APPENDIX 3.10

THERMAL PROPERTIES OF ALUMINUM HONEYCOMB

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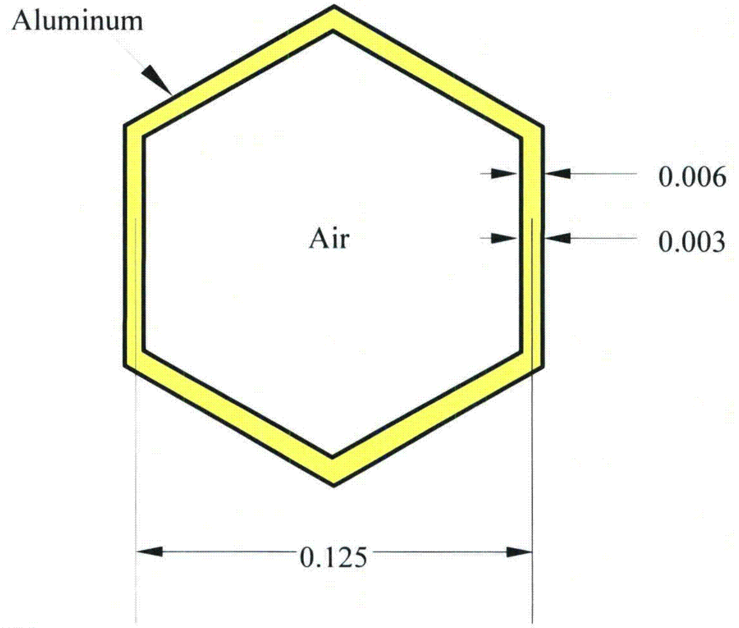
THERMAL PROPERTIES OF ALUMINUM HONEYCOMB



Specifications [1]:

Cell width: 0.125 in.
Cell wall thickness: 0.006 in.
Cell wall material: 5052 aluminum

Material Properties	Aluminum[2]	Air[3]
Thermal conductivity (Btu/h-ft-°F)	79.200	$1.484 \times (10)^{-2}$ at 68° $1.840 \times (10)^{-2}$ at 212°F
Density (lb_m/ft^3)	167.600	0.080
Specific heat (Btu/lb_m)	0.216	0.240

A control volume of a single cell is chosen to find the thermal properties (thermal conductivity, specific heat, and density) of the impact absorber. The control volume consists of the air space within a cell and one-half the thickness of the wall surrounding the cell. One-half the wall thickness is chosen because each interior cell shares each wall with an adjacent cell. The impact absorber is assumed to be infinite in the radial direction, so that edge effects of the absorber are not considered in calculating the thermal properties. The absorbers within the packages have a sufficiently large number of cells so that the partial cells along the edges do not have a significant effect on the thermal properties

(a) Total area of cell control volume: $1.3530\ (10)^{-2}\ \text{in}^2$
(b) Area of cell aluminum: $1.2990\ (10)^{-3}\ \text{in}^2$
(c) Area of air within each cell (b - a): $1.2230\ (10)^{-2}\ \text{in}^2$
(d) Aluminum weighted area (b/a): $0.0961\ \text{in}^2$
(e) Air weighted area (c/a): $0.9039\ \text{in}^2$
(f) Effective axial conductivity (k_{ae}):

$$k_{ae} = 1.84(10)^{-2}(0.9039) + 79.2\ (0.0961) = 7.63\ \text{Btu/h-ft-°F}\ (212°\text{F})$$
$$k_{ae} = 1.484(10)^{-2}(0.9039) + 79.2\ (0.0961) = 7.62\ \text{Btu/h-ft-°F}\ (68°\text{F})$$

(g) Effective density (re):

$$r_e = 0.08(0.9039) + 167.6(0.0961) = 16.2\ \text{lbm/ft}^3\ (68°\text{F})$$
$$r_e = 0.06(0.9039) + 167.6(0.0961) = 16.2\ \text{lbm/ft}^3\ (212°\text{F})$$

(h) Effective specific heat c_{pe}:

$$c_{pe} = (0.08(0.24)(0.9039) + 167.6(0.216)(0.0961))/16.2 = 0.22\ \text{Btu/lb}_m\ (68°\text{F})$$
$$c_{pe} = (0.06(0.24)(0.9039) + 167.6(0.216)(0.0961))/16.2 = 0.22\ \text{Btu/lb}_m\ (212°\text{F})$$

In the radial direction, heat is conducted through the aluminum cell walls and air. The effective radial thermal conductivity (k_{re}) is found by weighting the conductivities of the air and aluminum with their receptive areas. The area for heat transfer in the radial direction is calculated from the width and unit depth:

(i) Area of air within each cell: $0.119\ \text{in}^2$
(j) Area of aluminum wall: $0.006\ \text{in}^2$
(k) Area of control volume: $0.125\ \text{in}^2$

(l) Effective radial conductivity k_{re}

$$k_{re} = (0.119(1.484(10)^{-2})) + 0.006(79.2))/0.125 = 3.82\ \text{Btu/h-ft-°F}\ (68°\text{F})$$

Because the thermal properties vary little at 68°F and 212°F, the values calculated at 68°F are arbitrarily chosen for the thermal analysis.

In summary, the thermal properties of the impact absorber are as follows:

k_{ae} = 7.62 Btu/h-ft-°F
k_{re} = 3.82 Btu/h-ft-°F
c_{pe} = 0.22 Btu/lb$_m$-°F
r_e = 16.2 lbm/ft^3

REFERENCES

1. *Honeycomb Tube-Core Energy Absorption Cylinder Data Sheet 2800.* Hexcel International, Dublin, CA (January 1988).

2. J. Davis et al. *Metals Handbook.* Vol. 2, 10th ed., ASM International (1990).

3. *P/THERMAL 2.6* (material library). PDA Engineering, PATRAN Division, Costa Mesa, CA (March 1993).

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APPENDIX 3.11

BENCHMARK OF THE P/THERMAL CODE AGAINST A DOCUMENTED SHIPPING CASK THERMAL PROBLEM

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BENCHMARK OF THE P/THERMAL CODE AGAINST A DOCUMENTED SHIPPING CASK THERMAL PROBLEM

1. INTRODUCTION

The certification of shipping containers often requires extensive use of thermal analysis codes such as P/Thermal. In these problems, radiative heat transfer is often the dominant phenomenon being modeled and is highly nonlinear. For this reason, a thermal benchmark problem developed specifically for cask analysis consisting primarily of radiative heat transfer has been documented by Glass.[1] The general purpose thermal analysis software P/Thermal was used to compute the thermal response of the benchmark shipping cask problem. The benchmark calculation provided in this appendix was reported by Hensel.[2]

1.1 Benchmark Problem

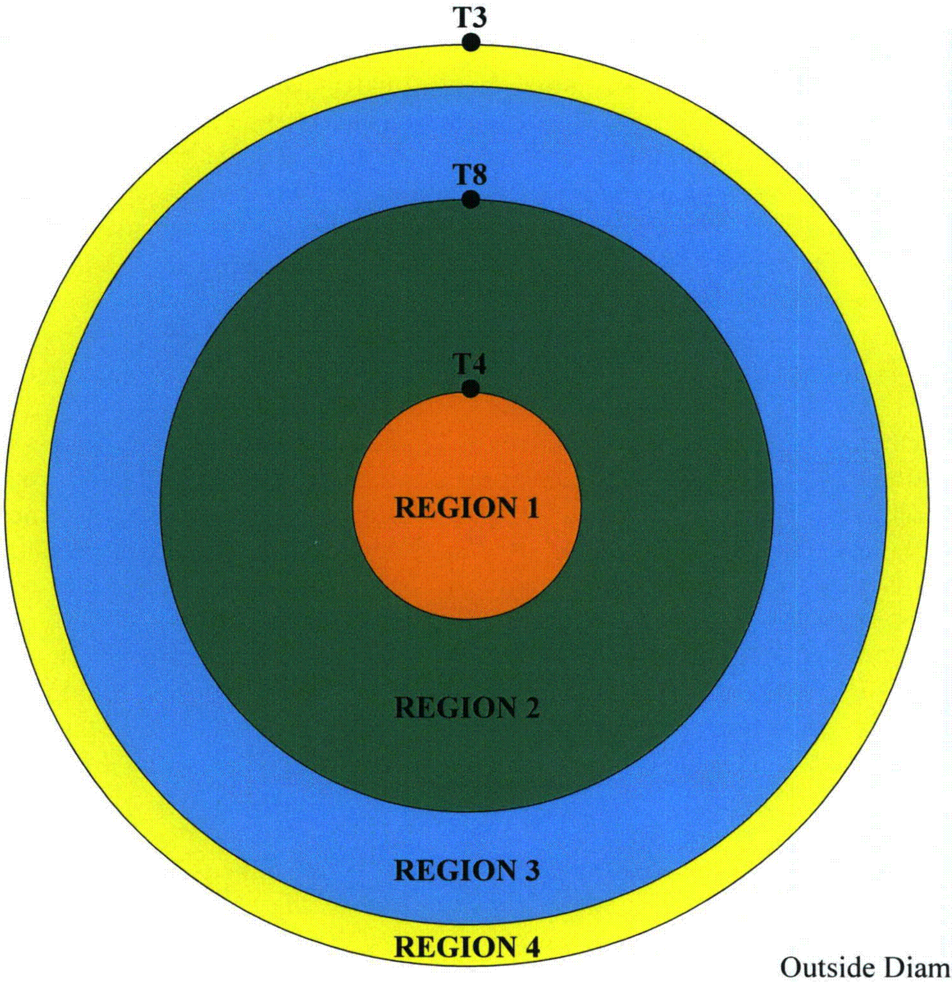
The simple geometry of the benchmark problem is illustrated in Figure 1. The cask is symmetric axially and azimuthally. Region 3 is void and the constant thermal properties for regions 1, 2, and 4 are presented in Table 1. All surface emissivities and absorptivities are assumed to be 1. All convective heat transfer is neglected. Region 2 radiates heat to region 4, and region 4 radiates to the ambient. Region 1 is a heat source of 3702.6 Btu/h-ft^3.

The benchmark problem consists of two parts. In the first part, a steady-state solution is required for an ambient temperature of 130°F. In the second part, a 90-min transient solution is required using the steady-state solution as the initial conditions. For the first 30 min of the transient, the ambient is 1475°F (which is the accident fire condition in 10 CFR 71.73), and during the final 60 min, the ambient is 130°F.

Although the geometry of this benchmark facilitates a one-dimensional model (radial), a two-dimensional Cartesian model in the azimuthal plane of the cask was used. This model, although somewhat cumbersome, illustrates the code capabilities by rigorously computing the axisymmetric solution in Cartesian space. Region 4 was modeled using three elements radially and 60 elements circumferentially.

1.2 Benchmark Results

The results of the analysis, in comparison with published temperatures at the three locations depicted in Figure 1 at three different times during the transient are presented in Table 2. Clearly, the results show that the analysis code P/Thermal computes the thermal response of this benchmark problem to an acceptably high level of accuracy.



	Outside Diameter (inches)
1	6.90
2	15.25
3	21.25
4	21.50

Figure 1. Benchmark Problem Geometry

Table 1. Thermal Properties Used in the Benchmark Problem

Material	Conductivity (Btu/h-ft-°F)	Specific heat (Btu/lbm-°F)	Density (lbm/ft^3)
Region 1	139.7	0.214	169
Region 2	26	0.113	489
Region 4	26	0.113	489

Table 2. Comparison of P/Thermal Calculation and Published Values

Time (min)	Temperature (°F)					
	P/Thermal Value at T3	**Published Value**	**P/Thermal Value at T8**	**Published Value**	**P/Thermal Value at T4**	**Published Value**
0	278.5	278.6	399.8	399.2	417.5	417.2
30	1275.8	1272.2	706.8	708.8	505.1	505.4
90	397.5	397.4	568.5	568.4	595.9	595.4

2. REFERENCES

1. R. E. Glass. *Sample Problem Manual for Benchmarking of Cask Analysis Codes.* SAND88-0190 TTC-0780 UC-71, Sandia National Laboratory, Albuquerque, NM 07115 (February 1988).

2. S. J. Hensel to R. J. Gromada. *Benchmark of P/Thermal Code Against a Documented Shipping Cask Thermal Problem (U).* SCS-CMG-930016, Westinghouse Savannah River Company, Aiken, SC 29808 (May 2, 1993).

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APPENDIX 3.12

PATRAN-PLUS AND P/THERMAL CODE DESCRIPTIONS

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PATRAN-PLUS AND P/THERMAL CODE DESCRIPTIONS

1. INTRODUCTION

PATRAN (version 2.5) is the pre- and post-processing software package for the finite element modeling of the 9965, 9968, 9972, 9973, 9974, and 9975 shipping packages. The P/Thermal (version 2.6) software package is used to solve for temperatures. PATRAN and P/Thermal, both developed by PDA Engineering[1] of Costa Mesa, California, are tightly coupled. Because P/Thermal performs the calculations for temperatures, the majority of this discussion will focus upon the use of P/Thermal.

PATRAN was used for all aspects of model development. Dimensions from the package drawings were input to create the axisymmetric model for each package. The model geometry was then meshed, and loads and boundary conditions, including internal heat generation, heat flux, radiation, and convection, were applied. The model is output in a neutral file and analysis is completed with P/Thermal.

P/Thermal is a thermal modeling and analysis software package optimized for large, highly nonlinear models. The code supports a wide range of complex boundary conditions and includes a library of 37 convection correlations as well as an extensive material database. P/Thermal solves for temperature distributions using any combination of the five primary heat transfer modes; namely, conduction, convection, radiation, phase change, and advection. Radiation viewfactors between element surfaces are calculated with a companion program to P/Thermal, P/Viewfactor. Radiation properties may be a function of both wavelength and direction. P/Viewfactor is integrated into P/Thermal in such a way as to make its operation transparent to the user.

2. JUSTIFICATION

Numerous thermal analysis programs exist to calculate the temperature profiles within the shipping packages. The most common software appears in a guide from Lawrence Livermore National Laboratory.[2] P/Thermal meets or exceeds the capabilities of each of these programs based upon the description of the programs' advertised capabilities.

P/Thermal is relatively new and is gaining acceptance as a reliable thermal analysis code. Numerous benchmark problems have been correctly solved by P/Thermal, such as the UK-1 problem posed by the Nuclear Committee on Reactor Physics, which has defined a standard problem set for benchmarking thermal codes.

P/Thermal agrees closely with the analytical solution for the Kershaw problem. The Kershaw problem is a standard benchmark designed to test for errors introduced by skewed meshes. Many available thermal analysis codes fail this test.

3. CAPABILITIES

P/Thermal supports a wide range of boundary conditions such as nodal, surface, and volumetric heat sources, nodal temperatures, and convective and radiative surfaces. All boundary conditions may be input as constant, time-dependent, or temperature-dependent, and can be defined by any combination of microfunctions or user-subroutines.

P/Thermal creates a resistor-capacitor network using all finite element cross-derivative terms. This allows an exact mathematical representation of the model. The element library includes two-dimensional and three-dimensional elements as well as axisymmetric bar, triangle, quadrilateral, tetrahedral, wedge, and hexahedral elements.

The solution scheme offers several explicit and implicit algorithms. Automatic selection of implicit or explicit solution techniques can be specified on a node or time step basis. Convergence is based partially on an estimated maximum error that protects against false convergence in stiff thermal problems. Convergence is also based upon the maximum iterative relaxation and system energy balance.

4. INPUT AND OUTPUT

The PATRAN neutral file is output by PATRAN after the model has been completed. The neutral file contains all node and element data, boundary condition assignments, and material property definitions. The neutral file is named PATRANOUT.

A total of five files are required for the P/Thermal analyses of the shipping packages: MATDAT, TEMPLATEDAT, QINDAT, MICRODAT, and VFCTL. Several other files are created during execution of the program, but may be ignored for the purpose of this discussion because they are used only for internal record keeping. A brief description of the six necessary input files follows:

PATRANOUT:	neutral file of model data
MATDAT:	material properties
TEMPLATEDAT:	convection correlations, radiative surface properties
QINDAT:	all P/Thermal run control parameters
MICRODAT:	internal and solar heat source data
VFCTL:	radiation viewfactor convergence criteria and options

The files MATDAT, TEMPLATEDAT, and MICRODAT for the 9975 NCT thermal analyses are attached as representative input.

The first step in running P/Thermal is to invoke the script PATQ and select menu option 2 (PATQ-2) to translate the neutral file (PATRANOUT) into a resistor-capacitor network. PATQ-3 also reads in the TEMPLATEDAT file and produces eleven output files containing resistor and capacitor data. After successful completion of PATQ-2, PATQ menu option 3 (PATQ-3) is selected to generate radiation viewfactors. After the viewfactors have been created, PATQ menu option 4 (PATQ-4) is picked to create a new FORTRAN main program source file, Q/TRAN, from existing files. The executable file produced from Q/TRAN (QTRANEXE) is normally submitted to a batch queue and iterates until convergence is achieved.

Output from P/Thermal is in the form of nodal results files. Nodal results files contain all nodes in the model and the temperatures at the nodes. These files are read into PATRAN when the model is post-processed to view the results, normally as fringe or contour plots.

5. REFERENCES

1. PDA Engineering. 1975 Redhill Avenue, Costa Mesa, CA 92626.

2. L. E. Fischer, et al. Packaging Review Guide for Reviewing Safety Analysis Reports for Packaging. UCID-21218, Lawrence Livermore Laboratory, pp 5-4 to 5-6, (October 1988).

```
Jul 16 1994 13:49:48                 mat.dat                    Page 1

*
*     The material properties in this sample MAT.DAT file are in SI units
*     The table entries use the index independent variable option
*     All tables have been bounded - this is good practice for all tables
*
MPID 100301 CONSTANT F 1.0
ENERGY ABSORBER --> Thermal Conductivity (Btu/hr-ft-F)
MDATA 3.82
/
MPID 100303 CONSTANT F 1.0
ENERGY ABSORBER --> Thermal Conductivity (Btu/hr-ft-F)
MDATA 7.62
/
MPID 100304 CONSTANT F 1.0
ENERGY ABSORBER --> Density (lbm/ft**3)
MDATA 16.2
/
MPID 100305 CONSTANT F 1.0
ENERGY ABSORBER --> Specific heat (Btu/lbm)
MDATA 0.22
/
MPID 100601 ITABLE  F 1.0
CELOTEX --> Thermal Conductivity
MDATA 76.0  0.031
MDATA 77.0  0.031
MDATA 187.0 0.034
MDATA 295.0 0.036
MDATA 439.0 0.038
MDATA 532.0 0.029
MDATA 533.0 0.029
/
MPID 100604 ITABLE  F 1.0
CELOTEX --> Density
MDATA 76.5  16.86
MDATA 77.0  16.86
MDATA 187.0 17.36
MDATA 295.0 17.86
MDATA 439.0 18.54
MDATA 532.0 19.54
/
MPID 100605 ITABLE F 1.0
CELOTEX --> Specific Heat
MDATA 76.0  0.306
MDATA 77.0  0.306
MDATA 187.0 0.360
MDATA 295.0 0.417
MDATA 439.0 0.489
MDATA 532.0 0.493
MDATA 533.0 0.493
/
MPID 100701 CONSTANT  F  1.0
UPPER PLATE (ALUMINUM) --> Thermal Conductivity
MDATA 126.0
/
MPID 100704 CONSTANT F 1.0
UPPER PLATE (ALUMINUM) --> Density
MDATA 169.3
/
MPID 100705 CONSTANT F 1.0
UPPER PLATE (ALUMINUM) --> Specific Heat
MDATA 0.216
/
MPID  35701  TABLE  FAHRENHEIT  1.0
STEEL, STAINLESS 304 --> Thermal Conductivity (Btu/(hr*ft*F))
References:  1,4,37
Data Quality:  EXCELLENT
MDATA -3.28000E+02  3.99150E+00
MDATA -1.48000E+02  6.28963E+00
MDATA  3.20000E+01  7.74108E+00
MDATA  2.12000E+02  9.43444E+00
MDATA  9.32000E+02  1.25793E+01
MDATA  1.29200E+03  1.49983E+01
MDATA  1.29300E+03  1.49983E+01
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AIR --> Thermal Conductivity (Btu/(hr*ft*F))
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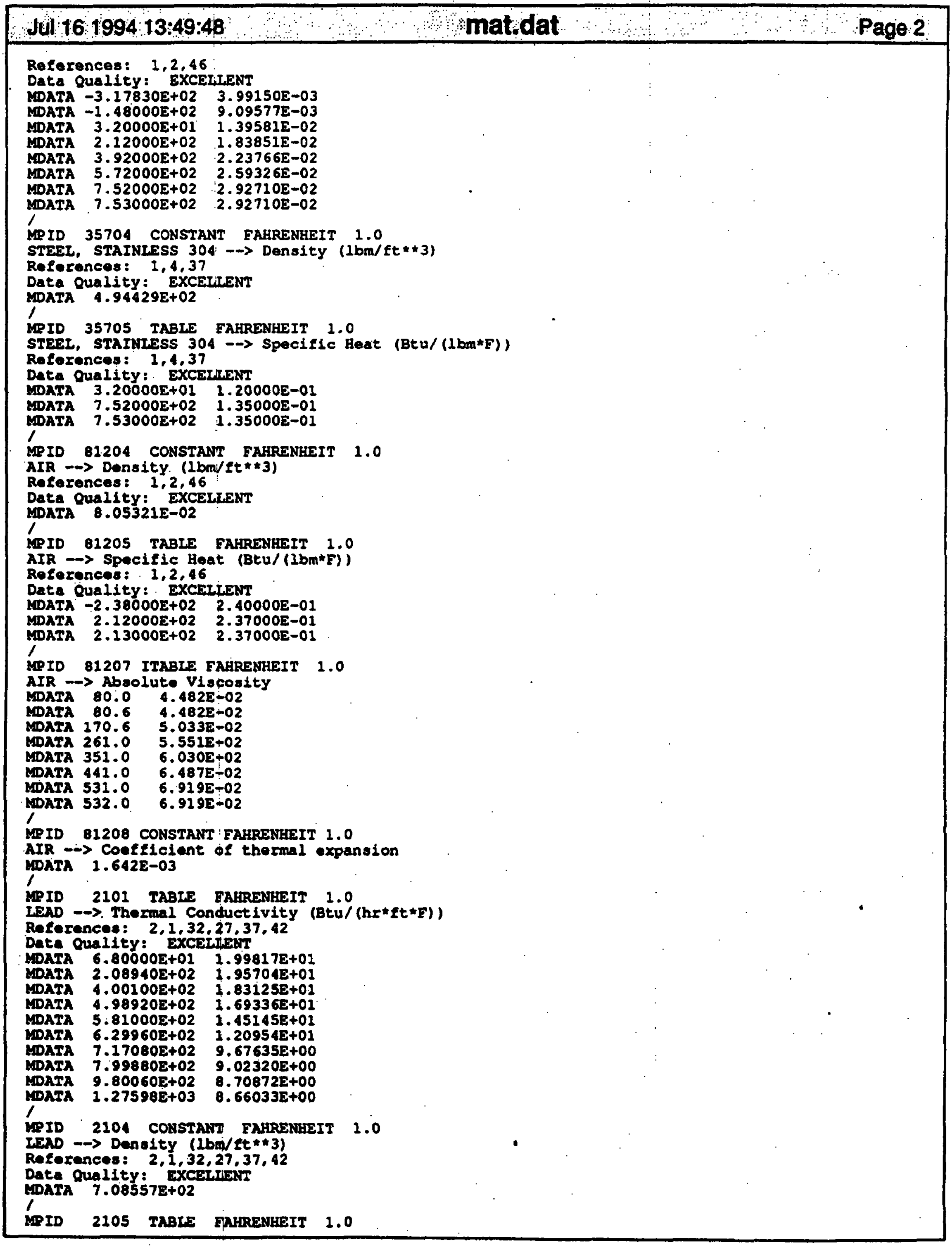

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Jul 16 1994 13:49:48                  mat.dat                          Page 2
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MDATA  2.12000E+02  1.83851E-02
MDATA  3.92000E+02  2.23766E-02
MDATA  5.72000E+02  2.59326E-02
MDATA  7.52000E+02  2.92710E-02
MDATA  7.53000E+02  2.92710E-02
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References:  1,4,37
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MDATA  4.94429E+02
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STEEL, STAINLESS 304 --> Specific Heat (Btu/(lbm*F))
References:  1,4,37
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MDATA  7.53000E+02  1.35000E-01
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Data Quality:  EXCELLENT
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MDATA  2.12000E+02  2.37000E-01
MDATA  2.13000E+02  2.37000E-01
/
MPID  81207 ITABLE FAHRENHEIT  1.0
AIR --> Absolute Viscosity
MDATA  80.0   4.482E-02
MDATA  80.6   4.482E-02
MDATA 170.6   5.033E-02
MDATA 261.0   5.551E+02
MDATA 351.0   6.030E+02
MDATA 441.0   6.487E-02
MDATA 531.0   6.919E-02
MDATA 532.0   6.919E-02
/
MPID  81208 CONSTANT FAHRENHEIT 1.0
AIR --> Coefficient of thermal expansion
MDATA  1.642E-03
/
MPID   2101  TABLE  FAHRENHEIT  1.0
LEAD --> Thermal Conductivity (Btu/(hr*ft*F))
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MDATA  2.08940E+02  1.95704E+01
MDATA  4.00100E+02  1.83125E+01
MDATA  4.98920E+02  1.69336E+01
MDATA  5.81000E+02  1.45145E+01
MDATA  6.29960E+02  1.20954E+01
MDATA  7.17080E+02  9.67635E+00
MDATA  7.99880E+02  9.02320E+00
MDATA  9.80060E+02  8.70872E+00
MDATA  1.27598E+03  8.66033E+00
/
MPID   2104  CONSTANT  FAHRENHEIT  1.0
LEAD --> Density (lbm/ft**3)
References:  2,1,32,27,37,42
Data Quality:  EXCELLENT
MDATA  7.08557E+02
/
MPID   2105  TABLE  FAHRENHEIT  1.0
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LEAD --> Specific Heat (Btu/(lbm*F))
References:  2,1,32,27,37,42
Data Quality:  EXCELLENT
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MDATA  7.52000E+02  1.50000E-01
MDATA  1.11200E+03  1.70000E-01
MDATA  1.29200E+03  2.00000E-01
MDATA  1.40540E+03  2.00000E-01
MDATA  1.41440E+03  1.64800E+00
MDATA  1.42340E+03  1.68000E-01
MDATA  1.74200E+03  1.60000E-01
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MPID   3001  TABLE  FAHRENHEIT  1.0
PLUTONIUM --> Thermal Conductivity (Btu/(hr*ft*F))
References:  20,31,3,27,43,42,41,36,44
Data Quality:  EXCELLENT
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MDATA -8.14000E+01  1.93527E+00
MDATA -4.54000E+01  2.66100E+00
MDATA  6.26000E+01  4.59627E+00
MDATA  1.34600E+02  5.80581E+00
MDATA  2.06600E+02  7.25726E+00
MDATA  2.42600E+02  7.74108E+00
MDATA  2.66000E+02  9.19253E+00
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/
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References:  20,31,3,27,43,42,41,36,44
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MDATA  1.19862E+03
/
MPID   3005  TABLE  FAHRENHEIT  1.0
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References:  20,31,3,27,43,42,41,36,44
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MDATA  2.12000E+02  3.28000E-02
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MDATA  3.02000E+02  2.94000E-02
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```
Jul 18 1994 13:58:59                template.dat                          Page 1

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*
*  Note:  All lines beginning with an "*" are comment lines.
*
*#############################################################################
*
*  MID Template
*  Format:  "MID  Tid  Kx  Ky  Kz  Rho  Cp  PHID"
*
*-----------------------------------------------------------------------------
*
* MID's
* 1001 --> air gaps
* 1002 --> SECN
* 1003 --> ENS(A-C)
* 1004 --> PRIM
* 1005 --> PUO2
* 1006 --> CELOTEX
* 1007 --> PLATEA (1100 AL)
* 1008 --> PLATEB ( LEAD )
* 1009 --> FOOD
* 1011 --> SHELL (DRUM)
* 1012 --> AIR UNDER DRUM LID
* 1013 --> LEAD SHLD (9968 ONLY)
* 1014 --> CHARRED CELOTEX REGION (1.4")
*
*     Tid     Kx     Ky     Kz      Rho     Cp      PHID
*     ---    ---    ---    ---      ---    ---      ----
MID  1001  81201  81201  81201   81204  81205       0
MID  1002  35701  35701  35701   35704  35705       0
MID  1003 100301 100303 100301  100304 100305       0
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MID  1005   3001   3001   3001    3004   3005       0
MID  1006 100601 100601 100601  100604 100605       0
MID  1007 100701 100701 100701  100704 100705       0
MID  1008   2101   2101   2101    2104   2105       0
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MID  1014 100601 100601 100601  100604 100605       0
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*#############################################################################
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*  MACRO Templates
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*           "Micro_id_1  Micro_id_2  ...  Micro_Id_n"
*
*-----------------------------------------------------------------------------
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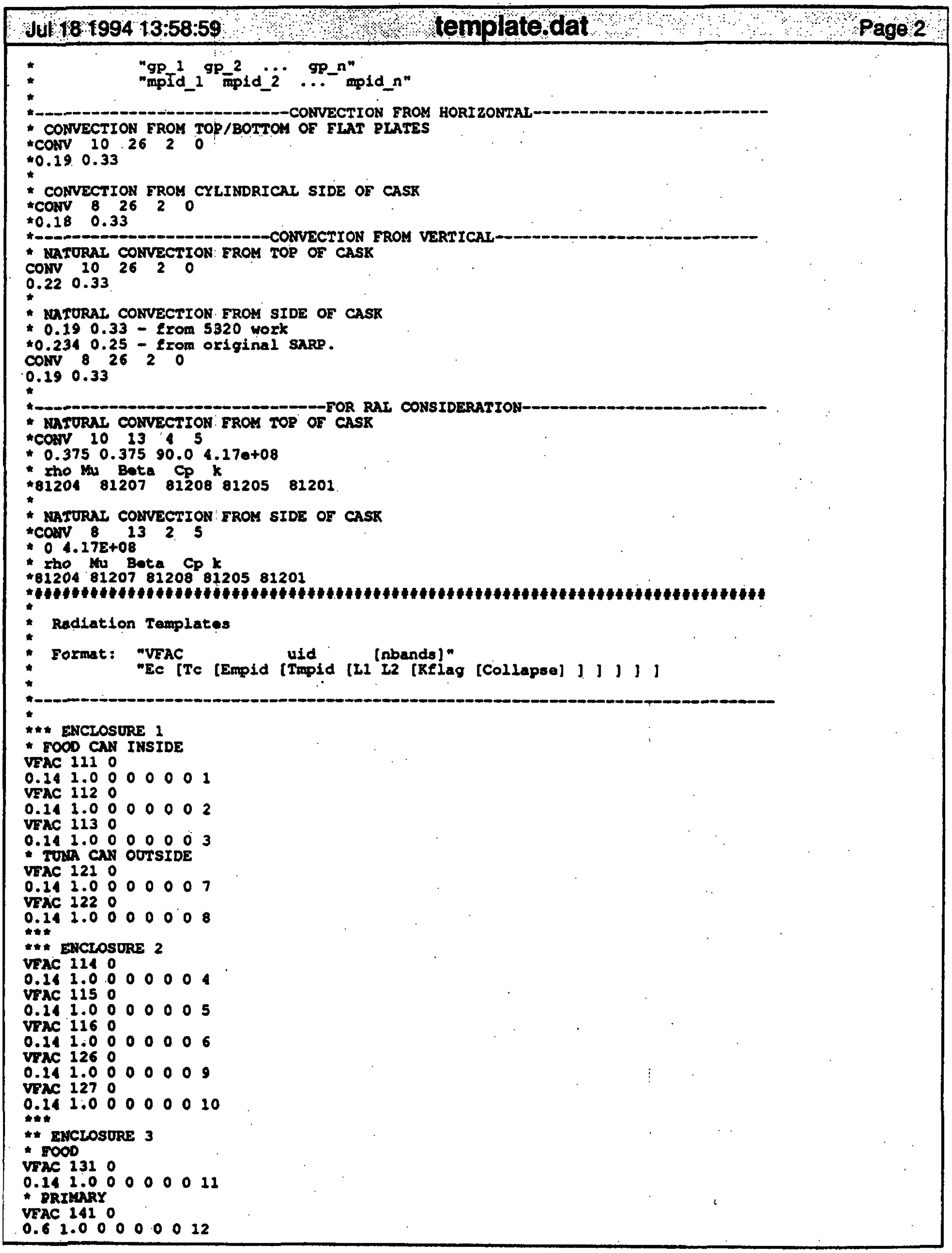
*  TMACROfunction Template 17
* Solar flux to side of drum
MACRO  20  1  0  0 0.65
120
*
* Solar flux to top of drum
MACRO  22  1  0  0  0.65
122
*
* Volumetric heat generation for top tuna can
MACRO  13  1  0  0  1.0
113
*
* Volumetric heat generation for bottom tuna can
MACRO  15  1  0  0  1.0
115
*
* Heat flux rejection to ambient by radiation.
MACRO  16  1 9999 0 0.21
116
*
*#############################################################################
*
*  CONV Templates
*  Format:  "CONV  uid  cfig  #gp  #mpid"
```



Jul 18 1994 13:58:59 **template.dat** Page 2

```
*          "gp_1  gp_2  ...  gp_n"
*          "mpid_1  mpid_2  ...  mpid_n"
*
*--------------------------CONVECTION FROM HORIZONTAL------------------------
* CONVECTION FROM TOP/BOTTOM OF FLAT PLATES
*CONV  10  26  2  0
*0.19 0.33
*
* CONVECTION FROM CYLINDRICAL SIDE OF CASK
*CONV  8  26  2  0
*0.18  0.33
*------------------------CONVECTION FROM VERTICAL----------------------------
* NATURAL CONVECTION FROM TOP OF CASK
CONV  10  26  2  0
0.22 0.33
*
* NATURAL CONVECTION FROM SIDE OF CASK
* 0.19 0.33 - from 5320 work
*0.234 0.25 - from original SARP.
CONV  8  26  2  0
0.19 0.33
*
*------------------------------FOR RAL CONSIDERATION-------------------------
* NATURAL CONVECTION FROM TOP OF CASK
*CONV  10  13  4  5
* 0.375 0.375 90.0 4.17e+08
* rho Mu  Beta  Cp  k
*81204  81207  81208 81205  81201
*
* NATURAL CONVECTION FROM SIDE OF CASK
*CONV  8   13  2  5
* 0 4.17E+08
* rho  Mu  Beta  Cp k
*81204 81207 81208 81205 81201
*###############################################################################
*
*  Radiation Templates
*
*  Format:  "VFAC          uid       [nbands]"
*           "Ec [Tc [Empid [Tmpid [L1 L2 [Kflag [Collapse] ] ] ] ] ]
*
*-------------------------------------------------------------------------------
*
*** ENCLOSURE 1
* FOOD CAN INSIDE
VFAC 111 0
0.14 1.0 0 0 0 0 0 1
VFAC 112 0
0.14 1.0 0 0 0 0 0 2
VFAC 113 0
0.14 1.0 0 0 0 0 0 3
* TUNA CAN OUTSIDE
VFAC 121 0
0.14 1.0 0 0 0 0 0 7
VFAC 122 0
0.14 1.0 0 0 0 0 0 8
***
*** ENCLOSURE 2
VFAC 114 0
0.14 1.0 0 0 0 0 0 4
VFAC 115 0
0.14 1.0 0 0 0 0 0 5
VFAC 116 0
0.14 1.0 0 0 0 0 0 6
VFAC 126 0
0.14 1.0 0 0 0 0 0 9
VFAC 127 0
0.14 1.0 0 0 0 0 0 10
***
** ENCLOSURE 3
* FOOD
VFAC 131 0
0.14 1.0 0 0 0 0 0 11
* PRIMARY
VFAC 141 0
0.6 1.0 0 0 0 0 0 12
```

