with kinetic energy proportional only to a drop of 120 - 31-1/4 = 88-3/4 in. This means that energy <u>2.22</u> times the specified 40 in. drop was successful absorbed elastically.

2.8.3.2 <u>Puncture Side Wall</u> - 88-3/4 in. Drop Analysis. The stainless steel outer shell, as the member directly exposed to penetration by the steel piston, is not critical. The piston merely cuts partly into the wall, due to the back-up effects of the uranium cylinder.

The uranium cylinder (as tested) is taken as a model, but calculations are now made on a full size cylinder analyzed as a separate body in an elastic drop up to 88-3/4 in.



Consider 1G Load on Cantilever

D = 26 in., d = 19 in.

ℓ = 95 in., L = 190 in.

Vol. = (531-284) in.^{2} (190 in.) = 46,930 in.^{3} total

Wt = 46,930 (0.683) = 32,000 lb total

I = 0.0491 ($26^4 - 19^4$) = 16,041 in.^{4}

Z = 16,041/13 = 1235 in.

$$M_c = \frac{w\ell}{2} = \frac{32,000}{2}\ \frac{95}{2} = 760,000 \text{ in. lb}$$

$$\delta = \frac{w\ell^3}{8EI} = \frac{16,000\ (95)^3}{8(29)\ 10^6\ (16,041)} = 0.0369 \text{ in.}$$

$$S_b = \frac{M_c}{Z} = \frac{760,000}{1235} = 615 \text{ psi}$$

From Marks Handbook, sixth edition, page 5-44:

$$U_{cantilever} = \frac{n^2}{m}\left(\frac{K}{c}\right)^2 \frac{S^2V}{2E} \text{ for uniform load}$$

$$n = 2 \quad m = 8 \quad K = \text{rad. gyr.} = \frac{\sqrt{D^2 + d^2}}{4} \text{ for tube section}$$

$$c = D/2$$

Therefore,

$$U_{cant.} = \frac{(2)^2}{8}\ \frac{4}{16}\ \frac{(D^2 + d^2)}{D^2}\ \frac{S^2V}{2E} = \frac{D^2 + d^2}{16D^2}\ \frac{S^2V}{E} \text{ for 1/2 beam lgth.}$$

$$U_B = \frac{D^2 + d^2}{8D^2} \frac{S^2 V}{E} \quad \text{for full length beam as above}$$

$$= \frac{26^2 + 19^2}{8 \times 26^2} \frac{S^2(46{,}930)}{29\ (10^6)} = \frac{674 + 361}{8\ (676)} S^2 \frac{1615}{10^6} = \frac{310}{10^6} S^2$$

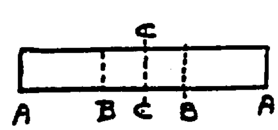
Now S = 615 psi for 1G load

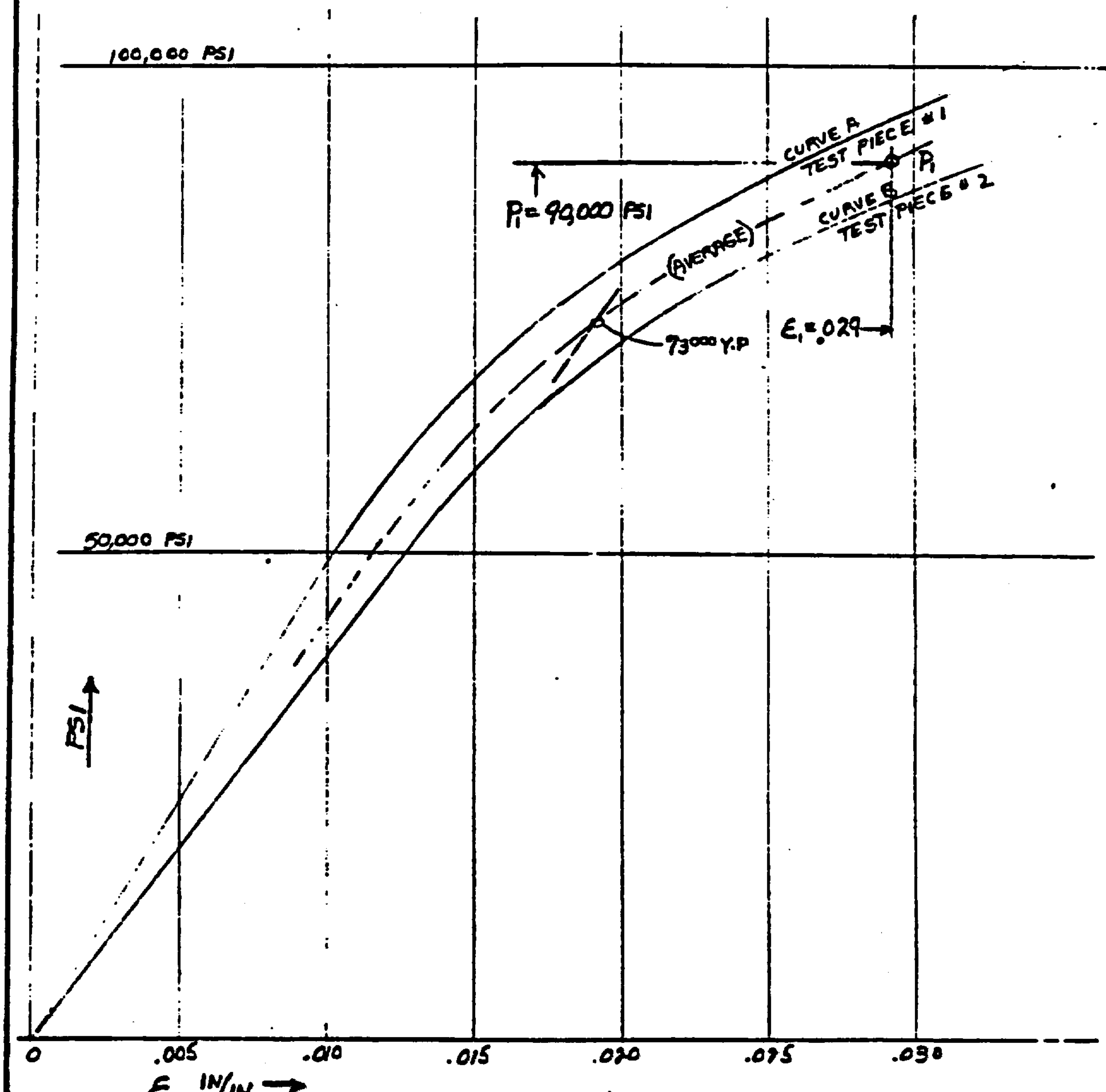
$$U_B = \frac{310\ (615)^2}{10^6} = 117 \text{ in. lb} \quad \text{Note: } U_B \propto S^2 \propto (G's)^2$$

Line	G's	S psi	δ in.	$(G's)^2$	U_B in. lb	Height Drop
1	1	615.	0.00369	1	117	
2	50	30,750	0.1845	2500	292,500	
3	104.5	64,300	0.386	10,920	1,280,000	40
4	156.	96,000	0.575	24,280	2,840,000	88-75

The stress of 96,000 psi is reached "instantaneously" and only at the top mid point of the beam. This peak is quite consistent with nominal properties of unalloyed cast uranium. Static compression, stress-strain curves for cast, unalloyed depleted uraniium are shown in Fig. 2-23.

The specification is limited to the values of Line 3. The joints are actually at positions B and the moment and stress is reduced to 4/9.





STATIC COMPRESSION STRESS-STRAIN CURVES
UNALLOYED DEPLETED URANIUM
"AS CAST" FOR SHIELDING - N.L.C. FEB. 1970
BACKOS

FIGURE 2-23

$$\frac{M_B}{M_C} = \frac{(2/3\ Wt)(2/3\ell)}{(Wt)(\ell)} = 4/9 \quad \therefore\ S_B = \frac{4}{9} S_C = \frac{4}{9}(64{,}300)$$

$$= \underline{28{,}600\ \text{psi}}$$

2.8.3.3 Results. Since the "solid" cylinder of the tests (equivalent to full depth penetration weld) has withstood at its midsection 96,000 psi, it would be theoretically possible to reduce the depth of an outside weld for position B so that Z for the weld area is only

$$Z_{B2} = \frac{28{,}600}{96{,}000}\,1235 = \underline{368}$$

to find the i.d. which corresponds to this Z value, let

$$Z_{B2} = 368 = \frac{0.098}{26}(26^4 - d^4) = 0.00378\,[457{,}000 - d^4]$$

$$d^4 = \frac{1725 - 368}{0.00378} = 359{,}000$$

$$d = 24.5\ \text{in.} \quad \therefore\ t = \frac{26 - 24.5}{2} = \underline{3/4\text{-in. weld req'd min.}}$$

To be quite conservative, it is desirable to double this depth of weld, using 2 layers of 3/4-in. penetration welds (in offset relationship), providing continuous beam strength in an outer annulus 1-1/2 in. thick out of a total of 3-1/2-in. wall. The inner 2 in. would be machined with interlocking steps (four of 1/2-in. each) providing concentric shear rings and an effective shielding pattern as shown on Fig. 2-24.

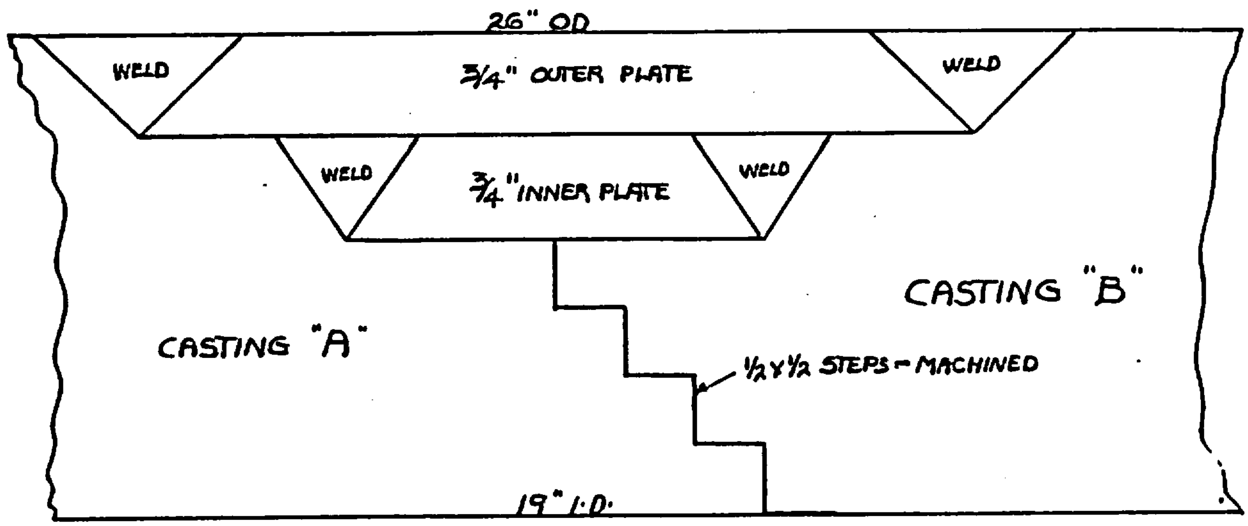


FIGURE 2-24 . Depleted Uranium Joint Detail

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SECTION 3.0

THERMAL EVALUATION

3.0 THERMAL EVALUATION

Although Model FSV-1 in Configurations A, B, C and D is not currently used for the transport of high temperature gas-cooled (HTGR) spent fuel elements, the following thermal evaluation is included to document the thermal performance of the package. The contents of Model FSV-1 in Configurations A, B, C and D will not exceed the 4.1 kW of decay heat from six (6) spent fuel elements.

3.1 DISCUSSION

Model FSV-1 in Configurations A, B, C, and D is designed and evaluated for the normal conditions of transport and the hypothetical accident condition.

3.2 SUMMARY OF THERMAL PROPERTIES OF THE MATERIALS

Table 3-1 lists the thermal properties of the materials which constitute the cask as they were used in the analysis. References for these properties may be found in Section 3.2 of Vol. II.

3.3 TECHNICAL SPECIFICATIONS OF COMPONENTS

3.3.1 Spent Fuel Heat Generation

The fuel blocks being shipped in this cask have been irradiated, and the fissionable fuel has been partially consumed. Due to residual isotope activity, there is a continuing "after-heat" which decays with time, depending on the isotope half-life. This activity is absorbed by the fuel and cask components and is realized in the form of heat. This heat generation is predictable and has been used in the calculations.

It is assumed that the spent fuel is loaded into the shipping cask no sooner than 100 days after the reactor is shut down. Thus the maximum heat generation that the cask need be designed for is obtained from fuel loaded 100 days after the reactor shutdown.

TABLE 3-1
THERMAL PROPERTIES OF MATERIALS

Helium

$K = 1.29 \times 10^{-3} * T°R^{0.674}$ Btu/hr-ft-°F

$C_p = 1.242$ Btu/lb-°F

Air

$K = 0.0146 + 1.695 \times 10^{-5} * T°F$ Btu/hr-ft-°F

$C_p = 0.25$ Btu/lb-°F

Stainless Steel (Type 304)

$K = 29.1 - 0.0059 * T$ °F

$C_p = 55$ Btu/ft^3-°F

$\epsilon = 0.8$

$\alpha = 9.5 \times 10^{-6}$ in./in.-°F

Depleted Uranium

$K = 14.8$ Btu/hr-ft°F

$C_p = 38$ Btu/ft^3-°F

$\epsilon = 0.5$

$\alpha = 9.6 \times 10^{-6}$ in./in.-°F

Spent Fuel Block

$K = 10.0$ Btu/hr-ft-°F

$C_p = 32$ Btu/ft^3 - hr

$\epsilon = 0.8$

The fuel element after-heat was calculated at GA in analysis prior to this one. The calculated heat generation recommended for thermal analysis purposes is 2322 Btu/hr per fuel block at 100 days and 1101 Btu/hr at 200 days. Of these quantities, 88% is realized within the fuel block and the remaining 12% is generated within the first inch of the surrounding shielding.

The decay heat generation is summarized in Table 3-2.

3.3.2 Cask Dimension

Manufacturing tolerances allow a rather significant variation in the raidal gaps. Although it is very unlikely that the parts would ever be manufactured and assembled such that one cask had either all maximum or minimum gaps, the analyses were made using both extreme cases to illustrate the maximum possible range of temperatures that may be encountered. These gaps are illustrated on Fig. 1. The fire accident (Case 3) was calculated using only the minimum gaps in order to illustrate the worst condition for the inner part of the cask.

The significant radial dimensions shown on Fig. 3-1 were used with appropriate coefficients of thermal expansion. Thus, the correct gaps were recalculated as the cask changed in temperature. The net effect of this is to decrease the gap sizes under normal conditions when the inner shells are hotter than the outer shells. In the fire accident, however, the hotter outer shells will expand away from the inner shells, increasing the resistance of the gap and retarding the heat flow into the inner part of the assembly.

TABLE 3-2
CALCULATED AFTER-HEAT GENERATION
OF FUEL BLOCK (INC. Pa 233)
Btu/hr

Day Time days	Betas	Gammas	Total
100	1353.	969.	2322.
150	967.	540.	1507.
200	767.	334.	1101.

FIGURE WITHHELD UNDER 10 CFR 2.390

Fig. 3-1 Model FSV-1 shipping cask diameters and tolerances at major shells (all dimensions in inches)

3.4 THERMAL EVALUATION OF THE MODEL FSV-1 PACKAGE

3.4.1 Summary of Results

Steady-state and transient thermal analyses were conducted on thermal models of each end of the cask, the models far enough down the length of the cask to eliminate any end effects. Since no unexpected results were obtained from the analysis of the relatively simple lower end, only the temperatures of the upper end are summarized in Table 3-3.

It is noteworthy that the surface of the cask is below 212°F, although high enough to cause discomfort to personnel in contact with it. The solar heating is a significant contributor to the total cask heat.

The FSV-1 cask in Configurations A, B, C and D may be wrapped in a reinforced plastic material such as Herculite to keep the exterior of the cask clean and to prevent "weeping." Although two or three layers of this material (0.02 in. thick) coupled with a potential air-gap between layers increases the overall thermal resistance slightly, the results listed in Table 3-3 are conservatively high temperatures for this condition. The temperatures in Table 3-3 are based on 4.1 kilowatts of heat generation in the cask. When the cask is wrapped with reinforced plastic, the allowable heat generation is 0.5 kilowatts.

TABLE 3-3
SUMMARY OF RESULTS

		Temperatures (°F)					Fire Acc. Maximum Temps.
		130° Ambient			-40° Ambient		
	Location	100 Day Heat		200 Day Heat	100 Day Heat		
No.	Gap Tolerances	Max Gaps	Min Gaps	Max Gaps	Max Gaps	Min Gap	Min Gap
1	Cask Seal	141	137	133	-14	-15	1220
2	Container Seal	155	146	137	3	0	655
3	Fuel Surface - Max	278	266	200	153	143	284
4	Fuel Centerline - Max	284	272	203	160	149	291
5	Container Wall - Max	174	159	147	28	14	502
6	Inner Shell - Max	161	149	141	13	2	715
7	Shielding - Center	152	146	137	3	0	829
8	Outer Shell - Max	146	144	134	-4	-3	1397

The cask surface temperature can be assumed to be the same as the outer shell temperature.

Figures 3-5 and 3-8 are the calculated temperature matrices from the computer output. Locations 1 - 8 are identified on Fig. 3-5.

3.4.2 Thermal Model

Basic temperatures were calculated by a numerical finite-difference method. A digital computer code, RAT*, was used to perform the actual calculations.

The cask system was modeled in a form suitable for input to this code. The regions modeled are shown on Figs. 3-2 and 3-3.

RAT is a digital computer code that is applicable to calculating transient temperatures in a two-dimensional network of points. It may also be used to obtain steady-state solutions by extending a transient calculation to the point where time dependence of results becomes negligible.

The network is specified by establishing a grid system, locating individuial materials within that grid system, and identifying the applicable thermal parameters that define those materials. The grid system must be a regular one specified by two sets of grid lines parallel to the coordinate axes in one of the following three systems: orthogonal (X-Y), cylindrical (R-Z), or circular (R-θ):

The materials are located by subdividing the grid system into blocks, or regions of adjacent points. Each block is defined by its four bounding

*RAT is an acronym for "radial-axial temperatures."

FIGURE WITHHELD UNDER 10 CFR 2.390

Fig. 3-2. Temperature locations noted in Table **3-1** and Fig. 3-5 Cask Model Upper-End.

FIGURE WITHHELD UNDER 10 CFR 2.390

Fig. 3-3. Cask model - lower end.

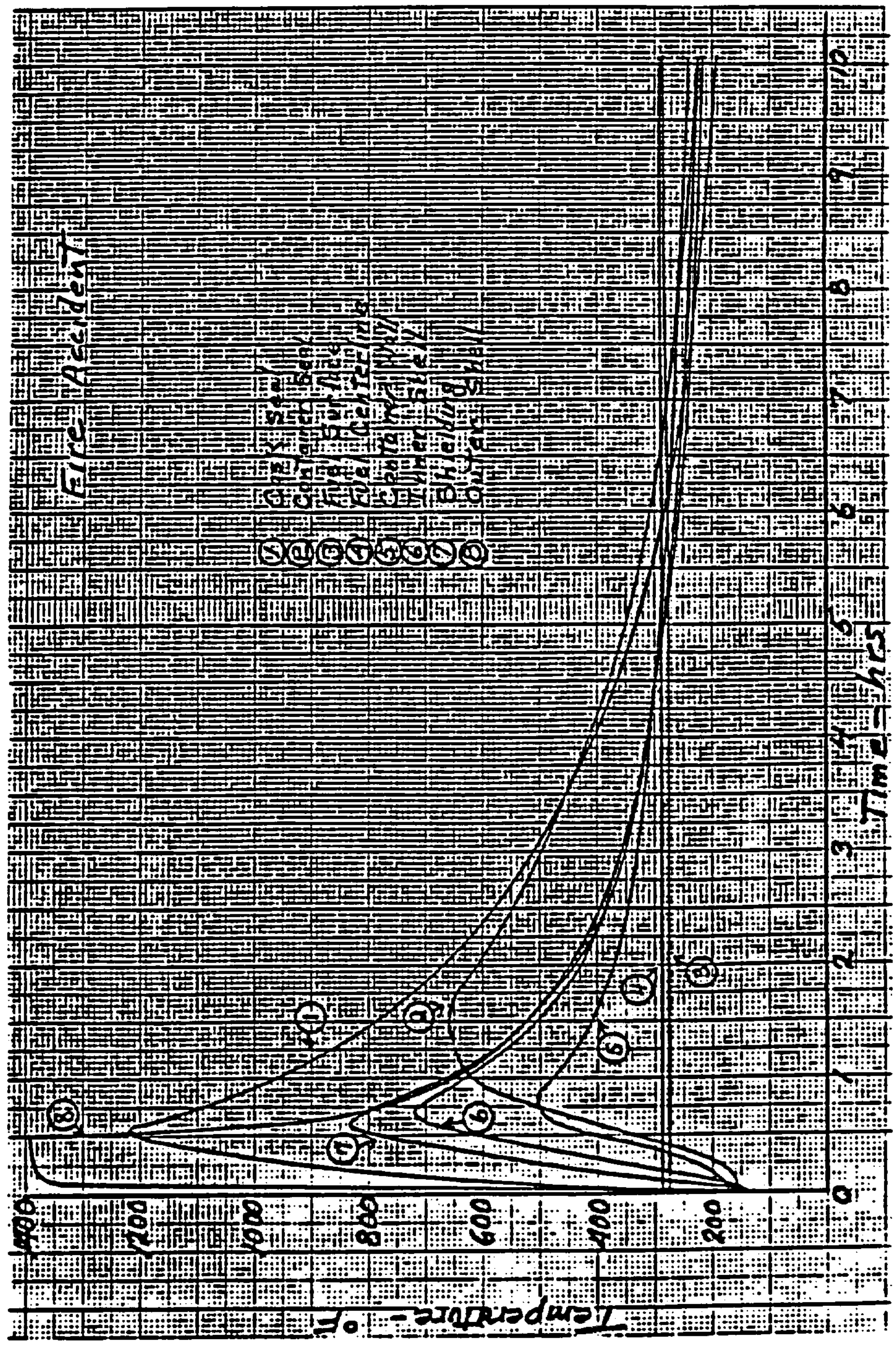


Fig. 3-4. Fire accident.

TEMPERATURE GRID
THE RADIAL DIRECTION IS HORIZONTAL
THE AXIAL DIRECTION IS VERTICAL
THE TEMPERATURES ARE IN DEGREES FAHRENHEIT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130
2	0	139	139	139	139	139	138	138	138	138	138	138	138	138	138	139	138	138	139	138	138	137	137	137	137
3	0	140	140	139	139	139	139	139	139	139	139	139	139	139	138	138	138	138	139	138	138	138	137	137	137
4	0	140	140	140	140	139	139	139	139	139	139	139	139	139	139	139	138	138	139	138	138	138	138	137	137
5	0	141	141	140	140	140	140	140	140	140	139	139	139	139	139	139	138	138	139	138	138	138	138	138	138
6	0	141	141	141	141	141	141	141	141	141	141	141	141	141	140	140	138	138	138	138	138	138	138	138	138
7	0	143	142	142	142	142	142	142	142	142	141	141	142	142	140	140	139	139	139	139	138	138	138	138	138
8	0	143	143	143	143	143	143	143	143	143	142	142	142	142	140	140	139	139	139	139	139	138	138	138	138
9	0	145	145	144	144	144	144	144	144	144	143	143	143	143	141	141	139	139	139	139	139	139	138	138	138
10	0	146	146	145	145	145	145	145	145	145	144	144	144	144	141	141	140	140	140	140	139	139	138	138	138
11	0	147	146	146	146	146	146	146	146	146	145	145	145	145	144	143	140	140	140	140	140	139	138	138	138
12	0	148	148	147	147	147	147	147	147	147	146	146	146	146	146	146	142	142	142	140	140	140	139	139	139
13	0	149	149	148	148	148	147	147	147	147	147	147	147	147	147	147	143	143	143	140	140	140	139	139	139
14	0	150	150	149	149	148	148	148	148	146	148	148	148	147	147	147	144	144	143	141	141	140	139	139	139
15	0	151	151	150	150	149	148	149	149	148	148	148	148	148	148	148	144	144	141	141	141	141	140	139	139
16	0	152	152	151	151	150	150	150	149	149	149	148	148	148	148	148	145	145	142	142	141	141	140	140	140
17	0	231	230	229	227	226	206	175	156	150	149	149	149	149	149	149	146	146	142	142	142	141	140	140	140
18	0	232	231	230	228	227	209	180	158	150	150	149	147	147	147	147	146	146	142	142	142	142	140	140	140
19	0	234	233	231	230	229	213	187	170	158	151	149	147	147	147	147	146	146	143	143	142	142	141	140	140
20	0	235	234	233	231	230	214	189	172	159	153	150	147	147	147	147	147	146	143	143	143	142	141	141	141
21	0	236	235	234	232	231	218	190	173	160	153	150	147	147	147	147	147	144	143	143	143	143	141	141	141
22	0	238	238	236	234	233	218	192	174	161	155	151	148	148	148	147	144	144	144	144	143	143	141	141	141
23	0	242	241	240	238	237	222	195	177	164	157	153	149	149	149	145	145	145	144	144	144	144	141	141	141
24	0	247	246	245	243	242	228	198	180	166	159	155	150	150	150	146	146	145	145	145	145	145	142	142	142
25	0	252	252	250	248	247	231	202	183	169	161	157	152	152	152	147	146	146	146	146	146	145	142	142	142
26	0	258	257	255	253	252	234	206	186	171	164	158	153	153	153	148	147	147	147	147	146	146	142	142	142
27	0	262	261	260	258	257	239	209	188	173	165	160	154	154	154	148	148	148	147	147	147	147	142	142	142
28	0	265	264	263	261	260	242	211	190	174	166	161	155	155	155	149	148	148	148	148	147	147	142	142	142
29	0	270	269	267	265	264	246	214	192	176	168	162	156	156	156	149	149	149	149	148	148	147	143	142	142
30	0	275	274	272	270	266	249	216	194	178	169	163	157	157	157	150	149	149	149	149	148	148	143	143	143
31	0	278	277	275	273	271	252	218	196	179	170	164	158	158	157	150	150	150	149	149	149	148	143	143	143
32	0	280	279	277	275	273	254	220	197	180	171	164	158	158	158	151	150	150	150	149	149	148	143	143	143
33	0	281	280	278	276	275	255	221	197	180	172	165	158	158	158	151	150	150	150	150	149	149	143	143	143
34	0	282	281	279	276	275	255	221	197	180	172	165	159	158	158	151	150	150	150	150	149	149	143	143	143
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Fuel Block

U_{238}

Container

Inner shell

U_{238}

Outer Shell

Fig. 3-5. Model FSV-1 shipping cask thermal analysis.
130°F day, 100 day heat
Maximum gaps - Reference Case

TEMPERATURE GRID
THE RADIAL DIRECTION IS HORIZONTAL
THE AXIAL DIRECTION IS VERTICAL
THE TEMPERATURES ARE IN DEGREES FAHRENHEIT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130
2	0	138	138	138	138	138	138	138	138	138	137	137	137	137	137	137	137	137	137	137	137	137	136	136	136
3	0	139	139	138	138	138	138	138	138	138	138	138	138	138	138	137	137	137	137	137	137	137	137	137	187
4	0	139	139	139	139	139	138	138	138	138	138	138	138	138	138	138	139	137	137	137	137	137	137	137	137
5	0	140	140	139	139	139	139	139	139	139	139	138	138	138	138	138	138	137	137	137	137	137	137	137	137
6	0	140	140	140	140	140	140	140	140	140	140	140	140	140	139	139	138	138	138	138	137	137	137	137	137
7	0	141	141	141	141	141	141	141	141	141	140	140	140	140	139	139	138	138	138	138	138	137	137	137	137
8	0	142	142	142	142	142	141	141	141	141	141	141	141	141	139	139	138	138	138	138	138	138	137	137	137
9	0	143	143	143	143	143	143	143	143	143	142	142	142	142	140	140	138	138	138	138	138	138	138	138	138
10	0	144	144	144	144	144	144	144	144	144	143	143	143	143	140	140	139	139	139	139	138	138	138	138	138
11	0	145	145	145	144	144	144	144	144	144	144	144	144	144	143	141	139	139	139	139	139	138	138	138	138
12	0	146	146	146	145	145	145	145	145	145	144	144	144	144	144	144	140	140	140	139	139	139	138	138	138
13	0	147	147	147	146	146	146	146	146	146	145	145	145	145	145	145	141	141	141	139	139	139	138	138	138
14	0	148	148	148	147	147	146	146	146	146	146	146	146	146	146	145	142	142	142	140	140	139	139	139	139
15	0	149	149	148	148	148	147	147	147	146	146	146	146	146	146	146	143	143	140	140	140	140	139	139	139
16	0	150	150	149	149	149	148	148	146	146	146	146	146	146	146	146	143	143	141	141	140	140	140	139	139
17	0	226	225	224	222	221	201	172	153	147	147	147	147	147	146	146	144	144	141	141	141	141	140	140	140
18	0	227	227	225	224	222	204	176	155	148	148	146	145	145	145	145	144	144	141	141	141	141	140	140	140
19	0	229	228	227	225	224	208	183	168	155	148	147	145	145	145	145	144	144	142	141	141	141	140	140	140
20	0	230	230	228	226	225	211	185	168	146	149	147	145	145	145	145	144	144	142	142	142	141	141	140	140
21	0	231	231	229	228	227	212	186	169	146	150	147	145	145	145	145	145	142	142	142	142	141	141	141	141
22	0	233	233	231	229	229	213	187	170	147	150	148	145	145	145	145	143	143	142	142	142	142	141	141	141
23	0	237	236	234	233	232	216	190	172	149	152	148	145	145	145	144	144	143	143	143	143	142	142	142	142
24	0	241	241	239	237	236	220	192	174	140	153	149	146	146	146	144	144	144	144	144	143	143	142	142	142
25	0	247	246	244	242	241	225	196	176	142	154	150	147	147	146	145	145	145	144	144	144	144	143	142	142
26	0	251	250	249	247	246	229	198	178	143	155	151	147	147	147	146	145	145	145	145	144	144	143	143	143
27	0	255	254	253	251	250	232	201	180	144	156	152	148	148	147	146	145	145	145	145	145	144	143	143	143
28	0	258	257	256	254	252	234	202	181	145	157	152	148	148	148	146	146	145	145	145	145	144	143	143	143
29	0	262	261	259	257	256	237	204	182	146	157	153	148	148	148	146	146	146	145	145	145	144	143	143	143
30	0	266	265	263	261	260	241	207	184	147	158	153	149	149	149	147	146	146	146	146	145	145	143	143	143
31	0	269	268	266	264	263	243	208	185	148	159	154	149	149	149	147	147	146	146	146	146	145	144	143	143
32	0	271	270	268	266	264	244	209	186	148	159	154	149	149	149	147	147	146	146	146	146	145	144	143	143
33	0	272	271	269	267	265	245	210	186	149	159	154	149	149	149	147	147	147	146	146	146	145	144	144	143
34	0	272	271	269	267	266	246	210	186	149	159	154	150	149	149	147	147	147	146	146	146	145	144	144	144
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 3-6. Model FSV-1 shipping cask thermal analysis.
130°F day,
100 day heat
Minimum gaps - Reference Case