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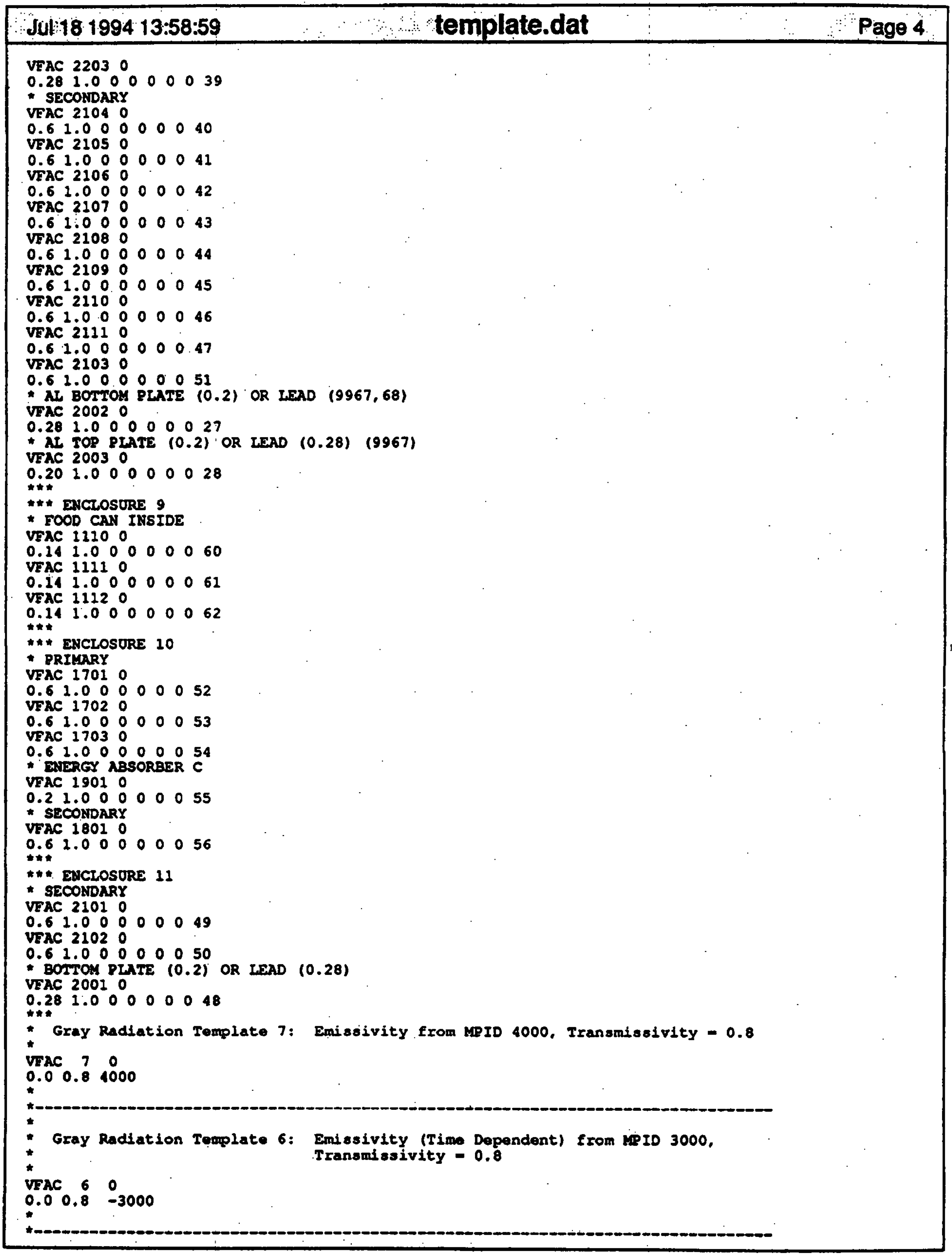
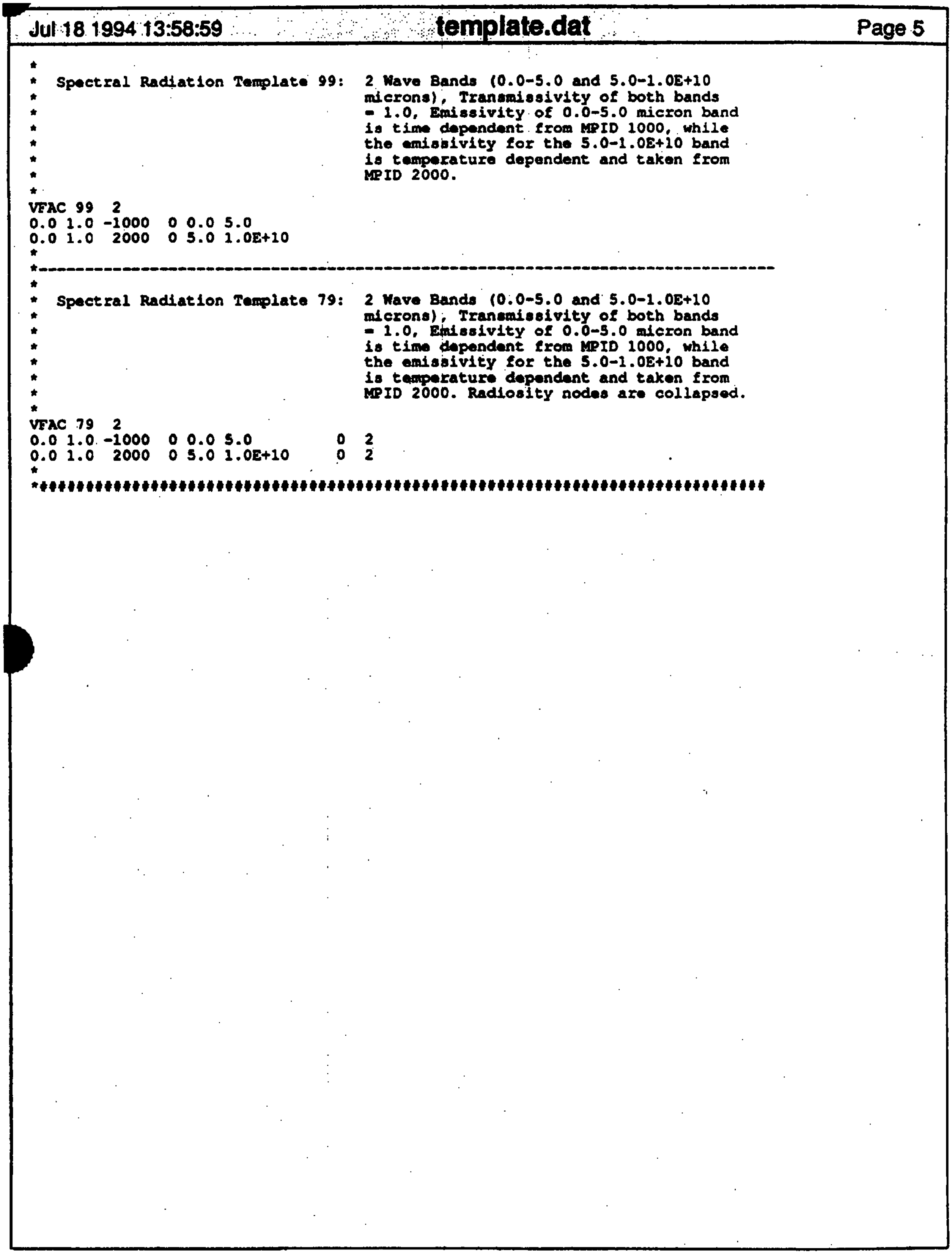
```
VFAC 142 0
0.6 1.0 0 0 0 0 0 13
VFAC 143 0
0.6 1.0 0 0 0 0 0 14
* ENERGY ABSORBER C
VFAC 151 0
0.2 1.0 0 0 0 0 0 29
***
*** ENCLOSURE 4
* PRIMARY
VFAC 171 0
0.6 1.0 0 0 0 0 0 15
VFAC 172 0
0.6 1.0 0 0 0 0 0 16
* ENERGY ABSORBER B
VFAC 201 0
0.2 1.0 0 0 0 0 0 26
***
*** ENCLOSURE 5
* PRIMARY
VFAC 173 0
0.6 1.0 0 0 0 0 0 17
VFAC 174 0
0.6 1.0 0 0 0 0 0 18
VFAC 175 0
0.6 1.0 0 0 0 0 0 19
VFAC 176 0
0.6 1.0 0 0 0 0 0 20
VFAC 177 0
0.6 1.0 0 0 0 0 0 21
VFAC 178 0
0.6 1.0 0 0 0 0 0 22
* ENERGY ABSORBER C
VFAC 168  0
0.2 1.0 0 0 0 0 0 36
* SECONDARY
VFAC 181 0
0.6 1.0 0 0 0 0 0 23
VFAC 182 0
0.6 1.0 0 0 0 0 0 24
VFAC 183 0
0.6 1.0 0 0 0 0 0 25
* AL BOTTOM PLATE(0.2)  OR LEAD (9967,68) (.28)
VFAC 202 0
0.28 1.0 0 0 0 0 0 50
***
*** ENCLOSURE 6
* PUO2 BUTTON
VFAC 91 0
1.0
* TUNA CAN INSIDE
VFAC 117 0
0.14 1.0 0 0 0 0 0 30
VFAC 118 0
0.14 1.0 0 0 0 0 0 31
VFAC 119
0.14 1.0 0 0 0 0 0 32
***
*** ENCLOSURE 7
* PUO2 BUTTON
VFAC 911 0
1.0
* TUNA CAN
VFAC 1171
0.14 1.0 0 0 0 0 0 33
VFAC 1181
0.14 1.0 0 0 0 0 0 34
VFAC 1191
0.14 1.0 0 0 0 0 0 35
***
*** ENCLOSURE 8
* LEAD SHIELD(0.28) or CELOTEX(0.5)
VFAC 2201 0
0.28 1.0 0 0 0 0 0 37
VFAC 2202 0
0.28 1.0 0 0 0 0 0 38
```



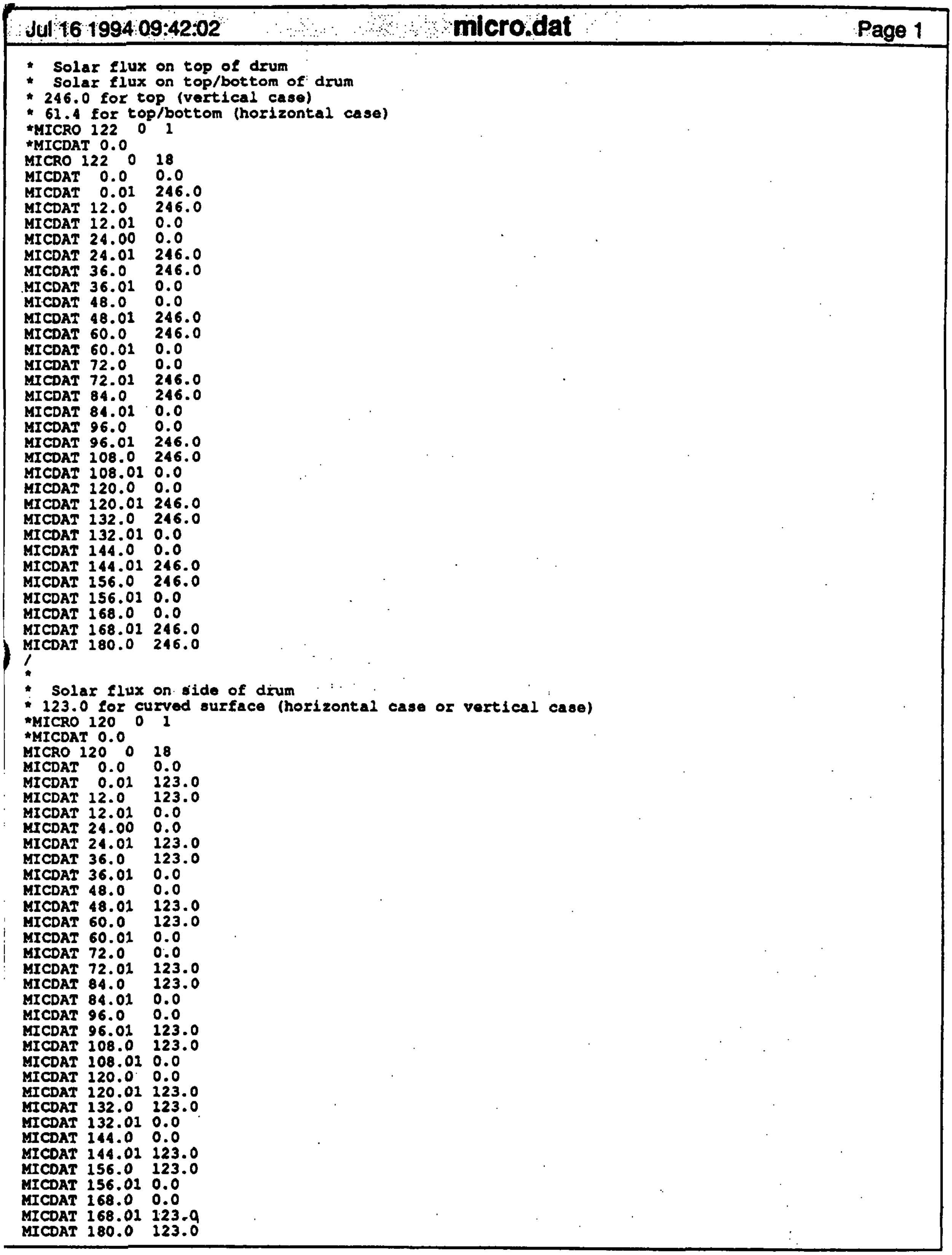
Jul 18 1994 13:58:59 **template.dat** Page 4

```
VFAC 2203 0
0.28 1.0 0 0 0 0 0 39
* SECONDARY
VFAC 2104 0
0.6 1.0 0 0 0 0 0 40
VFAC 2105 0
0.6 1.0 0 0 0 0 0 41
VFAC 2106 0
0.6 1.0 0 0 0 0 0 42
VFAC 2107 0
0.6 1.0 0 0 0 0 0 43
VFAC 2108 0
0.6 1.0 0 0 0 0 0 44
VFAC 2109 0
0.6 1.0 0 0 0 0 0 45
VFAC 2110 0
0.6 1.0 0 0 0 0 0 46
VFAC 2111 0
0.6 1.0 0 0 0 0 0 47
VFAC 2103 0
0.6 1.0 0 0 0 0 0 51
* AL BOTTOM PLATE (0.2) OR LEAD (9967,68)
VFAC 2002 0
0.28 1.0 0 0 0 0 0 27
* AL TOP PLATE (0.2) OR LEAD (0.28) (9967)
VFAC 2003 0
0.20 1.0 0 0 0 0 0 28
***
*** ENCLOSURE 9
* FOOD CAN INSIDE
VFAC 1110 0
0.14 1.0 0 0 0 0 0 60
VFAC 1111 0
0.14 1.0 0 0 0 0 0 61
VFAC 1112 0
0.14 1.0 0 0 0 0 0 62
***
*** ENCLOSURE 10
* PRIMARY
VFAC 1701 0
0.6 1.0 0 0 0 0 0 52
VFAC 1702 0
0.6 1.0 0 0 0 0 0 53
VFAC 1703 0
0.6 1.0 0 0 0 0 0 54
* ENERGY ABSORBER C
VFAC 1901 0
0.2 1.0 0 0 0 0 0 55
* SECONDARY
VFAC 1801 0
0.6 1.0 0 0 0 0 0 56
***
*** ENCLOSURE 11
* SECONDARY
VFAC 2101 0
0.6 1.0 0 0 0 0 0 49
VFAC 2102 0
0.6 1.0 0 0 0 0 0 50
* BOTTOM PLATE (0.2) OR LEAD (0.28)
VFAC 2001 0
0.28 1.0 0 0 0 0 0 48
***
*  Gray Radiation Template 7:  Emissivity from MPID 4000, Transmissivity = 0.8
*
VFAC  7  0
0.0 0.8 4000
*
*-------------------------------------------------------------------------------
*
*  Gray Radiation Template 6:  Emissivity (Time Dependent) from MPID 3000,
*                              Transmissivity = 0.8
*
VFAC  6  0
0.0 0.8  -3000
*
*-------------------------------------------------------------------------------
```



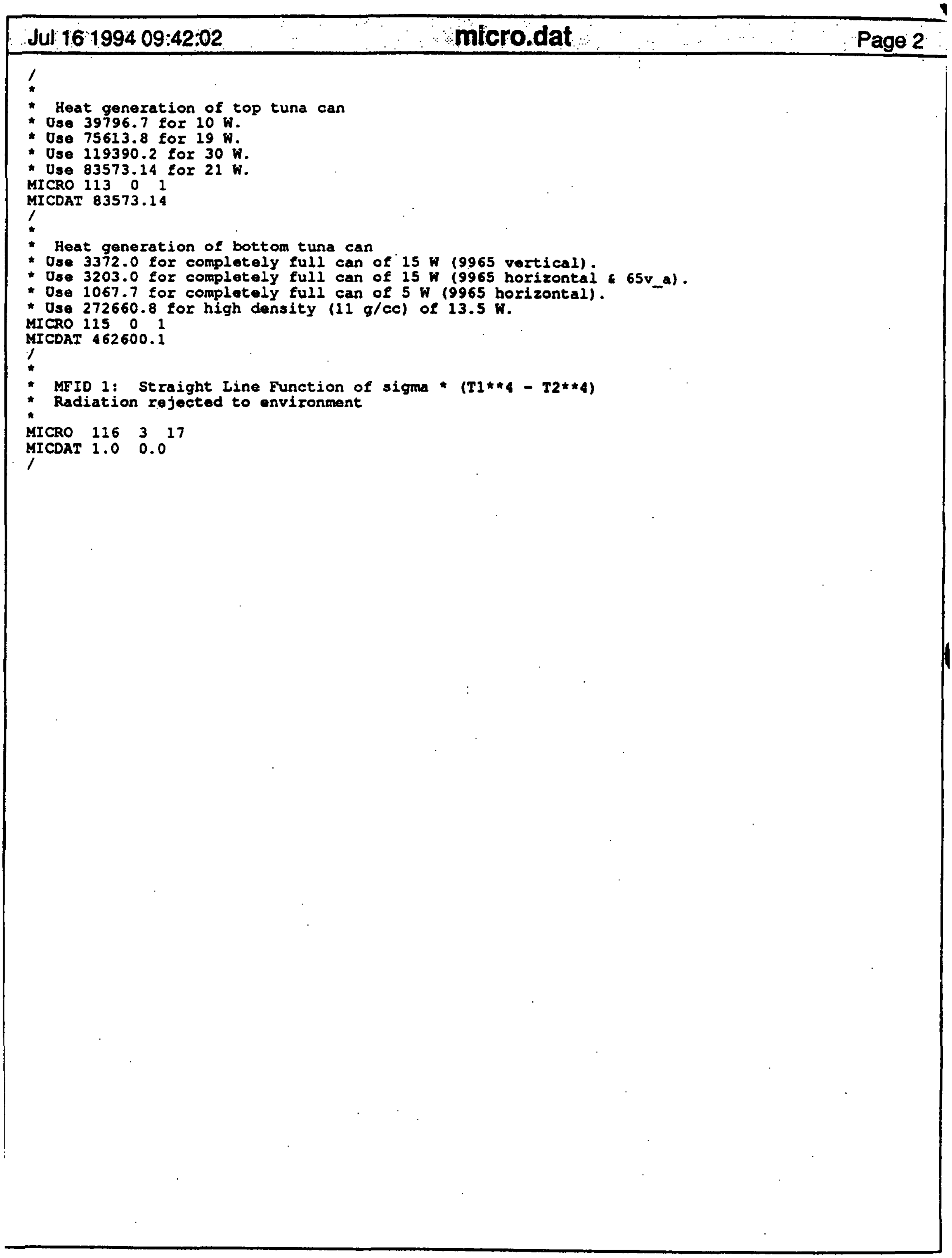
Jul 18 1994 13:58:59 **template.dat** Page 5

```
*
*  Spectral Radiation Template 99:  2 Wave Bands (0.0-5.0 and 5.0-1.0E+10
*                                   microns), Transmissivity of both bands
*                                   = 1.0, Emissivity of 0.0-5.0 micron band
*                                   is time dependent from MPID 1000, while
*                                   the emissivity for the 5.0-1.0E+10 band
*                                   is temperature dependent and taken from
*                                   MPID 2000.
*
VFAC 99  2
0.0 1.0 -1000  0 0.0 5.0
0.0 1.0  2000  0 5.0 1.0E+10
*
*------------------------------------------------------------------------------
*
*  Spectral Radiation Template 79:  2 Wave Bands (0.0-5.0 and 5.0-1.0E+10
*                                   microns), Transmissivity of both bands
*                                   = 1.0, Emissivity of 0.0-5.0 micron band
*                                   is time dependent from MPID 1000, while
*                                   the emissivity for the 5.0-1.0E+10 band
*                                   is temperature dependant and taken from
*                                   MPID 2000. Radiosity nodes are collapsed.
*
VFAC 79  2
0.0 1.0 -1000  0 0.0 5.0        0  2
0.0 1.0  2000  0 5.0 1.0E+10    0  2
*
*#############################################################################
```



Jul 16 1994 09:42:02 **micro.dat** Page 1

```
*  Solar flux on top of drum
*  Solar flux on top/bottom of drum
* 246.0 for top (vertical case)
* 61.4 for top/bottom (horizontal case)
*MICRO 122  0  1
*MICDAT 0.0
MICRO 122  0  18
MICDAT  0.0   0.0
MICDAT  0.01  246.0
MICDAT 12.0   246.0
MICDAT 12.01  0.0
MICDAT 24.00  0.0
MICDAT 24.01  246.0
MICDAT 36.0   246.0
MICDAT 36.01  0.0
MICDAT 48.0   0.0
MICDAT 48.01  246.0
MICDAT 60.0   246.0
MICDAT 60.01  0.0
MICDAT 72.0   0.0
MICDAT 72.01  246.0
MICDAT 84.0   246.0
MICDAT 84.01  0.0
MICDAT 96.0   0.0
MICDAT 96.01  246.0
MICDAT 108.0  246.0
MICDAT 108.01 0.0
MICDAT 120.0  0.0
MICDAT 120.01 246.0
MICDAT 132.0  246.0
MICDAT 132.01 0.0
MICDAT 144.0  0.0
MICDAT 144.01 246.0
MICDAT 156.0  246.0
MICDAT 156.01 0.0
MICDAT 168.0  0.0
MICDAT 168.01 246.0
MICDAT 180.0  246.0
/
*
*  Solar flux on side of drum
* 123.0 for curved surface (horizontal case or vertical case)
*MICRO 120  0  1
*MICDAT 0.0
MICRO 120  0  18
MICDAT  0.0   0.0
MICDAT  0.01  123.0
MICDAT 12.0   123.0
MICDAT 12.01  0.0
MICDAT 24.00  0.0
MICDAT 24.01  123.0
MICDAT 36.0   123.0
MICDAT 36.01  0.0
MICDAT 48.0   0.0
MICDAT 48.01  123.0
MICDAT 60.0   123.0
MICDAT 60.01  0.0
MICDAT 72.0   0.0
MICDAT 72.01  123.0
MICDAT 84.0   123.0
MICDAT 84.01  0.0
MICDAT 96.0   0.0
MICDAT 96.01  123.0
MICDAT 108.0  123.0
MICDAT 108.01 0.0
MICDAT 120.0  0.0
MICDAT 120.01 123.0
MICDAT 132.0  123.0
MICDAT 132.01 0.0
MICDAT 144.0  0.0
MICDAT 144.01 123.0
MICDAT 156.0  123.0
MICDAT 156.01 0.0
MICDAT 168.0  0.0
MICDAT 168.01 123.0
MICDAT 180.0  123.0
```



Jul 16 1994 09:42:02 **micro.dat** Page 2

```
/
*
*  Heat generation of top tuna can
* Use 39796.7 for 10 W.
* Use 75613.8 for 19 W.
* Use 119390.2 for 30 W.
* Use 83573.14 for 21 W.
MICRO 113  0  1
MICDAT 83573.14
/
*
*  Heat generation of bottom tuna can
* Use 3372.0 for completely full can of 15 W (9965 vertical).
* Use 3203.0 for completely full can of 15 W (9965 horizontal & 65v_a).
* Use 1067.7 for completely full can of 5 W (9965 horizontal).
* Use 272660.8 for high density (11 g/cc) of 13.5 W.
MICRO 115  0  1
MICDAT 462600.1
/
*
*  MFID 1:  Straight Line Function of sigma * (T1**4 - T2**4)
*  Radiation rejected to environment
*
MICRO  116  3  17
MICDAT 1.0  0.0
/
```

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APPENDIX 3.13

SOLAR ABSORPTANCE AND EMITTANCE OF STAINLESS STEEL AT 400 K

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SOLAR ABSORPTANCE AND EMITTANCE OF STAINLESS STEEL AT 400 K

1. INTRODUCTION

Stainless steel is the material used for the 9972, 9973, 9974, and 9975 drums. In 10 CFR 71, §71.71(c)(1), the solar heat flux requirements are specified. Applying an absorptance of unity and simultaneously using an appropriate low emittance for a surface that has not been treated is not realistic. An analysis was performed and reported by S. J. Hensel and J. K. Thomas [1] to determine a conservative realistic solar absorptance and surface emittance.

2. ANALYSIS

The solar absorptance and emittance at 400 K for various steel surface conditions have been computed using normal spectral data from the literature. The integral for total solar absorptance was computed with the solar radiation assumed to be emitted from a blackbody at 5800 K. The integral for total emittance was computed with the spectral emission assumed to be that from a blackbody at 400 K. Obviously, the solar absorptance and emittance can be quite different since the solar spectrum is concentrated at a much lower wavelength than the emissions at 400 K.

The radiative surface property data as a function of wavelength for stainless steel were taken from two references.[2,3] The data have been grouped into eight cases.

Case	Description
1	303 stainless ground rough[2]
2	303 stainless lapped[2]
3	303 stainless machined fine[2]
4	303 stainless lapped[2]
5	303 stainless sandblasted lightly[2]
6	stainless as received (close to polished)[3]
7	stainless as received (medium)[3]
8	stainless as received (very dull surface)[3]

The spectral data are approximately linear on a log-log plot and can be described by the functional form $a=Al^m$, where A and m are constants (absorptance and emittance at a given wavelength l are equal). The coefficients for the eight data sets just listed are shown in Table 1.

Table 1. The Data Set Coefficients

Case	A	m
1	0.42296	-0.396
2	0.29744	-0.436
3	0.46425	-0.452
4	0.32381	-0.479
5	0.57185	-0.215
6	0.3363	-0.428
7	0.44668	-0.322
8	0.5274	-0.245

The integrals for total solar absorptance and emittance were computed using trapezoidal integration. The wavelength step size and the range of integration were varied to ensure convergence. The results of the analysis are provided in Table 2.

Table 2. Analysis Results

Case	Solar Absorptance	Emittance (400°K)
1	0.485	0.168
2	0.347	0.108
3	0.545	0.162
4	0.385	0.107
5	0.612	0.343
6	0.391	0.124
7	0.498	0.210
8	0.570	0.296

Clearly, 0.57 is a conservative solar absorptance and 0.12 is a conservative emittance for the as-received data, and a solar absorptance of 0.65 bounds all data examined. Angular effects have been neglected in this analysis. The emittance is relatively constant with respect to off-normal angles at the low solar wavelengths, but increases at large off-normal angles in the longer infrared wavelengths. Thus, neglecting angular effects tends to under predict the emittance at the infrared wavelengths, which is conservative for the present application.

3. REFERENCES

1. S. J. Hensel and J. K. Thomas to R. Maurer. *Solar Absorptance and Emittance of Stainless Steel at 400 K (U).* SCS-CMG-930019, Westinghouse Savannah River Company, Aiken, SC 29808 (May 28, 1993).

2. D. K. Edwards and I. Catton. *Radiation Characteristics of Rough and Oxidized Metals.* Advances in Thermophysical Properties at Extreme Temperatures and Pressures, 3rd Symposium of Thermophysical Properties, Lafayette, IN, pp 192-193 (1965).

3. Y. S. Touloukian and D. P. DeWitt. *Thermal Radiative Properties of Metallic Elements and Alloys.* Vol. 7, pp 1257 and 1264 (1970).

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APPENDIX 3.15

PACKAGE TEST SELECTION JUSTIFICATION

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WESTINGHOUSE SAVANNAH RIVER COMPANY

INTER-OFFICE MEMORANDUM

SRT-EMS-940047

July 19, 1994

TO: R. J. Gromada, 773-53A

FROM: S. J. Hensel, 773-42A

J W Jerrell 7-27-94

J. W. Jerrell Technical Reviewer Date

JR Pelfrey 7-28-94

J. R. Pelfrey Manager Date

Package Test Selection Justification (U)

Two packages were selected to be fire tested in the Sandia radiant heat facility. The purpose of these tests is to benchmark the fiberboard HAC fire analysis model against package test data, and provide evidence of satisfactory package performance during the HAC fire. The 9973 was tested after a 30 ft. top down drop and puncture, and an undamaged 9975 containing a heater was tested to determine heat source effects. The selection of these packages was based on worst case package vulnerability to the HAC fire. These two packages provide enough test data to serve as an HAC fire benchmark.

Package Test Selection Justification

Package damage was first determined based on drop test results and simple analysis [1]. In Table 1 the cane fiberboard thicknesses in radial and axial (from drum lid to upper bearing plate) directions are presented for both undamaged and damaged packages. The axial damaged thicknesses are based on top down drop tests, and the radial damage thicknesses are based on side drop tests.

The cane fiberboard thickness is critical to protecting internal package components from excessive temperatures during the Hypothetical Accident Case (HAC) fire. The fiberboard sacrificially decomposes while effectively insulating internal components. Although Table 1 illustrates the damage effects in terms of fiberboard thickness, the damage effects in terms of a thermal response during HAC fire is not well understood and needs to be addressed.

A series of 1-D transient HAC fire analyses were performed to assess the effects of decreased (damaged) fiberboard thickness on package performance. A generic schematic of both the axial and radial geometries under consideration is shown in Figure 1. The details concerning fiberboard thickness, outer radial dimension (drum diameter), and metal backing material and thickness are package specific. A listing of all configurations analyzed is shown in Table 2. All models listed in Table 2 are based on damaged dimensions except the last two.

Each 1-D model was analyzed using a uniform 100°F initial temperature, a 30 minute fire of 1475°F, and an ambient temperature of 100°F. The surface emmitance throughout the transient was 1.0, and natural convection to the ambient was considered during cooling. The back side of the metal plates were insulated. Cane fiberboard thermal properties used in the HAC analysis were those developed by Hensel and Gromada [2]. The results of the analysis in terms of peak temperature at the metal/fiberboard interface are shown in Table 3. These peak temperatures occurred from 1 to 2 hours after the fire, depending on the case under consideration.

Using Table 3, the results can be categorized onto three groups; radial, axial with 0.5 in. aluminum backing, and axial with 1.5 in. lead backing. Fiberboard thickness, geometry, and the thermal inertia of the metal backing impact peak temperature. A plot of the peak temperature rise at the fiberboard/metal interface versus fiberboard thickness is shown in Figure 2. The relative effects of thermal inertia (product of density and specific heat) of the metal backing can be easily determined by comparing a unit plate surface area and various materials and thicknesses. The thermal inertia of 0.25 in. thick stainless steel is 33% greater than 0.5 in.

thick lead, while the thermal inertia of 1.5 in. thick lead is 80% greater than 0.5 in. thick aluminum. The temperature gradient across the metal backing was less than 1°F throughout the transient for all cases.

Extrapolation of the analysis curves shown in Figure 2 can be used to determine the temperature rise during an HAC fire given fiberboard damage in terms of its damaged thickness. The damaged and undamaged fiberboard thicknesses for each package have been presented in Table 1. Using Table 1 and Figure 2, the radial temperature rise and axial temperature rise have been determined and are shown in Table 4.

The results in Table 4 suggest that the 9973 and 9975 radial drop test is more vulnerable to the HAC fire than the axial drop test. The 9973 and 9975 are also the most vulnerable undamaged packages. However, the radial damage effects would actually be small in terms of the overall package due to its local (asymmetric) effect. Therefore, the most vulnerable damaged package is the 9973 after an axial drop, and the most vulnerable undamaged package is the 9975. A top down drop is preferred to a bottom drop since the temperature sensitive seals are located at the top of the package.

Based on the results in Table 4, a decision was made to fire test a damaged 9973 (top down drop and puncture) and an undamaged 9975 containing an internal heat source (21 Watts). Results of these tests are to be used in benchmarking the fiberboard HAC fire model and to demonstrate that the package can survive the sequential HAC test series. Using Table 3, the results can be categorized into three groups; radial (0.5 in. lead or 0.25 in. stainless steel), axial with 0.5 in. aluminum backing, and axial with 1.5 in. lead backing. This study did not include the effects of the heat source on the peak temperature increases. The purpose of the study was only to estimate the effects of the HAC fire using a simple 1-D analysis and not determine detailed thermal effects.

Table 1: Fiberboard Thicknesses (in.)