TEMPERATURE GRID
THE RADIAL DIRECTION IS HORIZONTAL
THE AXIAL DIRECTION IS VERTICAL
THE TEMPERATURES ARE IN DEGREES FAHRENHEIT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0	-39	-39	-39	-39	-39	-39	-39	-39	-39	-39	-39	-39	-39	-39	-39	-39	-39	-39	-39	-39	-39	-39	-39	-39
2	0	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14	-15	-15	-15
3	0	[illegible]	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14
4	0	[illegible]	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-13	-14	-14	-14
5	0	[illegible]	-13	-13	-13	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-12	-13	-13	-13	-13	-13	-13	-13	-13	-13
6	0	[illegible]	-12	-12	-12	-12	-12	-12	-12	-12	-10	-10	-10	-10	-11	-11	-12	-12	-12	-12	-12	-13	-13	-13	-13
7	0	-12	-12	-12	-11	-11	-11	-10	-10	-10	-10	-10	-10	-10	-11	-11	-12	-12	-12	-12	-12	-12	-12	-12	-12
8	0	-12	-12	-12	-11	-10	-10	-10	-9	-9	-9	-9	-9	-9	-10	-10	-11	-11	-11	-12	-12	-12	-12	-12	-12
9	0	[illegible]	-8	-8	-7	-7	-6	-6	-5	-5	-5	-5	-5	-5	-9	-10	-11	-11	-11	-11	-11	-11	-12	-12	-12
10	0	[illegible]	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-9	-9	-9	-10	-10	-10	-10	-11	-11	-11	-11
11	0	[illegible]	-0	-0	-0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-5	-5	-8	-9	-9	-9	-9	-10	-11	-11	-11
12	0	[illegible]	5	4	3	2	1	1	1	0	0	0	0	0	0	1	-6	-6	-7	-8	-9	-9	-11	-11	-11
13	0	[illegible]	[illegible]	7	5	4	4	3	3	3	3	2	2	2	2	2	-4	-5	-5	-8	-8	-8	-10	-10	-10
14	0	[illegible]	8	7	6	5	4	4	4	4	3	3	3	3	3	2	-3	-3	-3	-7	-7	-7	-10	-10	-10
15	0	[illegible]	8	8	7	6	6	6	6	4	4	4	4	3	3	3	-2	-2	-6	-6	-6	-6	-9	-9	-9
16	0	[illegible]	9	8	7	7	7	7	4	4	4	4	4	4	4	4	-1	-1	-5	-5	-5	-6	-9	-9	-9
17	0	[illegible]	103	101	99	97	49	6	6	6	5	5	5	4	4	4	-0	-0	-4	-5	-5	-5	-8	-8	-9
18	0	[illegible]	104	102	100	98	56	6	6	6	6	3	1	1	1	0	0	-0	-4	-4	-4	-5	-8	-8	-8
19	0	[illegible]	106	104	102	100	78	44	25	13	7	4	1	1	1	0	0	0	-4	-4	-4	-4	-8	-8	-8
20	0	[illegible]	107	[illegible]	103	102	83	51	30	16	8	4	1	1	1	0	0	0	-3	-4	-4	-4	-8	-8	-8
21	0	[illegible]	[illegible]	107	105	104	85	53	32	17	9	5	1	1	1	1	0	-3	-3	-3	-3	-4	-7	-7	-7
22	0	111	111	109	107	106	88	55	34	18	10	6	1	1	1	1	-2	-3	-3	-3	-3	-3	-7	-7	-7
23	0	[illegible]	114	113	111	110	91	58	36	20	12	7	2	2	2	-1	-2	-2	-2	-2	-2	-3	-6	-6	-6
24	0	[illegible]	120	118	116	115	[illegible]	62	40	23	15	9	4	4	4	-1	-1	-1	-1	-1	-2	-2	-5	-5	-5
25	0	[illegible]	126	124	122	121	101	66	43	26	17	11	6	6	5	-0	-0	-0	-0	-0	-1	-1	-5	-5	-5
26	0	[illegible]	131	130	128	127	[illegible]	70	46	29	19	13	7	7	7	0	0	0	-0	-0	-0	-0	-5	-5	-5
27	0	137	136	135	133	132	111	74	49	31	21	14	8	8	8	1	1	0	0	0	0	-0	-5	-5	-5
28	0	[illegible]	140	138	136	135	114	76	50	32	22	15	9	9	9	1	1	1	1	0	0	0	-5	-5	-5
29	0	[illegible]	145	143	141	140	118	79	53	34	24	17	10	10	10	2	2	1	1	1	1	0	-5	-5	-5
30	0	151	150	149	146	145	123	83	56	36	25	18	11	11	11	3	2	2	2	2	1	1	-4	-4	-5
31	0	[illegible]	154	152	150	149	[illegible]	85	57	37	27	19	12	12	12	3	3	3	2	2	2	1	-4	-4	-4
32	0	[illegible]	157	155	153	151	[illegible]	87	59	38	27	20	12	12	12	4	3	3	3	2	2	2	-4	-4	-4
33	0	159	[illegible]	156	154	153	129	88	59	39	[illegible]	20	13	13	13	4	3	3	3	3	2	2	-4	-4	-4
34	0	[illegible]	159	157	155	154	[illegible]	[illegible]	60	39	[illegible]	20	13	13	13	4	3	3	3	3	2	2	-4	-4	-4
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 3-7. Model FSV-1 shipping cask thermal analysis.
-40°F Day
100 Day Heat
Maximum Gap

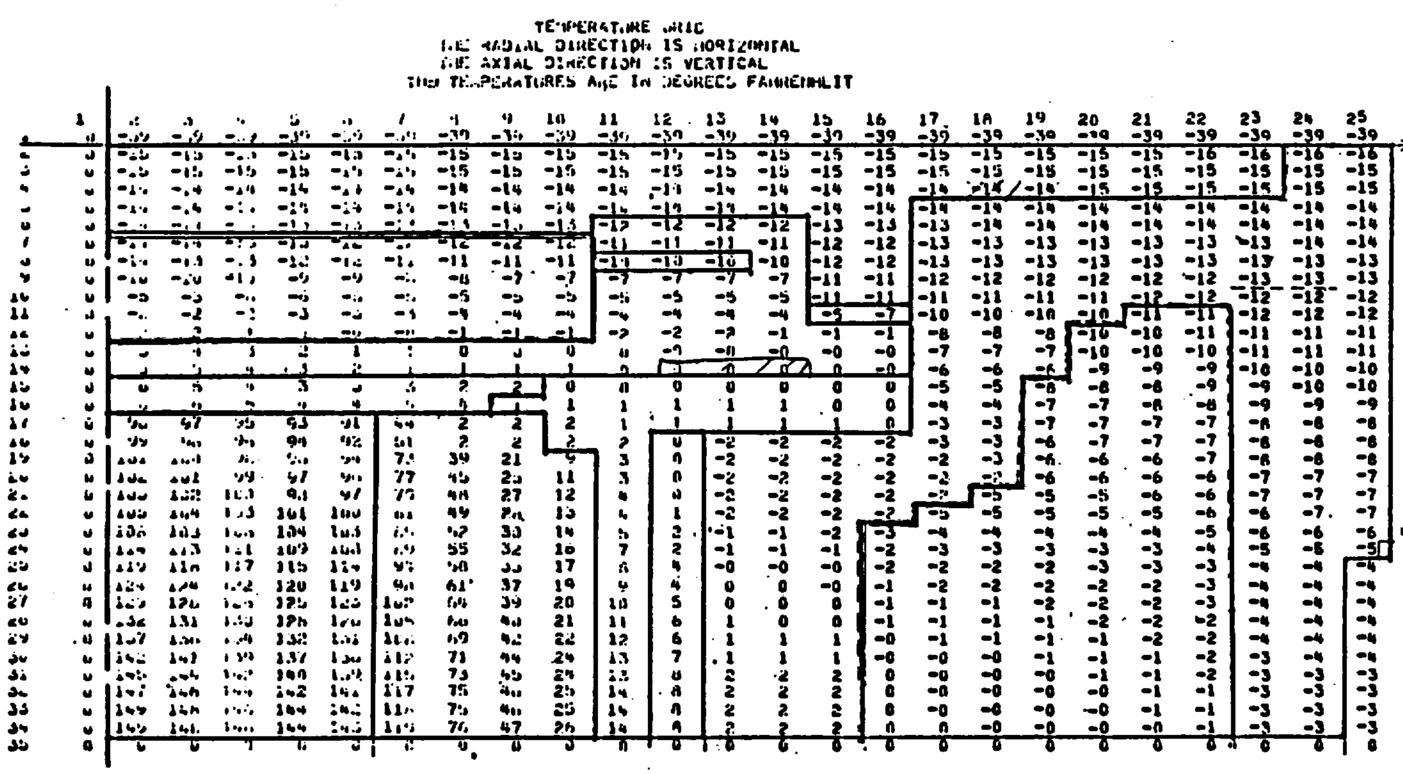


Fig. 3-8. Model FSV-1 shipping cask thermal analysis.
-40°F day
100 day heat
Minimum Gaps

grid lines and the material that it contains. The material is given in terms of a material numbering system. Parameters that define each material are the applicable thermal properties and the volumetric heat generation rate.

Blocks of materials may be separated by narrow gaps that contain stagnant gases. The gases are located in terms of a gas numbering system and are defined by their individual thermal conductivities. Heat transfer across these gaps is by one-dimensional conduction and radiation.

Boundary conditions at external boundaries are specified either by sink temperature and unit surface conductance or by the thermal parameters of a flowing coolant. These parameters are the coolant properties and flow conditions.

The thermal parameters for the materials, gases, and coolants may be given in functional form. Many of the calculation variables are available for use in these functions.

3.4.3 Analysis

Ambient Conditions

a. The maximum temperature day is defined as having an air temperature of 130°F with full sun. Further, it was assumed that the cask and trailer are in still air with no convective cooling other than free convection. Using a correlation for free convection around a horizontal cylinder, the following function was used to calculate heat transfer coefficient (Ref. 1).

$$h = 0.221\ (S_t - T_a)^{0.25}$$

where S_t = cask surface temperature, and
T_a = ambient temperature.

Thermal radiation from the cask to its surrounding was also calculated. It was assumed that the emissivity of the cask was 0.6 and that the absorbtivity of the ambient surroundings was 1.0. Thus, using standard correlations:

$$Fe = \varepsilon_1 = 0.6$$

Solar heating was imposed on the thermal model in the form of surface heat generation. Since the model is a two-dimensional, radial-axial one, there can be no circumferential variation. Thus, the heat generation was imposed around the entire circumference of the cask. The net effect is for a higher than actual total heat input with conservatively high internal temperatures.

The net solar heating is 96 Btu/hr-ft^2. Past experience with shipping cask analysis has shown that the thermal response of a cask is very slow and that is is not necessary to calculate with a time dependent solar heating function. Thus, steady-state temperaures were calculated.

b. Minimum Temperature Day

The minimum temperature day was defined as an ambient condition of -40°F with no solar heating. The same free convection heat transfer coefficient as was used for the 130°F day was incorporated, as was the ability of the cask to radiate heat to its surroundings. If it were to be assumed that the truck was moving and that a relatively high air velocity existed on the cask surface, the cask surface-to-air Δt would be nil and the cask internal temperatures would drop accordingly.

c. Fire Accident

The fire accident is defined as a surrounding ambient condition of 1475°F. An overall surface heat transfer coefficient (h) simulating a strong convection condition was assumed. Reasonable values of h_c for hot, blowing gasses are in the range of 100 to 300 Btu/hr-ft²-°F. The equivalent surface coefficient for thermal radiation (h_r) is approximately 30 Btu/hr-ft²-°F at a median cask surface temperature. This assumes, again, that the emissivity of the fire is 1.0. In total, an h of 300 was concluded to be a maximum reasonable value for the fire accident.

3.5 APPENDIX

3.5.1 RAT - Program Abstracts

RAT is a digital computer program for calculating transient and steady-state temperature distributions in two dimensions. The configurations of the bodies must be described by block boundaries and grid lines in either a rectangular, a cylindrical, or a polar coordinate system. Material properties may differ among blocks. Coolant streams are accommodated at external boundaries only.

Finite-difference heat transport equations, which may be nonlinear, are formulated for each cell defined by the grid lines and the heat paths between adjacent cells. The system of these equations is solved by an alternating direction method that has been found to be stable and efficient for most practical problems.

Some useful features of RAT are:

a. Director FORTRAN IV input of material and coolant properties in functional form.

b. Simple geometrical input.

c. Thermal radiation across internal gaps.

d. Anisotropic (bi-directional) material properties are permitted.

One small subroutine is written in machine language. Therefore, special attention is required in converting the code for use on different machines.

RAT calculates transient steady-state temperatures in two-dimensional problems by the finite difference method. The system to be analyzed may be bounded by flowing coolants and may contain internal gaps. There may be radiation across these gaps. Material and coolant thermal parameters may be functions of many different calculation variables, such as time and local temperature.

Restrictions: (1) The grid lines systems must be orthogonal in the rectangular, cylindrical, or polar coordinate system. (2) All radiation is treated one-dimensionally. (3) The size of a problem is governed by the following maximum values:

Radial Points	Axial Points	Radial Block Boundaries	Axial Block Boundaries	Blocks	Materials
35	35	23	23	110	15

Size:	Date:	Author:	Custodian:
47K	10/64	M. Troost	J. F. Petersen

Method: Overall effective values, which may include convection and radiation effects, are determined for the conductance points. The transient heat balance equations are then solved for the temperatures at the points using the method of Ref. 2.

Remarks: There are four versions of RAT. These versions differ from one another only in their dimensions. The program described here is the standard version. The other three versions have dimensions which give the following maximum values governing problem size:

Version	Radial Points	Axial Points	Radial Block Boundaries	Axial Block Boundaries	Blocks	Materials
A	25	50	16	28	110	15
B	27	40	25	32	110	15
C*	11	136	6	36	110	15

*This version has limited storage for material and coolant property functions.

3.5.2 Example Application of the RAT Code

The computer program RAT was developed at GA and is relatively unknown outside of the company. In order to illustrate the validity of this program as a thermal analysis tool, a text book transient problem was used as a standard of comparison. The text and problem are noted in Ref. 3. A summary of the results obtained by duplicating the problem with RAT is given on Fig. 3-9 along with the text results. It is noted that the computed results correlate closely with the text data.

The thermal model for the study is shown on Fig. 3-10 with the dimensional input data and samples of the computed results at selected times on the subsequent figures.

References

1. Aerospace Applied Thermodynamics Manual, SAE.

2. Peaceman, D. W., and Rachford, H. H., "The Numerical Solution of Parabolic and Elliptic Differential Equations," I. Soc. Indust. Appl. Math. 3 (1), 28 (1955).

3. Schneider, P. J., Conduction Heat Transfer, Addison-Wesley Company, Inc., Reading Mass., p. 236.

GA Documentation

1. Petersen, J. F., "Conversion of RAT, TAC, and RAT3D to FORTRAN V," ARD:12:69, March 10, 1969.

2. Ludwig, D. L., "A User's Manual for the RAT Heat Transfer Code," Gulf General Atomic Informal Report GAMD-8360, November 9, 1967.

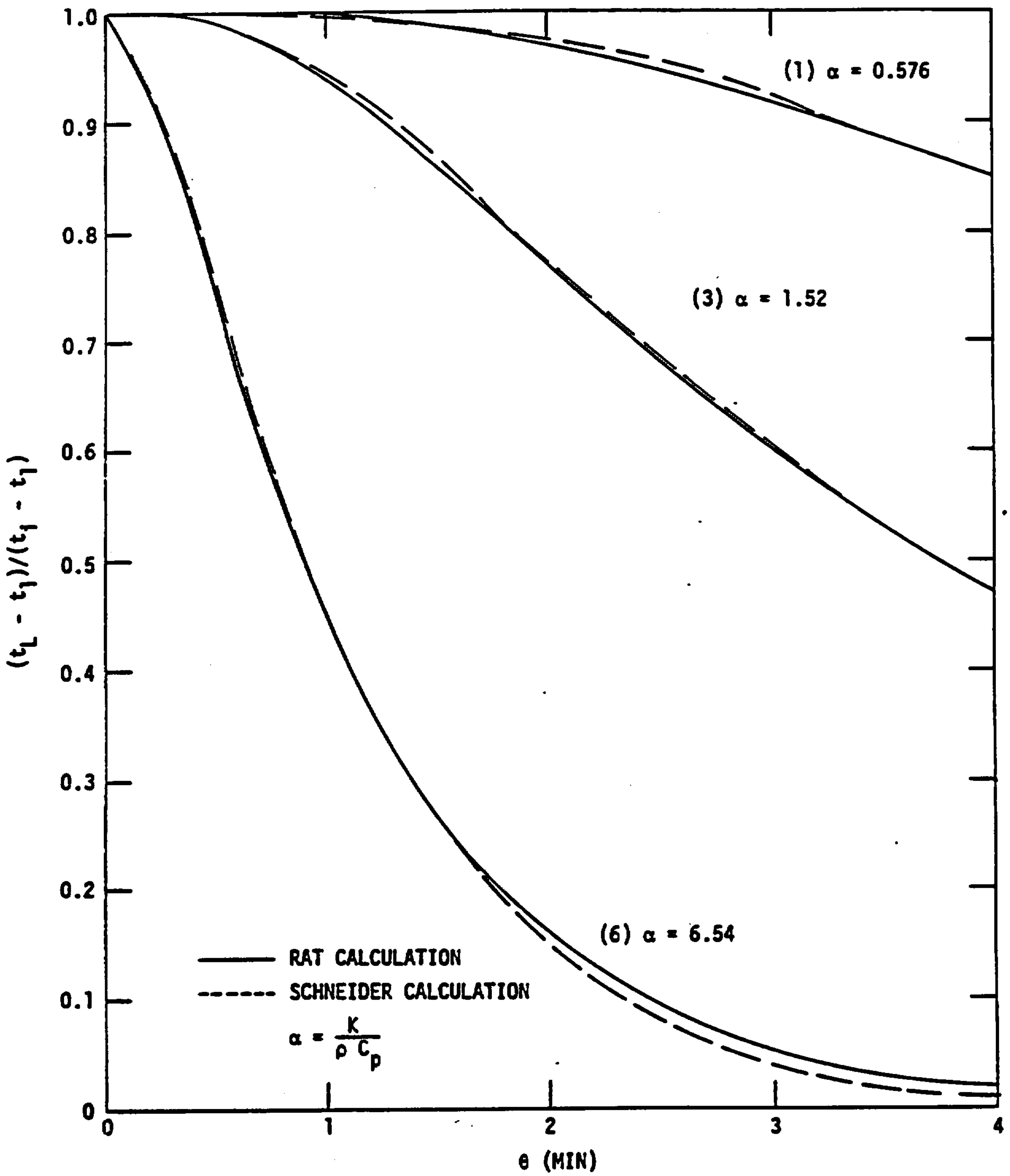
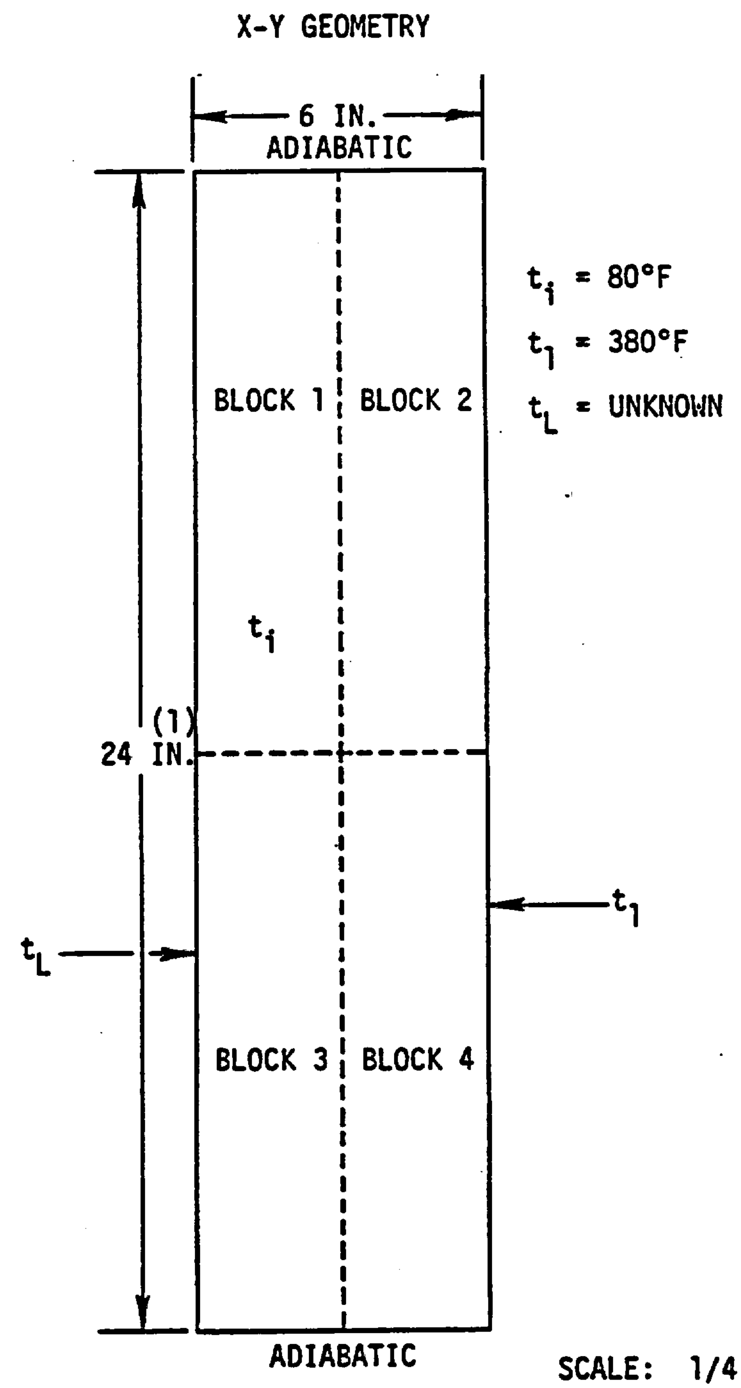


FIGURE 3-9 **Results-RAT and text comparison**



(1) NOTE: THIS DIMENSION IS NOT RELEVANT TO THE PROBLEM

FIGURE 3-10 Thermal model - RAT test case transient 0 to 4 min

HAT RESULTS 30 SEP 69 PAGE 6

HAT - A TWO-DIMENSIONAL TRANSIENT HEAT TRANSPORT CODE, R-A, X-Y OR R-TH GEOMETRY, GENERAL ATOMIC
CASE 1 FOR NICKEL - DIFFUSIVITY = 0.576
CHECK TEMP. RISE AT INSULATED REAR FACE OF A PLANE WALL 6 IN.
THICK VERSUS TIME

PRINT OF THE INPUT

PROPERTIES OF THE BLOCKS

BLOCK NUMBER	LOW RADIAL BOUNDARY	HIGH RADIAL BOUNDARY	LOW AXIAL BOUNDARY	HIGH AXIAL BOUNDARY	SOLID MATERIAL NUMBER	RADIAL GAP THICKNESS	RADIAL GAP MATERIAL	AXIAL GAP THICKNESS	AXIAL GAP MATERIAL
1	.000 IN.	3.000 IN.	.000 IN.	12.000 IN.	1	-.0000 IN.	-0	-.0000 IN.	-0
2	3.000 IN.	6.000 IN.	.000 IN.	12.000 IN.	1	-.0000 IN.	-0	-.0000 IN.	-0
3	.000 IN.	3.000 IN.	12.000 IN.	24.000 IN.	1	-.0000 IN.	-0	-.0000 IN.	-0
4	3.000 IN.	6.000 IN.	12.000 IN.	24.000 IN.	1	-.0000 IN.	-0	-.0000 IN.	-0

Note: It is a program requirement that there be at least two blocks in each direction

RAT RESULTS

RESULTS

COOLANT TEMPERATURES

	INLET	OUTLET	FLOW (LB/HR)
INNER RADIAL	-459	80	0
OUTER RADIAL	0	0	0
UPPER AXIAL	0	0	0
LOWER AXIAL	0	0	0

THE CURRENT TIME IS .0000 HR. OR .0017 MIN. OR .10000 SEC.

TEMPERATURE GRID
THE RADIAL DIRECTION IS HORIZONTAL
THE AXIAL DIRECTION IS VERTICAL
THE TEMPERATURES ARE IN DEGREES FAHRENHEIT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0							
2	80	80	80	80	80	80	81	380							
3	80	80	80	80	80	80	81	380							
4	80	80	80	80	80	80	81	380							
5	80	80	80	80	80	80	81	380							
6	80	80	80	80	80	80	81	380							
7 t_L	80	80	80	80	80	80	81	380 t_1							
8	80	80	80	80	80	80	81	380							
9	80	80	80	80	80	80	81	380							
10	80	80	80	80	50	80	81	380							
11	80	80	80	80	80	80	81	380							
12	80	80	80	80	80	80	81	380							
13	80	80	80	80	80	80	81	380							
14	0	0	0	0	0	0	0	0							

(1) CASE FOR NICKEL
$\alpha = 0.576$

HAT RESULTS

RESULTS

COOLANT TEMPERATURES

	INLET	OUTLET	FLOW (LB/HR)
INNER RADIAL	-459	81	0
OUTER RADIAL	0	0	0
UPPER AXIAL	0	0	0
LOWER AXIAL	0	0	0

THE CURRENT TIME IS .0200 HR. OR 1.2000 MIN. OR 71.99999 SEC.

TEMPERATURE GRID
THE RADIAL DIRECTION IS HORIZONTAL
THE AXIAL DIRECTION IS VERTICAL
THE TEMPERATURES ARE IN DEGREES FAHRENHEIT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0							
2	81	81	65	96	128	196	310	380							
3	81	81	65	96	128	196	310	380							
4	81	81	65	96	128	196	310	380							
5	81	81	65	96	128	196	310	380							
6	81	81	65	96	128	196	310	380							
7	81	81	65	96	128	196	310	380							
8	81	81	65	96	128	196	310	380							
9	81	81	65	96	128	196	310	380							
10	81	81	65	96	128	196	310	380							
11	81	81	65	96	128	196	310	380							
12	81	81	65	96	128	196	310	380							
13	81	81	65	96	128	196	310	380							
14	0	0	0	0	0	0	0	0							

CASE FOR NICKEL
$\alpha = 0.576$

KAT RESULTS

RESULTS

COOLANT TEMPERATURES

	INLET	OUTLET	FLOW (LB/HR)
INNER RADIAL	-459	91	0
OUTER RADIAL	0	0	0
UPPER AXIAL	0	0	0
LOWER AXIAL	0	0	0

THE CURRENT TIME IS .0367 HR. OR 2.2000 MIN. OR 131.99998 SEC.

TEMPERATURE GRID
THE RADIAL DIRECTION IS HORIZONTAL
THE AXIAL DIRECTION IS VERTICAL
THE TEMPERATURES ARE IN DEGREES FAHRENHEIT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0							
2	91	91	101	125	170	239	330	380							
3	91	91	101	125	170	239	330	380							
4	91	91	101	125	170	239	330	380							
5	91	91	101	125	170	239	330	380							
6	91	91	101	125	170	239	330	380							
7	91	91	101	125	170	239	330	380							
8	91	91	101	125	170	239	330	380							
9	91	91	101	125	170	239	330	380							
10	91	91	101	125	170	239	330	380							
11	91	91	101	125	170	239	330	380							
12	91	91	101	125	170	239	330	380							
13	91	91	101	125	170	239	330	380							
14	0	0	0	0	0	0	0	0							

CASE FOR NICKEL
$\alpha = 0.576$

RAT RESULTS

RESULTS

COOLANT TEMPERATURES

	INLET	OUTLET	FLOW (LB/HR)
INNER RADIAL	-459	108	0
OUTER RADIAL	0	0	0
UPPER AXIAL	0	0	0
LOWER AXIAL	0	0	0

THE CURRENT TIME IS .0533 HR. OR 3.2000 MIN. OR 191.99998 SEC.

TEMPERATURE GRID
THE RADIAL DIRECTION IS HORIZONTAL
THE AXIAL DIRECTION IS VERTICAL
THE TEMPERATURES ARE IN DEGREES FAHRENHEIT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0							
2	108	108	122	151	198	262	339	380							
3	106	108	122	151	198	262	339	380							
4	108	108	122	151	198	262	339	360							
5	108	108	122	151	198	262	339	380							
6	108	108	122	151	198	262	339	380							
7	108	108	122	151	198	262	339	380							
8	108	108	122	151	198	262	339	360							
9	166	108	122	151	198	262	339	380							
10	108	108	122	151	198	262	339	380							
11	108	108	122	151	198	262	339	380							
12	108	108	122	151	198	262	339	380							
13	108	108	122	151	198	262	339	360							
14	0	0	0	0	0	0	0	0							

CASE FOR NICKEL
$\alpha = 0.576$

HEAT RESULTS

RESULTS

COOLANT TEMPERATURES

	INLET	OUTLET	FLOW (LB/HR)
INNER RADIAL	-459	124	0
OUTER RADIAL	0	0	0
UPPER AXIAL	0	0	0
LOWER AXIAL	0	0	0

THE CURRENT TIME IS .0667 HR. OR 4.0000 MIN. OR 239.99997 SEC.

TEMPERATURE GRID
THE RADIAL DIRECTION IS HORIZONTAL
THE AXIAL DIRECTION IS VERTICAL
THE TEMPERATURES ARE IN DEGREES FAHRENHEIT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0							
2	124	124	139	169	215	274	343	380							
3	124	124	139	169	215	274	343	380							
4	124	124	139	169	215	274	343	380							
5	124	124	139	169	215	274	343	380							
6	124	124	139	169	215	274	343	380							
7	124	124	139	169	215	274	343	380							
8	124	124	139	169	215	274	343	380							
9	124	124	139	169	215	274	343	380							
10	124	124	139	169	215	274	343	380							
11	124	124	139	169	215	274	343	380							
12	124	124	139	169	215	274	343	380							
13	124	124	139	169	215	274	343	380							
14	0	0	0	0	0	0	0	0							

CASE FOR NICKEL
$\alpha = 0.576$

RAT RESULTS

RESULTS

COOLANT TEMPERATURES	INLET	OUTLET	FLOW (LB/HR)
INNER RADIAL	-459	80	0
OUTER RADIAL	0	0	0
UPPER AXIAL	0	0	0
LOWER AXIAL	0	0	0

THE CURRENT TIME IS .000 HR. OR .0017 MIN. OR .10000 SEC.

TEMPERATURE GRID
THE RADIAL DIRECTION IS HORIZONTAL
THE AXIAL DIRECTION IS VERTICAL
THE TEMPERATURES ARE IN DEGREES FAHRENHEIT

		1	2	3	4	5	6	7	8		9	10	11	12	13	14	15
1		0	0	0	0	0	0	0	0								
2		80	80	80	80	80	80	83	380								
3		80	80	80	80	80	80	83	380								
4		80	80	80	80	80	80	83	380								
5		80	80	80	80	80	80	83	380								
6		80	80	80	80	80	80	83	380								
7	t_L	80	80	80	80	80	80	82	380	t_1							
8		80	80	80	80	80	80	84	380								
9		80	80	80	[illegible]	80	80	85	380								
10		80	80	80	[illegible]	80	80	83	380								
11		80	80	80	[illegible]	[illegible]	[illegible]	[illegible]	380								
12		80	80	80	[illegible]	80	80	83	380								
13		80	80	80	80	80	80	83	380								
14		0	0	0	0	0	0	0	0								

(2) CASE FOR TIN
$\alpha = 1.52$

NAT RESULTS

RESULTS

COOLANT TEMPERATURES

	INLET	OUTLET	FLOW (LB/HR)
INNER RADIAL	-459	107	0
OUTER RADIAL	0	0	0
UPPER AXIAL	0	0	0
LOWER AXIAL	0	0	0

THE CURRENT TIME IS .0200 HR. OR 1.2000 MIN. OR 71.99999 SEC.

TEMPERATURE GRID
THE RADIAL DIRECTION IS HORIZONTAL
THE AXIAL DIRECTION IS VERTICAL
THE TEMPERATURES ARE IN DEGREES FAHRENHEIT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0							
2	107	107	121	150	197	261	338	380							
3	107	107	121	150	197	261	338	380							
4	107	107	121	150	197	261	338	360							
5	107	107	121	150	197	261	338	380							
6	107	107	121	150	197	261	338	380							
7	107	107	121	150	197	261	338	380							
8	107	107	121	150	197	261	338	380							
9	107	107	121	150	197	261	338	380							
10	107	107	121	150	197	261	338	380							
11	107	107	121	150	197	261	338	380							
12	107	107	121	150	197	261	338	380							
13	107	107	121	150	197	261	338	380							
14	0	0	0	0	0	0	0	0							

CASE FOR TIN
$\alpha = 1.52$

RAT RESULTS

RESULTS

COOLANT TEMPERATURES

	INLET	OUTLET	FLOW (LB/HR)
INNER RADIAL	-459	160	0
OUTER RADIAL	0	0	0
UPPER AXIAL	0	0	0
LOWER AXIAL	0	0	0

THE CURRENT TIME IS .0367 HR. OR 2.2000 MIN. OR 131.99998 SEC.