Package	Initial Radial	Iniaial Axial	Damaged Radial	Damaged Axial
9972	6.1	7.0	5.8	6.1
9973	5.6	4.0	5.3	3.4
9974	6.2	6.0	5.6	4.4
9975	4.8	5.0	4.5	3.8

Table 2: Summary of 1-D Analyses

1-D Package Model	Fiberboard Thickness (in.)	Metal Backing (in.)
9972 Axial	6.1	0.5 Aluminum
9973 Axial	3.4	0.5 Aluminum
9974 Axial	4.4	1.5 Lead
9975 Axial	3.8	0.5 Aluminum
9972 Radial	5.8	0.25 Stainless Steel
9975 Radial	4.5	0.5 Lead
9974 Axial*	6.0	1.5 Lead
9975 Radial*	4.8	0.5 Lead

* designates undamaged fiberboard dimensions

Table 3: Summary of 1-D Analyses Results

1-D Package Model	Thickness (in.)	Metal Backing (in.)	Peak Interface (°F)
9972 Axial	6.1	0.5 Aluminum	169.4
9973 Axial	3.4	0.5 Aluminum	212.7
9974 Axial	4.4	1.5 Lead	171.5
9975 Axial	3.8	0.5 Aluminum	205.4
9972 Radial	5.8	0.25 Stainless Steel	207.3
9975 Radial	4.5	0.5 Lead	233.8
9974 Axial*	6.0	1.5 Lead	153.6
9975 Radial*	4.8	0.5 Lead	226.3

* designates undamaged fiberboard dimensions

Table 4: Temperature Rise (°F) At Fiberboard/Metal Interface

Package	Undamaged Radial	Undamaged Axial	Damaged Radial	Damaged Axial
9972	101.1	55.0	107.3	69.4
9973	111.1	102.7	117.1	112.7
9974	99.1	53.6	111.1	71.5
9975	126.3	86.8	133.8	105.4

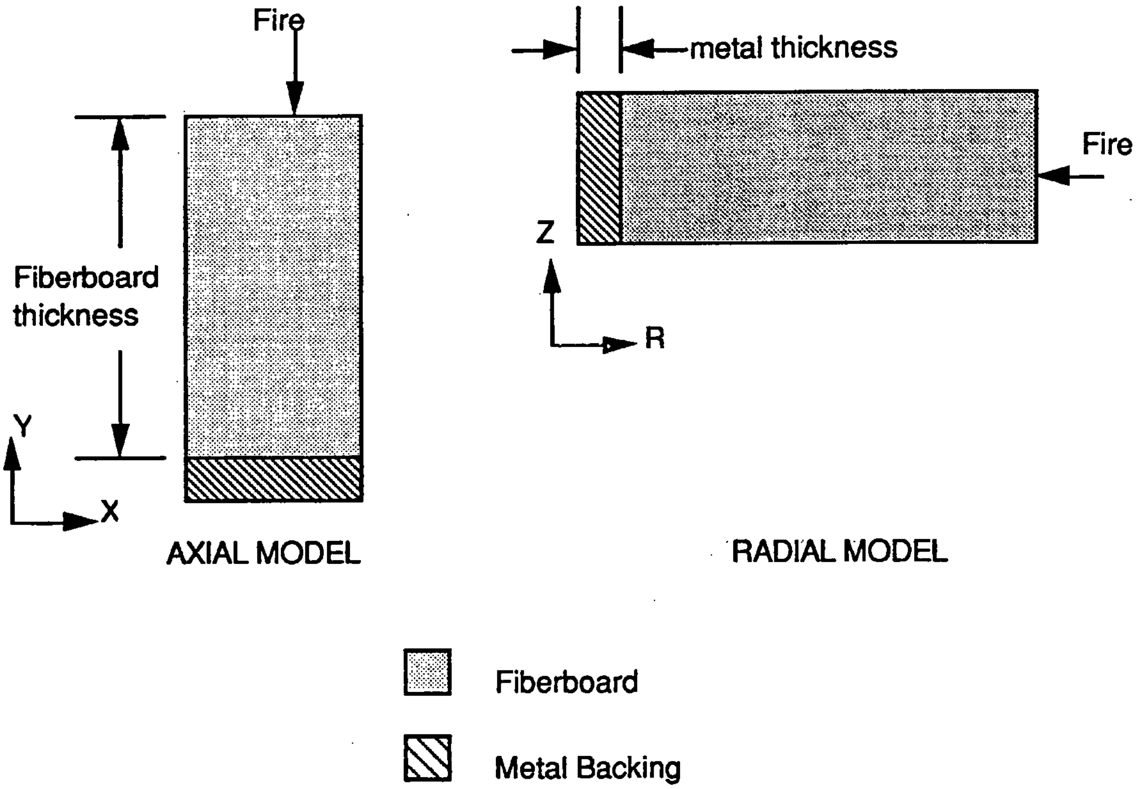

Figure 1 Generic Schematics of 1-D Models

SRT-EMS-940047
P. 6 of 6

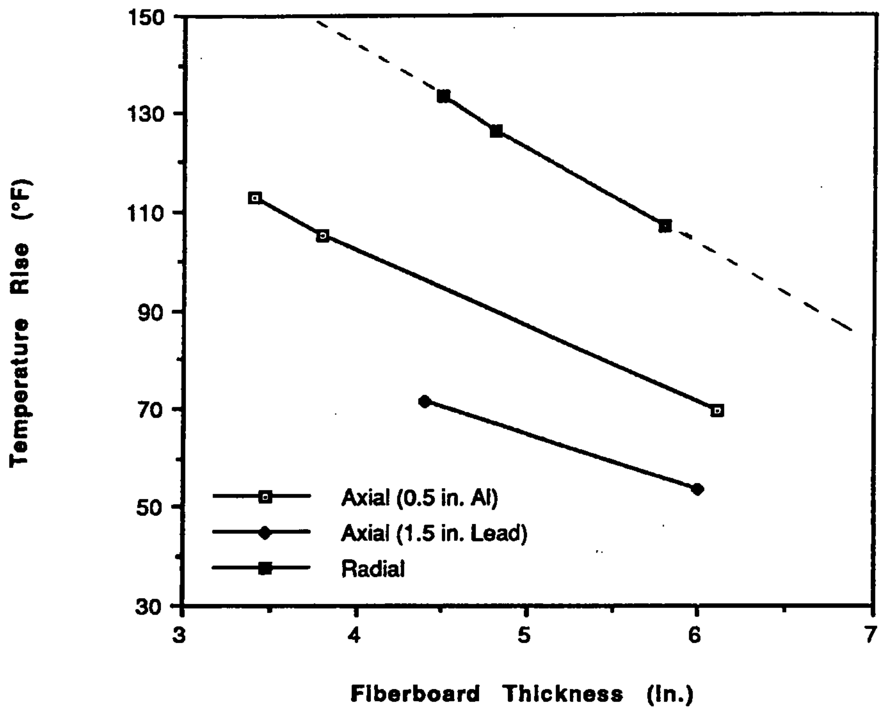

Figure 2. Peak Temperature Rise During HAC at Fiberboard/Metal Interface

References

[1] E-mail from M. Van Alstine, May 1994.

[2] Hensel S. J., and Gromada R. J., "Development of A Simulation (Thermophysical Property) Model for Cane Fiberboard Packages Subjected to A Hypothetical Accident Condition Fire", DOE Weapons Package Workshop, Knoxville, TN, May 1994.

APPENDIX 3.16

CELOTEX INSULATION THERMAL TEST

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September 29, 1982

TO: W. R. KENNEDY, 723-A

FROM: G. CADELLI, 723-9A

CELOTEX INSULATION THERMAL TEST

Introduction:

Celotex insulation is fiber board made from sugar cane fibers bonded together with an organic glue. It is used as an insulating and shock absorbent packing in radioactive material shipping packages. The insulation is manufactured by the Jim Walter Corp. and has a thermal conductivity of .031 BTU/(hr-ft-°F).

Summary:

Celotex insulation thermal tests were conducted by EED in September 1982 to establish temperature limits for shipping package application. The tests show that Celotex can be used at uniform temperatures up to 300°F with occasional excursions to a maximum temperature of 325°F without any apparent degradation of the thermal insulating or structural properties. Consequently, Celotex is acceptable for use in the 9965,9966 and 9967 shipping packages up to 30 watts of internal heat load.

Discussion:

Insulation temperature for normal conditions of transport reached a maximum of 317°F at contact with the primary containment vessel (PCV) during the SP-9965 shipping package furnace test. Since the insulation temperature is not uniform but decreases with increasing distance from the centerline, the average temperature of the insulation is below 300°F. No structural damage or discoloration of the Celotex was observed during the normal condition furnace test.

Four blocks of insulation - 8" x 4" with nominal thickness of 2 inches - were subjected to furnace temperatures of 200, 250, 300, 325 and 350°F. Fresh insulation was used for each temperature which was maintained for seven days. Each group of four blocks were placed in the furnace; two blocks were unweighted and two were loaded with 162 lbs. placed on each (~5 psi). (The 5 psi represents the static loading of a PCV, SCV and lead shield on the Celotex disks). Each block was weighed and measured before and after the test; values are shown in Table 1 and plotted in Figure 1. Photographs of the blocks at each temperature and relative heights of stacks are shown in Figure 2.

To simulate normal transport conditions, one unweighted block and one loaded block at each temperature was subjected to dropping a
25 lb. lead brick of contact area 8 in^2 from a height of four feet onto the test block.

Celotex releases flammable vapors at high temperature. In the range of 200 to 350 °F, no combustion occurred. At 300 °F the insulation had a slightly darkened appearance. The insulation at 325 °F was noticeable darker and the adhesive used to bond the 1/2-inch layers together began to separate. A temperature of 350 °F resulted in a very dark brown color (Figure 2) with the layers separating very easily. The drop test at 350 °F completely shattered the unloaded block and the loaded block had a section sheared as shown in Figure 3 and 4.

Table 1

TEMP. °F	WEIGHTED	AVE.WEIGHT LOSS - g	% LOSS	AVE.THICKNESS BEFORE - in.	AVE.THICKNESS AFTER - in.	AVE. % THICKNESS REDUCTION	DEPRESSION FROM DROP - in.	DISCOLORATION
200	NO	24.2	8.16	2.005	1.998	2.77	.469	NO
200	YES (5 psi)	23.5	8.13	2.052	1.889	7.63	.469	NO
250	NO	27.88	9.4	2.067	2.001	3.19	.375	NO
250	YES (5 psi)	26.75	9.14	2.045	1.842	9.95	.50	NO
300	NO	37.3	12.2	1.921	1.847	3.87	.438	SLIGHT DARKNESS
300	YES (5 psi)	34.54	11.37	1.90	1,709	10.06	.58	SLIGHT DARKNESS
325	NO	55.44	17.92	1.904	1.781	6.45	.406	DARK BROWN, CLUE SEPARATE
325	YES (5 psi)	51.65	16.46	1.934	1.632	15.6	.75	DARK BROWN, GLUE SEPARATE
350	NO	113.44	36,61	1.910	1,648	13.72	FELL APART	VERY DARK BROWN, CLUE SEPARATE
350	YES (5 psi)	104.49	32.86	1.942	1.366	29.63	.625	CHIPS CAME APART AFTER DROP

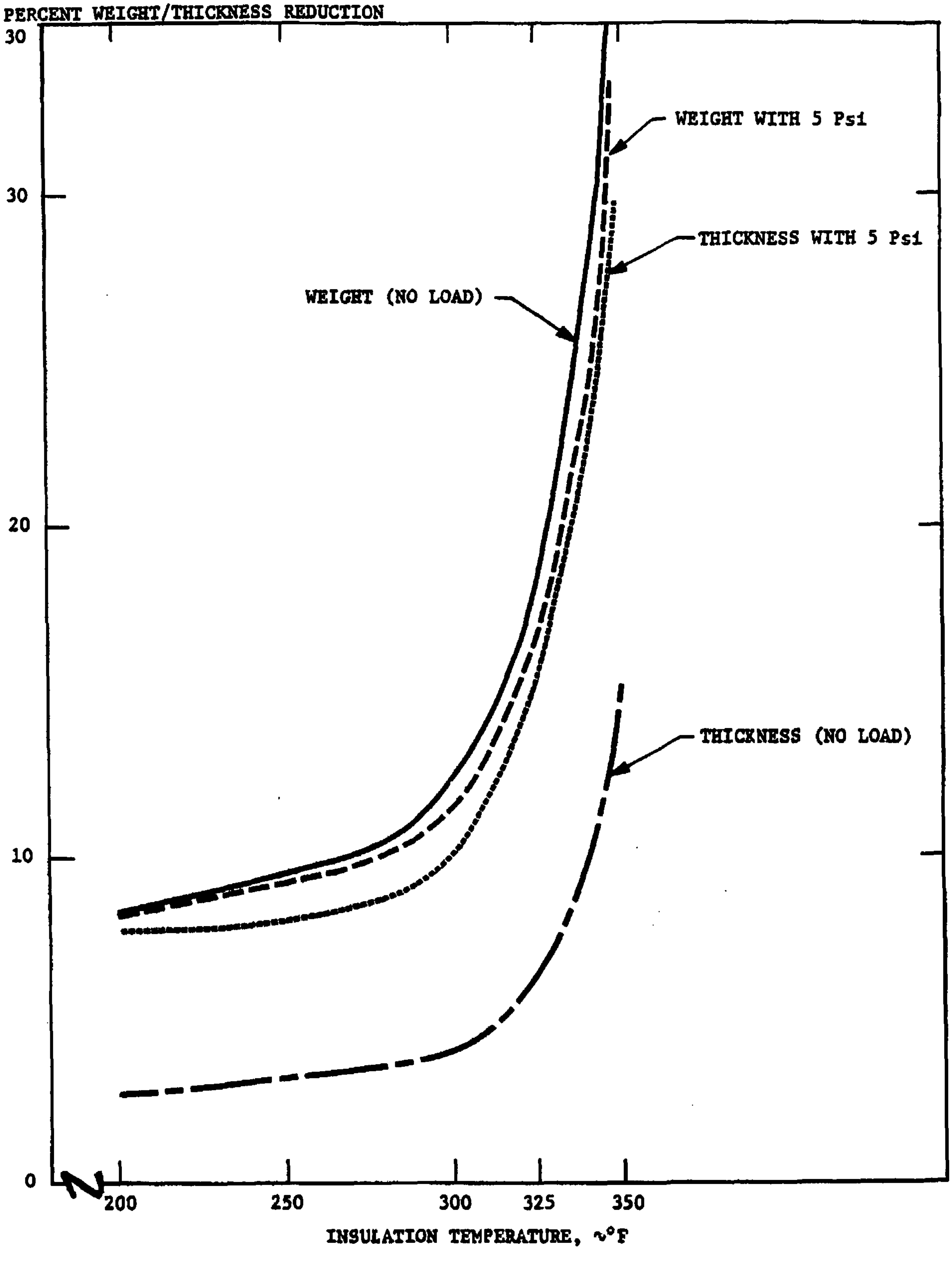

Figure 1 - "CELOTEX" FURNACE TEST

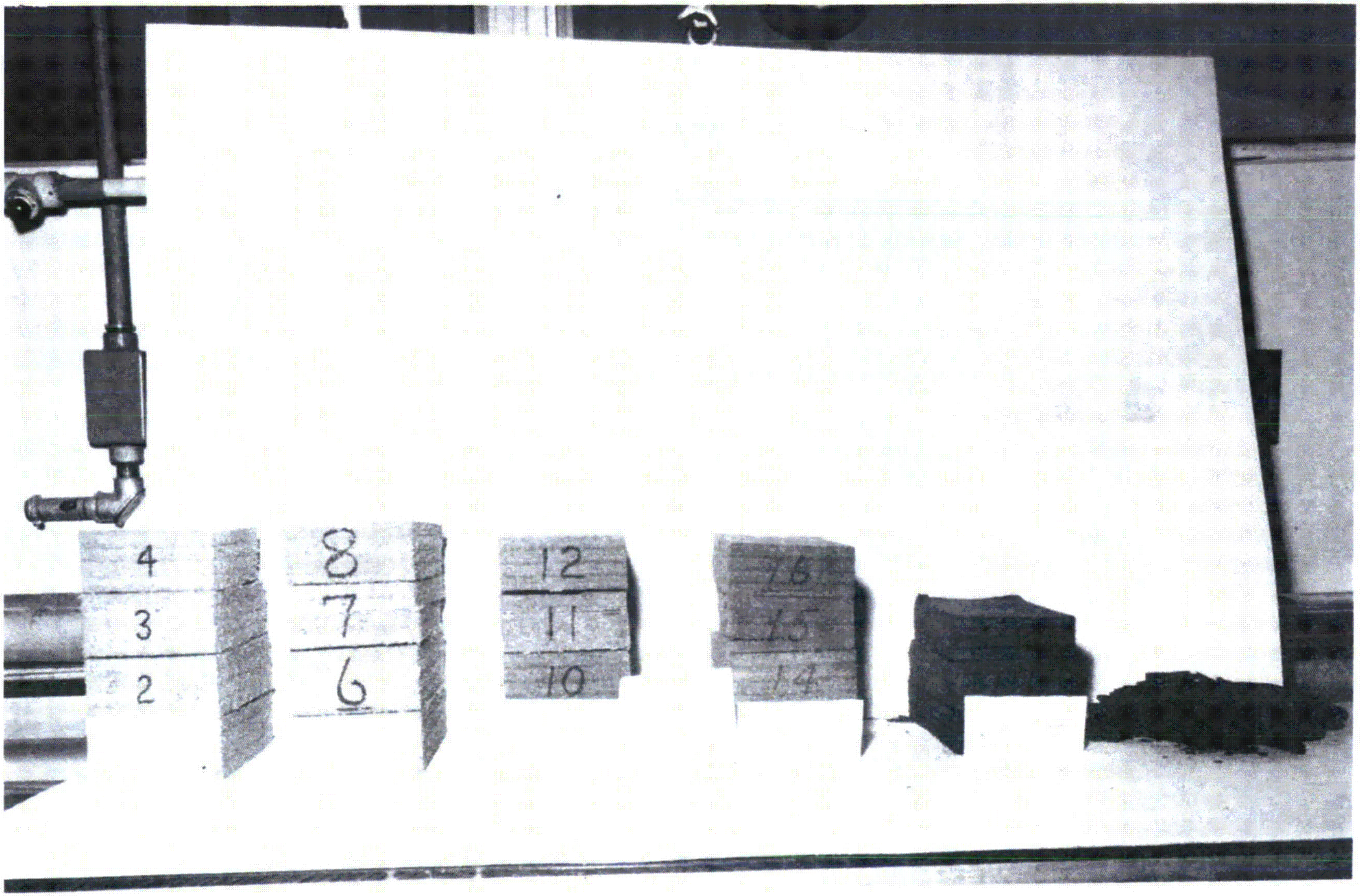

Figure 2 - DPSPF 34784-5

Figure 3 - DPSPF 34784-4

Figure 4 - DPSPF 34784-3

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APPENDIX 3.17

THERMAL ANALYSIS OF THE 9975 PACKAGE FOR WORST-CASE ORIENTATION AND CONTENTS DENSITY

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OSR 45-24# (Rev 5-19-2003)

Calculation Cover Sheet

Project 9975 Packaging Certification	**Calculation No.** M-CLC-F-00902, Rev. 1	**Project No.** N/A
Title Study of Analytical Models for the 9975 Package Thermal Analysis for Normal Conditions of Transport	**Functional Classification** SC	**Sheet 1 of** 22
	Discipline Mechanical	
Calc Level ☒ Type 1 ☐ Type 2	**Type 1 Calc Status** ☐ Preliminary ☒ Confirmed	
Computer Program No. MSC/THERMAL ☐ N/A	**Version/Release No.** 8.5	

Purpose and Objective

This calculation analyzes two basic models as the possible bounding configurations for the Pu and PuO_2 contents in the 9975 package. One configuration is the inverted configuration for the Pu metal content, and the second configuration is the upright configuration for the PuO_2 content. A third model with a 1/4 inch gap between the Pu metal and the containment vessel lid for the inverted configuration is also analyzed to study the effect of the air gap on vessel closure temperature distribution. The power content is 19 watts for each configuration.

The objective is to prove that the component temperatures for the bounding configuration are within their design temperature limits. The analyses will also show that overall, the upright configuration with PuO_2 is the more limiting configuration.

Summary of Conclusion

1. The analyses show that the inverted configuration with the Pu metal as the contents results in higher PCV closure temperatures. This temperature is strongly dependent on the air gap that will most likely exist in practical situations between the Pu metal and the underside of the PCV lid. Without the gap, the temperature at the point of contact (321°F) exceeds the metal limit temperature of 300°F in the 9975 SARP. This exceedance is local and does not impact the integrity of the closure. If a 1/4" gap to simulate plastic bag, product can rims, contact resistance, etc. is modeled, the maximum PCV temperature is 285°F which is well within the PCV temperature limit of 300°F.

2. The analyses show that the upright configuration with PuO_2 as the contents results in higher temperatures for all components except the PCV closure as mentioned above. The average gas temperature (313°F) inside the PCV is also higher for the upright configuration. Since the slightly higher temperatures in the PCV closure for the inverted configuration are in the strongest part of the closure, it is concluded that the upright configuration with PuO_2 as the contents is the more limiting configuration for 9975 thermal analyses.

Revisions

Rev No.	Revision Description
0	Original Issue
1	Corrected a typographical error on page 7. See page 2 for details.

Sign Off

Rev No.	Originator (Print) Sign/Date	Verification/ Checking Method	Verifier/Checker (Print) Sign/Date	Manager (Print) Sign/Date
1	N.K. GUPTA N.K. Gupta 4/29/04	Document Review	S. Y. Lee 4/29/04	C.P. Holding-Smith 5/3/04

Design Authority — (Print) N/A	**Signature**	**Date**
Release to Outside Agency – (Print) N/A	**Signature**	**Date**

Security Classification of the Calculation

Unclassified

Revisions

Revision	Description
0	Original Issue
1	Corrected a typographical error on page 7, paragraph 1, item 2, line 1. The reference to maximum PCV temperature is deleted.

1.0 Introduction

The 9975 package is used to transport Pu and Pu oxide in the DOE complex. The safety analysis report (SARP) [1] identifies two bounding transport configurations, one for the Pu metal and one for the Pu oxide. The conceptual model for the Pu metal is an inverted package configuration to simulate the package lying upside down for an extended period of time. The conceptual model for the Pu oxide is an upright package configuration with low density PuO_2 filled to the top to simulate the package in its normal transportation position. These models analyze extreme material geometries and densities to study the structural integrity of the primary and secondary containment vessels.

The package is filled with inert gases such as helium (He), carbon dioxide (CO_2), or nitrogen (N_2) to minimize the potential for deflagration inside the PCV. The thermal properties of CO_2 and N_2 are quite similar and, therefore, the resulting package temperatures with CO_2 or N_2 as the filling gas will be quite similar. The thermal conductivity of the helium is much higher than CO_2 or N_2 and the presence of helium will result in lower temperatures inside the PCV. The analysis in this calculation considers N_2 as the filling gas.

This calculation documents the thermal response for the above described configurations during normal condition of transport (NCT). The thermal analyses in this calculation mimic the analyses documented in Reference 2. The material properties are identical to the thermal analyses in Reference 2. The main differences are the changed boundary conditions and the payload location in the inverted package configuration for the Pu metal.

It should be noticed that the permitted payload configurations in the 9975 SARP were analyzed only in upright position which is the standard way of fastening and transporting the packages in the transport vehicle. The inverted configuration is an unlikely payload geometry considering its small size and metal to metal contact with the primary containment vessel (PCV). In practice there will always be small gap separating the payload and the vessel lid. Therefore, a third analytical model is prepared to study the effect of a ¼ inch gap on the temperature distribution in the containment vessels in the inverted Pu metal configuration. The analyses for these bounding cases will provide the basis for the adequacy of the analyses documented in the 9975 SARP [1].

2.0 Input

The new configurations were analyzed under the Normal Conditions of Transport (NCT). In the NCT analysis, the drum surface was exposed to solar heat flux. The material properties are identical to the analyses documented in Reference 2. The top of the drum is considered adiabatic to simulate the inverted package configuration. The bottom of the drum was adiabatic for the upright configuration. The exposed sides of the 9975 package exchanged heat through natural convection and radiation to an ambient temperature of 100°F. For all analyses, a 19 watt total decay power was uniformly distributed over the volume of the Pu metal or Pu oxide as an internal heat source.

2.1 Thermal Models

2.1.1 Geometry and Contents

Figure 1 shows a schematic of the upright Pu oxide configuration and Figure 2 shows a schematic of the inverted Pu metal configuration. The fill gases are similar to the other 9975 can configurations covered in Reference 1. The PCV has 75% CO_2 dilution and oxygen concentration is limited to 5%.[1] The Pu oxide configuration assumes that the oxide fills the three inner cans all the way to the PCV to impart maximum heat to the seal O-rings. The inverted Pu metal configuration has two models: 1) no air gap between the Pu metal and the PCV lid and, 2) a ¼ inch gap to simulate plastic bags, product can rim, etc. The dimensions of the inner cans, the outer cans, and metal cylinder are shown in Table 1.

2.1.2 Axisymmetric Thermal Models

Based on the 9975 package geometry, axisymmetric models were developed using the computer code MSC/PATRAN [3] and run with MSC/Thermal [3]. The color representations of the material composition of the two configurations (upright with PuO_2, and inverted with Pu metal and no air gap) are shown in Figures 3 and 4. Each finite element axisymmetric model contains roughly 8000 nodes.

Heat is transferred within the package by conduction and radiation. In all models, thermal radiation heat transfer was applied across all gaps filled with gas while natural convection was neglected in the internal gas spaces. Further, all gasses were assumed non-absorbing for thermal radiation and, hence, were treated as non-participating media in the radiation calculations. Convenience can wall thicknesses are not modeled in the finite element models. This simplification is reasonable due to small wall thickness and good thermal conductivity of the can walls. However, the radiation properties of the steel walls are used in the heat transfer calculations.

2.2 Normal Conditions of Transport

In 10 CFR-71.71(c) (1) the NCT are defined as an ambient temperature of 100°F in still air with solar heating of 800 W / m^2 on the exposed horizontal surface of the drum and 400 W / m^2 on the side. The solar absorptivity of the drum surface is assumed to 0.65 for the inverted case as recommended in Reference 4. However, the solar absorptivity of the drum surface is conservatively assumed to be 1.0 for the upright case. Heat transfer from the exposed surfaces of the drum to the ambient occurs via natural convection and radiation.

The convection heat transfer coefficients used are functions of the temperature difference between the drum surfaces and the ambient temperature. Heat transfer coefficients for

---

[1] The model has 100% N_2. This is acceptable since the thermal properties of N_2 and CO_2 are similar for the temperature range of interest.

natural convection were obtained from correlations in the MSC/Thermal code. Specifically, the natural convection correlations are for isothermal plates and have the form:

1. For a vertical isothermal plate with $\mathrm{Ra} < 1.0 \times 10^9$,

$$h = \left(\frac{k}{L}\right)\left(0.68 + \frac{0.670 \times \mathrm{Ra}^{0.25}}{\left[1.0 + \left(\frac{0.492}{\mathrm{Pr}}\right)^{9/16}\right]^{4/9}}\right).$$

2. For a vertical isothermal plate with $1.0 \times 10^9 < \mathrm{Ra}$,

$$h = \left(\frac{k}{L}\right)\left(0.825 + \frac{0.387 \times \mathrm{Ra}^{1/6}}{\left[1.0 + \left(\frac{0.492}{\mathrm{Pr}}\right)^{9/16}\right]^{8/27}}\right)^2$$

3. For a horizontal hot isothermal plate facing upward with $1.0 \times 10^7 < \mathrm{Ra} < 3.0 \times 10^{10}$,

$$h = \left(\frac{k}{L}\right)0.15 \times \mathrm{Ra}^{1/3}.$$

Where[2]: Ra = Rayleigh number based on plate height.
h = Convection heat transfer coefficient.
k = Thermal conductivity of gas (air).
L = Characteristic length of plate.

The thermal conductivity of fiberboard is based on heater experiments with the 9975 which showed the in-plane conductivity to be roughly twice the through-plane value [5].

A summary of the boundary conditions for the upright case follows:

1. The drum is in an upright position.
2. The bottom surface is adiabatic.
3. There is radiative heat transfer from drum sides and top to the ambient.
4. There is natural convection heat transfer from the drum sides and top to the ambient.
5. The ambient temperature is 100°F.
6. Insolation: 800 W/m^2 (253.6 Btu/hr-ft^3) on drum top and 400 W/m^2 (126.8 Btu/hr-ft^3) on drum side (solar absorptivity of the drum assumed unity).

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[2] Note that all properties in the correlations are based on the film temperature.

7. Undamaged fiberboard properties are applied to the fiberboard in the drum.
8. 19 watts total decay power.

A summary of the boundary conditions for the inverted case follows:

1. The drum is in an inverted position.
2. The top surface is adiabatic.
3. There is radiative heat transfer from drum sides and bottom to the ambient.
4. There is natural convection heat transfer from the drum sides and bottom to the ambient.
5. The ambient temperature is 100°F.
6. Insolation: 800 W/m^2 (253.6 $Btu/hr\text{-}ft^2$) on drum bottom and 400 W/m^2 (126.8 $Btu/hr\text{-}ft^2$) on drum side (solar absorptivity of the drum assumed 0.65 [4]).
7. Undamaged fiberboard properties are applied to the fiberboard in the drum.
8. 19 watts total decay power.

2.4 Thermal Properties

Conduction heat transfer through filling gas was considered (as appropriate) within the package, as indicated in Table 1. As mentioned previously, all gasses were assumed to be non-absorbing. The temperature ranges of the gasses were considered when assigning the constitutive properties, however, the gas pressure was assumed to remain at 1 atmosphere. This is a reasonable simplification since the thermal conductivity of gases is not dependent on pressure for moderate pressures. In addition, any increase in pressure due to hydrogen generation will only improve the conductance of the package.

The thermal properties of the packaging components used in the analyses are shown in Tables 3 and 4.

3.0 Analytical Methods and Computations

The general purpose conduction-radiation computer code MSC/Thermal was used to perform the computations [3]. This computer code meets site nuclear safety QA requirements [6]. Work was performed in accordance with the WSRC E-7 manual [7]. The thermal models of the storage configurations were created using the general purpose finite element pre and post processor of MSC/PATRAN [3].

4.0 Results

Steady state temperatures predicted by the models for the three models are shown in Table 5. Temperature profiles in the containment vessels for the three models are shown in Figures 5 – 7. The temperature profiles in the PCV closure for the three models are shown in Figures 8 - 10. The results show that the upright Pu oxide configuration has higher temperatures except in the PCV closure in the Pu metal inverted configuration. This was expected due to the overly conservative modeling of the Pu metal in the inverted model configurations. Following results are noteworthy:

1. The maximum predicted fiberboard temperature is approximately 254°F and occurs in the upright configuration for the Pu oxide payload.

2. The maximum SCV temperatures for the PuO_2 and the metal configurations are 262°F and 246°F respectively. The maximum temperatures for the PCV are 275°F for the PuO_2 case, 321°F for the metal without gap, and 285°F for the metal with ¼ inch gap. The results for the metal show the significance of any small air gap between the Pu metal and the PCV closure. It can be concluded that the upright configuration with PuO_2 remains as the bounding configuration.

3. The maximum PCV seal temperature is 274°F for the PuO_2 case, 278°F for the Pu metal with gap, and 293°F for the Pu metal without gap. These temperatures are well below the O-ring temperature limit of 400°F [1].

4. The highest average PCV gas temperature is 313°F for the PuO_2 case. The average gas temperature for the Pu metal case is 283°F. Average gas temperatures were calculated by volume averaging of nodal temperatures at select nodal locations in the cavities within the PCV. This averaging process was very conservative because the PCV cavity was divided in only 12 volumes to capture the significant temperatures (Appendix A). A more accurate estimate considering each element in the PCV cavity as separate volume will result in lower average gas temperature.

5. The maximum lead shielding temperature is 254°F and occurs in the PuO_2 case.

5.0 Conclusions

1. The analyses show that the inverted configuration with the Pu metal as the contents results in higher PCV closure temperatures. This temperature is strongly dependent on the air gap that will most likely exist in a practical situations between the Pu metal and the underside of the PCV lid. Without the gap, the temperature at the point of contact (321°F) exceeds the metal limit temperature of 300°F. This exceedance is local and does not impact the integrity of the closure. If a 1/4" gap to simulate plastic bag, product can rims, contact resistance, etc. is modeled, the maximum PCV temperature is 285°F which is more than 30°F lower than the PCV temperature without the gap and is well within the temperature limit of 300°F in the 9975 SARP.

2. The analyses show that the upright configuration with the PuO_2 as the contents results in higher temperatures for all components except the PCV closure as mentioned above. The average gas temperature (313°F) inside the PCV is also higher for the upright configuration. Since the slightly higher temperatures in the PCV closure for the inverted configuration are in the strongest part of the closure, it can be concluded that the upright configuration with PuO_2 as the contents is the more limiting configuration for the 9975 thermal analyses.