TEMPERATURE GRID
THE RADIAL DIRECTION IS HORIZONTAL
THE AXIAL DIRECTION IS VERTICAL
THE TEMPERATURES ARE IN DEGREES FAHRENHEIT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0							
2	160	160	175	203	243	293	350	380							
3	160	160	175	203	243	293	350	380							
4	160	160	175	203	243	293	350	380							
5	160	160	175	203	243	293	350	380							
6	160	160	175	203	243	293	350	380							
7	160	160	175	203	243	293	350	380							
8	160	160	175	203	243	293	350	380							
9	160	160	175	203	243	293	350	360							
10	160	160	175	203	243	293	350	380							
11	160	160	175	203	243	293	350	380							
12	160	160	175	203	243	293	350	380							
13	160	160	175	203	243	293	350	380							
14	0	0	0	0	0	0	0	0							

CASE FOR TIN
$\alpha = 1.52$

RAT RESULTS

RESULTS

COOLANT TEMPERATURES

	INLET	OUTLET	FLOW (LB/HR)
INNER RADIAL	-459	208	0
OUTER RADIAL	0	0	0
UPPER AXIAL	0	0	0
LOWER AXIAL	0	0	0

THE CURRENT TIME IS .0533 HR. OR 3.2000 MIN. OR 191.99998 SEC.

TEMPERATURE GRID
THE RADIAL DIRECTION IS HORIZONTAL
THE AXIAL DIRECTION IS VERTICAL
THE TEMPERATURES ARE IN DEGREES FAHRENHEIT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0							
2	208	208	219	242	274	313	357	380							
3	208	208	219	242	274	313	357	380							
4	208	208	219	242	274	313	357	380							
5	208	208	219	242	274	313	357	380							
6	208	208	219	242	274	313	357	380							
7	208	208	219	242	274	313	357	380							
8	208	208	219	242	274	313	357	380							
9	208	208	219	242	274	313	357	380							
10	208	208	219	242	274	313	357	380							
11	208	208	219	242	274	313	357	380							
12	208	208	219	242	274	313	357	380							
13	208	208	219	242	274	313	357	380							
14	0	0	0	0	0	0	0	0							

CASE FOR TIN
$\alpha = 1.52$

HAT RESULTS

RESULTS

COOLANT TEMPERATURES

	INLET	OUTLET	FLOW (LB/HR)
INNER RADIAL	-459	239	0
OUTER RADIAL	0	0	0
UPPER AXIAL	0	0	0
LOWER AXIAL	0	0	0

THE CURRENT TIME IS .0067 HR. OR 4.0000 MIN. OR 239.99997 SEC.

TEMPERATURE GRID
THE RADIAL DIRECTION IS HORIZONTAL
THE AXIAL DIRECTION IS VERTICAL
THE TEMPERATURES ARE IN DEGREES FAHRENHEIT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0							
2	239	239	248	267	293	325	361	380							
3	239	239	248	267	293	325	361	380							
4	239	239	248	267	293	325	361	380							
5	239	239	246	267	293	325	361	380							
6	239	239	248	267	293	325	361	380							
7	239	239	248	267	293	325	361	380							
8	239	239	248	267	293	325	361	380							
9	239	239	248	267	293	325	361	380							
10	239	239	248	267	293	325	361	380							
11	239	239	248	267	293	325	361	380							
12	239	239	248	267	293	325	361	380							
13	239	239	248	267	293	325	361	380							
14	0	0	0	0	0	0	0	0							

CASE FOR TIN
$\alpha = 1.52$

RAT RESULTS

INITIAL TEMPERATURE DISTRIB.

THE CURRENT TIME IS -.0000 HR. OR .0000 MIN. OR .00000 SEC.

TEMPERATURE GRID
THE RADIAL DIRECTION IS HORIZONTAL
THE AXIAL DIRECTION IS VERTICAL
THE TEMPERATURES ARE IN DEGREES FAHRENHEI

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0							
2	80	80	80	80	80	80	80	380							
3	80	80	80	80	80	80	80	380							
4	80	80	80	80	80	80	80	380							
5	80	80	80	80	80	80	80	380							
6	80	80	80	80	80	80	80	380							
7	80	80	80	80	80	80	80	380 t_1							
8 t_L	80	80	80	80	80	80	80	380							
9	80	80	80	80	80	80	80	380							
10	80	80	80	80	80	80	80	380							
11	80	80	80	80	80	80	80	380							
12	80	80	80	80	80	80	80	380							
13	80	80	80	80	80	80	80	380							
14	0	0	0	0	0	0	0	0							

(3) CASE FOR SILVER
$\alpha = 6.54$

RAT RESULTS

RESULTS

COOLANT TEMPERATURES

	INLET	OUTLET	FLOW (LB/HR)
INNER RADIAL	-459	155	0
OUTER RADIAL	0	0	0
UPPER AXIAL	0	0	0
LOWER AXIAL	0	0	0

THE CURRENT TIME IS .0083 HR. OR .5000 MIN. OR 30.00000 SEC.

TEMPERATURE GRID
THE RADIAL DIRECTION IS HORIZONTAL
THE AXIAL DIRECTION IS VERTICAL
THE TEMPERATURES ARE IN DEGREES FAHRENHEIT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0							
2	155	155	170	198	238	288	345	380							
3	155	155	170	198	238	288	345	380							
4	155	155	170	198	238	288	345	380							
5	155	155	170	198	238	288	345	380							
6	155	155	170	198	238	288	345	380							
7	155	155	170	198	238	288	345	380							
8	155	155	170	198	238	288	345	380							
9	155	155	170	198	238	288	345	380							
10	155	155	170	198	238	288	345	380							
11	155	155	170	198	238	288	345	380							
12	155	155	170	198	238	288	345	380							
13	155	155	170	198	238	288	345	380							
14	0	0	0	0	0	0	0	0							

CASE FOR SILVER
$\alpha = 6.54$

RAT RESULTS

RESULTS

COOLANT TEMPERATURES

	INLET	OUTLET	FLOW (LB/HR)
INNER RADIAL	-459	342	0
OUTER RADIAL	0	0	0
UPPER AXIAL	0	0	0
LOWER AXIAL	0	0	0

THE CURRENT TIME IS .0367 HR. OR 2.2000 MIN. OR 131.99998 SEC.

TEMPERATURE GRID
THE RADIAL DIRECTION IS HORIZONTAL
THE AXIAL DIRECTION IS VERTICAL
THE TEMPERATURES ARE IN DEGREES FAHRENHEIT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0							
2	342	342	344	349	356	365	374	380							
3	342	342	344	349	356	365	374	380							
4	342	342	344	349	356	365	374	380							
5	342	342	344	349	356	365	374	380							
6	342	342	344	349	356	365	374	380							
7	342	342	344	349	356	365	374	380							
8	342	342	344	349	356	365	374	380							
9	342	342	344	349	356	365	374	380							
10	342	342	344	349	356	365	374	380							
11	342	342	344	349	356	365	374	380							
12	342	342	344	349	356	365	374	380							
13	342	342	344	349	356	365	374	380							
14	0	0	0	0	0	0	0	0							

CASE FOR SILVER
$\alpha = 6.54$

RAT RESULTS

RESULTS

COOLANT TEMPERATURES

	INLET	OUTLET	FLOW (LB/HR)
INNER RADIAL	-459	367	0
OUTER RADIAL	0	0	0
UPPER AXIAL	0	0	0
LOWER AXIAL	0	0	0

THE CURRENT TIME IS .0533 HR. OR 3.2000 MIN. OR 191.99998 SEC.

TEMPERATURE GRID
THE RADIAL DIRECTION IS HORIZONTAL
THE AXIAL DIRECTION IS VERTICAL
THE TEMPERATURES ARE IN DEGREES FAHRENHEIT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0							
2	367	367	367	369	372	375	378	380							
3	367	367	367	369	372	375	378	380							
4	367	367	367	369	372	375	378	380							
5	367	367	367	369	372	375	378	380							
6	367	367	367	369	372	375	378	380							
7	367	367	367	369	372	375	378	380							
8	367	367	367	369	372	375	378	380							
9	367	367	367	369	372	375	378	380							
10	367	367	367	369	372	375	378	380							
11	367	367	367	369	372	375	378	380							
12	367	367	367	369	372	375	378	380							
13	367	367	367	369	372	375	378	380							
14	0	0	0	0	0	0	0	0							

CASE FOR SILVER
α = 6.54

RAT RESULTS

RESULTS

COOLANT TEMPERATURES

	INLET	OUTLET	FLOW (LB/HR)
INNER RADIAL	-459	374	0
OUTER RADIAL	0	0	0
UPPER AXIAL	0	0	0
LOWER AXIAL	0	0	0

THE CURRENT TIME IS .0667 HR. OR 4.0000 MIN. OR 239.99997 SEC.

TEMPERATURE GRID
THE RADIAL DIRECTION IS HORIZONTAL
THE AXIAL DIRECTION IS VERTICAL
THE TEMPERATURES ARE IN DEGREES FAHRENHEIT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0	0	0	0	0	0	0	0							
2	374	374	375	375	376	378	379	380							
3	374	374	375	375	376	378	379	380							
4	374	374	375	375	376	378	379	380							
5	374	374	375	375	376	378	379	380							
6	374	374	375	375	376	378	379	380							
7	374	374	375	375	376	378	379	380							
8	374	374	375	375	376	378	379	380							
9	374	374	375	375	376	378	379	380							
10	374	374	375	375	376	378	379	380							
11	374	374	375	375	376	378	379	380							
12	374	374	375	375	376	378	379	380							
13	374	374	375	375	376	378	379	380							
14	0	0	0	0	0	0	0	0							

CASE FOR SILVER
$\alpha = 6.54$

910013 NC

GADR 55
Volume I

CONDUCTION HEAT TRANSFER

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10-6 Infinite plate. Consider the heating or cooling of a large plate of uniform thickness $L = 2\delta_1$. The temperature distribution through the plate, $t(x,\theta)$, is initially ($\theta = 0$) some arbitrary function of x as $t(x,0) = t_i(x)$, whereupon both face surfaces $x = 0$ and L are suddenly changed to and maintained at a uniform temperature t_1 for all $\theta > 0$.

The solution for the temperature history $t(x,\theta)$ must satisfy the characteristic partial-differential equation of Fourier, (1-8), as

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial \theta}, \tag{10-6}$$

and the initial and boundary conditions

$$\begin{aligned} T &= T_i(x) && \text{at } \theta = 0; && 0 \le x \le L, \\ T &= 0 && \text{at } x = 0; && \theta > 0, \\ T &= 0 && \text{at } x = L; && \theta > 0, \end{aligned}$$

where, for convenience, we let $T = t - t_1$ so that $T_i(x) = t_i(x) - t_1$. Integrating (10-6) by the separation of variables method (Article 5-8) leads to product solutions of the form

$$T_\lambda = e^{-\lambda^2\alpha\theta}(C_1 \cos \lambda x + C_2 \sin \lambda x),$$

if the separation constant is chosen as $-\lambda^2$. In these solutions $C_1 = 0$ if T is to vanish at $x = 0$ for all $\theta > 0$. If T is also to vanish at $x = L$ for all $\theta > 0$, then $\sin \lambda L = 0$, so that $\lambda = n\pi/L$. This requires that the eigenvalues be integral as $n = 1, 2, 3, \cdots$. The solution, which now takes the form

$$T = \sum_{n=1}^{\infty} C_n e^{-(n\pi/L)^2\alpha\theta} \sin \frac{n\pi}{L} x,$$

is to finally satisfy the initial condition that

$$T_i(x) = \sum_{n=1}^{\infty} C_n \sin \frac{n\pi}{L} x.$$

This result is recognized as a Fourier sine-series expansion of the arbitrary function $T_i(x)$, for which the constant amplitudes C_n are given by

$$C_n = \frac{2}{L}\int_0^L T_i(x) \sin \frac{n\pi}{L} x dx.$$

The complete solution is therefore

$$T = \frac{2}{L}\sum_{n=1}^{\infty} e^{-(n\pi/2)^2\Theta} \sin \frac{n\pi}{L} x \int_0^L T_i(x) \sin \frac{n\pi}{L} x dx, \tag{10-7}$$

where Θ is the Fourier modulus in (10-2) with $\delta_1 = L/2$. The solution (10-7) is also that for an insulated rod of length L with end temperatures maintained at t_1, the rod heating or cooling from an initial temperature state $t_i(x)$.

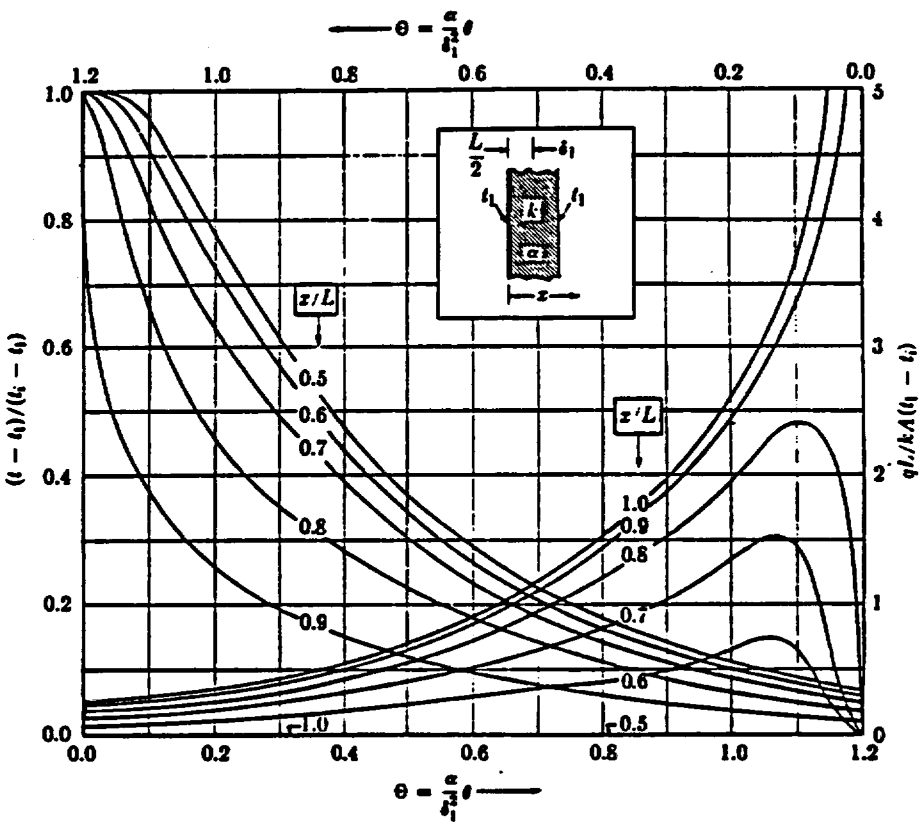


Fig. 10-2. Temperature history and instantaneous heat rate as a function of the Fourier modulus Θ for an infinite plate with negligible surface resistance.

Consider the special case represented by a uniform initial temperature $t_i(x) = t_i$. This is a practical case where $T_i(x) = t_i - t_1$, and for which (10-7) reappears in the particular form

$$\frac{t - t_1}{t_i - t_1} = \frac{4}{\pi}\sum_{n=1}^{\infty}\frac{1}{n}e^{-(n\pi/2)^2\Theta}\sin\frac{n\pi}{L}x; \quad n = 1, 3, 5, \cdots. \tag{10-8}$$

Then the instantaneous rate at which heat is conducted across any plane of area A in the wall is $q = -kA\partial t/\partial x$, or

$$q(x,\theta) = 4\left(\frac{kA}{L}\right)(t_1 - t_i)\sum_{n=1}^{\infty} e^{-(n\pi/2)^2\Theta}\cos\frac{n\pi}{L}x; \quad n = 1, 3, 5, \cdots. \tag{10-9}$$

Notice that the heat flow is initially infinite at the two surfaces. The temperature history (10-8) and instantaneous heat rate (10-9) are shown in Fig. 10-2 for various stations in the plate.

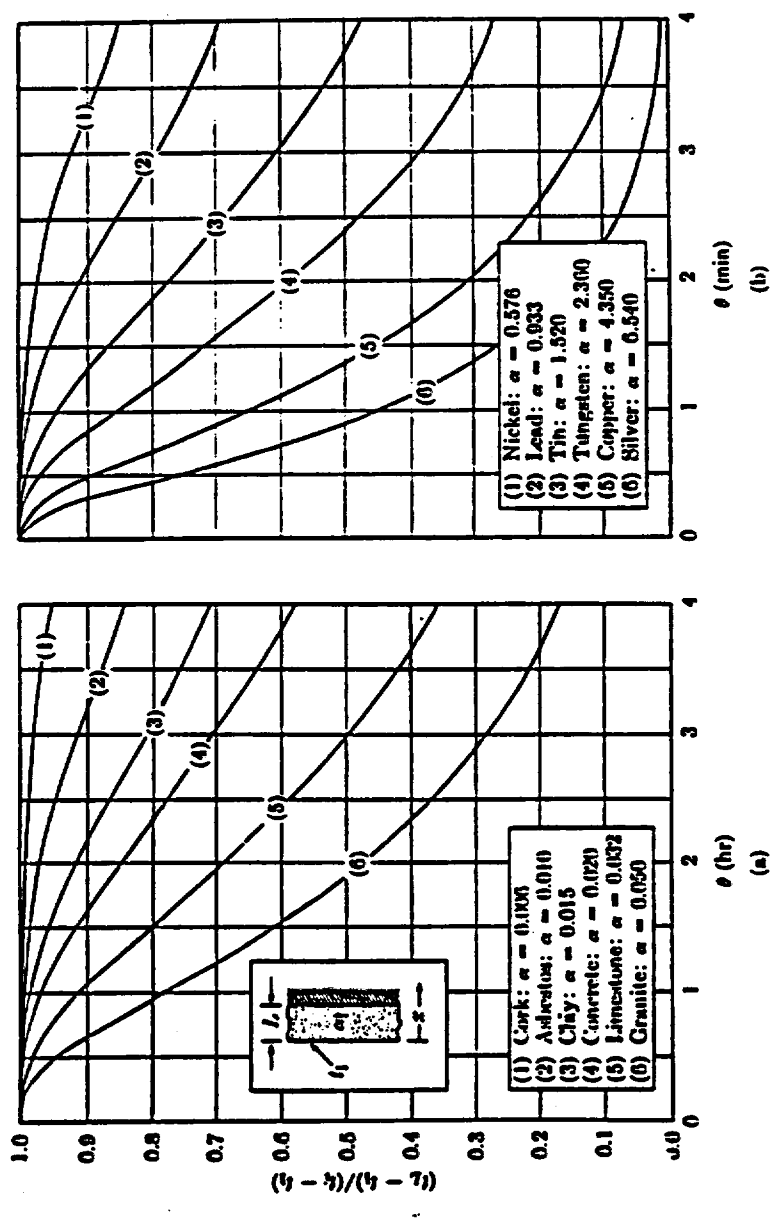


Fig. 10-3. Temperature rise at the insulated rear face of a plane wall 6" thick, for various building materials (a) and pure metals (b).

Integration of (10-9) with respect to θ from $\theta = 0$ to θ gives for the cumulative heat rate in the plate

$$Q(x,\theta) = \frac{4}{\pi^2}\left(\frac{kAL}{\alpha}\right)(t_1 - t_i)\sum_{n=1}^{\infty}\frac{1}{n^2}[1 - e^{-(n\pi/2)^2\Theta}]\cos\frac{n\pi}{L}x;$$

$$n = 1, 3, 5, \cdots. \quad (10\text{-}10)$$

The series (10-8) has been accurately computed by Olson and Schultz (1) for the mid-plane temperature history at $x = L/2$ as given by

$$\frac{t(L/2,\theta) - t_1}{t_i - t_1} = \frac{4}{\pi} = [e^{-(1/4)\pi^2\Theta} - \tfrac{1}{3}e^{-(9/4)\pi^2\Theta} + \tfrac{1}{5}e^{-(25/4)\pi^2\Theta} - \cdots] = P(\Theta). \quad (10\text{-}11)$$

Values of $P(\Theta)$ for the plate are listed in Table A-8 of the Appendix, and later on we shall show how this particular series can be combined with an analogous series for the cylinder and semi-infinite solid to obtain solutions for a variety of other cases of practical interest.

EXAMPLE 10-2. As an example in the use of the plate series $P(\Theta)$, suppose that a large mass of combustible material is piled up against the 6″-thick wall of a large room. If a flash fire suddenly raises and maintains the temperature of the outside wall surface at t_1, how long will it take for the inside surface to reach the ignition temperature of the combustible material?

Solution. If the dimensions of the room are large compared with the wall thickness, then its walls can be approximated by an infinite plate 6″ thick and at a uniform temperature t_i preceding its exposure to fire at the face surface $x = 0$. Suppose further that the combustible material is of low thermal conductivity; the face surface at $x = L$ is then considered to be adiabatic.

A solution to the problem of the infinite plate with one insulated face is also encompassed in (10-8), for if we consider a plate of double thickness $2L$ with each face at t_1, then its mid-plane (around which the temperature is symmetrical) can be taken as the adiabatic face of the original plate. The temperature history at this adiabatic face is given by (10-11).

Values of $P(\Theta)$ with $L = 1$ are taken from Table A-8 and plotted in Fig. 10-3 for walls of various building materials in (a), and for large pure-metal walls in (b). Note that the units of time in (a) and (b) are hours and minutes respectively.

From these results we see that the walls of higher diffusivity have shorter allowable heating times, the duration being comparatively short for the metal walls. For example, if the ignition temperature of the stored material is 140°F, and the fire raises the outside surface temperature of the walls (initially at 80°F) to 380°F, then it would take a 6″ clay wall over three hours to reach $(t_L - t_1)/(t_i - t_1) = (140 - 380)/(80 - 380) = 0.8$, as compared with just three minutes for a 6″ lead wall.

SECTION 4.0

CONTAINMENT

4.0 CONTAINMENT

4.1 CONTAINMENT BOUNDARY

The following components of Model FSV-1 in Configurations A, B, C and D form the containment boundary as described in Section 1.0:

Cask body
Cask closure with O-rings
Center plug with O-rings
Purge connection cover with O-rings

4.2 CONTAINMENT DURING THE NORMAL CONDITIONS OF TRANSPORT

The radioactive contents of Configurations A, B, C and D will be solid, nonfissile, irradiated, and contaminated hardware removed from various light water nuclear reactors. Irradiated hardware from a light water nuclear reactor is assumed to have corrosion products, known as crud, on the surface. Dry crud can be in the form of small respirable particles and thus is the basis for the containment requirements. The radionuclide content of crud was obtained from an Electric Power Research Institute document, EPRI-NP-2735, and the quantity of crud was estimated from the quantity of crud found on spent fuel assemblies. Identities and characteristics of the radionculides in the crud are provided in Table 4-1.

The actual quantity of crud can vary with each shipment, and the quantity used for this containment evaluation is based on the surface area of 12 BWR control rod blades and is realistic for the shipment of solid, nonfissile, irradiated, and contaminated hardware.

TABLE 4-1
RADIONUCLIDE INVENTORY

Radionuclide	Curies/Cask (2 yr decay)	A_2 (curies)	A_2/Cask
Co-60	44.91	7	6.42
Co-58	0.39	20	19.5×10^{-3}
Mn-54	31.59	20	1.59
Fe-59	12.0×10^{-4}	10	12.0×10^{-5}
Fe-55	1464	1000	1.47
Cr-51	3.0×10^{-6}	600	5.01×10^{-9}
Ni-63	0.54	100	5.4×10^{-3}
Total	1542		9.51

$$\text{Composite } A_2 = \frac{1542 \text{ curies/cask}}{9.51\ A_2\text{/cask}} = \underline{162.10 \text{ curies}}$$

The regulatory limit for release of radioactive material during the normal conditions of transport is $A_2 \times 10^{-6}$ curies per hour. ANSI N14.5 - 1977 provides the following formula for determining the corresponding allowable leakage rate.

$$L_N = \frac{R_N}{C_N}$$

where L_N = leakage rate in cm^3 per sec,
R_N = release rate in curies per sec, and
C_N = specific activity in the package in curies per cm^3.

Therefore:

$$R_N = \frac{A_2 \times 10^{-6}\ \text{Ci}}{1\ \text{h}} \times \frac{1\ \text{h}}{60\ \text{min}} \times \frac{1\ \text{min}}{60\ \text{sec}}$$

$$= \frac{162 \times 10^{-6}}{3600} = 4.5 \times 10^{-8}\ \frac{\text{Ci}}{\text{sec}}$$

$$C_N = \frac{\text{total curies}}{\text{volume of package } (\text{cm}^3)}$$

$$= \frac{1542\ \text{Ci}}{650{,}000\ \text{cm}^3} = 2.4 \times 10^{-3}\ \frac{\text{Ci}}{\text{cm}^3}$$

and

$$L_N = \frac{4.5 \times 10^{-8}\ \text{Ci/sec}}{2.4 \times 10^{-3}\ \text{Ci/cm}^3} = \underline{\underline{1.9 \times 10^{-5}\ \frac{\text{cm}^3}{\text{sec}}}}$$

This is a conservative containment evaluation since all of the crud is assumed to consist of dry particles that behave as a gas and no credit is taken for lack of a driving force.

4.3 CONTAINMENT DURING THE HYPOTHETICAL ACCIDENT CONDITIONS

The regulatory limit for the release of radioactive material for the hypothetical accident conditions is A_2 curies in one week. ANSI N14.5-1977 provide the following formula for determining the corresponding allowable leakage rate.

$$L_A = \frac{R_A}{C_A} \quad ,$$

where L_A = leakage rate in cm^3 per sec,
R_A = release rate in curies per sec, and
C_A = specific activity in the package in curies per cm^3.

Therefore:

$$R_A = \frac{A_2 \text{ Ci}}{\text{week}} \times \frac{\text{week}}{7 \text{ days}} \times \frac{\text{days}}{24 \text{ h}} \times \frac{1 \text{ h}}{60 \text{ min}} \times \frac{\text{min}}{60 \text{ sec}}$$

$$= \frac{162.1}{604{,}800} = 2.7 \times 10^{-4} \frac{\text{Ci}}{\text{sec}}$$

$$C_A = \frac{\text{total curies}}{\text{volume of package } (cm^3)}$$

and

$$L_A = \frac{2.7 \times 10^{-4}\ \text{Ci/sec}}{2.4 \times 10^{-3}\ \text{Ci/cm}^3} = \underline{\underline{1.1 \times 10^{-1}\ \text{cm}^3\text{/sec}}}\ .$$

In Table 3-3 and Fig. 3-4, the seal temperature during the hypothetical fire accident is shown to reach 1220°F and remain above 1200°F for 15 minutes. Reference 2-19 indicates that the metal O-ring seals can perform their function up to 1300°F. Therefore, containment will be maintained during the hypothetical fire accident conditions.

4.4 CONTAINMENT DESIGN AND TEST CRITERIA

The allowable release of radioactive material increases following the hypothetical accident conditions, therefore the allowable leakage rate also increases. Following the hypothetical accident conditions, the allowable leakage rate is 1.1×10^{-1} cm^3/s, compared to an allowable leakage rate of 1.9×10^{-5} for the normal conditions of transport. The lower allowable leakage rate of 1.9×10^{-5} cm^3/s is therefore the basis for containment design and containment test criteria.

4.4.1 Periodic Leakage Testing

ANSI N14.5-1977 requires that the periodic (or annual) leakage test be accomplished with a test procedure that has a sensitivity that is one-half of the maximum permissible leakage rate. The maximum permissible leakage rate is 1.9×10^{-5} cm^3/s and, therefore the minimum test sensitivity must be 1×10^{-5} cm^3/s. After consideration of the containment boundary and the packaging design, a sniffer type, Helium Mass Spectrometer leakage test with a senstivity of 1×10^{-7} atm.cm^3/s is selected as the appropriate test procedure.

4.4.2 Assembly Verification Leakage Testing

Prior to each shipment of radioactive material, a leakage test of the containment boundary seals will be accomplished in compliance with ANSI N14.5-1977. Because the maximum allowable leakage is less than 1×10^{-3} cm^3/s, a soap bubble leak test with a sensitivity of 1×10^{-3} $atm.cm^3/s$ has been selected.

SECTION 5.0

SHIELDING EVALUATION

5.0 SHIELDING EVALUATION

5.1 MODEL FSV-1, Configurations A, B, C, and D

5.1.1 Discussion and Results

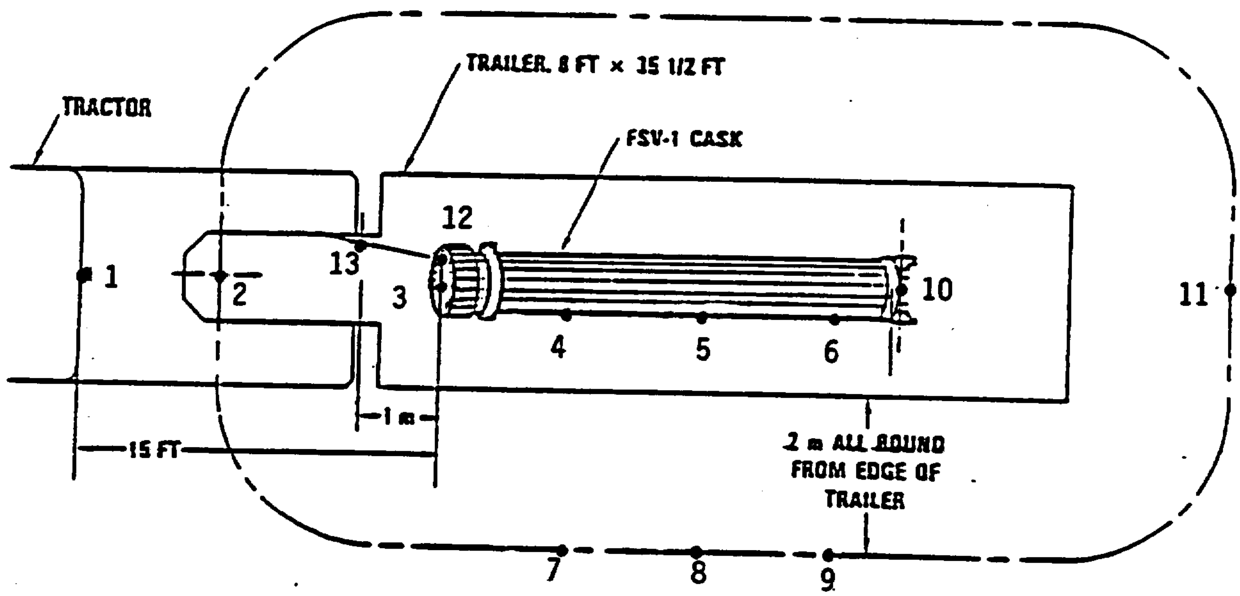
The shielding evaluation considered the worst-case waste loading with ten flattened BWR control rod blades (CRB) and 48 upper roller ball/axle corners (corner) removed from the BWR control rods. The waste was assumed to contain a total of 27,000 Ci of Co-60 gamma source distributed as 1500 Ci per CRB and 250 Ci per corner. These activity levels are about 25% to 50% above the average activities measured at a number of commercial BWR plants. The curie content assumed for the shielding evaluation envelopes all possible waste loadings with and without additional shielding requirements. A lower curie content will require that less or no shielding to be added.

Figure 5-1 shows the normal loading configuration for the above-specified waste contents. The roller ball/axle corners are contained in a closed stainless steel tube 6 in. O.D., 2 in. thick, and 153 in. long, and axially spaced 3 in. apart for dose reductions purposes. The flattened CRBs surround the shield tube, as illustrated in Fig. 5-1. The CRBs and shield tube are topped with three or four velocity limiters removed from the control rods to fill-up the burial liner. To avoid dose peaking outside the cask, five flattened CRBs are inverted as indicated in Fig. 5-1.

The evaluation assumed that shielding for the upper roller ball/axle corners would maintain its effectiveness under both normal and accident conditions. However, movement of the temporary shield tube and CRBs to a worst-case orientation was allowed within the burial liner for the accident conditions. Radiation dose rates external to the cask under normal transport conditions are shown in Fig. 5-2, including the points at the cask surface, at 2 m from the edge of the vehicle, and in normally occupied positions of the vehicle. Figure 5-2 also presents the maximum dose rates at 1 m from the cask surface under hypothetical accident conditions. The dose rates are within the regulatory limit in all cases, demonstrating the adequacy of shielding.

FIGURE WITHHELD UNDER 10 CFR 2.390

Fig. 5-1. Liner loading configuration for shielding analysis



Normal Conditions of Transport		
Point	Location	Dose Rate (mrem/h)
1	Cab	2*
2	2 m from transporter (front)	3
3	Cask surface (front)	40
4	Cask surface (side)	95
5	Cask surface (side)	70
6	Cask surface (side)	95
7	2 m from transporter (side)	6
8	2 m from transporter (side)	7
9	2 m from transporter (side)	6
10	Cask surface (rear)	150
11	2 m from transporter (rear)	3
12	Cask surface (front)	1
13	1 m from cask surface (front)	<1

Hypothetical Accident Conditions		
Point	Location	Dose Rate (mrem/h)
13	1 m from cask surface (front)	<100

*Less than 1 mrem/h if the shielding effect of the velocity limiters is considered.