Table 1: External Dimensions of Product or Product Containers

Container	Diameter X Height (in.) Used in Model
Outer Product Can	4.385 X 5.125
Inner Product Can	3.75 X 5.0
Pu Metal Cylinder	0.618 X 1.2

Table 3: Emissivity of Package Components

Component	Emissivity
Aluminum plates, honeycomb	0.20
Fiberboard	0.50
Lead/ Lead shield stainless steel liner	0.28
Drum Inner Surface	0.30
Drum Outer Surface (Initial HAC and NCT)	0.21
Drum Outer Surface (fire phase HAC)	0.90
Drum Outer Surface (post-fire phase HAC)	0.80
3013 Container	0.30
BNFL Middle Can	0.30
BNFL Convenience Can	0.20
Pu Oxide	0.90
Pu Metal	0.90
Rocky Convenience Can	0.20
SRS Convenience Can	0.20
PVC/SCV	0.30

Table 4: Constitutive Properties of Packaging Materials

Material	**Density (lbm/ft^3) @ T(°F)**	**Conductivity (Btu/hr.-ft.- °F) @ T(°F)**	**Heat Capacity (Btu/lbm °F) @ T(°F)**
Air	0.080532	0.01396 @ 32 0.01839 @ 212 0.02238@ 392 0.02593 @ 572	0.237 @ 212
Nitrogen (N$_2$)	0.0713	0.01514@ 80.0 0.01927@ 260.0 0.02302 @ 440.0 0.02646 @ 620.0	0.2486 @ 80.0 0.2498 @ 260.0 0.2521 @ 440.0 0.2569 @ 620.0
Honeycomb energy absorber (radial)	16.2	3.82	0.22
Honeycomb energy absorber (axial)	16.2	7.62	0.22
Pre-fire fiberboard (radial)	16.86 @ 77 17.36 @ 187 17.86 @295	0.0723	0.306 @ 77 0.360 @ 187 0.417 @ 295
Pre-fire fiberboard (axial)	16.86 @ 77 17.36 @ 187 17.86 @295	0.031 @ 77 0.034 @ 187 0.029 @ 533	0.306 @ 77 0.360 @ 187 0.417 @ 295
Aluminum	169.3	126.0	0.216
Stainless steel (304)	494.4	7.74 @ 32 9.43 @ 212 12.58 @ 932	0.12 @ 32 0.135 @ 752
Stainless steel (316)	514.3	8.79 @ 261 10.58 @ 621	0.12 @ 261 0.13 @ 621
Lead	708.5	19.6 @ 209 18.3 @ 400	0.0305 @ 32 0.0315 @212 0.0338 @ 621.5
Pu oxide	124.8	0.0460	0.022
Pu metal	1198.6	7.26 @ 207 7.74 @ 243 9.19 @ 266 18.39 @ 1112	0.032 @ 32 0.0328 @ 212 0.174 @ 257 0.0294 @ 347 0.0399 @ 842

Table 5 - Steady State NCT Temperatures (°F) for the Two Bounding Configurations

Location	Upright (Pu Oxide)	Inverted (Pu Metal)	
		No Gap	With Gap
Drum Top	255	198	197
Drum Bottom	234	212	212
Drum Side (Mid-Height)	210	180	181
Fiberboard (Mid-Height)	240	220	218
SCV O-ring	254	238	235
PCV O-ring	274	293	278
SCV	262	246	242
PCV	275	321	285
Maximum Pu/PuO_2	397	359	1245
Maximum Fiberboard Temperature	254	227	225
Maximum Lead Temperature	254	227	226
Average Gas Temperature	312.57	283	283

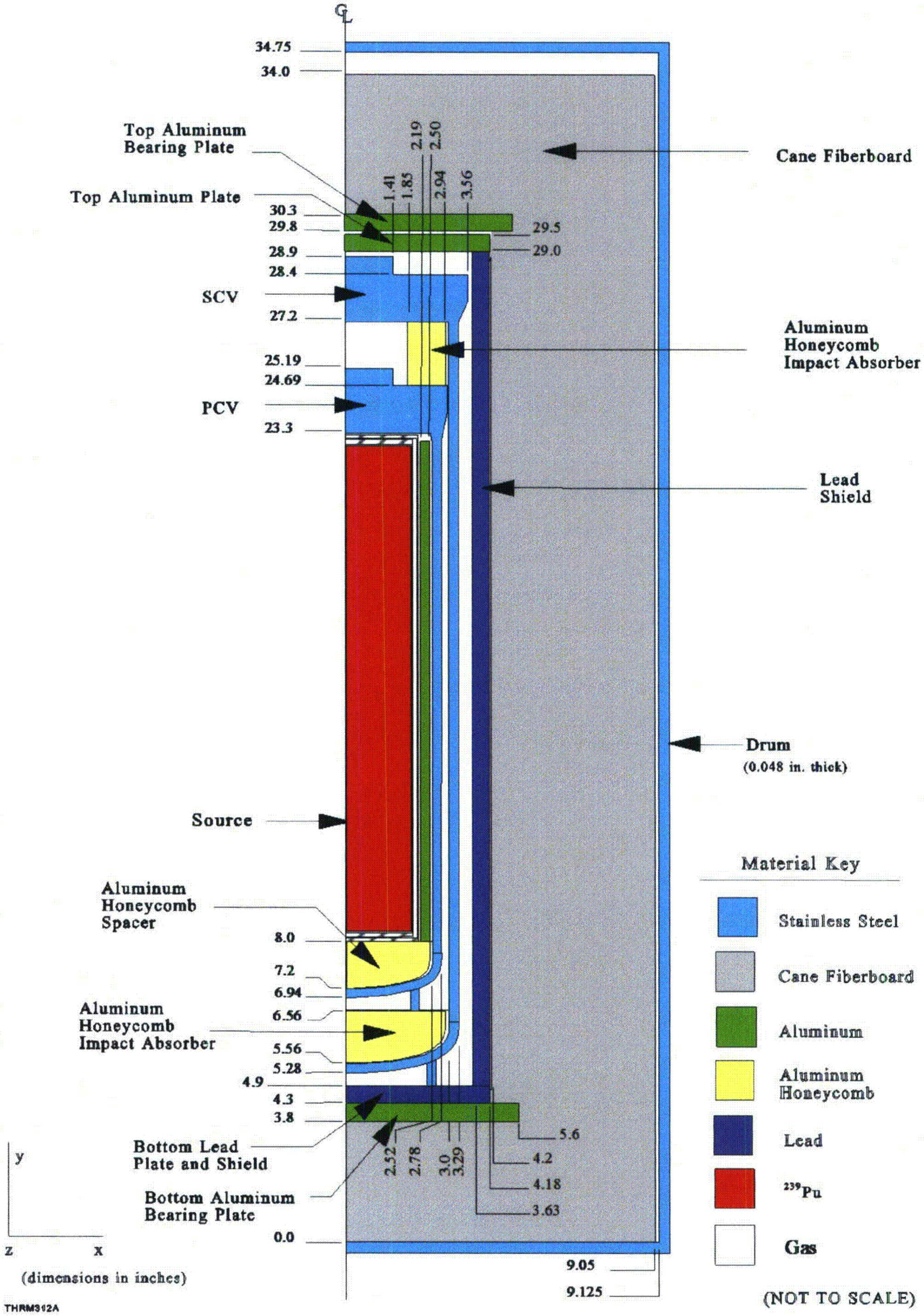


Figure 1 - 9975 Package Thermal Model –
Vertical Orientation, Minimum-Density Oxide Source

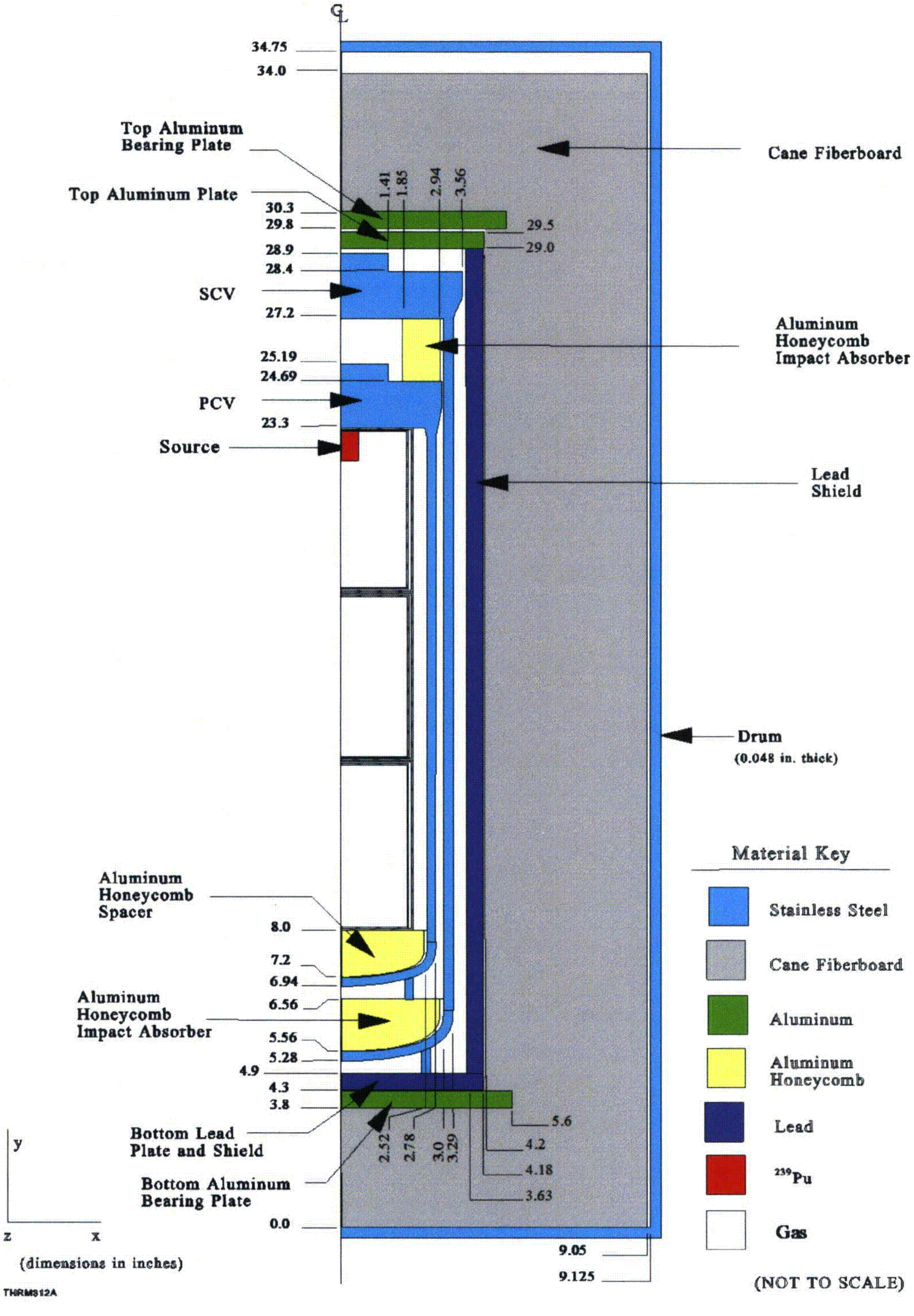


Figure 2 - 9975 Package Thermal Model -
Inverted Orientation, Single Maximum-Density Oxide Source

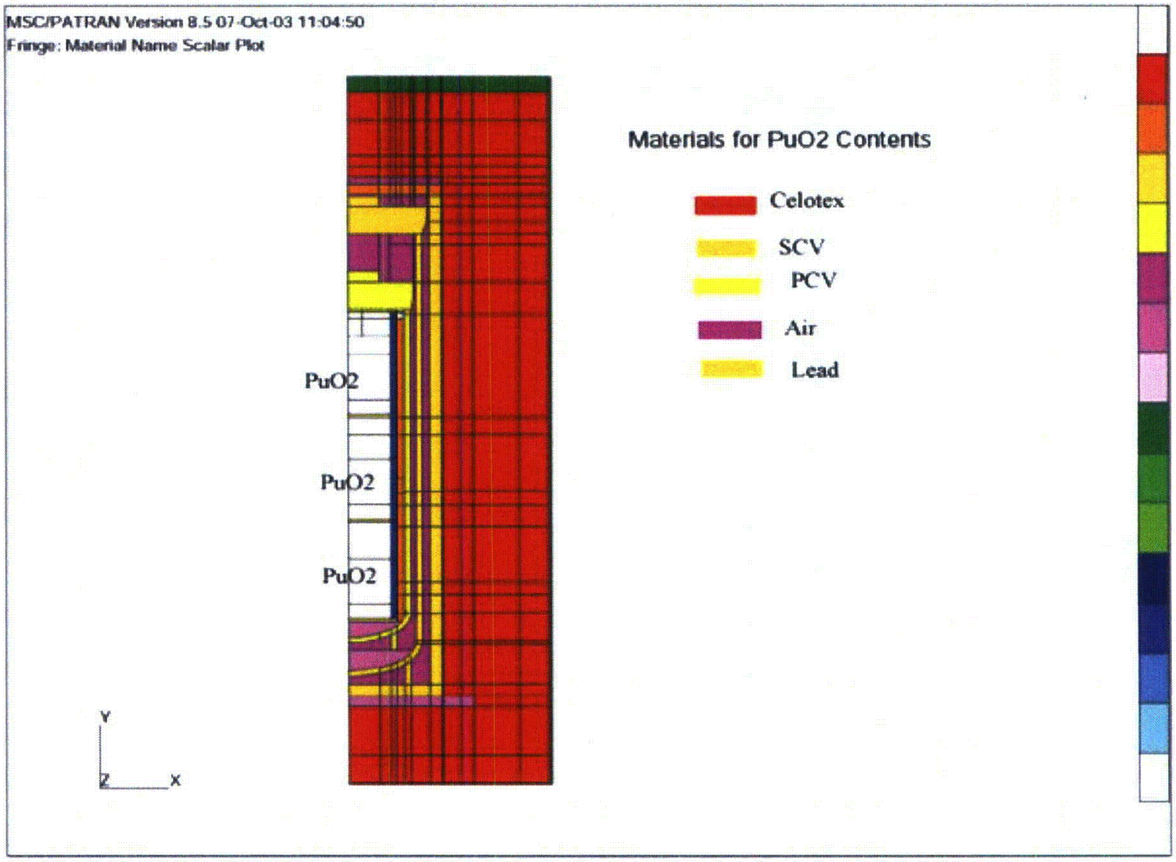


Figure 3. Color Representation of Material Location in PuO_2 Configuration. (The finite element mesh is not included)

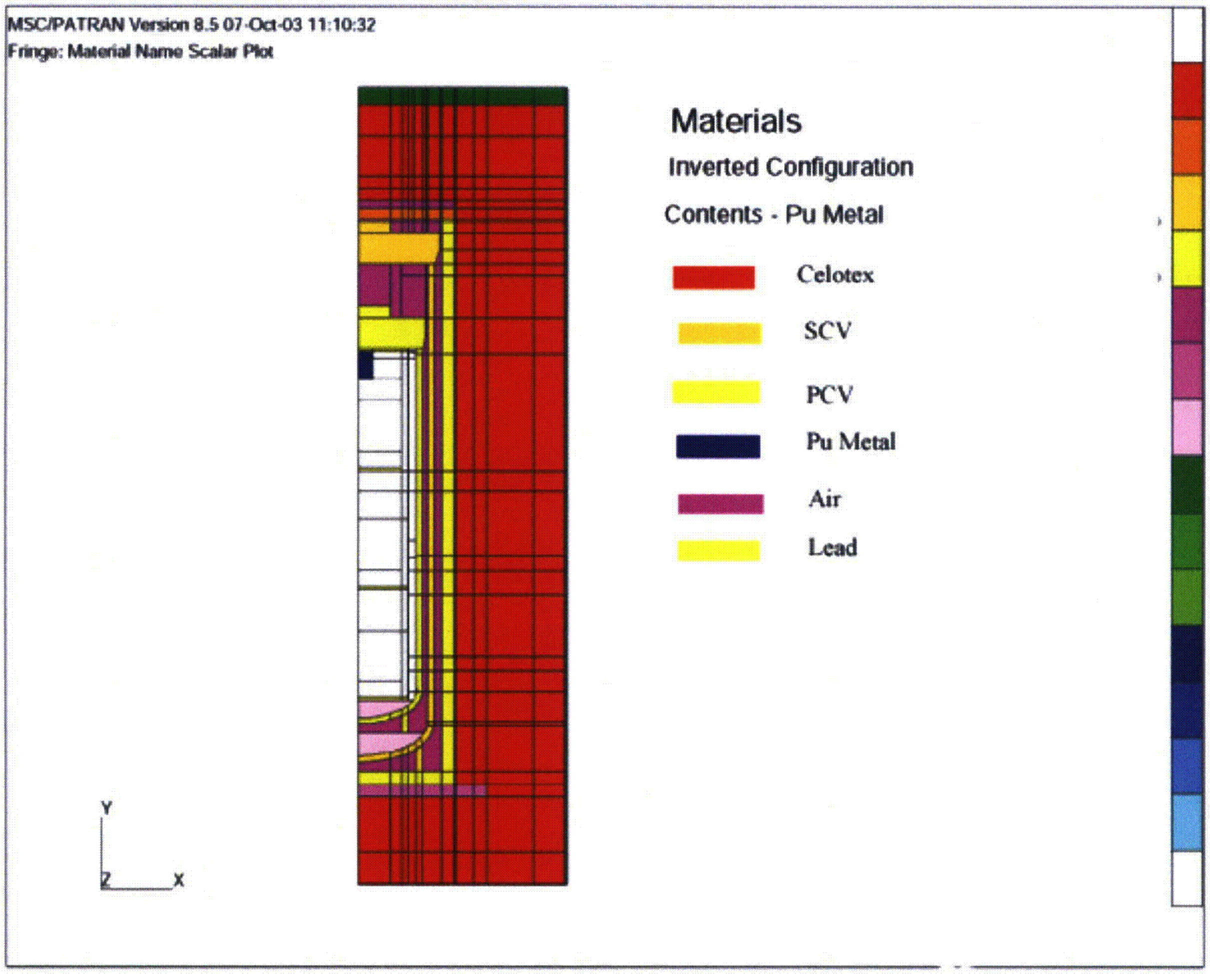


Figure 4. Color Representation of Material Locations in Inverted Pu Configuration (No Gap)

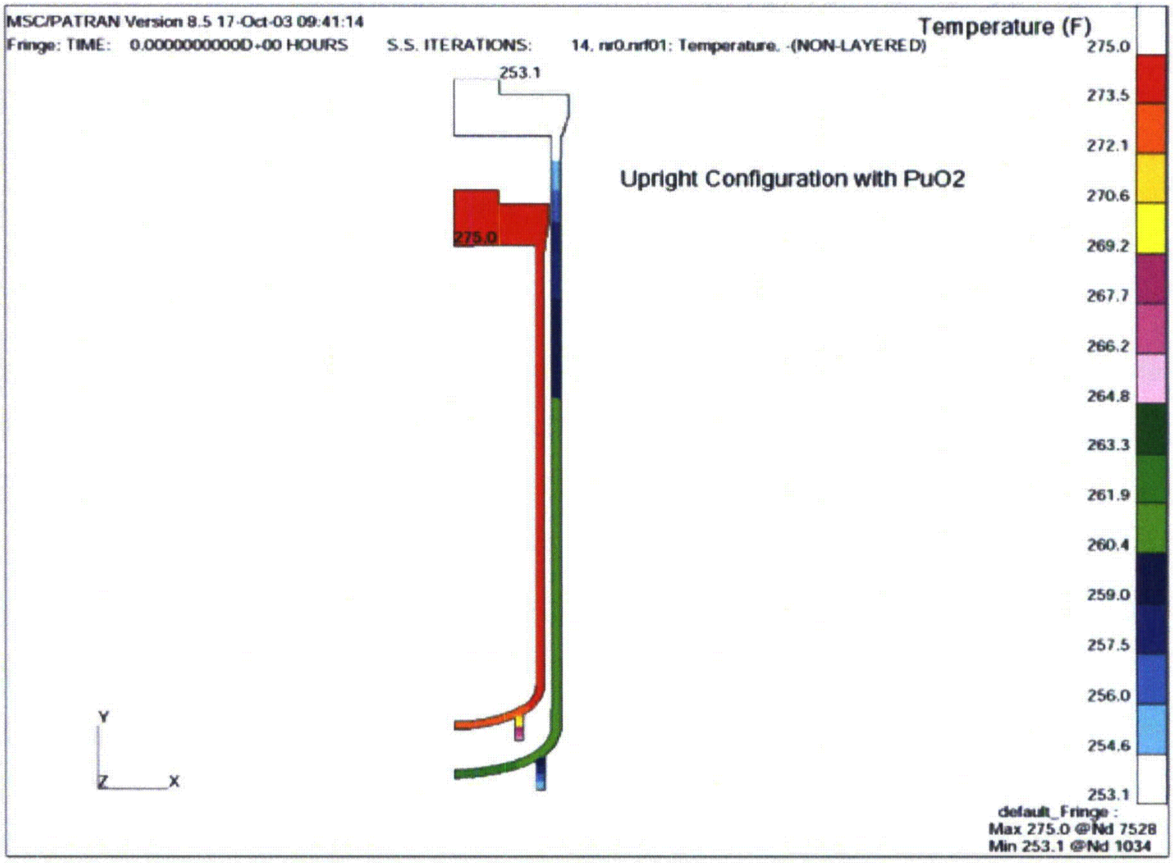


Figure 5 – Vessels Temperature Contours for Upright Configuration (PuO_2)

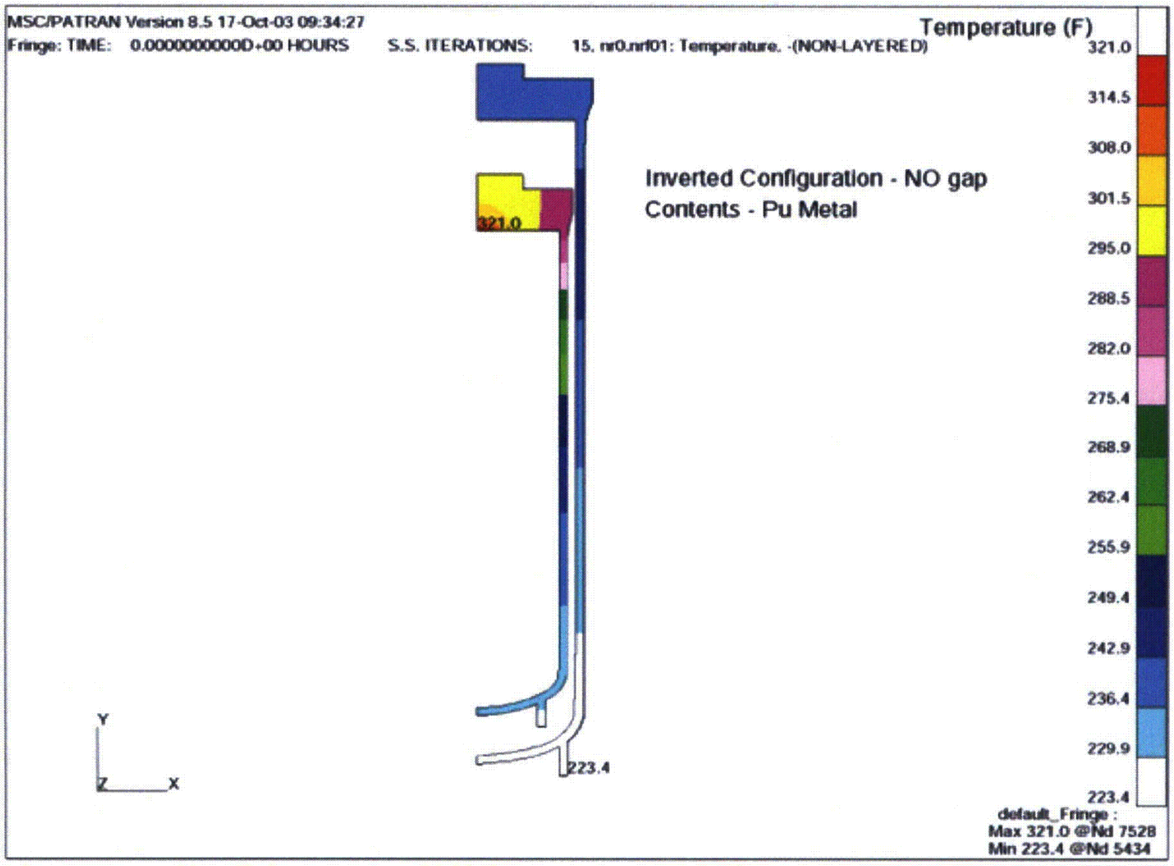


Figure 6 – Vessel Temperature Contours for the Inverted Configuration (No Gap)

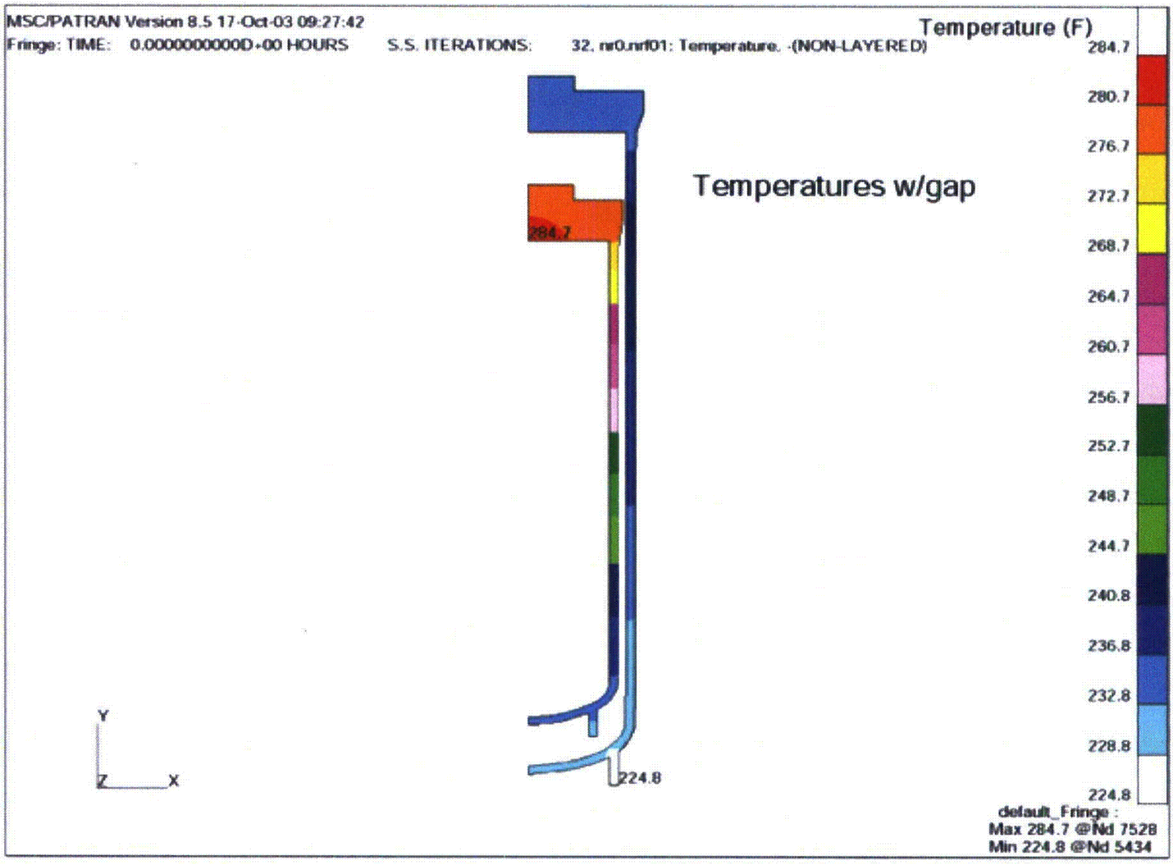


Figure 7 – Vessel Temperature Contours for the Inverted Configuration (1/4" Gap)

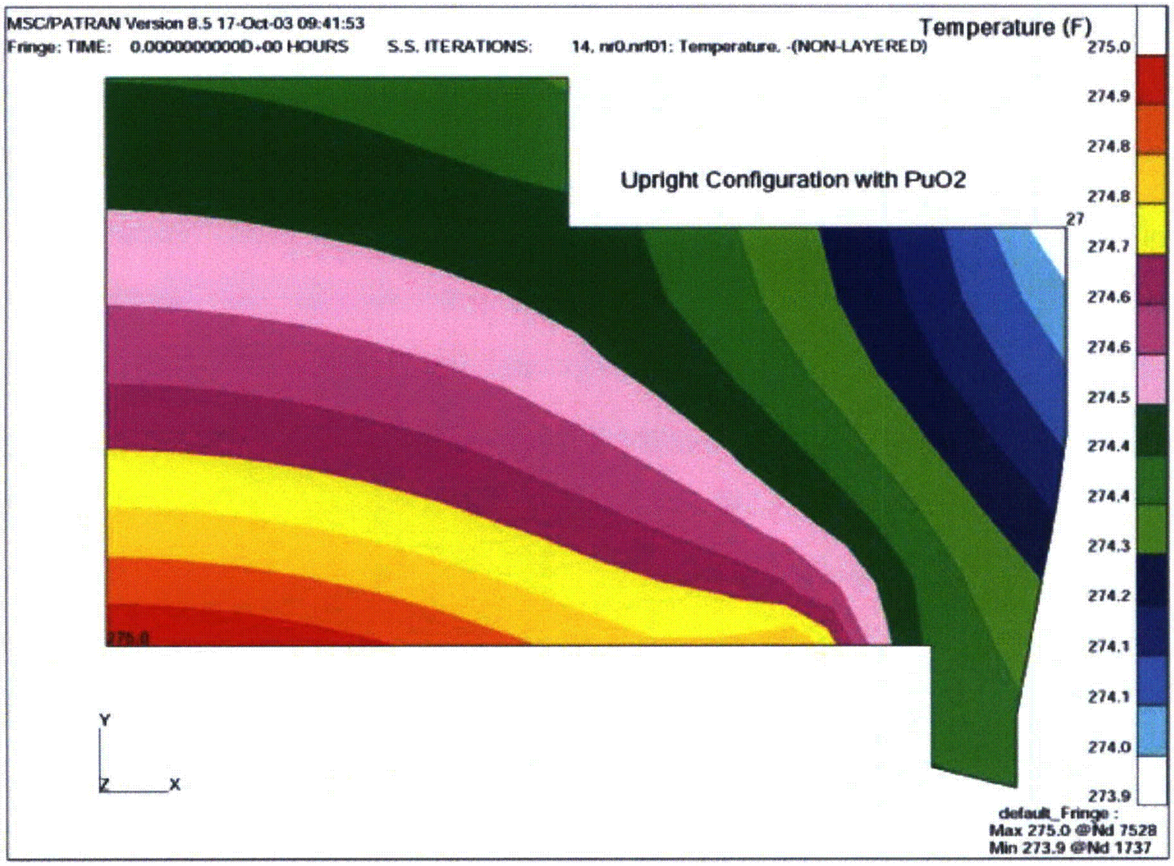


Figure 8 – Closure Temperature Contours for the Upright Configuration

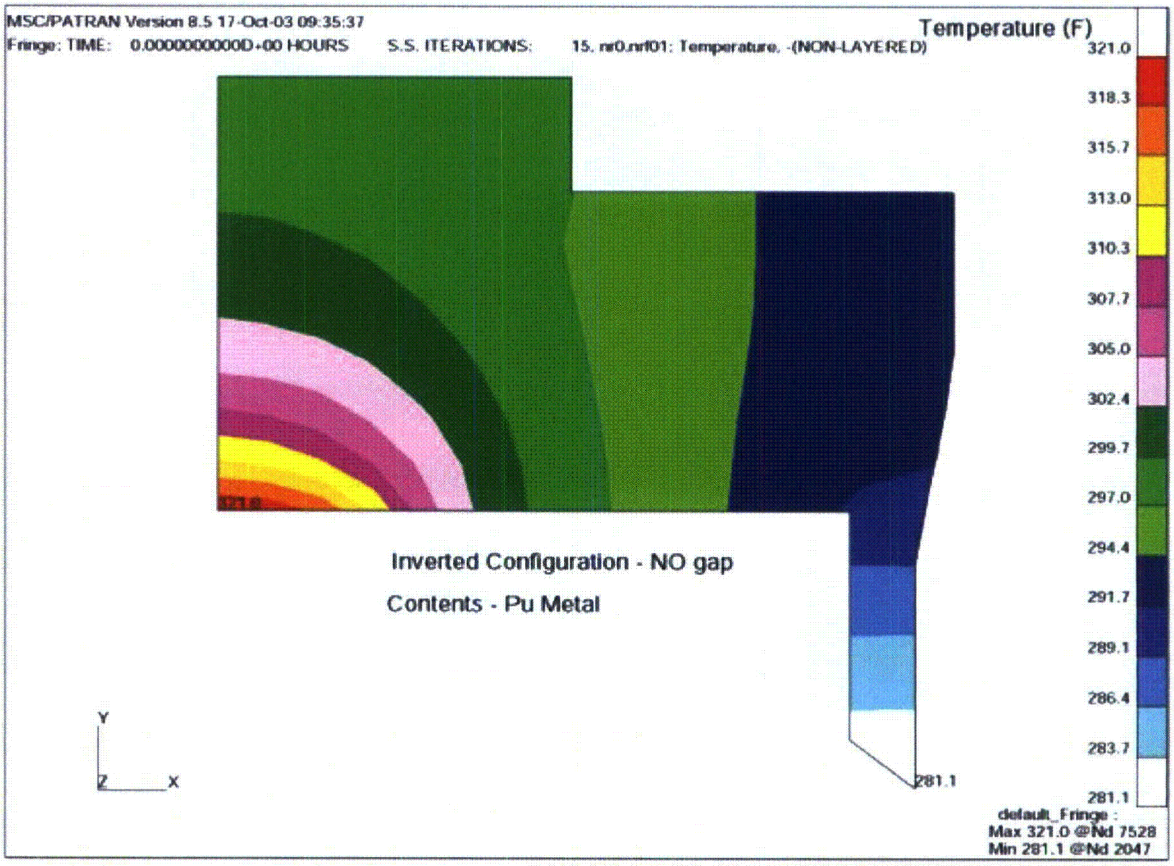


Figure 9 – Closure Temperature Contours for the Inverted Configuration (No Gap)

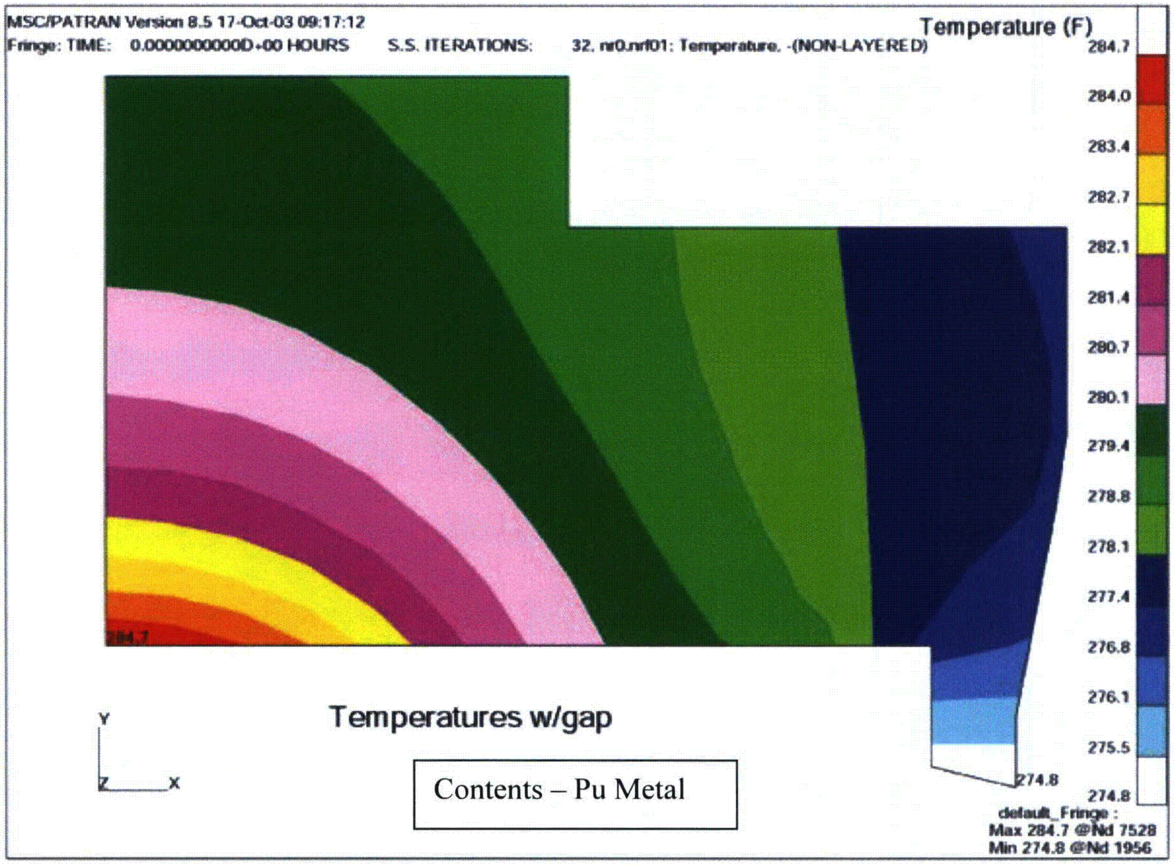


Figure 10 – Closure Temperature Contours for the Inverted Configuration (with Gap)

5.0 References

1. Safety Analysis Report for 9975 Packaging (U), WSRC-SA-2002-00008, 2003.
2. Gupta, N. K., "Thermal Analysis of the 9975 Package for NCT and HAC", M-CLC-F-00590 Rev. 7, WSRC, 2003.
3. MSC/Patran and MSC/Thermal v. 8.5, MacNeal-Schwendler Corporation, Los Angeles, CA 90041.
4. S. J. Hensel and J. K. Thomas, Solar Absorptance and Emittance of Stainless Steel at 400K (U), SCS-CMG-930019, Westinghouse Savannah River Company, Aiken, SC (May 1993).
5. Jerrell, J. W., Van Alstine, M. N., and Gromada, R. J., Normal Conditions of Transport Thermal Analysis and Testing of a Type B Drum Package, PVP-Vol. 307, pp. 111-117.
6. Gupta, N. K., "Validation of MSC/THERMAL Finite Element Software for Thermal Analysis at the Savannah River Site", G-VVR-G-00011, Rev. 0, 2001.
7. Westinghouse Savannah River Co., Conduct Of Engineering Manual, E-7, 1998.

Appendix A

Average Air Temperature calculations plutonium oxide with sleeve and N2 in the cans - solar

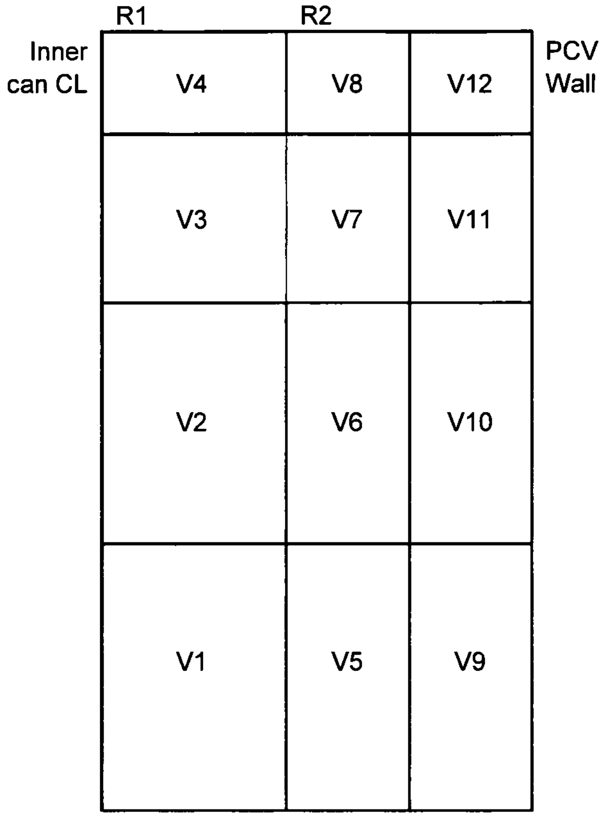
R1	R2	h	Volume	
0	1.7	2.69	12.21	V1
0	1.7	4.7	21.34	V2
0	1.7	4.47	20.29	V3
0	1.7	3.23	14.66	V4
1.7	2.2	2.69	8.24	V5
1.7	2.2	4.7	14.40	V6
1.7	2.2	4.47	13.69	V7
1.7	2.2	3.23	9.89	V8
2.2	2.52	2.69	6.38	V9
2.2	2.52	4.7	11.15	V10
2.2	2.52	4.47	10.61	V11
2.2	2.52	3.23	7.66	V12
		V (Total)	150.53	

Average Volume Temperature

V	T1	T2	T3	T4	T (Ave)	V*T
V1	274	274	330	393	317.8	3880.2
V2	330	393	325	397	361.3	7707.7
V3	325	397	324	389	358.8	7279.8
V4	389	324	275	275	315.8	4629.8
V5	274	275	276	330	288.8	2379.2
V6	276	330	277	325	302.0	4347.7
V7	277	325	277	324	300.8	4117.8
V8	277	324	275	275	287.8	2846.9
V9	275	275	274	276	275.0	1755.1
V10	274	276	274	277	275.3	3069.3
V11	274	277	276	277	276.0	2927.0
V12	275	277	274	275	275.3	2109.3
					VT (Total)	47049.8

Average Air Temperature

Tave 312.57



APPENDIX 3.19

THERMAL ANALYSIS OF 9975 PACKAGE TO EVALUATE LEAD SHIELDING DESIGN CHANGES FOR NORMAL CONDITIONS OF TRANSPORT (NCT) AND HYPOTHETICAL ACCIDENT CONDITIONS (HAC), REV 2

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Calculation Cover Sheet

Project N/A	Calculation No. M-CLC-A-00289	Project No. N/A
Title: Thermal Analysis of 9975 Package to Evaluate Lead Shielding Design Changes for the Normal Conditions of Transport (NCT) and the Hypothetical Accident Conditions (HAC)	Functional Classification SC Discipline Mechanical	Sheet 1 of 24
Calc Level ☒ Type 1 ☐ Type 2	Type 1 Calc Status ☐ Preliminary ☒ Confirmed	
Computer Program No. NA ☐ MSC.PATRAN.THERMAL	Version/Release No. Version 2003, Rev. 2	

Purpose and Objective

This calculation documents the thermal calculations for the 9975 package to evaluate the design changes in the lead shielding geometry. The calculations are based on the earlier analyses performed for the certification of the 9975 package. Only the Food Can configuration of the 9975 is analyzed in this report as it yields the highest average gas temperature inside the primary containment vessel (PCV). Revision 1 of this calculation documents the impact of 0.020 inches gap between the lead surface and the stainless steel jacket.

The objective of the analyses is to demonstrate that the 9975 components meet the thermal requirements given in 10 CFR 71 and that the structural integrity of the 9975 package is not affected by the lead shielding design changes.

Summary of Conclusion

1. It is found that the maximum temperatures of the PCV, secondary containment vessel (SCV), PCV & SCV O-rings, new lead shielding, and the fiberboard are consistent with the temperatures calculated previously during NCT and HAC in the 9975 SARP, Rev. 0.

2. The component temperatures increase about 1°F due to the presence of 0.020 inches gap. This increase in temperatures is small and the maximum temperatures are well below the design temperatures. Therefore, it can be safely concluded that the structural integrity of the 9975 package is not affected by the lead shielding design changes.

Revisions

Rev. No.	Revision Description
1	See page 2
2	See page 2

Sign Off

Rev. No.	Originator (Print) Sign/Date	Verification/ Checking Method	Verifier/Checker (Print) Sign/Date	Manager (Print) Sign/Date
2	N. K. Gupta N.K. Gupta 10/22/09	Design Review	Tsu-Te Wu 10/22/09	Patricia L. Lee 10/22/09

Design Authority – (Print) ~~Joseph L. Murphy~~ J.W McEvoy 10-22-09 for per telecon 10-22-09	Signature for McEvoy	Date 10-22-09
Release to Outside Agency – (Print) N/A	Signature N/A	Date N/A

Security Classification of the Calculation (U)

Revisions

Revision	Description
0	Original Issue
1	This revision incorporates the analysis with the 0.020 inches gap between the lead surface and the stainless steel jacket.
2	The revision updates the Functional Classification of this calculation from 'SS' to 'SC' to make it consistent with the classification of the 9975 package.

Table of Contents

Tables

Figures

1.0 Introduction

Thermal analyses covering Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) of various configurations of the 9975 package are covered in Ref. 1. Some recent inspections of the 9975 packages have revealed the formation of lead carbonate as a result of its exposure to the impact absorbing fiberboard (Celotex) discs. It is believed that the vapors emanating from the glue holding the Celotex discs together caused the formation of a white thin layer of lead carbonate on the lead surfaces. Some preliminary thermal investigations showed that such thin layer of lead carbonate did not impair the thermal response of the package. Following this preliminary investigation, a mechanical fix to prevent the formation of lead carbonate was finalized. This fix consists of putting a stainless steel sheet 0.036 inches thick on each side of the lead shielding. This report documents the thermal analysis of the 9975 package with the improved lead shielding design.

A design change was approved to allow for a 0.020 inch gap between the stainless steel jacket and the lead surface to facilitate the shielding fabrication. This gap is small and is not expected to have any significant impact on the thermal performance of the 9975 package. Revision 1 of the calculation documents a sensitivity analysis to ensure that the temperature design limits of the lead shield, containment vessels and their O-rings are not exceeded due to the inclusion of this gap. Since NCT with insolation bounds the other NCT and HAC thermal loadings, only the solar condition is analyzed.

The analyses in this report are based on the models and assumptions in Reference 1. Thermal models use a content configuration consisting of 2 g/cc PuO_2 in the air environment. This content configuration is conservative and gives higher content temperatures than the configurations where PuO_2 has a density less than or equal to 1 g/cc and the gas environment of 75% helium and 25% air (≈ 5% oxygen) [6]. Also, NCT temperatures bound HAC results and this observation is consistent with the results in Reference 1. Small variations in the density of the Pu bearing materials will not alter these observations.

2.0 Input and Assumptions

2.1 Thermal Models

2.1.1 Geometry and Contents

A review of the 9975 configuration showed that the Food Can configuration had the highest average gas temperature inside the primary containment vessel (PCV). Even though the maximum contents temperature is not the highest for this configuration, the low thermal conductivity of the plutonium oxide results in higher average content temperatures. A schematic of the contents of the 9975 package with the Food Can containers is shown in Figure 1. Dimensions of the containers/cans are shown in Table 1. The Food Can configuration consists of two stacked cans within the PCV. The cans sit on the honeycomb at the bottom of PCV. The payload in the two cans is the calcined plutonium oxide powder with specific gravity of 2 g/cc. The volumetric thermal load of 19 watts is distributed uniformly in the two inner cans. The Food Can configuration does not utilize 3013 vessels for the payload.

Figure 2 shows the schematic of the 9975 package. The dimensions of the various components shown in Figure 2 are the nominal dimensions in all configurations. The only difference is the contents geometry inside the PCV. The geometry evaluated in this report also includes the changes made to the lead shielding geometry to address the lead carbonate formation on the lead shielding surface. These changes, shown in Figure 3, include enclosing the lead shield inside a 0.036 inches thick stainless steel jacket. The color part of Figure 3 shows the implementation of these changes in the thermal model.

The details of the 0.020 inch gap between the lead surface and the stainless steel jacket are shown in Figure 3A. To facilitate modeling, the gap is assumed to be uniform in the axial direction. The assumption of uniform gap is conservative and should result in slightly higher temperatures for the components because the overall conductance of the package is slightly reduced. The gap is assumed to be filled with air. Figure 3A shows the implementation of these changes in the thermal model.

2.1.2 Axisymmetric Thermal Models

Based on the 9975 package geometry, axisymmetric models were developed in PATRAN and run with MSC/Thermal. A color representation of the material composition of a 9975 package, which does not include the finite element mesh, is shown in Figure 4. Finite element mesh used in the model is shown in Figure 5.

Heat is transferred within the 9975 package by conduction and radiation. In all models, thermal radiation heat transfer was applied across all gaps filled with gas while natural convection was neglected in the internal gas spaces. Further, all gasses were assumed non-absorbing for thermal radiation and, hence, were treated as non-participating media in the radiation calculations. Air was assumed inside the PCV and the carbon dioxide was assumed to fill the annular space between the PCV and the SCV (see note). The Pu oxide was assumed to completely fill the inner cans.

Note: An investigation was conducted on the sensitivity of package temperatures to the type of fill gases used. It was found that the maximum temperature variation was less than 2°F when CO_2 is replaced by air between the PVC and SCV. This variation is small and it will not impact the structural integrity of the PCV or the SCV.

2.2 Normal Conditions of Transport

In 10 CFR-71.71(c) (1) the NCT are defined as an ambient temperature of 100°F in still air with solar heating of 800 W / m^2 on the top of the drum and 400 W / m^2 on the side. The 9975 drum is assumed to be upright and to have an adiabatic bottom surface. Heat transfer from the side and top of the drum to the ambient occurs via natural convection and radiation.

The convection coefficients used are functions of the temperature difference between the drum surfaces and the ambient temperature. Heat transfer coefficients for natural convection were obtained from correlations in the MSC/Thermal code. Specifically, the natural convection correlations are for isothermal plates and have the form:

1. For a vertical isothermal plate with $\mathrm{Ra} < 1.0 \times 10^9$,

$$h = \left(\frac{k}{L}\right)\left(0.68 + \frac{0.670 Ra^{0.25}}{\left[1.0 + \left(\frac{0.492}{\mathrm{Pr}}\right)^{9/16}\right]^{4/9}}\right).$$

2. For a vertical isothermal plate with $1.0 \times 10^9 < \mathrm{Ra}$,

$$\mathrm{h} = \left(\frac{\mathrm{k}}{\mathrm{L}}\right)\left(0.825 + \frac{0.387 \mathrm{Ra}^{1/6}}{\left[1.0 + \left(\frac{0.492}{\mathrm{Pr}}\right)^{9/16}\right]^{8/27}}\right)^2$$

3. For a horizontal hot isothermal plate facing upward with $1.0 \times 10^7 < \mathrm{Ra} < 3.0 \times 10^{10}$,

$$h = 0.15\left(\frac{k}{L}\right) Ra^{1/3}.$$

Where[1]: Ra = Rayleigh number based on plate height.
h = Convection heat transfer coefficient.
k = Thermal conductivity of gas (air).
L = Characteristic length of plate.

The thermal conductivity of fiberboard is based on previous heater experiments with the 9975 which showed the in-plane conductivity to be roughly twice the through-plane value [3].

A summary of the boundary conditions for the analyses follows:

1. The drum is in an upright position.
2. The bottom surface is adiabatic.
3. There is radiative heat transfer from drum sides and top to the ambient.
4. There is natural convection heat transfer from the drum sides and top to the ambient.
5. The ambient temperature is 100°F.

---

[1] Note that all properties in the correlations are based on the film temperature.

6. Insolation: 800 W/m^2 on drum top and 400 W/m^2 on drum side (solar absorptivity of the drum assumed unity).
7. Undamaged fiberboard properties are applied to all the fiberboard in the drum.
8. 19 watts total decay power.

2.3 Hypothetical Accident Conditions

During the HAC transient, the ambient temperature was 1475°F for the first 30 minutes and 100°F thereafter. The initial condition for the HAC transient was identical to the steady-state NCT, except insolation was excluded. In the 30 minute fire phase, all sides of the drum (including the bottom) are heated by forced convection and radiation. The cooldown phase occurs immediately after the 30 minute fire. During this phase the drum is exposed to a 100°F ambient temperature and insolation on the drum top and side (as in NCT) is included. During the cooldown phase, the bottom of the drum transfers heat to the ambient by radiation only. The top and sides of the drum transfer heat to the ambient via both radiation and natural convection. The entire HAC transient consists of the 30 minute fire plus 3 hours of cooldown. The conditions for the three phases of the HAC are given below.

For the initial phase of the HAC:

1. The drum is in an upright position.
2. The bottom surface is adiabatic.
3. There is radiation heat transfer from the sides and top of the drum to the ambient.
4. There is natural convection heat transfer from the drum sides and top to the ambient. Convection coefficients were obtained from correlations for natural convection in MSC/Thermal.
5. The ambient temperature is 100°F.
6. No insolation.
7. Undamaged fiberboard properties are applied to all the fiberboard in the drum.
8. 19 watts total decay power.

For the fire phase of the HAC:

1. The drum is in an upright position.
2. There is forced convection from all surfaces of the drum. The convection coefficients, based on a 20 m/s air velocity, are:
   i. 5.9 Btu/hr-ft^2 °F for the top and bottom of the drum.
   ii. 3.0 Btu/hr-ft^2 °F for the side of the drum.
3. There is thermal radiation heat transfer from all surfaces of the drum to the ambient.
4. The ambient temperature is 1475°F.
5. No insolation.
6. Fire phase fiberboard properties are applied to all the fiberboard in the drum.
7. 19 watts total decay power.

For the post-fire phase of the HAC:

1. The drum is in an upright position.
2. There is thermal radiation from the top, sides and bottom of the drum to the ambient.
3. There is natural convection from the top and sides of the drum to the ambient. Convection coefficients were obtained from correlations for natural convection in MSC/Thermal.
4. The ambient temperature is 100°F.
5. Insolation: 800 W/m^2 on drum top and 400 W/m^2 on drum side (solar absorptivity of the drum assumed unity).
6. "Char layer" properties are applied to the outer 1.4 inch layer of the top, bottom and sides of the fiberboard contained in the drum.
7. Fire phase properties are applied to the all fiberboard not in the 1.4 inch outer layer.
8. 19 watts total decay power.

A parametric study was performed in the year 2000 to study the impact of a uniform 1.38 inches wide radial gap in the Celotex discs on the lead shielding temperature during an HAC fire event [5]. The gap was envisioned to have been formed as a result of the postulated HAC 30-ft drops. The analysis simulated a direct thermal radiation path from the drum surface to the lead shield during the HAC fire event. That analysis is not repeated here since the important parameters like emissivity of the lead shield surface have been kept the same. An emissivity of 0.28 (same as lead) is used for the lead shield stainless steel sheath. This is approximately the same as 0.3 used for other stainless steel components in this analysis. A maximum lead shield temperature of 428°F was reported in that analysis [5].

2.4 Thermal Properties

Conduction heat transfer through carbon dioxide and air were considered (as appropriate) within the package, as indicated in Table 1. As mentioned previously, all gasses were assumed to be non-absorbing. The temperature ranges of the gasses were considered when assigning the constitutive properties, however, the gas pressure was assumed to remain at 1 atm.

The thermal properties of the packaging components used in the analyses are based on earlier 9975 analyses [1] and are shown in Tables 2 and 3.

3.0 Analytical Methods and Computations

The general purpose conduction-radiation computer code MSC/Thermal (also known as P/Thermal) was used to perform the computations [2]. This computer code meets the SRS nuclear safety QA requirements [3]. Work was performed in accordance with the WSRC E-7 manual [4]. The thermal models of the storage configurations were created using the pre-processor of the general purpose finite element software PATRAN [2].

4.0 Results

Steady state temperatures predicted by the models for NCT are given in Table 4. This table has been modified to include the temperatures due to the 0.020 inch gap between the lead surface and the stainless steel lead jacket. HAC transient temperatures are given in Tables 5 and 6. Temperature profiles for the whole package during NCT with insolation are shown in Figure 6. Figure 7 shows the temperature profiles for the PCV and Figure 8 shows the temperature profiles for the fiberboard. For practical purposes, all the component temperatures are consistent with the earlier analyses. The following results are noteworthy:

1. The maximum predicted temperature of the fiberboard is approximately 256°F and occurs at the interface of the lead shield and the fiberboard at the bottom of the package.

2. During NCT, the maximum SCV temperature is 267°F and the maximum PCV temperature is 282°F. The maximum temperatures are below the design limit of 300°F for both vessels.

3. During NCT, the maximum PCV seal temperature is 276°F and the maximum SCV seal temperature is 259°F. The maximum temperatures are below the design limit of 400°F for both vessel seals

4. During NCT, the PuO_2 centerline temperatures for the two cans are 412°F and 411°F based on 19 watts source.

5. During NCT, the average PCV gas temperature with Pu oxide is 317°F (Appendix 1). The gas temperature was 313°F in the earlier analyses [1]. An increase of 4°F will result in an insignificant increase in the internal pressure of the PCV and will not impact the earlier conclusions regarding the structural integrity of the PCV. Average gas temperatures were calculated by volume averaging of nodal temperatures at select nodal locations in the cavities within the PCV.

6. Except near the outer region of the package, component temperatures at the end of the 30 minute HAC fire are lower than during NCT (with insolation). The temperatures are about 90°F cooler inside the PCV at the end of the HAC fire compared with NCT (with insolation). Post fire temperatures are all lower than the temperatures for NCT with insolation.

7. Maximum lead shield temperature under NCT is 256°F and is consistent with 250°F for the Food Can Configuration in earlier analyses [1]. The maximum lead shield temperature during HAC fire events, including cooldown, is 197°F. These temperatures are well below the maximum temperature of 428°F [5] for the lead shield as explained in Section 2.3 above in this analysis.

8. The temperature gradient through the PCV/SCV walls is less than 2°F.

9. The maximum temperatures due to the 0.020 inch air gap between the lead shield jacket and the lead are listed in Table 4. These temperatures are only about 1°F higher than the temperatures without the gap. This is expected due to the slight reduction in the package conductance as a result of the inclusion of the air gap.

5.0 Conclusions

The maximum temperatures during NCT with insolation and during HAC are consistent with the temperatures found in earlier analyses [1]. Therefore, it can be safely concluded that the structural integrity of the 9975 package is not affected by the geometry changes in the lead shielding design.

Table 1: External Dimensions of Containers

Container	Diameter X Height (in.) Used in Model
Food Can	4.25 X 7 Outer Can 4.0625 X 6.25 Inner Can

Table 2: Emissivity of Package Components

Component	Emissivity
Aluminum plates, honeycomb	0.20
Fiberboard	0.50
Lead/ Lead shield stainless steel liner	0.28
Drum Inner Surface	0.30
Drum Outer Surface (Initial HAC and NCT)	0.21
Drum Outer Surface (fire phase HAC)	0.90
Drum Outer Surface (post-fire phase HAC)	0.80
Pu Oxide	0.90
Convenience Can	0.20
PVC/SCV	0.30

Table 3: Constitutive Properties of Packaging Materials

Material	**Density (lbm/ft^3) @ T(°F)**	**Conductivity (Btu/hr.-ft.- °F) @ T(°F)**	**Heat Capacity (Btu/lbm °F) @ T(°F)**
Helium	0.010497	0.0910 @ 120 0.0985 @ 212 0.1226 @ 392	1.24
Air	0.080532	0.01396 @ 32 0.01839 @ 212 0.02238@ 392 0.02593 @ 572	0.237 @ 212
Carbon Dioxide (CO_2)	0.1122	0.00958@ 80.0 0.01183 @ 170.0 0.01422@ 260.0 0.01674 @ 350.0	2.0823E-01@ 80.0 2.1517E-01@ 170.0 2.2521E-01@ 260.0 2.3429E-01@ 350.0
Honeycomb energy absorber (radial)	16.2	3.82	0.22
Honeycomb energy absorber (axial)	16.2	7.62	0.22
Pre-fire fiberboard (radial)	16.86 @ 77 17.36 @ 187 17.86 @295	0.0723	0.306 @ 77 0.360 @ 187 0.417 @ 295
Pre-fire fiberboard (axial)	16.86 @ 77 17.36 @ 187 17.86 @295	0.031 @ 77 0.034 @ 187 0.029 @ 533	0.306 @ 77 0.360 @ 187 0.417 @ 295
During fire fiberboard (Fire Phase)	15.40 @ 80 15.40 @ 475 8.5 @ 810 3.5 @ 1500	0.035 @ 80 0.450 @ 170 0.550 @ 200 0.090 @ 210 0.070 @ 500	0.25 @ 80 0.50 @ 475 0.50 @ 810 0.50 @ 1500
Post-fire fiberboard (Char Layer)	8.1	0.07 @ 100 0.07 @ 140 1.0 @ 200 0.3 @ 300 0.07 @ 500	0.25
Aluminum	169.3	126.0	0.216
Stainless steel (304)	494.4	7.74 @ 32 9.43 @ 212 12.58 @ 932	0.12 @ 32 0.135 @ 752
Stainless steel (316)	514.3	8.79 @ 261 10.58 @ 621	0.12 @ 261 0.13 @ 621
Lead	708.5	19.6 @ 209 18.3 @ 400	0.0305 @ 32 0.0315 @212 0.0338 @ 621.5
Pu oxide	124.8	0.0460	0.022
Pu metal	1198.6	7.26 @ 207 7.74 @ 243 9.19 @ 266 18.39 @ 1112	0.032 @ 32 0.0328 @ 212 0.174 @ 257 0.0294 @ 347 0.0399 @ 842

Table 4: NCT Temperatures

Components	Solar (°F)		Shade (°F)
	Without Gap	With Lead Shield Gap	
PCV	282	283	188
SCV	267	268	171
PCV O-rings	276	277	181
SCV O-rings	259	260	161
Celotex Max	256	256.7	158
Celotex (mid height/mid thickness)	225	225	127
Contents Max	412	413	323
Average Gas in PCV	317	318	<< 317
Lead shielding	256	257	159
Drum surface	255	255	101

Table 5: HAC Temperatures (Without Gap)

Components	30-Minutes Fire (°F)	Post Fire		Post Fire Steady State
		Temp (°F)	Time (hr)	
PCV	188	208	> 3.00	208
SCV	174	197	1.75	189
PCV O-rings	181	203	> 3.00	203
SCV O-rings	161	186	3.00	186
Contents Max	323	343	> 3.00	343
Lead shielding	173	197	1.25	177

Table 6: Post Fire Temperatures with Solar (Without Gap)

Time (Hr)	PCV (°F)	SCV (°F)	PCV O-rings (°F)	SCV O-rings (°F)	Contents Max (°F)	Lead shielding (°F)
0	188	174	181	161	323	173
0.25	189	180	181	162	323	184
0.50	190	185	182	164	323	190
0.75	192	189	183	167	324	194
1.00	195	192	184	170	325	196
1.25	197	194	185	173	326	197
1.50	198	196	187	176	328	197
1.75	200	197	189	178	329	197
2.00	202	197	191	181	331	197
2.25	203	197	193	182	332	195
2.50	204	197	194	184	334	192
2.75	205	196	196	185	336	189
3.00	206	195	197	186	337	187
Steady State	208	189	203	186	343	177

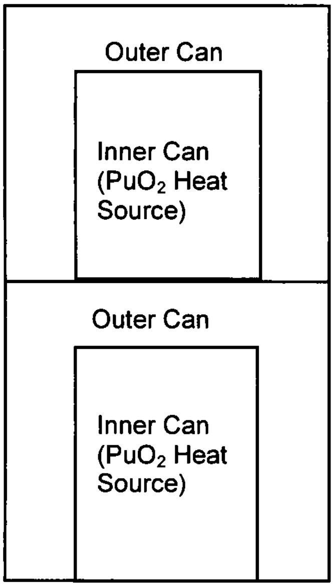


Figure 1: Schematic of food can configuration

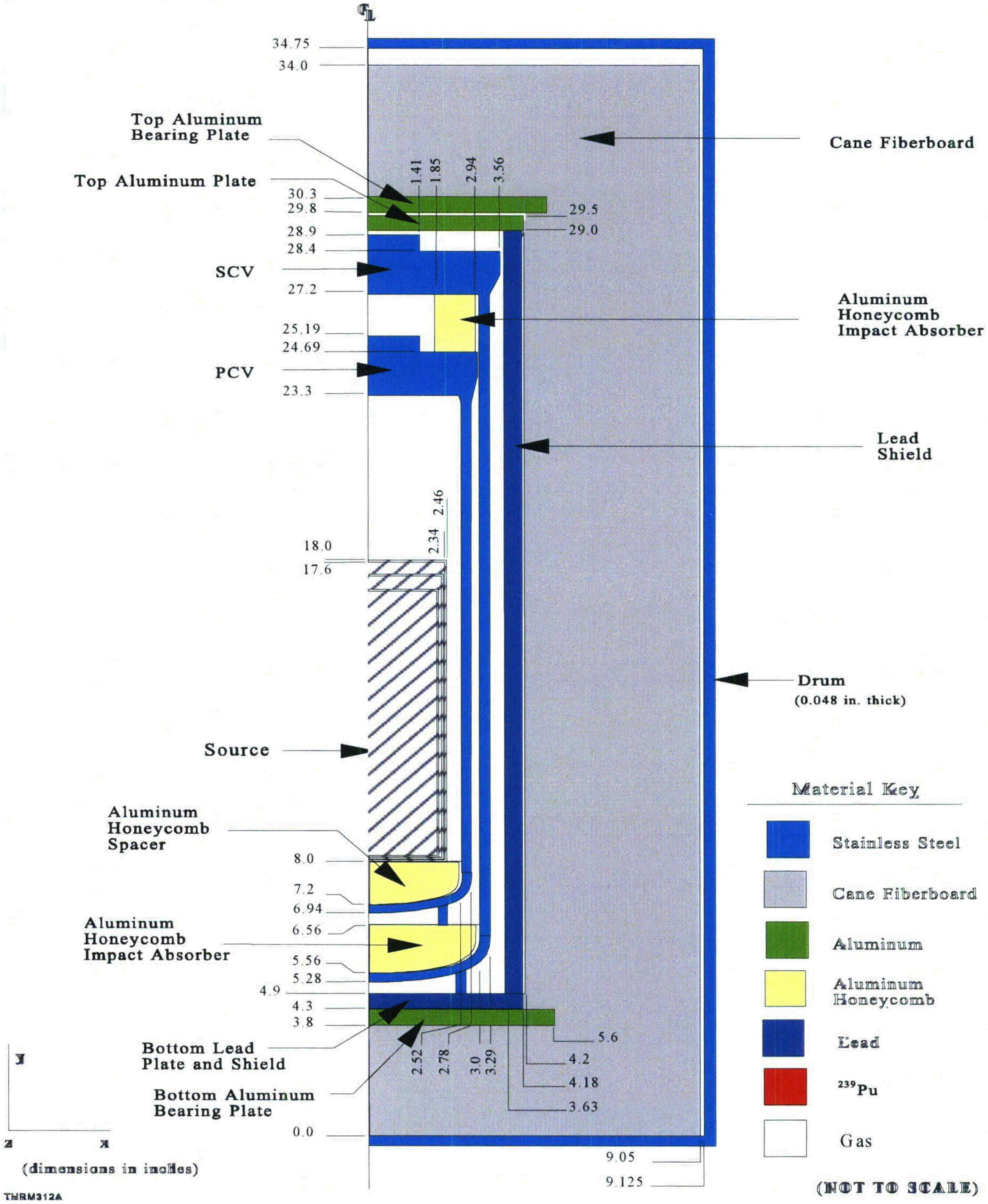


Figure 2: Typical schematic of 9975 package (payload dimensions vary)

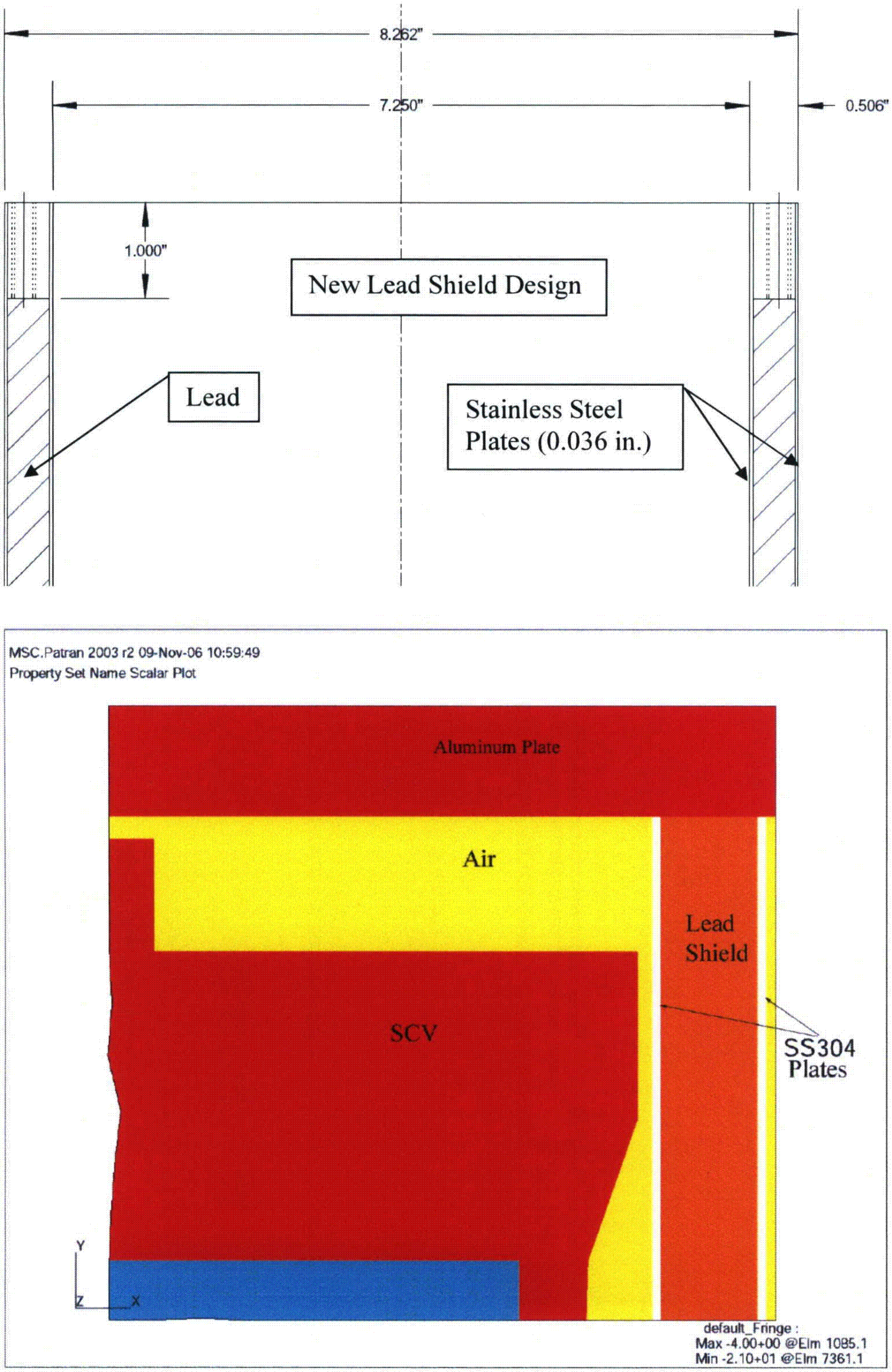
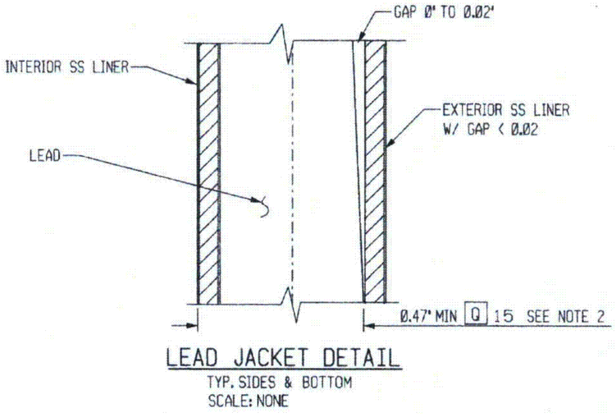


Figure 3: New lead shield design (above) and its color representation in the Model



(Drawing R-R2-F-0020, Rev. 10 [7])