Fig. 5-2. Calculated radiation dose rates for Model FSV-1, Configurations A, B, C and D

5.1.2 Source Specification

For shielding evaluation, a Co-60 source of 27,000 Ci was assumed with a distribution of 1,500 Ci per CRB and 250 Ci per corner. This assumption was conservative, as compared with actual measurements. The source in each CRB was treated as a volume source with an axial variation given in Table 5-1. Each corner was modeled as a point source without self-shielding effect for simplicity and conservatism. The axial activity profile for the CRB is a conservative representation of the variation in the neutron exposure history for each axial segment of the blade.

The velocity limiters placed above the CRBs and shield tube have low activity (about 10 Ci per velocity limiter). Their contribution to the dose rates external to the cask is negligible.

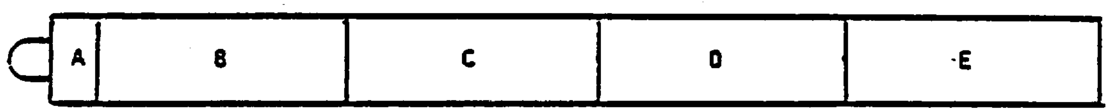
5.1.3 Model Specification

The packaging and the burial liner with shield ring were modeled in explicit detail. Applicable material thicknesses used in the shielding analysis and burial liner are shown in Table 5-2 along with the material densities. The loading configuration used in the shielding evaluation is depicted in Fig. 5-1 for normal transport conditions. The model for the accident condition is similar to that for the normal transport condition except the temporary shield tube is assumed to be in contact with the burial liner lid, which results in the maximum dose rate external to the cask.

5.1.4 Shielding Evaluation

The shielding analysis was performed with the PATH gamma shielding code (Section 5.2 Appendix) for both normal transport and accident conditions. A three-dimensional source-shield configuration was modeled to explicitly represent the cask, burial liner and waste contents.

TABLE 5-1
AXIAL DISTRIBUTION OF GAMMA SOURCE ACTIVITIES FOR CRB



Co 60 Activities				
Segment	Relative Strength	Concentration (Ci/cc)[a]	Volume (cc)	Activity (Ci)
A	1.000[b]	0.695	245	170
B	0.250[b]	0.174	3,847	669
C	0.130	0.090	3,847	346
D	0.090	0.063	3,847	242
E	0.027	0.019	3,847	73
			15,633	1,500

[a] Ci per cc of rod volume.

[b] The factor of 4 difference between segments A and B activities results from differences in steel densities, self-shielding factors and irradiation time.

TABLE 5-2
THICKNESS OF SHIELDING MATERIALS FOR THE
PACKAGING AND BURIAL LINER

Packaging	Thickness (in.)	Material Density (g/cm^3)
Side	3.5 depleted uranium	18.9
	1.625 stainless steel (total)	7.82
Top	2.25 depleted uranium	18.9
	4.313 stainless steel (total)	7.82
Bottom	11.0 stainless steel (total)	7.82
Burial Liner		
Cover	1/2 stainless steel	7.82
Bottom plate	3/4 stainless steel	7.82
Shield ring	13 ID x 17 OD x 4 LG, stainless steel	7.82
Shield tube	2 ID x 6 OD x 150 LG, stainless steel; lid = 5 in. thick; bottom = 4 in. thick	7.82

For normal transport conditions, gamma dose rates were calculated at key points of interest, including the cask surface, 2 m from the edge of the transporter and in the inhabited area of the tractor cab. The shielding effect of the velocity limiters was omitted for conservatism. Inclusion of the velocity limiters in the model would have lowered the dose rate at the closure end of the cask by a factor of 2 or more. Gamma dose buildup factors for iron were used in the PATH calculations. The PATH results at the side of the cask were corrected to account for the composite depleted uranium and stainless steel shields in the cask body.

For hypothetical accident conditions, the shield tube containing the corners was assumed to be free to move axially or radially. The corners remain in the shield tube. The worst-case accident condition occurs when the shield tube moves axially to the burial liner lid, resulting in the maximum accident dose rate at the top head of the cask.

The dose-rate results for both normal transport and accident conditions are summarized in Fig. 5-2. All the dose rates are less than the regulatory radiation limits. The shielding evaluation demonstrates that a waste loading configuration meeting normal transport requirements will comply with the 10CFR71 regulations for accident conditions.

5.2 APPENDIX

The PATH code, primarily a gamma shielding computer program, utilizes the common point-kernel integration technique to perform calculations of dose rates and shielding requirements for complex geometry and various source types. The code has been in production use for in-house shielding analysis and design work at GA Technologies for more than 10 yr.

The heart of the PATH code is the geometry routine, which defines the source-shield configuration by a set of possibly overlapping regions of simple shapes with a mother-daughter ordering scheme, and determines the path length in each region by a direct method. Regions are available in various shapes with any axial orientation including prisms, cylinders, spheres, and frustra of cones. Shield regions may be redefined between dose point calculations for making parameter studies.

The options of source types consist of point, line, disc, polygon, shell, cylinder, and prism sources in any spatial orientation. In addition, the X-Y-Z meshing mode is applicable for modeling geometrically complex source regions such as sphere, hemisphere, quarter cylinder, etc. The source terms can be desribed in two ways: source strengths (MeV/sec or photons/sec per unit mesh) at given energy levels, and/or isotopes with associated activities (Ci/unit mesh). The latter option can lead to output of the percent contribution to the total dose rate from each isotope for identifying the important contributors.

To minimzie the input requirements, a large amount of fixed data is built into the PATH library. The current library contains tables of mass-attenuation coefficients for 25 basic materials, decay gamma spectra of 125 isotopes, gamma buildup factors for 89 materials, and gamma flux-to-dose conversion factors. All these tables are periodically updated and expanded as needed to accommodate special source spectra, new materials, or revised data.

SECTION 6.0

CRITICALITY EVALUATION

6.0 CRITICALITY EVALUATION

The contents of Model FSV-1 in Configurations A, B, C, and D are restricted to solid, nonfissile, irradiated and contaminated hardware and neutron source components. Therefore, a criticality evaluation is not a part of this design report.

SECTION 7.0

OPERATING PROCEDURES

7.0 OPERATING PROCEDURES

The following information provides generic operating procedures. Specific operating instructions with the necessary administrative and quality assurance provisions should be prepared and followed.

7.1 PROCEDURE FOR LOADING THE PACKAGE (Configuration A - Dry Loading)

The following procedure is applicable for Model FSV-1 in Configuration A when used for the transport of solid, nonfissile, irradiated and contaminated hardware from a hot cell or other facility where dry loading is required.

<u>STEP</u>

1. <u>Receiving the shipping cask</u>.

2. Inspect tractor and semitrailer and clean as necessary.

3. Position the tractor and semitrailer in an area adjacent to the hot cell building designated for cask removal.

4. <u>Removing the cask from the semitrailer</u>.

5. Attach the cask lifting yoke to the truck crane and engage the yoke in the lifting sockets near the top of the cask.

6. Raise the cask to the vertical position.

7. Install the locking block on the inside of the semitrailer bottom support trunnion using the two 1/2" hex head bolts.

8. Remove the four 1-1/4" dia. socket-head cap screws that hold the cask to the bottom support trunnion.

STEP

9. Disengage the cask from the semitrailer and raise the cask over the hot cell roof. Position the cask over the roof plug penetration.

10. Lower the shipping cask onto the cask support in the low level cell.

11. Disengage the cask lifting yoke from the cask and store.

12. Remove the twenty-four 1-1/4" dia. socket head cap screws from the outer closure.

13. Remove the outer closure.

14. Visually inspect the seals and sealing surfaces. Replace any seal if it has nicks, cuts, scratches or other deformations that will adversely affect seal performance.

15. Remove the twelve inner closure cap screws.

16. Remove the inner closure.

17. Visually inspect the inner closure seals and seal surfaces. Replace any seal if it has nicks, cuts, scratches or other deformations that will adversely affect seal performance.

18. Inspect the cavity of the inner container for damage and or debris. Remove debris and evaluate any damage before proceeding.

19. Load irradiated and contaminated hardware into the inner container.

20. Remotely replace the inner closure and visually inspect the closure for damage or poor fit. If necessary, take corrective action before proceeding.

STEP

21. Visually inspect and install the twelve inner closure cap screws. Replace any cap screws found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact or not cause for replacement.

22. Torque the inner closure cap screws to 19-21 ft-lb.

23. Replace the outer closure.

24. Visually inspect and install the 24 1-1/4" dia. socket head cap screws in the outer closure. Replace any cap screws found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

25. Torque the outer closure cap screws to 10-30 ft-lb.

26. <u>Returning the loaded cask to the semitrailer</u>.

27. Engage the lifting yoke in the cask lifting sockets.

28. Raise the cask through the hot cell roof plug penetration and position it over the semitrailer.

29. Place the bottom of the cask in the trunnion portion of the rear support.

30. Install four cap screws to hold the bottom of the cask to the trunnion. Tighten to 522-550 ft-lb.

31. Remove the trunnion locking block from the rear support.

STEP

32. Lower the cask until it rests on the front support and install the tie-down strap. Tighten the bolts to 120-125 ft-lb.

33. Torque closure bolts to 950-1000 ft-lb and install lockwire and a tamper-proof seal on an adjacent pair of bolts.

34. Preparation for leakage test.

35. Pressurize the cask to 14-16 psig through the purge connection.

36. Install the purge connection cover and torque bolts to 15-20 ft-lb.

37. After waiting 15 minutes, brush the closure head, center plug, and purge connection cover with a liquid soap solution and search for bubbles. No indication of bubbles allowed.

38. Remove the purge connection cover and depressurize the cask.

39. Visually examine the purge cover seals and sealing surface. Replace any seal that has nicks, cuts, scratches or other deformations that will adversely affect seal performance.

40. Visually inspect the purge cover bolts. Replace any bolts found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

41. Reinstall the purge connection cover and torque bolts to 15-20 ft-lb.

STEP

42. Preparing for departure.

43. Visually inspect the package. Correct any deficiencies before departure.

44. Survey the shipping cask for external radiation and loose contamination. External radiation and loose contamination shall not exceed the limits of 10CFR71.47 and 10CFR71.87.

45. Attach the proper label to the shipping cask.

46. Display the proper placards on the tractor and semitrailer.

47. Prepare the necessary shipping papers.

48. Dispatch the shipment.

7.2 PROCEDURES FOR UNLOADING THE PACKAGE (Configuration A - Unloading)

The following procedure is applicable for Model FSV-1 in Configuration A when used for the transport of solid, nonfissile irradiated and contaminated hardware to a receiving facility or disposal site. The specific procedures for receiving and unloading the cask shall be in compliance with 10CFR20.205.

STEP

1. Receiving the shipping cask.

2. Verify that placards, labels, and shipping papers are correct.

3. Inspect and clean the tractor, semitrailer, and cask as required.

STEP

4. Removing the cask from the semitrailer.

5. Loosen the four socket-head cap screws that attach the bottom of the shipping cask to the rear support.
CAUTION: Do not remove.

6. Remove tie-down strap from front support.

7. Attach the cask lifting apparatus to the crane hook.

8. Engage the cask lifting apparatus in the recessed lifting sockets. Use handcrank to lock the balls into the sockets.

9. Raise the cask to the vertical position.
CAUTION: Do not lift cask while attached to semitrailer.

10. Install the locking block on the inside of the rear support to hold the trunnion in position.

11. Remove the four (4) socket-head cap screws that attach the bottom of the shipping cask to the rear support.

12. Raise the cask to clear the rear support.

13. Move the cask into the hot cell for unloading.

14. Disengage the cask lifting yoke and store.

15. Remove the twenty-four 1-1/4" dia. socket head cap screws from the outer closure.

STEP

CAUTION: The next three steps may have to be done remotely.

16. Remove the outer closure.

17. Remove the twelve inner closure cap screws.

18. Remove the inner closure.

19. Unload the irradiated hardware and verify that the contents and debris have been completely removed from the inner container.

20. Examine the inner closure seals and sealing surfaces. Replace any seal that has nicks, cuts, scratches or other deformations that will adversely affect seal performance.

21. Replace the inner closure and examine it for damage or poor fit. If necessary, take corrective action.

22. Visually inspect and install the twelve inner closure cap screws. Replace any cap screws found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact or not cause for replacement.

23. Torque the inner closure cap screws to 19-21 ft-lb.

24. Replace the outer closure.

STEP

25. Visually inspect and install the 24 1-1/4" dia. socket head cap screws in the outer closure. Replace any cap screws found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

26. Torque the outer closure cap screws to 10-30 ft-lb.

27. Returning the loaded cask to the semitrailer.

28. Engage the lifting yoke in the cask lifting sockets.

29. Remove the cask from the hot cell receiving facility and return it to the semitrailer.

30. Position the cask above the rear support and lower the cask.

31. Install the four socket-head cap screws which attach the cask to the rear support.

32. Remove the locking block from the rear support.

33. Lower the cask onto the front support.

34. Release the cask lifting apparatus from the cask.

35. Install the tie-down strap at the front support.

36. Torque the four socket head cap screws that attach the bottom of the cask to the rear support to 522-500 ft-lb.

7.3 PROCEDURE FOR LOADING THE PACKAGE (Configuration B, C, and D - Wet Loading)

The following procedure is applicable for Model FSV-1 in Configurations B, C, and D when used for the transport of solid, nonfissile, irradiated and contaminated hardware from a nuclear reactor storage pool.

STEP

1. Receiving the shipping cask.

2. Inspect tractor and semitrailer and clean as necessary.

3. Position tractor and semitrailer in the truck bay area of the reactor building.

4. Removing the cask from the semitrailer.

5. Remove the tie-down strap from the front support.

6. Loosen the four socket-head cap screws that attach the bottom of the cask to the rear support. **CAUTION:** Do not remove.

7. Loosen the (24) socket-head cap screws in the cask closure. **CAUTION:** Do not remove.

8. Remove the three socket-head set screws in the top of the cask closure. Install the closure lifting bail.

9. Remove the center plug and the purge connection cover from the bottom of the cask. Visually inspect the O-ring seals and the sealing surfaces. Examine the seals and sealing surface. Replace the seal if it has nicks, cuts, scratches or other deformations that will adversely affect seal performance.

STEP

10. Attach the lifting yoke/lifting adapter assembly to the crane hook.

11. Open the hydraulic cylinder bypass valve and manually engage the cask lifting yoke into the cask lifting sockets.

12. Raise the cask to a vertical position.
CAUTION: Verify that crane is not lifting trailer.

13. Install the locking block on the inside of the rear support to hold the trunnion in position.

14. Remove the four socket-head cap screws which attach the cask to the rear support.

15. Transfer the cask assembly to the refueling floor.

16. Connect the hydraulic pump unit and hoses to the cask lifting yoke hydraulic cylinder.

17. Preparation of cask for burial liner loading.

18. Remove the twenty-four (24) socket-head cap screws from the cask closure and visually inspect them for damage. Replace any cap screws found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

19. Remove the cask closure using the previously installed closure lifting bail. Visually inspect the O-ring seals and the sealing surfaces. Replace the seal if it has nicks, cuts, scratches or other deformations that will adversely affect seal performance.

STEP

20. Visually inspect the interior of the cask for damage or debris and to confirm that the bottom interface plate is in place. Remove debris and evaluate any damage and take corrective action if necessary.

21. Preparations to move the cask into the pool.

22. Install the two closure head guide pins in the cask at 90° to the lifting sockets and tighten with a hand wrench to an estimated 100 ft-lb torque.

23. Close the bypass valve on the yoke hydraulic cylinder and attach, the hydraulic hand pump and hoses to the cylinder on the yoke.

24. Position the crane over the cask, lower the hook until the positioning guide funnels extending from the lifting yoke pivot pin come to rest on the guide pins. Close the yoke using the bleed valve on the hand pump unit to engage the balls on the yoke into the cask sockets.

25. Attach the liftoff cables for pivoting the lift hangers off the palms of the sister hook when in the pool.

26. Raise the cask.

27. Move cask to proper position over the pool and lower the cask into the pool until it rests on the pool floor.

28. Lower crane hook sufficiently to allow lift hangers to be removed from sister hook.

STEP

29. Actuate the hand pump to open the yoke.

CAUTION: Make certain that the yoke has opened.