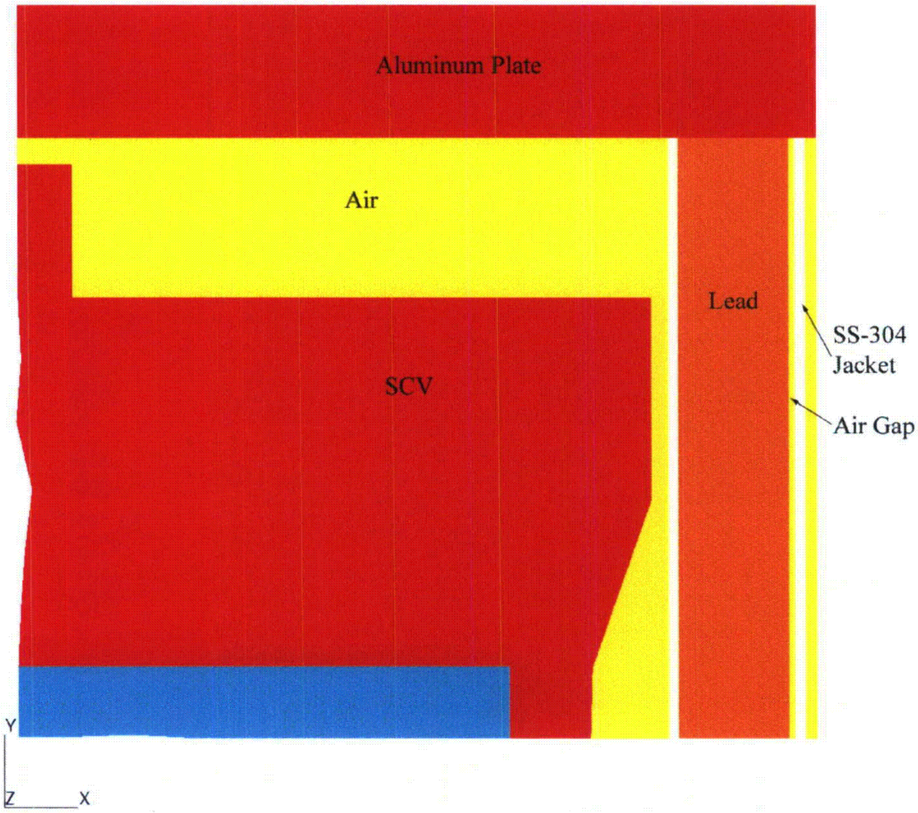


Figure 3A – Lead shield jacket and gap

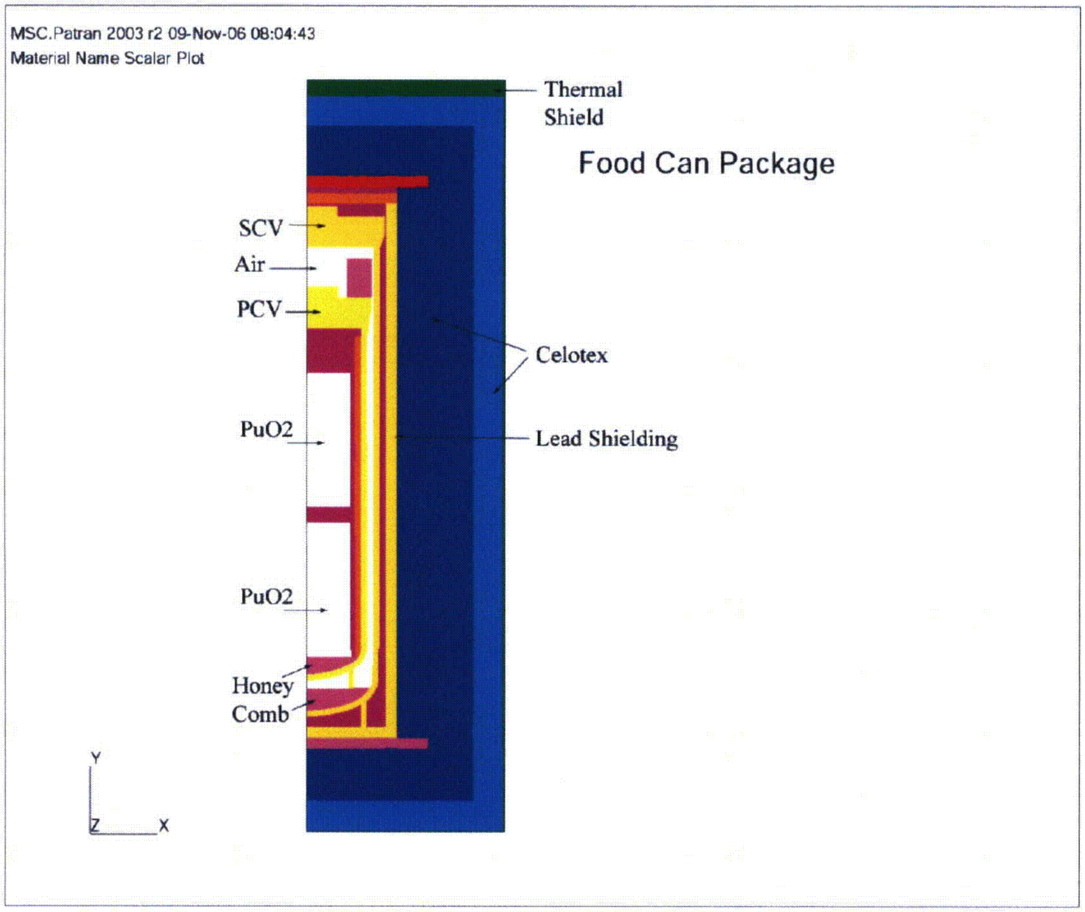


Figure 4: Color representation of material location in Food Can

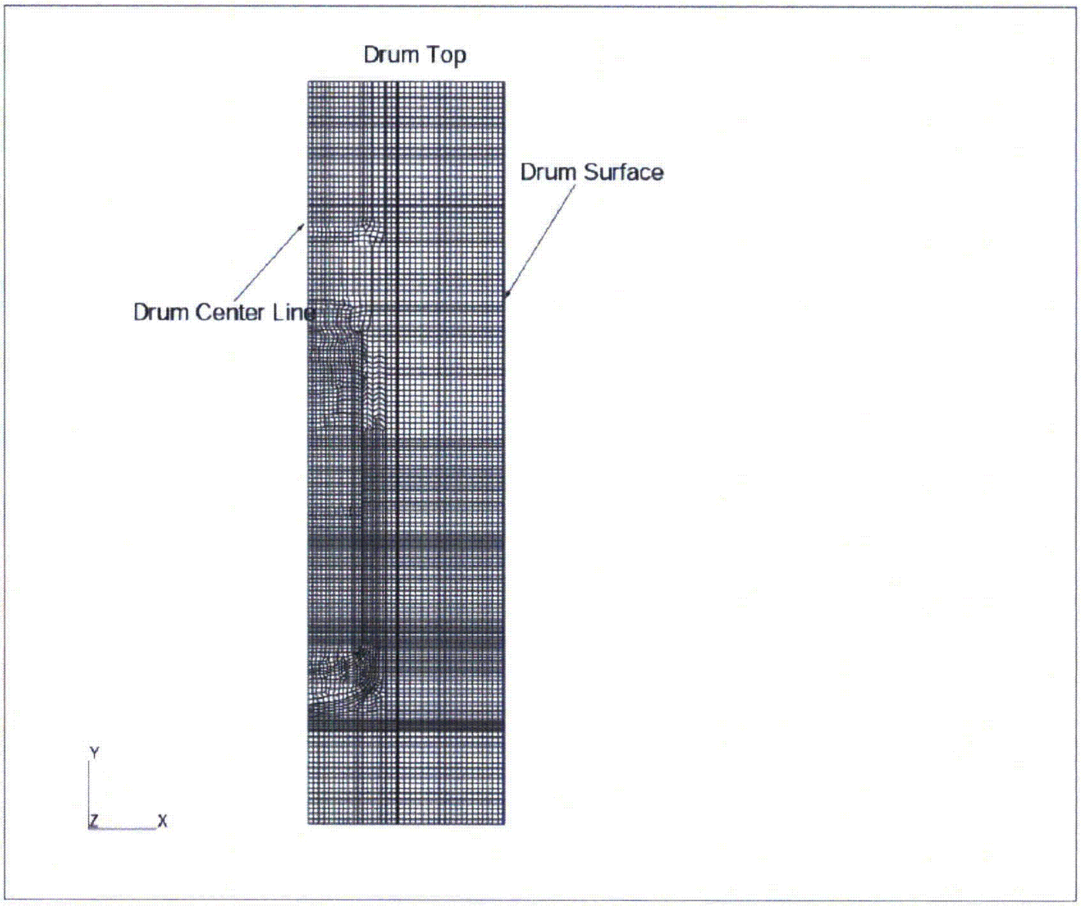


Figure 5: Typical mesh used in MSC/Thermal model

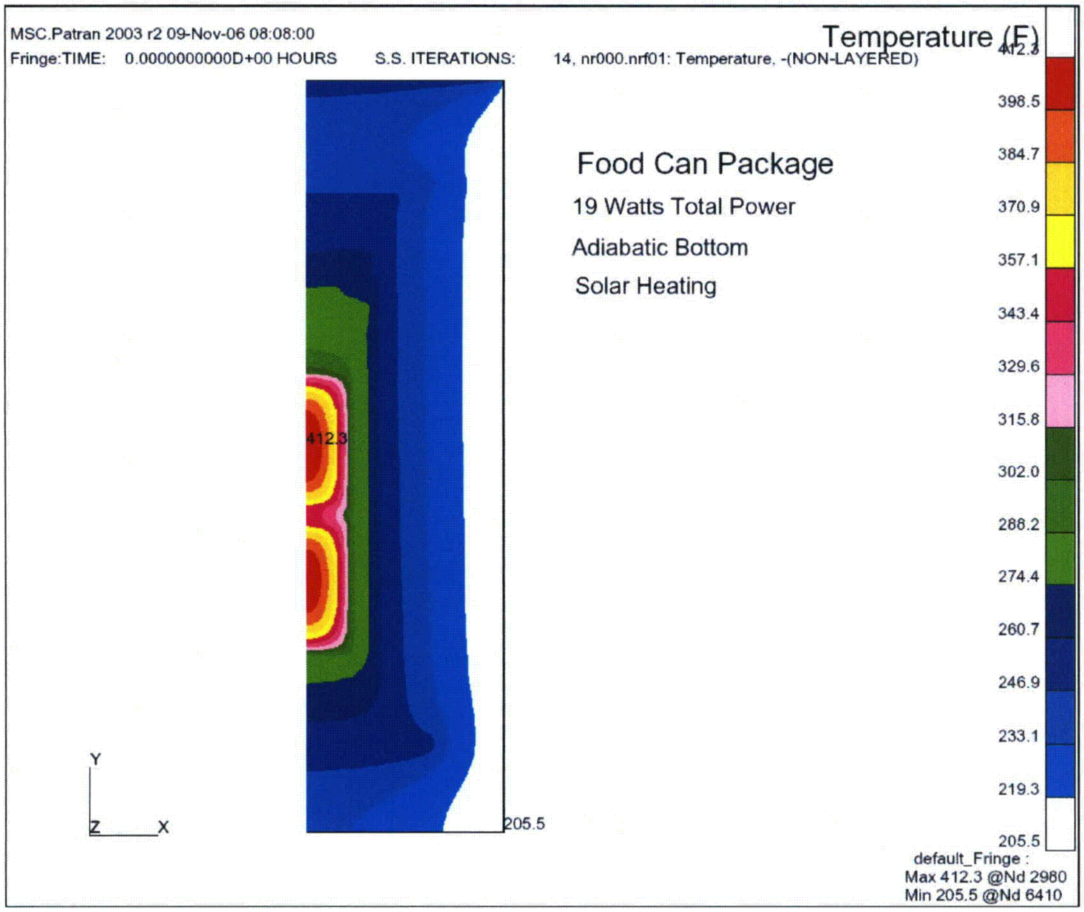


Figure 6: Package temperature profile during NCT (No gap)

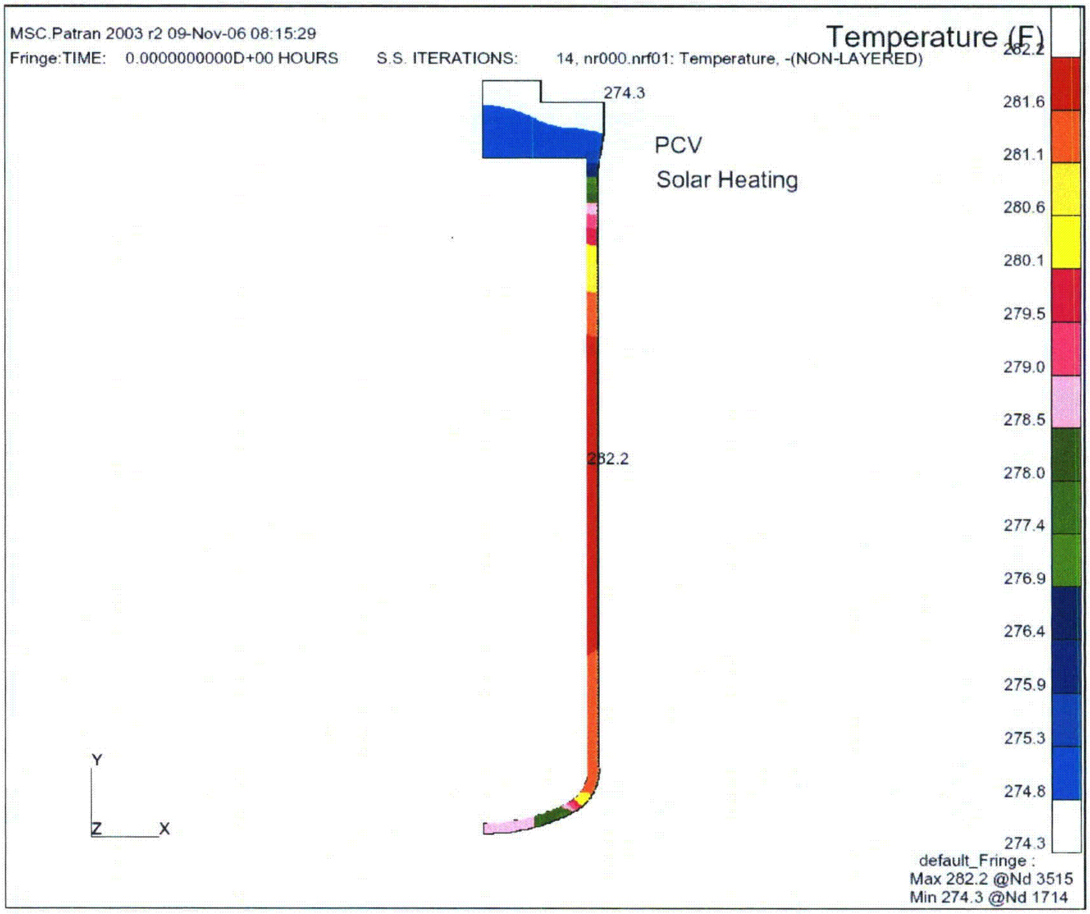


Figure 7: PCV temperature contours (No gap)

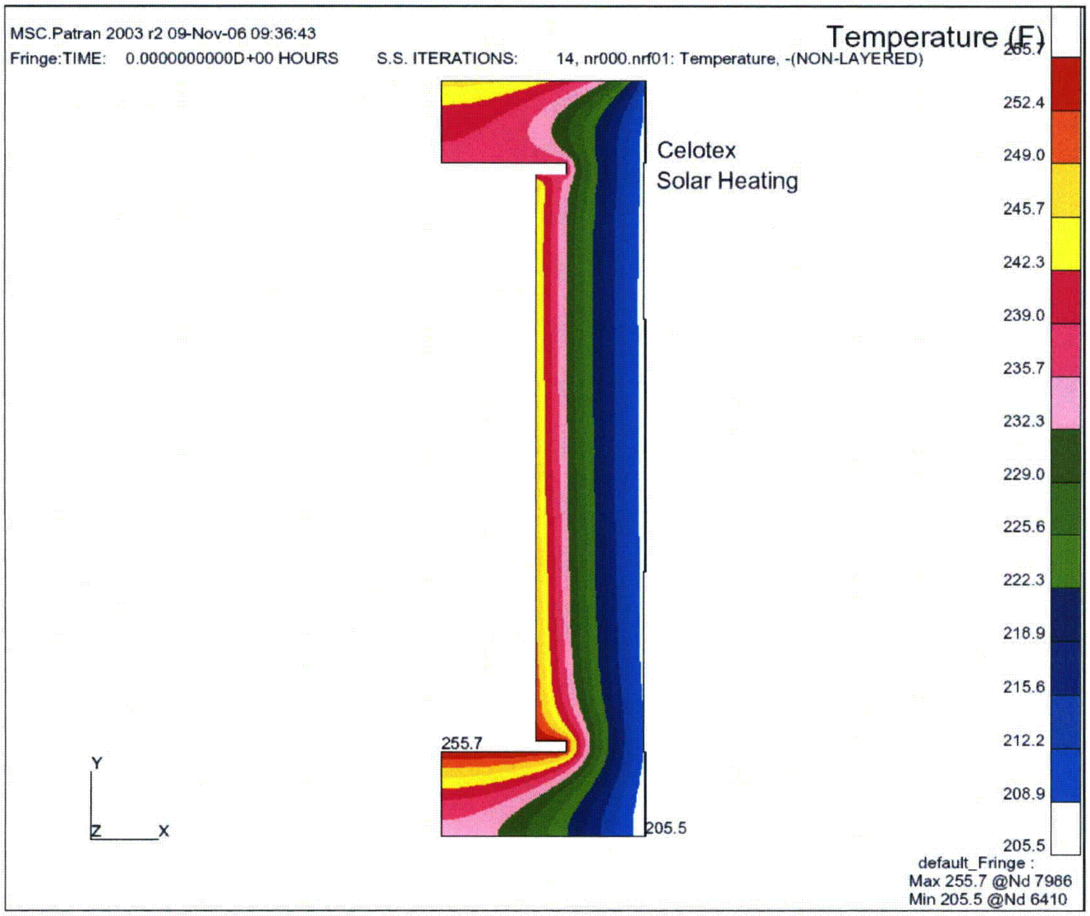


Figure 8: Fiberboard temperature profile during NCT (No gap)

6.0 References

1. Gupta, N. K., "Thermal Analyses of the 9975 Package for Normal Conditions of Transport and Accident Conditions", M-CLC-F-00590, Rev. 8, (2003).
2 MSC/PATRAN/PTHERMAL Version 2003 Rev. 2, MSC.Software Corp., Santa Ana, CA.
3. Gupta, N. K., "MSC/PATRAN/THERMAL Software Quality Assurance Plan, Rev. 0, G-SQP-A-00004, (2005).
4. Westinghouse Savannah River Co., Conduct of Engineering Manual, E-7, (2006).
5. The Effect of a Celotex Gap on 9975 Package Temperatures during the HAC-Fire and Cooldown Transients, M-CLC-F-00667, Rev. 0, (2000).
6. Gupta, N. K., "Thermal Analyses of Low Density Pu Oxide in Helium/Air Environment in 9975 Packaging", M-CLC-F-00995, Rev. 2, (2005).
7. Drawing R-R2-F-0020, Rev. 10, 9975 Shipping Package Shielding (U), Washington Savannah River Co., February 2008.

Appendix 1

Average Gas Temperature in PCV in Food Can Configuration (With Gap)

R1	R2	h	Volume	
0	0.7	3.662	5.64	V1
0	0.7	2.96	4.56	V2
0	0.7	3.209	4.94	V3
0	0.7	5.471	8.42	V4
0.7	1.4	3.662	16.91	V5
0.7	1.4	2.96	13.67	V6
0.7	1.4	3.209	14.82	V7
0.7	1.4	5.471	25.27	V8
1.4	2.52	3.662	50.71	V9
1.4	2.52	2.96	40.99	V10
1.4	2.52	3.209	44.44	V11
1.4	2.52	5.471	75.76	V12

V(Total) 306.13

Average Volume Temperature

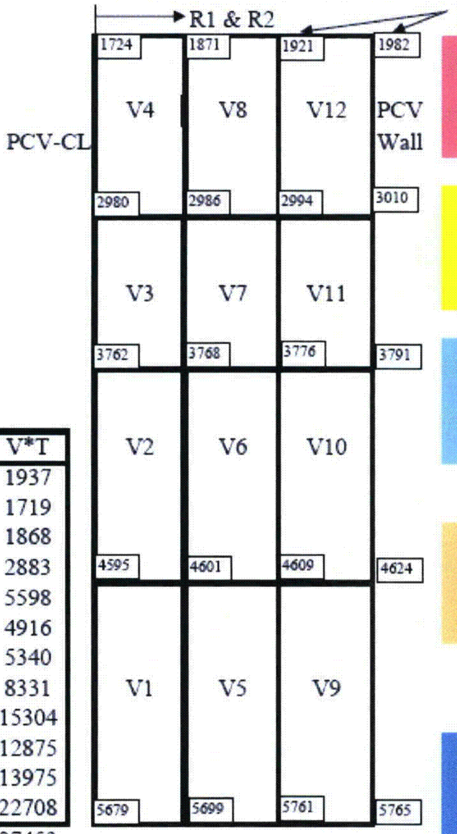
	T1	T2	T3	T4	Ave. T	V*T
V1	280	280	402	412	344	1937
V2	402	412	346	350	377	1719
V3	346	350	404	413	378	1868
V4	404	413	276	276	342	2883
V5	280	280	362	402	331	5598
V6	362	402	328	346	360	4916
V7	328	346	363	404	360	5340
V8	363	404	276	276	330	8331
V9	280	283	283	362	302	15304
V10	283	362	283	328	314	12875
V11	283	328	283	363	314	13975
V12	283	363	277	276	300	22708

VT-Total = 97453

Average Air Temperature

Tavg **318**

R1 & R2 are from the PCV Centerline



Nodes	Temp
1724	276
1871	276
1921	276
1982	277
2980	413
2986	404
2994	363
3010	283
3762	350
3768	346
3776	328
3791	283
4595	412
4601	402
4609	362
4624	283
5697	280
5699	280
5761	280
5765	283

APPENDIX 3.22

NCT and HAC Thermal Analysis for the 9975 Package for NRC Certification

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Calculation Cover Sheet

Project N/A	Calculation No. M-CLC-A-00441	Project No. N/A
Title NCT and HAC Thermal Analyses for the 9975 Package for NRC Certification	Functional Classification SC	Sheet 1 of 39
	Discipline Mechanical	
Calc Level ☒ Type 1 ☐ Type 2	Type 1 Calc Status ☐ Preliminary ☒ Confirmed	
Computer Program No. NA ☐ FLUENT and MSC.PATRAN.THERMAL	Version/Release No. PATRAN Version 2008, Rev. 1 FLUENT Version 6.3	
Purpose and Objective This calculation evaluates the thermal performance of the 9975 package during Normal Conditions of Transport (NCT) and the Hypothetical Accident Conditions (HAC) per NRC regulations in 10 CFR Part 71. The objective of the calculation is to demonstrate that the maximum component temperatures are below their design limits.	DC/RO Date: 3/10/14 UNCLASSIFIED DOES NOT CONTAIN UCNI DC & Reviewing Official: Cynthia Holding-Smith (Cynthia P. Holding-Smith)	

Summary of Conclusion

1. The analyses show that the maximum temperatures of the 9975 package components during NCT and HAC are below their design limits.
2. The maximum pressures in the PCV and SCV are below their existing MNOP values and, therefore, there is no impact on the existing structural analyses.
3. ANSYS FLUENT can be used in place of P/Thermal for package thermal analysis, but the existing P/Thermal results are also valid.

Revisions

Rev. No.	Revision Description
0	Original Issue
1	The insolated NCT package results were used as initial conditions of the 30-min fire simulation for the HAC calculations to address NRC review comments

Sign Off

Rev. No.	Originator (Print) Sign/Date	Verification/ Checking Method	Verifier/Checker (Print) Sign/Date	Manager (Print) Sign/Date
1	S. Y. Lee SYLee 3/6/2014	Document Review	F. G. Smith, III FGSmith 3/6/14	M. K. Harris MKHarris 3/6/14

Additional reviewer (Print) N/A	Signature	Date
Design Authority – (Print) Dan Leduc	Signature	Date
Release to Outside Agency – (Print) N/A	Signature N/A	Date N/A

Security Classification of the Calculation

Unclassified

Revisions

Revision	Description
0	Original Issue
1	The Rev 0 Calc Note was revised to include the HAC results combined with the insolated NCT package results used as initial pre-fire temperatures of the 30-min fire simulation to address NRC review comments

Nomenclature

h = Convection Heat Transfer Coefficient (Btu/hr-ft^2-°F)
k = Thermal Conductivity (Btu/hr-ft-°F)
k_i = Thermal Conductivity at i region (Btu/hr-ft-°F)
k_g = Thermal Conductivity for gas region (Btu/hr-ft-°F)
L = Characteristic Length (ft)
Pr = Prandtl Number
q = Heat transfer rate per unit length
q_{cond} = Conductive heat transfer rate per unit length
R_o = Universal gas constant (= 10.73 psi-ft.^{3}/lb-moles-R)
r_i = Radius at i region
Ra = Rayleigh Number
T = Temperature (°F)
T_i = Temperature at i region (°F)
T_{final} = Final absolute temperature during HAC (R)

Acronyms and Abbreviations

DOE	Department of Energy
DOT	Department of Transportation
FLUENT	ANSYS software
HAC	Hypothetical Accident Conditions
MSC	MacNeal Schwendler Corporation
MNOP	Maximum Normal Operation Pressure
NASA	National Aeronautics and Space Administration
NCT	Normal Conditions of Transport
PCV	Primary Containment Vessel
RAM	Radioactive Material
SAR	Safety Analysis Report
SCV	Secondary Containment Vessel
SS	Stainless Steel or Steady State

1.0 Introduction and Background

This document describes the computational models for the thermal analyses of the Normal Conditions of Transport (NCT) and the Hypothetical Accident Conditions (HAC) for the 9975 package for NRC review and certification. 9975 is a DOE certified package that has been used in the DOE complex for transportation and long term storage of RAM.[1] The existing NCT and HAC thermal analyses were performed using the software PATRAN/Thermal or P/Thermal[2] which NRC does not use for review. These analyses are now performed using software ANSYS FLUENT[3] that is acceptable to NRC. The results from FLUENT models are compared with P/Thermal results using thermal models created on these computer codes. This comparison will corroborate the validity of the existing results for different content configurations that were obtained using P/Thermal and are therefore not repeated using FLUENT. Additional sensitivity analyses are performed to establish the safety margins and the robust nature of the 9975 package design. Figure 1 shows a schematic of the 9975 package.

The NCT results in the current DOE certified 9975 package were performed using a very conservative solar absorptivity value of 1.0 for the stainless steel drum surface. This assumption resulted in the fiberboard insulation temperature of 257°F that exceeded the fiberboard limit of 250°F. Analytical studies show that the realistic value for the solar absorptivity for the stainless steel surface fabricated from the rolling operation is about 0.5. [4, 5] The NCT analyses documented in this report use an absorptivity value of 0.5 to get more realistic component temperature results. Sensitivity studies are also performed to assess the impact of variability in the solar absorptivity for drum surface.

A sensitivity analysis is also performed to address the variability in the insulation thermal conductivity. The existing analyses were based on treating the insulation as an orthotropic substance. This assumption was based on insulation material tests and thermal prototype tests that were used to benchmark the existing NCT models. The sensitivity model uses a uniform thermal conductivity of the insulation but use a more realistic solar absorptivity of 0.5 as explained above.

The HAC thermal models described here are identical to the models in the current DOE certified 9975 package. Thermal models in this report are for an undamaged 9975 package to meet all the regulatory requirements during an HAC thermal event. The efficacy of the fiberboard insulation during regulatory fire was demonstrated in the fire test of a damaged 9973 package. The fire test and the simulation results for the 9973 package are described in Appendices 3.5 and 3.2, respectively.[1] The simulation of the damaged 9973 package using FLUENT computer code is not repeated in this calc. note.

Thermal models described in this report are created using modified shielding where the lead was encapsulated in a 0.036 inches stainless steel casing. The impact of this casing was studied earlier (Ref. 1, Appendix 3.19) when the modification was proposed and it was found to have minimal impact on the component temperatures. Therefore, the analyses in this report are good for packages with or without the shielding modifications.

The analyses in this report are based on PuO_2 source having a density of 2 g/cc and a heat rate of 19 watts. Only about 3 kg of 2g/cc source can be put in a 3013 container analyzed in this report. A 3 kg source will normally have heat rate well below 19 watts and, therefore, the analyses in this report are bounding. A short discussion is provided in the sensitivity analysis section to address the variability in the source density.

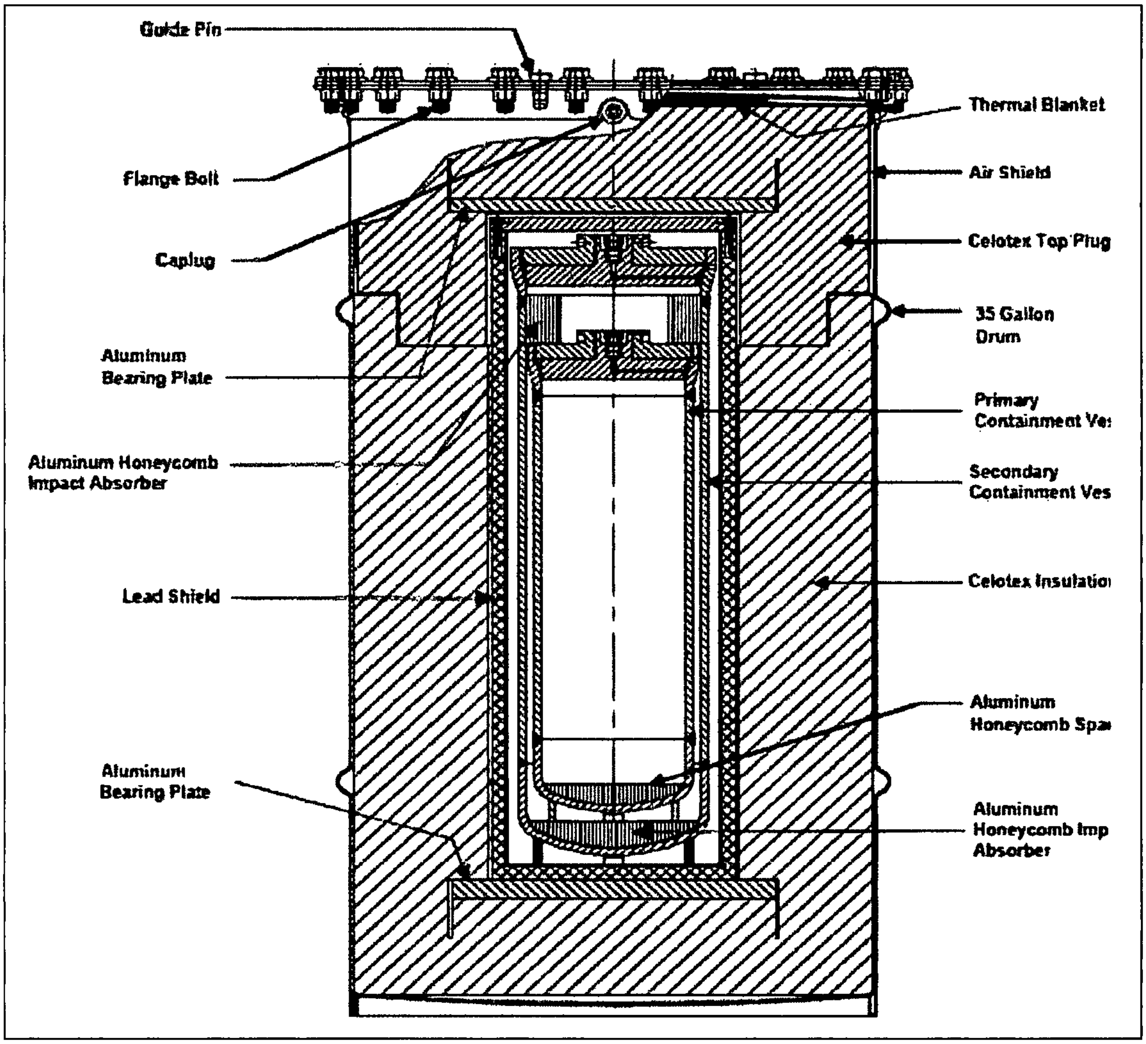

Figure 1: Schematic of the 9975

2.0 Inputs and Assumptions

Inputs consist of package geometry, material thermal properties, thermal loading, and boundary conditions. These inputs are used in creating finite element thermal models that are used to analyze the Normal Conditions of Transport (NCT) and the Hypothetical Accident Conditions (HAC). Assumptions are not listed separately but are documented and justified in the thermal models, as necessary. The terms 'heat source' and 'contents' are used interchangeably in this report and always refer to PuO_2.

2.1 Geometry

The package drawings included in Reference [6] give the geometrical details and the technical specifications of the package components. The technical specifications include the applicable ASME Code requirements for the components and materials. Package component design specifications relevant to the thermal analyses are summarized below.

Drum and Lid

The confinement for the package is a 35-gallon stainless steel drum with a removable closure lid, both constructed from 18-gauge 304L stainless steel sheet. The drum incorporates four vent holes located approximately 1 inch below the drum closure flange and 90° apart. The vent holes are closed with plastic Caplugs® to prevent entry of rainwater during NCT. In the HAC for thermal, the fusible Caplugs® are consumed and allow the drum to vent gases generated from thermal decomposition of the fiberboard insulation.

Fiberboard Insulation®

The insulation specified for this packaging is an industrial cane or softwood fiberboard with a nominal density of 15 lb/ft^3 in conformance with ASTM Specification C 208. A temperature limit of 250°F is imposed on the insulation as a bulk design ceiling for the fiberboard material under NCT.

In the HAC for thermal, the fiberboard insulation undergoes sacrificial decomposition adjacent to the drum surface, known as "charring." This feature is important to the package thermal performance and is incorporated into the thermal analysis. HAC thermal testing has shown that the thickness of uncharred fiberboard provides satisfactory thermal protection for the containment vessels. Adjacent to the drum vent holes, the Insulation Top Subassembly is protected from direct impingement of flames by a stainless steel Air Shield.

Shielding

The Package Shielding is located between the SCV and the Insulation Assembly and provides a measure of gamma shielding. The Shielding Body Subassembly is formed in part from a cylindrical stainless steel sleeve with a welded bottom. The Shielding Lid is ½-inch thick aluminum plate and is secured to Shielding Body with four bolts. The stainless steel cladding provides protection to the lead shielding against corrosion, found in some earlier packages fabricated without this protection.

Containment Vessel and Containment O-Rings

Together, the PCV and SCV provide double containment of the package contents and are designed, fabricated and examined in accordance with the ASME Code. The PCV weldment is constructed from 5-inch diameter, seamless Schedule 40, Type 304L stainless steel (SS) pipe. The SCV is constructed from 6-inch diameter, seamless Schedule 40, Type 304L stainless steel (SS) pipe.

A containment boundary is provided in part by the PCV/SCV bodies and by the outer O-ring mounted on the cone-seal plug and by the SS leak-test port plug. The O-ring material is Viton® GLT or GLT-S, a fluorocarbon elastomer with a service temperature range between -40°F and 400°F.[7]

Aluminum Spacer

An aluminum spacer is provided between the PCV and the top of the 3013 assembly to provide impact protection for the 3013 and to enhance heat transfer from the heat sources. The spacer is fabricated from aluminum 6061-T6 alloy.

Aluminum Honeycomb

PCV rests inside the SCV bottom on an aluminum honeycomb to provide impact protection during accident. Similarly, 3013 assembly rests inside the PCV bottom on an aluminum honeycomb to provide impact protection during accident. In addition, the honeycomb assemblies have better thermal conductivity than gases and, therefore, enhance heat dissipation under normal conditions.

2.2 Material Properties

General material properties for the NCT analyses are listed in Tables 1 and 2, and the nominal emissivities are listed in Table 3. Carbon dioxide is filled in the CV cavity and an inert gas, helium or nitrogen, is filled in the 3013 containers. Thermal properties of some materials such as stainless steel 304L, lead and air have been retained from the existing thermal analyses in Reference [1]. These values were obtained from the material library in the software P/thermal. These properties are consistent with the values found in other material property references.

The surface emissivity values are for the gray surfaces. The values assumed in Table 3 are somewhat subjective and have been found to match the test data well. These values have been successfully used in the analyses of other certified packages. The CV and the 3013 vessels are machined stainless steel components with clean surfaces. These surfaces are not polished or shiny. The drum surface is assumed *as received (medium finish)*. The drum surface emissivity value (0.21) for the NCT is based on the detailed analysis for different types of drum surfaces.[2] The corresponding solar absorptivity is 0.498 (• 0.50), which means that half of the solar heat is absorbed into the drum surface. A sensitivity analysis is performed to evaluate variation in the drum surface finish for the NCT analyses. The drum surface emissivity value during HAC postfire phase is the minimum value (0.8) specified in the 10 CFR Part 71.73. A lower drum surface emissivity value results in higher component temperatures during postfire cooling. The aluminum component surfaces are assumed oxidized.

Table 1: Thermal Properties of Solid Packaging Materials

Metals	Density	Specific Heat C_p		Thermal Conductivity	
	(lbm/ft^3)	(°F)	(Btu/lbm-°F)	(°F)	(Btu/h-ft-°F)
Type 304 Stainless Steel[2]	494.4	32 752	0.12 0.135	32 212 932	7.74 9.43 12.58
1100 Aluminum[8]	169.3	all	0.216	all	126.0
5052 Aluminum Honeycomb (Appendix 3.10)	16.2	all	0.22	all	3.82 (radial) 7.62 (axial)
Aluminum Spacer (6061-T6)[9]	169.3	70 100 200 300 400	0.213 0.215 0.221 0.226 0.230	70 100 200 300 400	96.1 96.9 99.0 100.6 101.9
Kaowool Blanket[10]	6.0	all	0.26	100 500 1000 1500 1800	0.0201 0.0392 0.0833 0.1442 0.1825
Lead[2]	708.6	32 212 621.5	0.0305 0.0315 0.0338	209 400	19.6 18.3
Low-Density Plutonium Oxide Powder (2.0 g/cc)[11]	124.8	all	0.022	all	0.046
Air[2]	0.08053	212	0.237	32 212 392 572	0.01396 0.01839 0.02238 0.02593
Carbon Dioxide (CO_2)[12]	0.1122	80 170 260 350	2.0823E-01 2.1517E-01 2.2521E-01 2.3429E-01	80 170 260 350	.00958 .01183 .01422 .01674

Fill gas for the 3013 container packed in accordance with DOE Standard 3013 must be an inert gas, namely nitrogen or helium, with a maximum of 5% oxygen. Since thermal properties of nitrogen and air are practically the same, air is assumed in all the analyses. Helium has much higher thermal conductivity than air and it results in lower maximum component temperatures than air as a fill gas. As discussed earlier, the present analysis assumes that the cavity region between outer 3013 container and PCV is filled with CO_2 gas, and top region above the PuO_2 inside the convenience can is occupied by air.

Thermal properties of Celotex insulation during NCT and HAC are given in Table 2. Thermal properties for NCT analyses are based on testing and modified to benchmark the NCT models against tests. Thermal properties during HAC fire are lumped or effective properties to match the test data with the thermal models. Additional explanation is provided in section on HAC models.

Table 3 gives additional thermal properties of air needed for calculating natural convection coefficients.

The emissivities for the radiated surfaces of the package are provided in Table 4. Values used for emissivities of interior surfaces have always been somewhat subjective. The values used here have been found to simulate the measured temperatures well in controlled thermal tests of drum type packages including 9975, 9977, and Bulk Tritium Shipping Package. Due to low temperatures and small temperature gradients found in typical drum type packages, small variations in emissivity of interior surfaces have negligible effects (< 5°F) on component temperatures. Stainless steel rolled surfaces like air shield and convenience can have smoother surfaces (• = 0.2) than PCV and SCV (• = 0.3) and are, therefore, assigned lower values. Aluminum surfaces are assumed oxidized surfaces. For the drum surface emissivity during fire and post-fire, guidance is used from 10 CFR 71.73. PuO_2 source surface is rough and is assigned a high emissivity value of 0.9. Fiberboard surface is normally rough but a value of • = 0.50 was found to give a good fit for the test results in thermal test of the 9975 (Ref. 1 Appendix 3.1).

Table 2: Thermal Properties of Celotex Used in the NCT/HAC Thermal Analysis

Material	Density [a]		Specific Heat C_p		Thermal Conductivity		Phase Change [b]
	(°F)	(lbm/ft³)	(°F)	(Btu/lbm-°F)	(°F)	(Btu/h-ft-°F)	(Btu/lbm)
NCT – Celotex (radial) (Appendix 3.1)	77 187 295	16.87 17.36 17.86	77 187 295	0.306 0.360 0.417	all	0.0723	None
NCT – Celotex (axial) (Appendix 3.1)	77 187 295	16.87 17.36 17.86	77 187 295	0.306 0.360 0.417	77 187 295	0.031 0.034 0.036	None
HAC - Celotex (Uncharred) (Appendix 3.2)	80 475 810 1500	15.40 15.40 8.5 3.5	80 475 810 1500	0.25 0.50 0.50 0.50	80 170 200 210 500	0.035 0.045 0.055 0.090 0.070	50 at 200°F
HAC - Celotex (Charred) (Appendix 3.2)	all	8.1	all	0.250	100 140 200 300 500	0.07 0.07 1.0 0.30 0.07	None

a) Linear interpolation is used to determine thermal properties at intermediate densities
b) Latent heat of vaporization

Table 3: Thermal Properties of Gaseous Components

Material	Thermal Conductivity (Btu/hr ft °F)	Density (lbm/ft^3)	Specific Heat (Btu/lbm °F)	Thermal Expansion Coeff. (1/°F)	Viscosity (lbm/hr-ft)
Air at 1 atm pressure[2]	1.40E-02 @ 32.0°F 1.50E-02 @ 80.0°F 1.84E-02 @ 212.0°F 2.24E-02 @ 392.0°F 2.59E-02 @ 572.0°F 2.93E-02 @ 752.0°F	$\rho = \frac{1}{2.5203 \times 10^{-2}(T + 459.67)}$ T is in °F	0.24044	$\beta = \frac{1}{(T + 459.67)}$ T is in °F	4.80E-02@80.33°F 5.02E-02@170.33°F 5.53E-02@260.33°F 6.01E-02@350.33°F 6.89E-02@530.00°F 8.06E-02@800.00°F

Table 4: Surface Emissivities

Surface	Emissivity
Contents (Pu oxide,)	0.90
PCV/SCV/3013 Outer Can & Inner Can	0.30[20]
Air Shield/3013 Convenience Can	0.20
Drum Inner Surface	0.30
Drum Outer Surface (Initial HAC and NCT)	0.21
Drum Outer Surface (fire phase HAC)	0.90
Drum Outer Surface (Post-fire Phase HAC)	0.80
Aluminum Bearing Plates/Shield Lid/Spacer	0.20[21]
Impact Absorber (Aluminum Honeycomb)*	0.20[21]
Lead Shielding Body (includes Stainless Steel Liner)	0.30[20]
Fiberboard Insulation	0.50

* Modeled as solid.

2.3.1 Benchmark Models

2.3 Thermal Models

Thermal models described in this section include all the inputs and assumptions. The 3013 container assembly consists of an outer container, an inner container, and a product can. The product can is also called convenience can. The inner can and convenience can assemblies from different package users differ only slightly in geometric dimensions and have negligible effect on the maximum and average gas temperatures in the CV. This is due to the fact that the maximum and average temperatures strongly depend on the thermal conductivity and the decay rate of the heat source. The thermal conductivity (k) of the contents used in the models is for the lowest density (2 g/cc) PuO_2 and is the minimum value ($k = 0.046$ Btu/ft-hr-°F) while the heat rate used is the maximum value 19 watts. These parameter values give conservative (higher) CV components and average gas temperatures.

This section is divided into three subsections that describe Benchmark models, NCT models and HAC models. Benchmark models compare the results of P/Thermal models and the FLUENT models. Results from the FLUENT models form the basis for NRC certification. P/Thermal NCT models will demonstrate the consistency between the FLUENT and P/Thermal models. P/Thermal models are not repeated for HAC analyses and only FLUENT results are presented for the HAC fire analyses. It should be noted that each computer code is separately benchmarked to meet the SRS software quality requirements that consist of Software Quality Assurance Plan (SQAP) and a Test Plan that includes number of problems and solutions from text books, references, and other computer codes. These documents are presented as appendices for NRC information.

The benchmark models compare the results from FLUENT and P/Thermal computer codes. The results from different commercially available computer codes vary a little depending on the model assumptions, analyst experience with the code, computational algorithm and the geometrical complexity. To minimize these uncertainties, a simple model that mimics the 9975 geometry and its important attributes was constructed for comparison. Attributes that are maintained in the simple benchmark models are:

1. Package outer geometry in upright orientation
2. Amount of *insulation*
3. Containment vessels, shield and bearing plates are approximately combined into one stainless steel metal mass
4. 3013 outer container dimensions
5. Heat source heat rate of 19 watts
6. Boundary conditions

Small gaps, small thicknesses, vessel curved surfaces, and materials that are small in quantity are ignored. Since the method of application of convection correlations on the outer surfaces varies from code to code, only fixed convection coefficients for the outer geometry are applied. Experience has shown that convection effects in typical package internal gaps and cavities are negligible and, therefore, convection is applied on the outer surfaces only. In addition, P/Thermal does not have the capability to estimate convection effects inside the package cavities. Surface to surface radiation heat transfer is applied inside the gaps and cavities. Radiation heat transfer in cavities containing obstructing surfaces is included. Material properties are same as in the actual 9975 package but only fixed values close to the expected temperatures are applied. No attempt is made to ensure that the model weight is same as the actual package weight and only steady state analyses for NCT/Solar and NCT/Shade cases are examined.

The boundary conditions are:

1. Bottom adiabatic
2. Ambient temperature 100°F
3. Convection and radiation cooling to the ambient
4. Solar flux assuming an absorptivity of 0.50 for the stainless steel surface (medium finish, rolled) and thermal emissivity of 0.21.

P/Thermal is a conduction-radiation based computer code. The computational algorithm follows finite-difference resistor network formulation. Radiation heat transfer uses gray body assumption with view factor based resistor network formulation. ANSYS FLUENT is a full Navier-Stokes based equation solver via the Computational Fluid Dynamics (CFD) method. The code is an unstructured, finite volume-based solver, and it is used for a wide range of flow and heat transfer modeling applications. The code preprocessor provides geometric capabilities by using the facility of multi-block, or block-unstructured grids; *i.e.*, the grid may be constructed by gluing together an arbitrary number of topologically-rectangular grids, or blocks. The present work took a two-dimensional axisymmetric CFD approach considering the conduction-radiation coupled heat transfer mechanism. The modeling domains for the 9975 package considered for the benchmarking are shown in Fig. 2 to calculate the temperature distributions inside the domain of the benchmark model.

<u>P/Thermal Model and Results</u>

Since the package geometry is cylindrical and the boundary conditions are symmetrical, axisymmetric models are built. Figure 2 shows the geometry discretization of the model with colors representing the different materials. Figures show only <u>half</u> the model as a representative of axisymmetric package geometry.

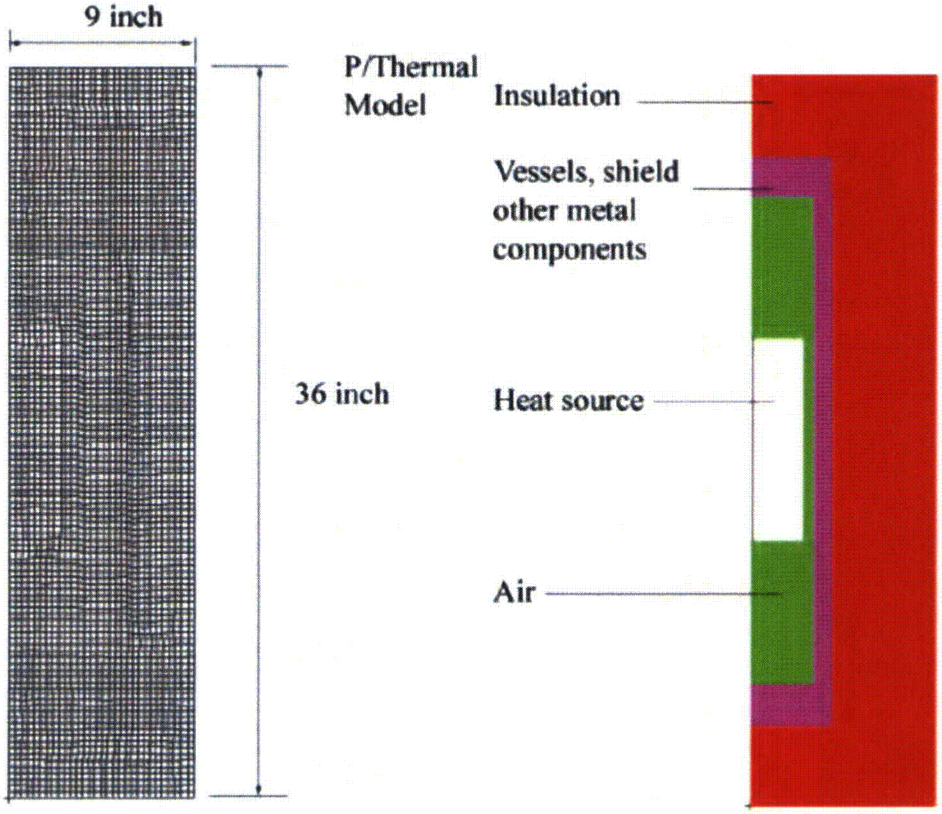

Figure 2: Model Discretization and Materials

Model temperatures for the insulation, vessels, and the heat source are shown in Table 5. The table presents maximum temperatures for the package components. Figure 3 shows the temperature profiles with solar and without solar (shade).

Table 5: P/Thermal Model Results

Analysis	Insulation (^oF)	Vessels (^oF)	Source (^oF)
Solar	249	250	438
Shade	193	194	388

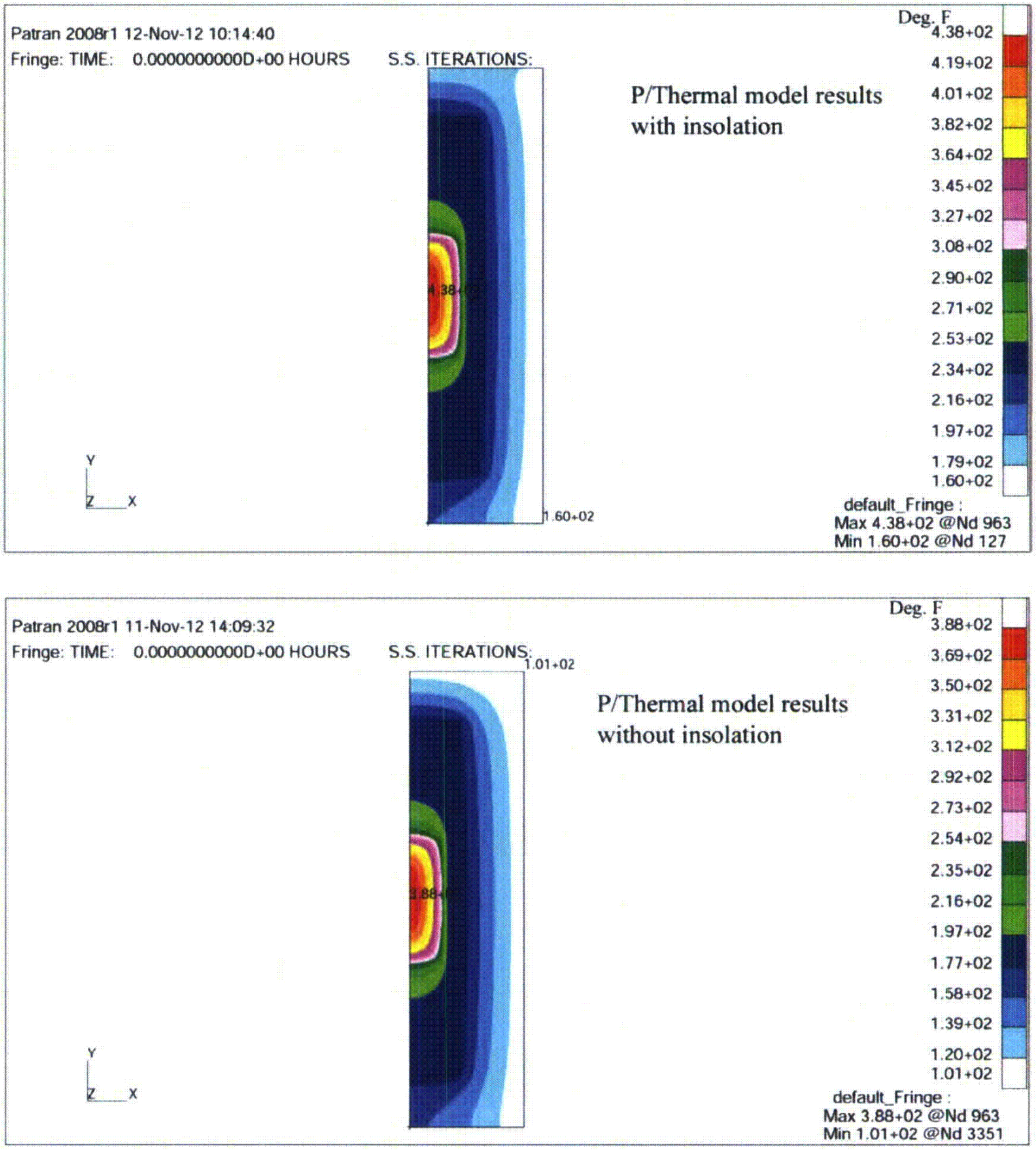

Figure 3: Benchmark model results with and without insolation

FLUENT Model and Comparison of P/Thermal Results

FLUENT model used the same package geometry as that of the P/Thermal model for the benchmark against the P/Thermal results. Figure 2 shows the model with colors representing the different materials. About 19,000 mesh nodes were used for the benchmarking analysis.

Figure 4 shows the temperature profiles with solar and without solar (shade). Maximum temperature predictions for the insulation, vessels, and the heat source are compared with those of the P/Thermal model in Table 6. The results show that The FLUENT model predicts the component temperatures within 1% relative difference, as compared with the P/Thermal model.

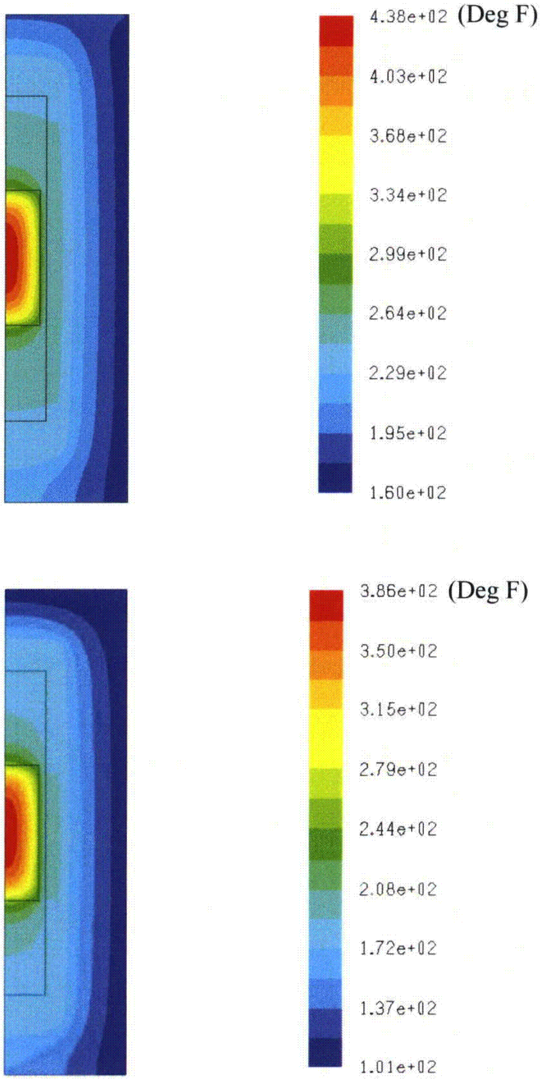

Figure 4: Benchmark model results with and without insolation (FLUENT model)

Table 6: Comparison of P/Thermal and FLUENT Models

Analysis	Insulation (^oF)		Vessels (^oF)		Source (^oF)	
	P/Thermal	FLUENT	P/Thermal	FLUENT	P/Thermal	FLUENT
Solar	249	252	250	253	438	438
Shade	193	192	194	193	388	386

Benchmark of FLUENT Model against Theoretical Results

Theoretical approach for combined conduction and radiation in a non-absorbing medium such as air is taken to verify the present FLUENT model under the simplified physical two-dimensional conditions of 9975 package as shown in Fig. 5. The thermal and material coefficients of the package and air medium were assumed to be independent of the temperature for the benchmarking analysis.

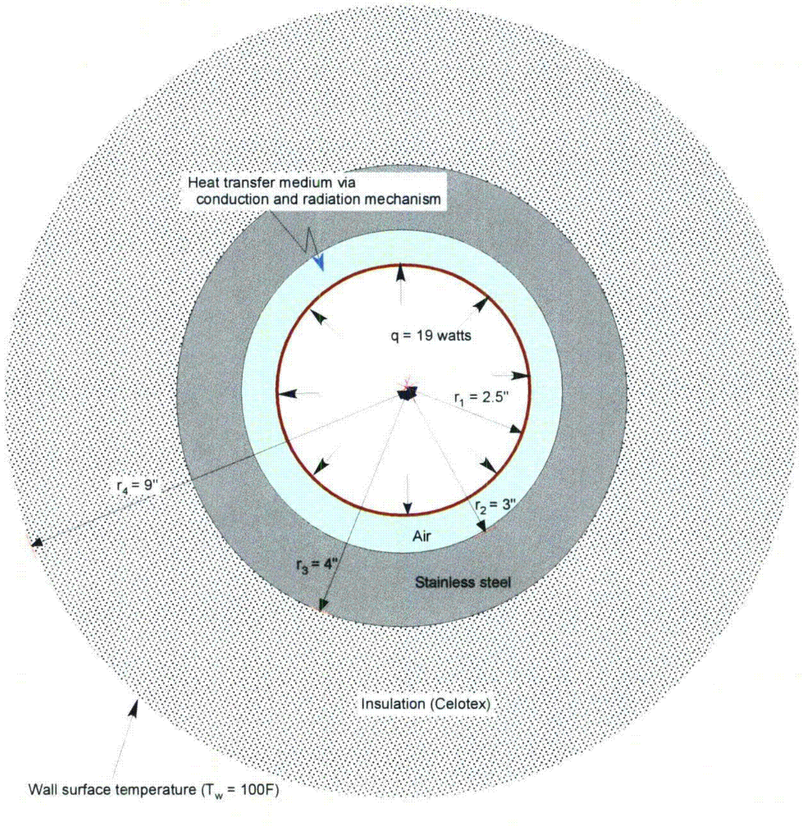

Figure 5: Theoretical steady state model to compute temperature distribution to include the conduction and radiation.

For the regions of the annular region of the cylindrical geometry, heat transfer rate per unit length through the annular insulation, stainless steel, and air region becomes

$$q = \frac{2\pi k_i}{\ln\left(r_{i+1} / r_i \right)} \left(T_i - T_{i+1} \right) \text{ for the solid region } \left(r_i \le r \le r_{i+1} \right) \quad (1)$$

$$q_{cond} = \frac{2\pi k_g}{\ln\left(r_2 / r_1 \right)} \left(T_1 - T_2 \right) \text{ for the air region } \left(r_1 \le r \le r_2 \right) \quad (2)$$

k_g in eq. (2) denotes thermal conductivities for the air region. Through the annular region with air thermal conductivity k_g $(r_1 \le r \le r_2)$, steady-state heat transfer rate per unit length (q) with radiative cooling (without convective cooling) becomes

$$\begin{aligned} q &= \left(q_{cond} + q_{rad} \right) \\ &= \frac{2\pi k_g}{\ln\left(r_2 / r_1 \right)} \left(T_1 - T_2 \right) + \frac{2\pi\sigma r_1}{1/\varepsilon_1 + \left(r_1 / r_2 \right)\left(1/\varepsilon_2 - 1 \right)} \left(T_1^{\,4} - T_2^{\,4} \right) \end{aligned} \quad (3)$$

q in eqs. (1) to (3) is given by the source term, 19 watts, at the inner wall surface under steady state condition. When the temperature at the outer wall boundary line (T_w = 100°F) is given by the boundary condition as shown in Figure 5, material component temperatures as well as wall temperature at the source surface of the annular cylinder (T_1) can be computed from Eqs. (1) and (3) for a given heat flux 47.63 W/m^2 at the source wall corresponding to the PuO_2 source (5 inch diameter) of 19 watts per unit height. In this case temperature solutions can be obtained by an iterative technique numerically. For the purpose of the CFD model benchmarking against the theoretically calculated results, the wall temperatures of the cylindrically annular geometry were computed by using the Excel spreadsheet when the heat flux is imposed on the source wall surface. Table 7 shows benchmarking results for the conduction-radiation coupled model in simplified annular cylinder as shown in Figure 6. The bemchmarking results show that FLUENT predicts each of the components within 0.5°F.

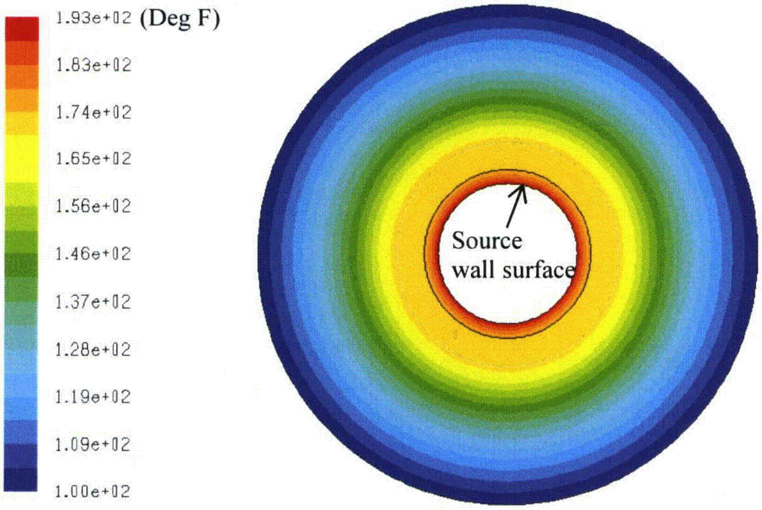

Figure 6: Benchmark model results without insolation (FLUENT model)

Table 7. Benchmarking results for the conduction-radiation coupled model in simplified annular cylinder as shown in Fig. 5

Parameters	Max. Temperature (°F)		
	Source Wall Surface	Stainless Steel	Insulation
Theoretical results	192.5	173.7	173.6
FLUENT	192.5	173.6	173.2

2.3.2 NCT Thermal Models

The models for the Normal Conditions of Transport (NCT) were developed for the actual 9975 geometry using both P/Thermal and FLUENT codes. The results from the two codes will demonstrate the consistency in the existing and the new results. The results from FLUENT provide the basis for the 9975 NRC review and certification. Boundary conditions used in the models either satisfied or were more limiting than those specified for NCT in 10CFR 71.71[14]. In the thermal analysis, the limiting components are the containment vessels, their O-ring seals, shielding and the insulation. Temperature limits for these components for the NCT are tabulated along with predicted maximum temperatures for each individual model configurations. The 9975 model for all NCT analyses includes interior metal surfaces, namely the aluminum base plates, aluminum spacers, stainless steel air shield and the cladding around the lead shielding. Figure 5 shows a material representation of an axisymmetric model of the 9975 package with one 3013 container.

Other specific applications of tabulated parameters are summarized in the description of the NCT model. The convection correlations are listed in Table 8.

The drum surface absorptivity for the solar radiation is based on *as received* stainless steel surface with a *medium* finish. The absorptivity and emissivity values are obtained by integrating the solar intensity and thermal radiations over the applicable wavelength spectrum.[11] A total absorptivity value of 0.498 (• 0.50) and a total emissivity value of 0.21 are used in the NCT analysis. A sensitivity analysis is performed to evaluate the variation in drum surface finish from polished to very dull surface. 10 CFR 71.71 prescribes a total insolation energy of 800 cal/cm^2 over a period of 12 hours on a horizontal surface and 400 cal/cm^2 over a period of 12 hours on the vertical surface. The package is normally transported in upright orientation. Therefore, the corresponding time averaged heat fluxes are 245.77 Btu/ft^2-hr on the top of the package and 122.88 Btu/ft^2-hr on the side of the package. The applied solar fluxes using absorptivity of 0.50 are 122.88 Btu/ft^2-hr on the top of the package and 61.44 Btu/ft^2-hr on the side of the package.

Description of the NCT Model

All NCT calculations were performed under the following conditions:

1. The drum is in an upright position.
2. The bottom surface is adiabatic.
3. There is radiative heat transfer from the sides and top of the drum to the ambient.

4. There is natural convection heat transfer from the sides and top of the drum to the ambient. Natural convection correlations used in the model are listed in Table 8.
5. The ambient temperature is 100°F.
6. Insolation is applied as solar heat flux. There is a total insolation heat fluence of 2,949 Btu/ft^2 (800 cal/cm^2) over a period of 12 hours on top of the drum and 1,474 Btu/ft^2 (400 cal/cm^2) over a period of 12 hours on the side of the drum. The surface absorptivity for clean drum surface is assumed to be 0.5. The corresponding time averaged heat fluxes are 245.77 Btu/ft^2-hr on the top of the package and 122.88 Btu/ft^2-hr on the side of the package. The applied solar fluxes are 122.88 Btu/ft^2-hr on the top of the package and 61.44 Btu/ft^2-hr on the side of the package. These heat fluxes are applied continuously rather than as a step function with a period of 12 hours.
7. The content contains heat source outputting a maximum of 19 watts uniformly distributed in the 3013 container.
8. The NCT thermal model is analyzed as a steady-state model.

Table 8: Natural Convection Heat Transfer Coefficients[2]

Model Orientation	**Surface**	**Correlation** (Btu/hr-ft^2-°F)
Vertical	isothermal plate with $Ra < 1.0 \times 10^9$	$h = \left(\frac{k}{L}\right)\left(0.68 + \frac{0.670 \times Ra^{0.25}}{\left[1.0 + \left(\frac{0.492}{Pr}\right)^{9/16}\right]^{4/9}}\right)$
Vertical	isothermal plate with $1.0 \times 10^9 < Ra$	$h = \left(\frac{k}{L}\right)\left(0.825 + \frac{0.387 \times Ra^{1/6}}{\left[1.0 + \left(\frac{0.492}{Pr}\right)^{9/16}\right]^{8/27}}\right)^2$
Horizontal	hot isothermal plate facing upward with $2.6 \times 10^4 Ra < 1.0 \times 10^7$	$h = \left(\frac{k}{L}\right) 0.54 \times Ra^{0.25}$
Horizontal	hot isothermal plate facing upward with $1.0 \times 10^7 < Ra < 3.0 \times 10^{10}$	$h = \left(\frac{k}{L}\right) 0.15 \times Ra^{1/3}$
Horizontal	hot isothermal plate facing downward with $3.0 \times 10^5 < Ra < 3.0 \times 10^{10}$	$h = \left(\frac{k}{L}\right) 0.27 \times Ra^{0.25}$

Where[1]: Ra = Rayleigh number based on plate height.
h = Convection heat transfer coefficient.

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[1] Note that all properties in the correlations are based on the film temperature.

k = Thermal conductivity of gas (air).
L = Characteristic length of plate.

The characteristic length L for the vertical plate is the height of the drum in upright orientation. For the horizontal plate it is: surface area/perimeter of the plate.

P/Thermal Model
Figure 7 shows the axisymmetric model created on P/Thermal. Only half the model is shown. The model has about 12,000 elements or cells. The colors represent the different materials.

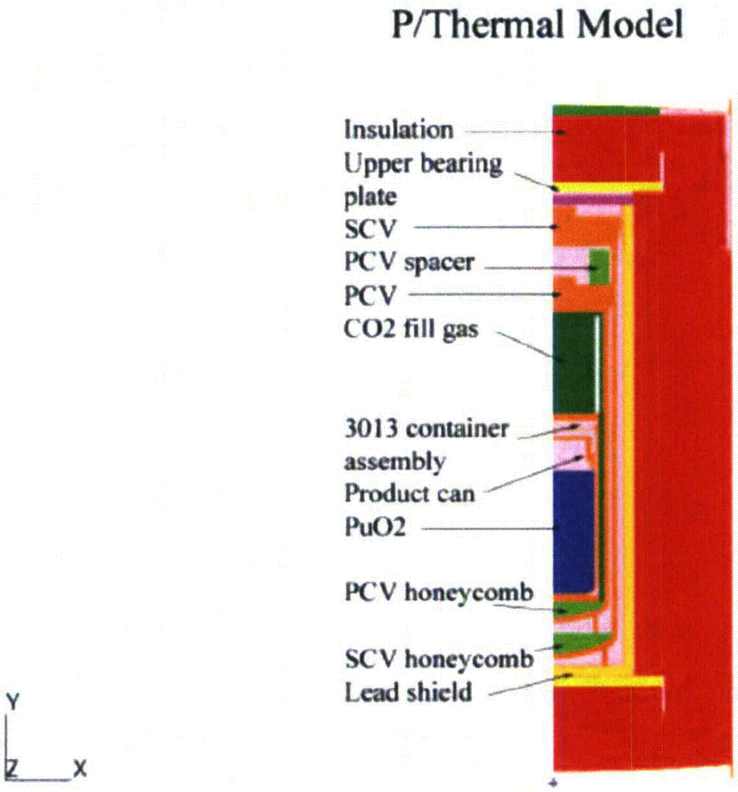

Figure 7: Material Representation of the 9975 Package P/Thermal Model

FLUENT Model
Figure 8 shows the FLUENT model created on Computational Fluid Dynamics (CFD) environment. The modeling analysis used the CFD method to solve the control volume-averaged energy balance equation for the entire computational domain via an iterative technique. The model has about 25,000 nodes based on axisymmetric two-dimensional approach, which represents a cylindrical 9975 package with respect to axisymmetric line as shown in Figure 8.