30. Raise the yoke/lifting adapter assembly off of the cask and move out of the way.

31. <u>Preparations to place the loaded burial liner into the cask.</u>

31a. Before putting the lid on the burial liner, verify that the liner is filled with waste and appropriate shoring to prevent movement of the contents during transport.

32. Using the hook tool raise the burial liner.

33. Move the burial liner laterally to the proper position over the cask.

34. Lower the burial liner into the cask. Align the keyway in the burial liner cover with the key in the upper end of the cask.

35. Lift the cask closure and place it into the pool over the cask.

36. Orient the closure head by aligning the keyway in the closure head with the key in the cask by using the keyway notch on the cask closure head lifting bail as the indexing mark.

37. Lower the cask closure over the guide pins in the cask and seat the closure on the cask.

STEP

38. Removing the cask from pool.

39. Lower the yoke to enable the yoke positioning guide funnels to engage the two guide pins.

40. Engage the yoke with the cask by opening the bleed valve on the hand pump.

41. Lower the hook, until the two redundant lift hangers can be pulled onto the palms of the sister hook using the liftoff cables.

42. Raise the cask out of the pool and allow to drain. To speedup draining, air may be introduced through the purge connection located in the bottom of the cask. Do not exceed 20 psig. Before application of air pressure, install four (4) equally spaced closure bolts and torque to 10-30 ft-lb. Verify that the cask is fully drained by introducing air through the purge connection (if not already done during draining) and note that air is exiting through the drain hole.

43. Move the cask to the washdown area.

44. Install remaining closure bolts and torque to 10-30 ft-lb.

45. Preparation of the cask for shipment.

46. Move the cask to the hatchway and lower the cask from the refueling floor to the semitrailer located in the truck bay area.

STEP

47. Place the bottom of the cask in the trunnion portion of the rear support.

48. Visually inspect and install four bolts to hold the bottom of the cask to the trunnion. Tighten bolts to 522-550 ft-lb. Replace any bolt found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

49. Remove the trunnion locking block from the rear support.

50. Lower the cask until it rests on the front support and install the tie-down strap. Tighten the bolts to 120-125 ft-lb.

51. Torque closure bolts to 950-1000 ft-lb and install lockwire and a tamper-proof seal on an adjacent pair of bolts.

52. Install the center plug in the cask. Visually inspect the center plug bolts and replace any bolt found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement. Torque the center plug bolts to 35-40 ft-lb. Install lockwire and a tamper-proof seal.

53. Preparation for leakage test.

54. Pressurize the cask to 14-16 psig through the purge connection.

55. Install the purge connection cover and torque bolts to 15-20 ft-lb.

STEP

56. After waiting 15 minutes, brush the closure head, center plug, and purge connection cover with a liquid soap solution and search for bubbles. No indication of bubbles allowed.

57. Remove the purge connection cover and depressurize the cask.

58. Visually inspect the purge cover seals and sealing surface. Replace the seal if it has nicks, cuts, scratches or other deformations that will adversely affect seal performance.

59. Visually inspect the purge cover bolts. replace any bolt found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

60. Reinstall the purge connection cover and torque bolts to 15-20 ft-lb.

61. Preparing for departure.

62. Visually inspect the package. Correct any deficiencies noted.

63. Survey the shipping cask for external radiation and loose contamination. External radiation and loose contamination shall not exceed the limits of 10CFR71.47 and 10CFR71.87.

64. Attach the proper label to the shipping cask.

65. Display the proper placards on the tractor and semitrailer.

66. Prepare the necessary shipping papers.

67. Dispatch the shipment.

7.4 PROCEDURES FOR UNLOADING THE PACKAGE (Configuration B, C, and D - Unloading)

The following procedure is applicable for Model FSV-1 in Configurations B, C, and D when used for the transport of solid, nonfissile irradiated and contaminated hardware to a disposal site. The specific procedures for receiving and unloading the cask shall be in compliance with 10CFR20.205.

STEP

1. Receiving the shipping cask.

2. Verify that placards, labels, and shipping papers are correct.

3. Inspect and clean the tractor, semitrailer, and cask as required.

4. Removing the cask from the semitrailer.

5. Loosen the four socket-head cap screws that attach the bottom of the shipping cask to the rear support.
   CAUTION: Do not remove.

6. Remove tie-down strap from front support.

7. Attach the cask lifting apparatus to the crane hook.

8. Engage the cask lifting apparatus in the recessed lifting sockets. Use handcrank to lock the balls into the sockets.

9. Raise the cask to the vertical position.
   CAUTION: Do not lift cask while attached to semitrailer.

STEP

10. Install the locking block on the inside of the rear support to hold the trunnion in position.

11. Remove the four (4) socket-head cap screws that attach the bottom of the shipping cask to the rear support.

12. Raise the cask to clear the rear support.

13. Move the cask to the unloading area and lower to the horizontal position on suitable supports.

14. Unloading the shipping cask.

15. Attach suitable lifting fixture to three (3) threaded holes in the outer closure to provide for horizontal removal.

16. Remove the twenty-four socket head cap screws from the closure. **CAUTION:** Next three steps must be performed remotely.

17. Remove the closure.

18. Attach a hook to the bar located in the slot in the cover on the burial liner.

19. Use suitable guide fixture to protect the cask surfaces and slide the burial liner from the cask.

20. Returning the cask to the semitrailer.

21. Remove the guide fixture.

STEP

22. Visually examine the cask sealing surfaces and cask interior for any damage or debris.

23. Visually examine the cask closure, especially the O-ring seals for any damage. Replace any seal that has nicks, cuts, scratches, or other deformations that will adversely affect seal performance.

24. Visually inspect for damage the twenty-four (24) socket head cap screws that hold the outer closure in place. Replace any cap screws found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

25. Install the cask closure and torque the twenty-four socket head cap screws to 95-100 ft-lb.

26. Raise the cask into the vertical position and return to the semitrailer.

27. Position the cask above the rear support and lower the cask.

28. Visually inspect and install the four socket-head cap screws which attach the cask to the rear support. Replace any cap screws found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

29. Remove the locking block from the rear support.

30. Lower the cask onto the front support.

STEP

31. Release the cask lifting apparatus from the cask.

32. Install the tie-down strap at the front support.

33. Torque the four socket head cap screws that attach the bottom of the cask to the rear support to 522-550 ft-lb.

7.5 PREPARATION OF AN EMPTY PACKAGE FOR TRANSPORT

The specific procedures for the shipment of an empty cask shall be in accordance with 49CFR173.427.

STEP

1. Visually inspect the package and correct any deficiencies.

2. Survey the shipping cask for loose contamination and external radiation.

3. Attach the proper label to the shipping cask.

4. Display the proper placards on the tractor and semitrailer.

5. Prepare the necessary shipping papers.

6. Dispatch the shipment.

7.6 PROCEDURE FOR LOADING THE PACKAGE (Configuration B, C, and D - Dry Loading)

The following procedure is applicable for Model FSV-1 in Configurations B, C, and D when used for the transport of solid, nonfissile, irradiated and contaminated hardware from facilities in which the cask is loaded dry.

STEP

1. Receiving the shipping cask.
2. Inspect tractor and semitrailer and clean as necessary.
3. Position tractor and semitrailer to facilitate cask removal.
4. Removing the cask from the semitrailer.
5. Remove the tie-down strap from the front support.
6. Loosen the four socket-head cap screws that attach the bottom of the cask to the rear support.
   CAUTION: Do not remove.
7. Loosen the (24) socket-head cap screws in the cask closure.
   CAUTION: Do not remove.
8. Remove the three socket-head set screws in the top of the cask closure. Install the closure lifting bail.
9. Remove the center plug and the purge connection cover from the bottom of the cask. Visually inspect the O-ring seals and the sealing surfaces. Examine the seals and sealing surface. Replace the seal if it has nicks, cuts, scratches or other deformations that will adversely affect seal performance.

STEP

10. Attach the lifting yoke/lifting adapter assembly to the crane hook, as applicable.

11. Manually engage the cask lifting yoke into the cask lifting sockets.

12. Raise the cask to a vertical position.
    CAUTION: Verify that crane is not lifting trailer.

13. Install the locking block on the inside of the rear support to hold the trunnion in position.

14. Remove the four socket-head cap screws which attach the cask to the rear support.

15. Transfer the cask assembly to the loading area of the facility.

16. Connect the hydraulic pump unit and hoses to the cask lifting yoke hydraulic cylinder, as applicable.

17. Preparation of cask for burial liner loading.

18. Remove the twenty-four (24) socket-head cap screws from the cask closure and visually inspect them for damage. Replace any cap screws found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

19. Remove the cask closure using the previously installed closure lifting bail. Visually inspect the O-ring seals and the sealing surfaces. Replace the seal if it has nicks, cuts, scratches or other deformations that will adversely affect seal performance.

STEP

20. Visually inspect the interior of the cask for damage or debris and to confirm that the bottom interface plate is in place. Remove debris and evaluate any damage and take corrective action if necessary.

21. Install the two closure head guide pins in the cask at 90° to the lifting sockets and tighten with a hand wrench to an estimated 100 ft-lb torque.

22. Preparations to place the burial liner into the cask.

22a. Before putting the lid on the burial liner, verify that the liner is filled with waste and appropriate shoring to prevent movement of the contents during transport.

23. Lift the burial liner.

24. Move the burial liner laterally to the proper position over the cask.

25. Lower the burial liner into the cask. Align the keyway in the burial liner cover with the key in the upper end of the cask.

26. Lift the cask closure and place it over the cask.

27. Orient the closure head by aligning the keyway in the closure head with the key in the cask by using the keyway notch on the cask closure head lifting bail as the indexing mark.

28. Lower the cask closure over the guide pins in the cask and seat the closure on the cask.

29. Install closure bolts and torque to 10 - 30 ft-lb.

30. Removing the cask from facility.

31. Lower the yoke to enable the yoke positioning guide funnels to engage the two guide pins, as applicable.

STEP

32. Engage the yoke with the cask by opening the bleed valve on the hand pump, as applicable.

33. Lower the hook, until the two redundant lift hangers can be pulled onto the palms of the sister hook using the liftoff cables, if applicable.

34. Move the cask to the set down area.

35. Remove guide pins

36. Install remaining closure bolts where the guide pins were and torque to 10-30 ft-lb.

37. Preparation of the cask for shipment.

38. Move the cask to the semitrailer.

39. Place the bottom of the cask in the trunnion portion of the rear support.

40. Visually inspect and install four bolts to hold the bottom of the cask to the trunnion. Tighten bolts to 522-550 ft-lb. Replace any bolt found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

41. Remove the trunnion locking block from the rear support.

42. Lower the cask until it rests on the front support and install the tie-down strap. Tighten the bolts to 120-125 ft-lb.

43. Torque closure bolts to 950-1000 ft-lb and install lockwire and a tamper-proof seal on an adjacent pair of bolts.

STEP

44. Install the center plug in the cask. Visually inspect the center plug bolts and replace any bolt found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement. Torque the center plug bolts to 35-40 ft-lb. Install lockwire and a tamper-proof seal.

45. Preparation for leakage test.

46. Pressurize the cask to 14-16 psig through the purge connection.

47. Install the purge connection cover and torque bolts to 15-20 ft-lb.

48. After waiting 15 minutes, brush the closure head, center plug, and purge connection cover with a liquid soap solution and search for bubbles. No indication of bubbles allowed.

49. Remove the purge connection cover and depressurize the cask.

50. Visually inspect the purge cover seals and sealing surface. Replace the seal if it has nicks, cuts, scratches or other deformations that will adversely affect seal performance.

51. Visually inspect the purge cover bolts. replace any bolt found to have stripped or galled threads or any visible deformation of the head or shank. Minor nicks, scrapes or upsets from normal wrench contact are not cause for replacement.

52. Reinstall the purge connection cover and torque bolts to 15-20 ft-lb.

STEP

53. Preparing for departure.

54. Visually inspect the package. Correct any deficiencies noted.

55. Survey the shipping cask for external radiation and loose contamination. External radiation and loose contamination shall not exceed the limits of lOCFR71.47 and lOCFR71.87.

56. Attach the proper label to the shipping cask.

57. Display the proper placards on the tractor and semitrailer.

58. Prepare the necessary shipping papers.

59. Dispatch the shipment.

SECTION 8.0

ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 ACCEPTANCE TESTS

There are no current plans to fabricate any additional units of the Model FSV-1 packaging, therefore, acceptance tests are not provided as a part of this consolidated design report.

8.2 MAINTENANCE PROGRAM

The following information constitutes a generic maintenance program. A specific maintenance plan with the necessary administrative and quality assurance provisions should be prepared and followed.

The maintenance program for the Model FSV-1 in Configurations A, B, C, and D consists of leak tests and visual inspections of the entire packaging. These tests and inspections must be accomplished within the twelve (12) months prior to any use of the packaging. Other inspection techniques may be used to verify the results of the visual inspection.

8.2.1. Visual Inspections

STEP

1. Remove the cask from the transport semitrailer.

2. Visually inspect the external surface of the cask to detect any gouges, dents or cracks.

3. Remove the outer closure from the cask body and remove the metal O-ring and the elastomer O-ring from the closure.

STEP

4. Visually inspect the closure for any damage especially the O-ring grooves.

5. Remove the two lifting sockets from the cask body.

6. Visually inspect the lifting sockets for galling or other damage. Inspect the two attach bolts and the threaded holes for each lifting socket.

7. Remove the purge connection cover from the bottom of the cask.

8. Remove the elastomer and the metal O-rings from the purge connection cover and visually inspect the cover for damage, especially the O-ring grooves.

9. Remove the quick disconnect fitting and visually inspect for damage.

10. Visually inspect the three purge connection cover attach bolts and the threaded holes in the cask body. Inspect the sealing surface for the O-rings in the cask body.

11. Remove the center plug from the bottom of the cask.

12. Remove the elastomer and the metal O-rings from the center plug and visually inspect the plug for damage, especially the O-ring grooves.

STEP

13. Visually inspect the four center plug attach bolts and the threaded holes in the cask body. Inspect the sealing surface for the O-rings in the cask body.

14. Visually inspect the four threaded inserts in the bottom of the cask and the four socket head cap screws used to attach the cask to the rear support on the semitrailer.

15. Visually inspect the interior of the cask body, especially the sealing surface at the open end.

16. Visually inspect the twenty-four closure attach bolts and the twenty-four threaded inserts in the cask body.

8.2.2 Leakage Tests

STEP

1. Install a new metal O-ring and a new elastomer O-ring in the grooves in the cask closure. A light film of vacuum grease may be applied.

2. Install a new elastomer O-ring and a new metal O-ring on the purge connection cover. A light film of vacuum grease may be applied.

3. Install a new elastomer O-ring and a new metal O-ring on the center plug. A light film of vacuum grease may be applied.

STEP

4. Install the cask closure and torque the twenty-four closure bolts to 500 ft-lb.

5. Install the center plug in the bottom of the cask and torque the four attach bolts to 40 ft-lb.

6. Pressurize the cask to 15 psig through the purge connection using helium.

7. Disconnect the supply hose.

8. Install the purge connection cover and torque the three (3) attach bolts to 20 ft-lb. Wait one (1) hour. Use a sniffer type Helium Mass Spectrometer to leak test the seals at the cask closure, the purge connection cover, and the center plug. The minimum test procedure sensitivity is 1×10^{-6} atm.cm^3/s. The maximum allowable leakage rate is 1.9×10^{-5} cm^3/sec.

9. Carefully loosen the twenty-four closure bolts and allow the cask pressure to decrease to ambient.

10. Retorque the twenty-four (24) closure bolts to 500 ft-lb.

11. Install the lifting sockets in the cask body. Torque the retaining bolts to 20 ft-lb.

12. Return the cask to the transport semitrailer.

8.2.3 Repairs

Any discrepancies identified during the visual inspection or the leak test shall be corrected and verified by repeating the appropriate inspection or test procedure. All repair materials and repair procedures shall be the same or equivalent to those used during the original fabrication.

SECTION 9.0

QUALITY ASSURANCE

The maintenance, repair, modification and use of Model FSV-1 in Configurations A, B, C, and D will be accomplished in accordance with a quality assurance program which meets the requirements of the program described in Subpart H of Title 10, Code of Federal Regulations Part 71 (10CFR71).