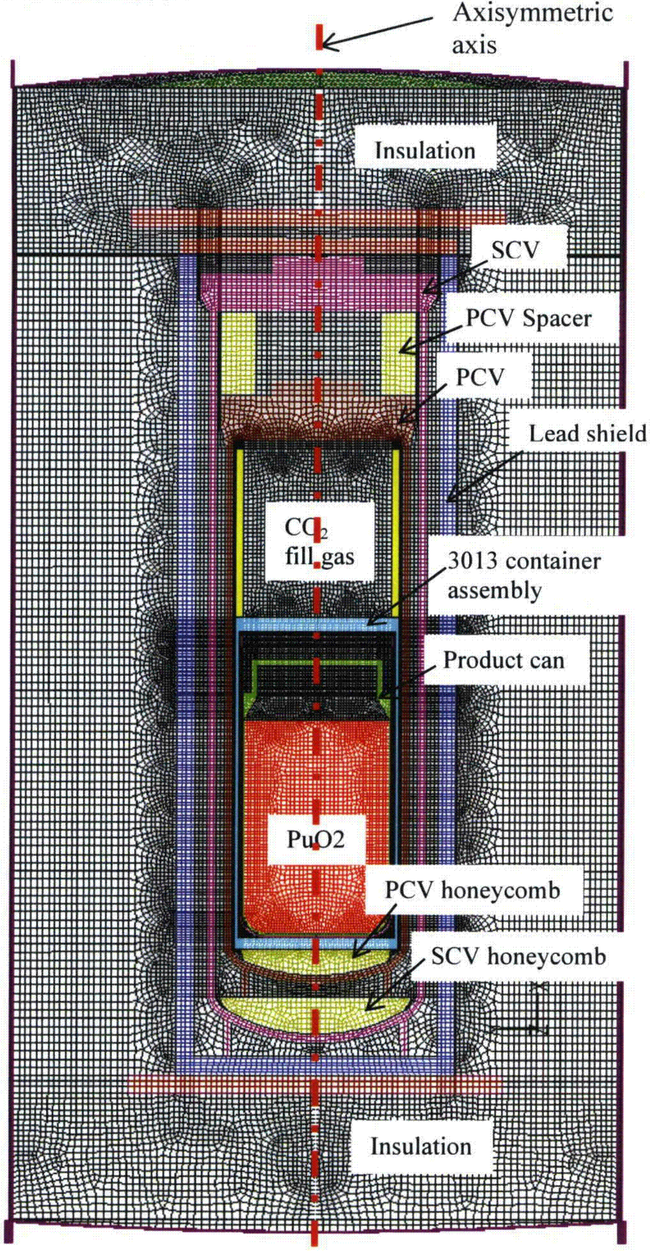

Figure 8: Material Representation of the 9975 Package in FLUENT Model

2.3.3 HAC Thermal Models

The HAC thermal model consists of three sequential phases, corresponding respectively to the pre-fire, fire and post-fire conditions. The pre-fire model, which is identical to the model for NCT except that insolation is neglected, determines the temperature profile in the package prior to the HAC fire transient. The pre-fire model considering *no insolation* is based on Table 1 in NRC Regulatory Guide 7.8 Rev. 1[15] and Section 3.5 of the NNSA

Packaging Safety Guide SG-100[16]. The fire transient determines the bounding package temperature, with respect to a 10 CFR 71.73 fire. The post-fire transient phase is used to predict the maximum temperature of the components of the 9975 immediately after the fire has been extinguished. The post-fire steady state phase determines the final HAC temperatures.

Thermal properties of the fiberboard during the HAC transient are given in Table 2. As indicated in Section 2, the fiberboard properties are effective properties to simulate the lumped effect of pyrolysis of fiberboard and the heat and mass transfer during the HAC fire event. The properties were determined by trial and error to match the temperatures observed during fire tests (Appendix 3.2, Reference [1]). Enhanced thermal properties essentially simulate heat and mass transfer of hot gases from the pyrolysis of fiberboard during fire into the virgin fiberboard. These properties are not applicable for the post-fire steady state conditions.

Thermal models for the 9975 pre-fire, fire and post-fire HAC are developed with the FLUENT general purpose heat transfer software. The models include interior metal surfaces, namely the aluminum base plates, aluminum spacers, stainless steel air shield and the cladding around the lead shielding. The limiting components of the package for the HAC are the containment vessel and the O-ring seals. Temperature limits for components of the 9975 for the HAC are tabulated along with predicted maximum temperatures for each model.

During the HAC transient, the ambient temperature was 1475°F for the first 30 minutes and 100°F thereafter. The initial condition for the HAC transient was identical to the steady-state NCT, except insolation was excluded. In the 30 minute fire phase, all sides of the drum (including the bottom) are heated by forced convection and radiation. The cooldown phase occurs immediately after the 30 minute fire. During this phase the drum is exposed to a 100°F ambient temperature and insolation on the drum top and side (as in NCT) is included. During the cooldown phase, the bottom of the drum transfers heat to the ambient by radiation only. The top and sides of the drum transfer heat to the ambient via both radiation and natural convection. The entire HAC transient consists of the 30 minute fire plus 8 hours of cooldown. The conditions for the three phases of the HAC are given below.

For the initial phase of the HAC:

1. The drum is in an upright position.
2. The bottom surface is adiabatic.
3. There is radiation heat transfer from the sides and top of the drum to the ambient.
4. There is natural convection heat transfer from the drum sides and top to the ambient.
5. The ambient temperature is 100°F.
6. Insolation.
7. Undamaged fiberboard properties are applied to all the fiberboards in the drum.

8. 19 watts total decay power.

For the fire phase of the HAC:

1. The package is in upright orientation. This simulates the package on a fire test stand raised about a meter from the combustible fuel surface.
2. There is forced convection from all surfaces of the drum. The convection coefficients are (Ref. 1 Appendix 3.2):
   - i. 5.9 Btu/hr-ft^2 °F for the top and bottom of the drum.
   - ii. 3.0 Btu/hr-ft^2 °F for the side of the drum.
3. There is thermal radiation heat transfer from all surfaces of the drum to the ambient.
4. The ambient temperature is 1475°F.
5. No insolation.
6. Fire phase fiberboard properties are applied to all the fiberboards in the drum[2].
7. 19 watts total decay power.

For the fire post-fire phase of the HAC:

1. The drum is in an upright position.
2. There is thermal radiation from the top, sides and bottom of the drum to the ambient.
3. There is natural convection from the top and sides of the drum to the ambient. Convection coefficients were obtained from correlations in Table 8.
4. The ambient temperature is 100°F.
5. There is a total insolation heat fluence of 2,949 Btu/ft^2 (800 cal/cm^2) over a period of 12 hours on top of the drum and 1,474 Btu/ft^2 (400 cal/cm^2) over a period of 12 hours on the side of the drum. Since the drum surface is dark and rough from the fire exposure, the surface absorptivity is assumed to be 1.0. The corresponding time averaged heat fluxes are 245.77 Btu/ft^2-hr on the top of the package and 122.88 Btu/ft^2-hr on the side of the package.
6. "Char layer" properties are applied to the outer 1.4 inch layer of the top, bottom and sides of the fiberboard contained in the drum[2]. The 1.4 inch char layer and the insulation region during the post-fire phase of the HAC are shown in Figure 9.
7. Fire phase properties are applied to the all fiberboard not in the 1.4 inch outer layer[2].
8. 19 watts total decay power.

Tables 1, 2, and 3 contain the material properties and Table 8 contains the convection correlations used in the HAC analyses.

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[2] The fiberboard properties used during the fire analyses were developed from extensive testing [4].

Post-Fire Steady State Phase:
The HAC fire models cannot predict the post-fire steady state behavior. The thermal properties of the charred fiberboard under steady state conditions are not known. Therefore, char properties are assumed same as air with zero transmissivity and no convection. In addition, the un-charred fiberboard thermal properties are assumed approximately same as the virgin fiberboard since most of this fiberboard was not greatly affected by the fire.

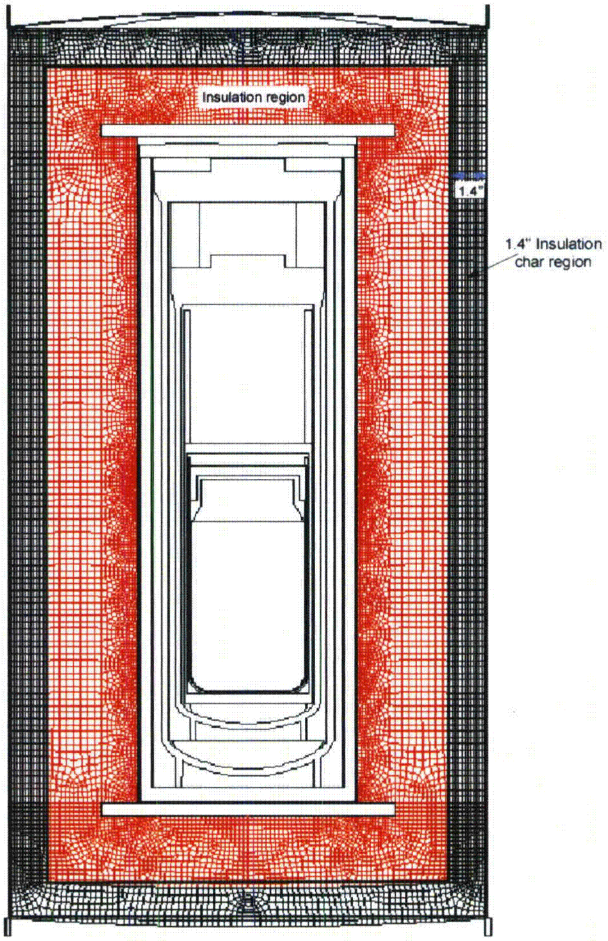


Figure 9: Insulation and char configurations in the Postfire HAC models

It is recognized that the temperature of the internal components of the package continues to rise after the fire has been extinguished. This phenomenon is due to the transfer of heat from higher temperature components lying near the hot outer surface of the package to the cooler inner components, as well as toward the outside surface of the package as it cools.

Following the fire the cooling rate of the package is controlled by heat generation from the internal 19W source, insolation and the amount of insulation surrounding the internal components.

3.0 Analytical Methods and Computations

The finite element models were developed and analyzed using the P/Thermal® and FLUENT general purpose heat transfer computer codes. The codes are verified in accordance with the SRNS software QA program.[17,18] The documentation is in accordance with the SRNS Conduct of Engineering Manual E7.[19] The results of the analyses are summarized in Section 4.0.

4.0 Results

4.1 NCT Analyses (NCT/Solar)

NCT analyses are performed using both P/Thermal and FLUENT codes.

4.1.1 NCT Temperatures

The NCT models using P/Thermal and FLUENT codes were analyzed for a total heat load of 19 watts. The steady state temperatures for the critical components are summarized in Table 9. A review of the Table 8 shows that maximum temperatures for the components are below their temperature design limits. The comparison for the two computer codes shows that the results are quite compatible and consistent. The component temperatures are well below their design limits.

Table 9: Maximum Component Temperatures during NCT Solar

Component	P/Thermal (°F)	FLUENT (°F)	Temperature Limit (°F)
PCV	236	239	400
PCV O-rings	219	219	400
SCV	223	225	400
SCV O-rings	212	216	400
Insulation	214	214	250
Drum	188	187	800
Contents	471	466	NA
Shield	215	216	622
PCV Cavity (Average)	273	271	313

Temperature plots for the full model, PCV, SCV and the insulation are shown in Sections 4.1.1 and 4.1.2.

P/Thermal Temperature Plots

Temperature profiles for the overall package are shown in Figure 10, temperature profiles for the PCV and SCV are shown in Figure 11, and temperature profiles for the insulation are shown in Figure 12.

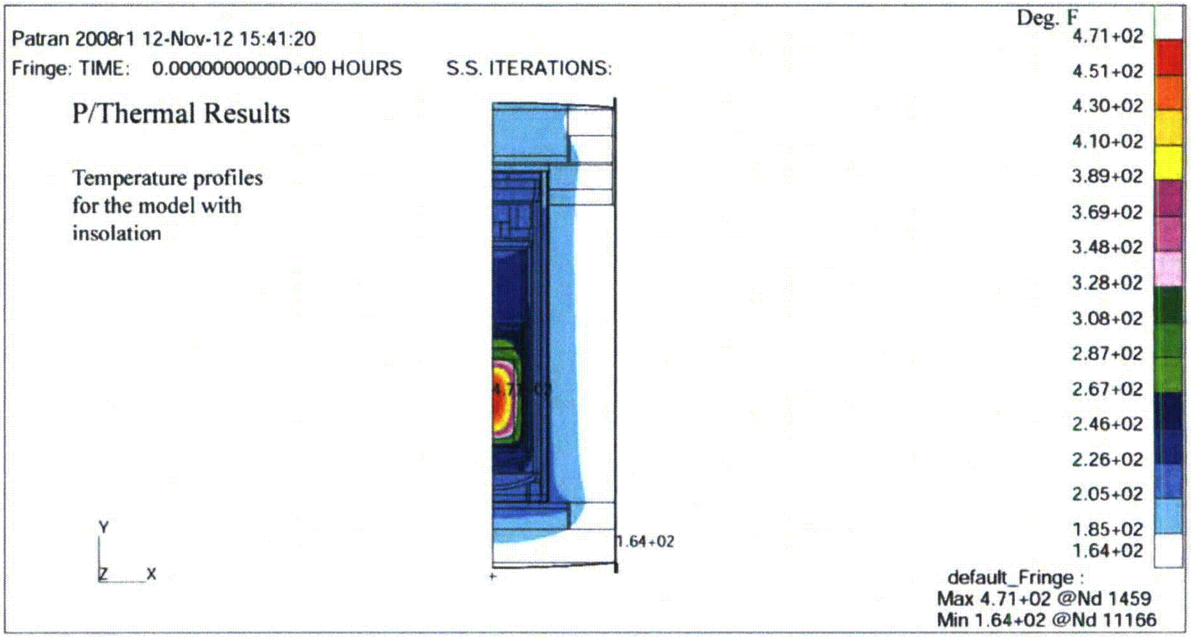


Figure 10: Temperature profiles for the NCT with Insolation

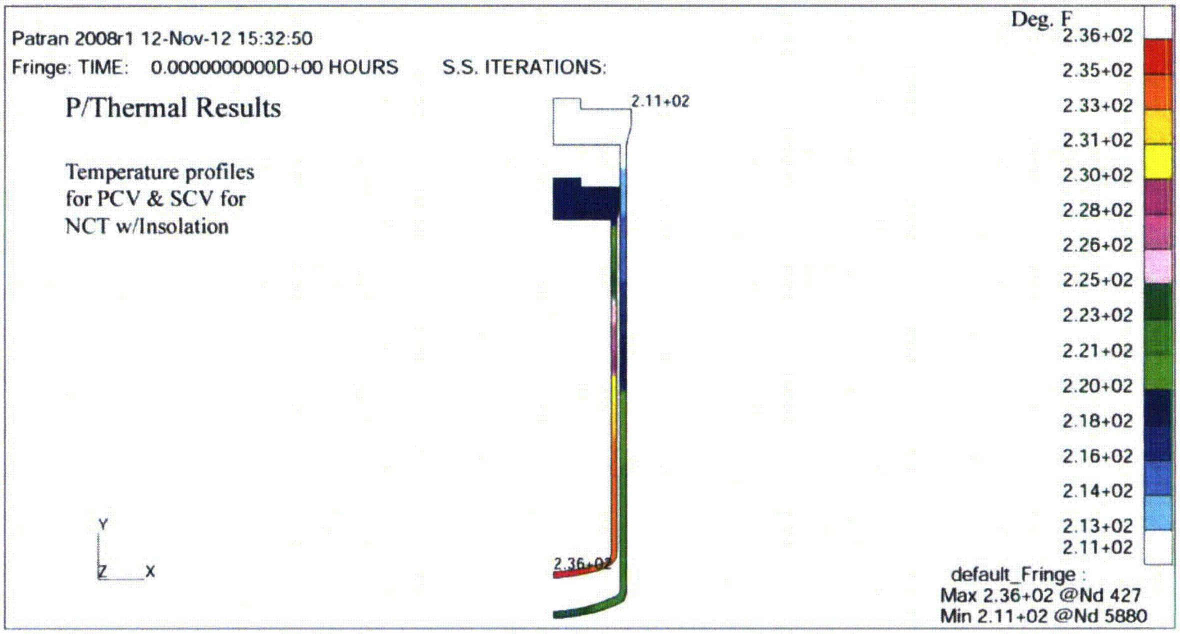


Figure 11: PCV/SCV temperature profiles for NCT with Insolation

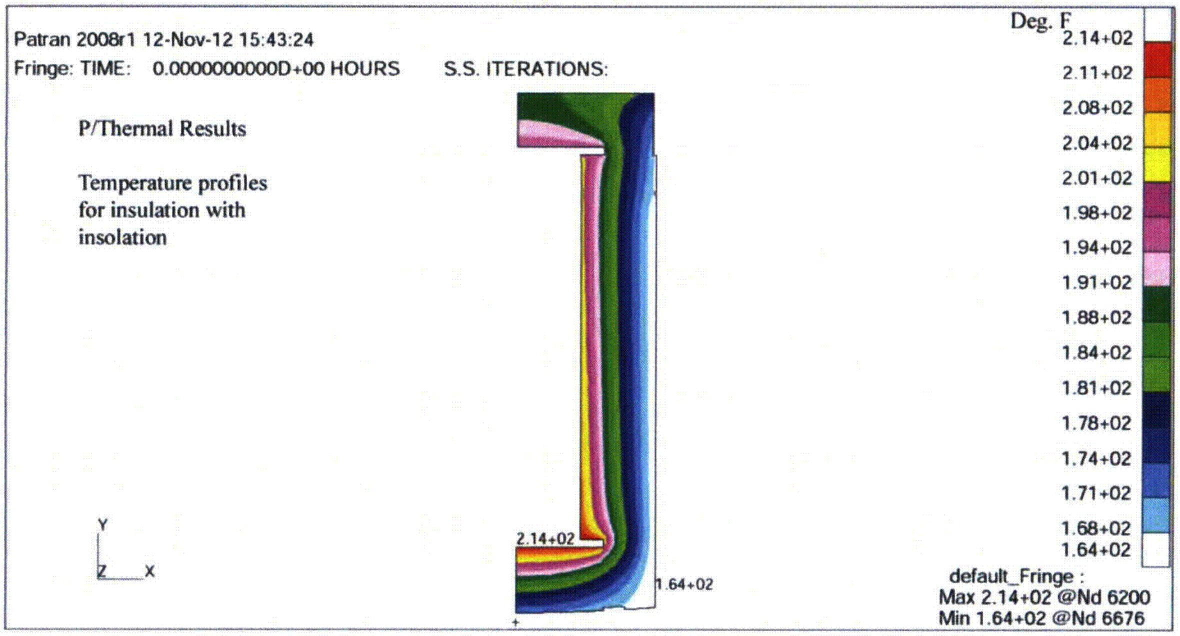


Figure 12: Insulation temperature profiles for the NCT with Insolation

FLUENT Temperature Plots

Temperature profiles for the overall package are shown in Figures 13, temperature profiles for the PCV and SCV are shown in Figure 14, and the temperature profiles for the insulation are shown in Figure 15.

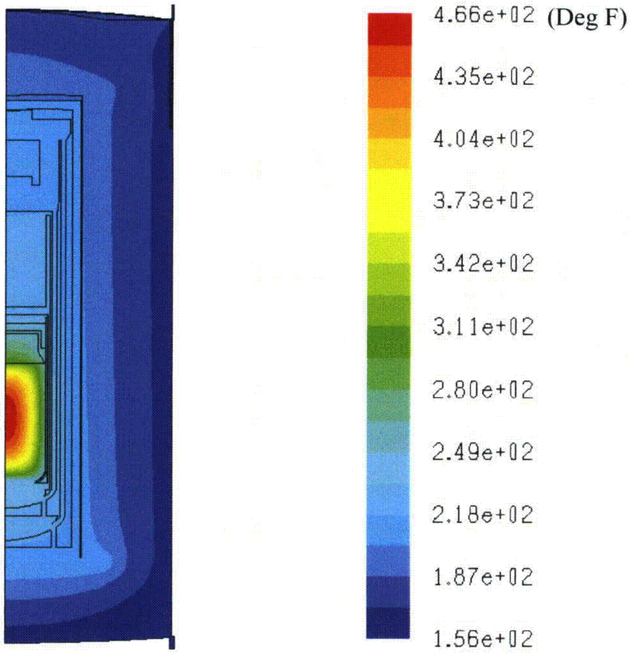


Figure 13: Temperature profiles for the NCT with Insolation

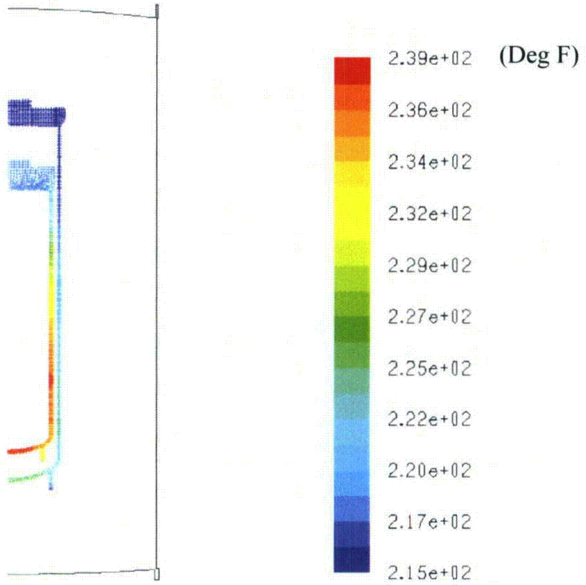


Figure 14: PCV/SCV temperature profiles for NCT with Insolation

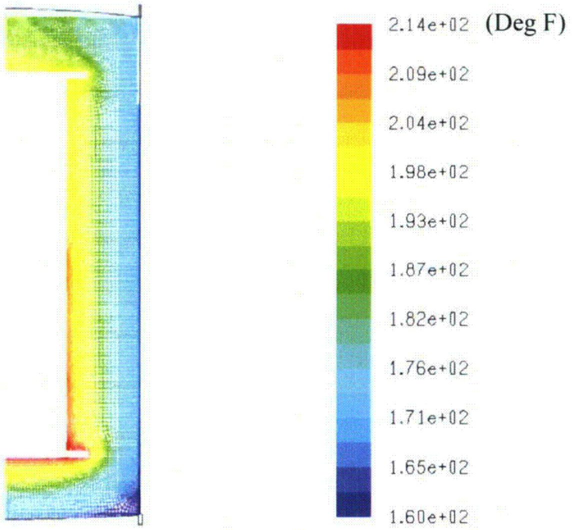


Figure 15: Insulation temperature profiles for the NCT with Insolation

As mentioned in Section 2.3.2, a sensitivity analysis was performed to study the impact of variation in drum surface finish on the NCT temperatures. The results of this analysis are summarized in Section 4.3. The sensitivity analysis shows that the component temperatures for the *as received (medium)* surface finish, assumed in the above results, bound the temperatures for the polished and very dull surface finishes.

4.1.2 NCT Results without Insolation (NCT/Shade)

The NCT/Shade models using P/Thermal and FLUENT codes were analyzed for a total heat load of 19 watts. The steady state temperatures for the critical components are summarized in Table 10. The comparison for the two computer codes shows that the results are quite compatible and consistent. NCT/Shade results form the initial conditions for the fire analysis.

Table 10: Maximum Component Temperatures during NCT Shade

Component	P/Thermal (°F)	FLUENT (°F)	Temperature Limit (°F)
PCV	181	181	400
PCV O-rings	162	160	400
SCV	167	166	400
SCV O-rings	154	156	400
Insulation	157	155	250
Drum (Bottom)	115	114	122[a]
Contents	419	411	NA
Shield	158	156	622
PCV Cavity (Average)	219	215	313

[a] 10 CFR 71.43(g)

Figure 16 shows the temperature profiles for the package. The results from FLUENT computer code form the basis (initial conditions) for the HAC analyses. As indicated before, HAC analyses were performed using FLUENT code only.

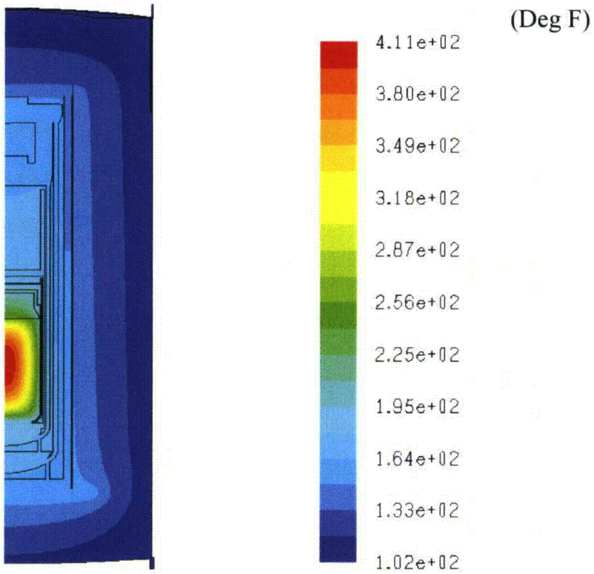


Figure 16: Temperature (°F) profiles for the NCT/Shade

4.1.3 Maximum Pressure Operating Pressure (MNOP) Evaluation

The maximum pressure evaluation follows the methodology followed in Appendix 3.6 of Reference [1]. Pressure contributions come from heating of the fill gases, helium production from PuO_2 alpha decay, and the radiolysis of moisture in the PuO_2. The pressure evaluation assumes that the product can, inner can, and the outer can leak into PCV. This gives pressure estimate in the PCV. Next, the PCV is also assumed to leak into SCV, this will yield pressure estimate into SCV.

The fill gases are assumed to be at the ambient temperature of 70°F and the normal atmospheric pressure of 14.7 psia. The time period for alpha decay is assumed to be 2 years and the moisture is assumed to be 25 grams, 0.5% of the 5 kg of PuO_2. The free volumes (gaseous spaces) in the various vessels were calculated in Ref. 1 Appendix 3.6 (Table 3) and are summarized in Table 11. The free volumes in each vessel include all the gaseous spaces following the leak. The corresponding gas masses (lb-moles) M are calculated using the perfect gas law $PV = MR_oT_{initial}$, where P is the pressure in psia, V is the free volume in ft^3, $R_o = 10.73$ psi-ft.^{3}/lb-moles-R is the universal gas constant, $T_{initial} = 529.6$ R is the absolute temperature in Rankin.

Table 11: Free Volumes and Gas Masses

Item	3013 Container	PCV	SCV
Free Volume, ft3	0.0423	0.1005	0.1986
Mass, lb-moles	1.09E-04	2.60E-04	5.14E-04

Per Ref. 1 Appendix 3.6, helium production in 2 years is 5.22E-06 lb-moles, and hydrogen from radiolysis is 3.062E-03 lb-moles. These gas masses remain same as they leak out into PCV or into the SCV. The total mass for these two gases is 3.06722E-03 lb-moles. The total of all gases in each of the three vessels is:

M (3013) = 1.09E-04 + 3.06722E-03 = 3.176E-03 lb-moles
M (PCV) = 2.60E-04 + 3.06722E-03 = 3.327E-03 lb-moles
M (SCV) = 5.14E-04 + 3.06722E-03 = 3.584E-03 lb-moles

The maximum pressures at the end of heating from all NCT thermal loading can now be calculated using the perfect gas law $PV = MR_oT_{final}$. $T_{final} = 271 + 459.6 = 730.6$ R. The pressure calculations are required for the PCV and the SCV only.

P (PCV) = MR_oT_{final}./V = 3.327E-03*10.73*730.6/0.1005 = 259.52 psia = 244.8 psig
P (SCV) = MR_oT_{final}./V = 3.584E-03*10.73*730.6/0.1986 = 141.47 psia = 126.8 psig

The MNOP calculations in Reference [1] are based on the maximum gas temperature of 313°F as determined in Appendix 3.17. Therefore, the MNOP estimates of the PCV, 365.4 psig, and the SCV, 165.4 psig from Appendix 3.6 of Reference [1] are bounding.

4.2 HAC Analyses

The HAC thermal analyses are performed using FLUENT only.

4.2.1 HAC Temperatures

The average gas temperature in the PCV is well below the maximum gas temperature of 313°F in Reference [1]. Therefore, the maximum pressure estimates of the PCV and the SCV in Reference [1] are bounding.

The results for the HAC fire include the temperatures for the pre-fire, fire, and the post-fire phases. For the analysis, the pre-fire temperatures are presented in Section 4.1.1 as NCT results with insolation, instead of NCT results with shade for the baseline analysis as done in Rev. 0,. In this case, the pre-fire results of the insolated NCT steady state temperatures form the initial pre-fire conditions for the 30 minute fire analysis. The post-fire transient phase is used to predict the maximum temperature of the components of the 9975 immediately after the fire has been extinguished.

The transient HAC post-fire phase used the initial conditions identical to the thermal results of the 30 minute fire starting with the insolated NCT steady state results. The results from the post-fire HAC model with NCT solar initial used for the pre-fire conditions are shown in Table 12. The tabulated results show the transient O-ring and maximum PCV and SCV temperatures in terms of the hours following the end of the fire. Maximum temperatures occurring during the transient are highlighted in bold red. Steady-state O-rings and maximum vessel temperatures, attained as the post-fire transient continues for an infinite period of time, are listed at the bottom of Table 12. The maximum temperatures of the limiting components and the contents and their design limits are summarized in Table 13. As shown in the table, the HAC results for the NCT solar pre-fire case are compared with those of the NCT shade. It is noted that the maximum PCV gas temperature for the NCT solar pre-fire temperatures is about 11 °F higher than that of the NCT shade initial during the transient post-fire phase.

The maximum temperature of the PCV occurs at about 1 hour into the post-fire phase. The contents reach their maximum value about 1.5 hours later than the maximum temperature of the PCV. Figure 17 shows the temperature profiles of the overall package at the moment the contents reach their maximum temperature. The maximum temperature of the PCV O-ring occurs at about 2 hours into the post-fire phase as shown in Figure 18. The maximum local SCV temperature of 309 °F shown in Figure 18 was localized on the vessel bottom within the first 30 minutes' period of HAC post-fire.

Table 12: Transient Post-Fire HAC Temperatures (°F) with NCT Solar Fire Initial

Time (hr)	PCV (°F)	O-rings (°F)	SCV (°F)	O-rings (°F)	Shield (°F)	Contents (°F)
0.0	255	222	273	226	327	466
0.5	288	237	309	248	332	471
1.0	296	251	297	259	297	485
1.5	293	259	282	262	273	498
2.0	285	262	270	262	254	505
2.5	279	262	261	260	240	506
3.0	274	260	255	255	228	504
3.5	268	256	250	250	217	500
4.0	262	251	244	244	210	495
4.5	256	246	239	239	206	490
5.0	251	241	234	234	203	484
5.5	246	236	230	230	200	479
6.0	242	231	225	225	198	474
7.0	234	223	218	218	194	466
8.0	228	217	212	212	191	460
SS	201	186	186	184	177	431
SS*	260	241	247	238	237	486

* Charred region filled with air (conduction only) and uncharred region with good fiberboard. These values are more realistic.

Table 13: Maximum Component Temperatures during HAC with NCT Solar Fire Initial

Component	Fire/Post-fire for NCT Shade Initial (°F)	Fire/Post-fire for NCT Solar Initial (°F)	Temperature Limit* (°F)
PCV/SCV	260	309	400
O-rings	241	262	400
Shield	237	332	662
Contents	486	506	N/A
Drum	1475	1475	2650
PCV Gas	292	303	313

* Drum limit based on the melting temperature of stainless steel; N/A – Not applicable.

Review of the results in Table 13 shows that the component temperatures are well below their design limits except for the SCV component temperature during the early period of the HAC post-fire. A comparison with NCT/Solar results (Table 9) shows that the maximum temperatures during HAC transient phase (Table 12) are above the NCT/Solar results. The component temperatures peak within 2.5 hours after the 30-minute fire. This is consistent with the fact that fiberboard insulation provides higher thermal conductivity during the fire transient as shown in Table 2. The HAC steady state temperatures are higher than the NCT/Solar steady state temperatures due to increased solar flux thermal loading on the fire blackened drum surface.

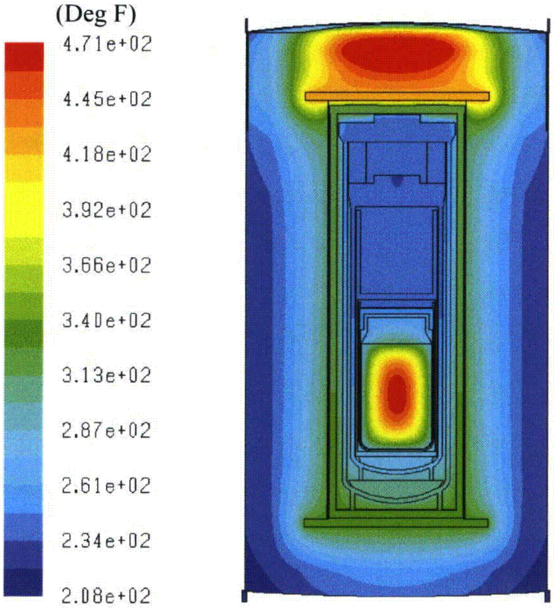


Figure 17. Package Temperatures during the 0.5 Hours' Period of Post-fire

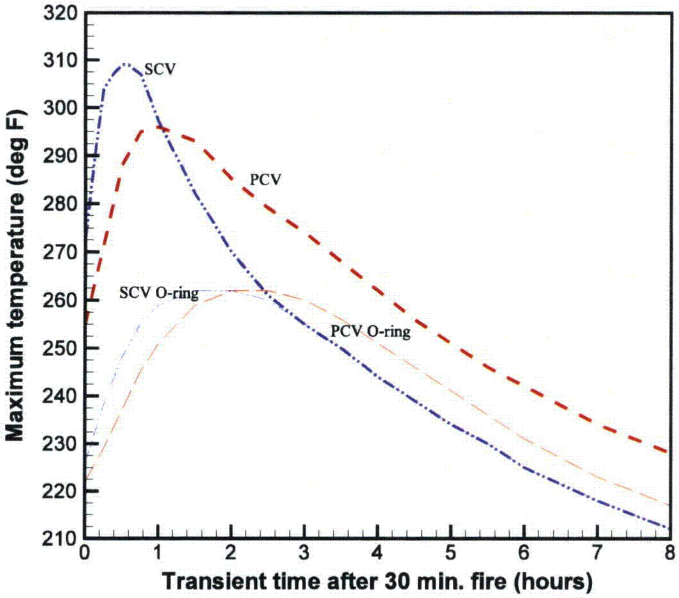


Figure 18: CV Temperatures during Post-fire with NCT Solar Fire Initial

4.2.2 HAC Pressure Evaluation

HAC pressure calculations follow the same steps as in MNOP calculations in Section 4.1.3. The gas molar masses remain the same as in Section 4.1.3. When the NCT solar steady state temperatures are used as the initial phase of the fire, the final temperature during HAC is 303°F, i.e. $T_{final} = 459.6 + 303 = 762.6$ R. The pressures can now be calculated.

$P (PCV) = MR_oT_{final}./V = 3.327E\text{-}03*10.73*762.6/0.1005 = 270.9$ psia = 256.2 psig
$P (SCV) = MR_oT_{final}./V = 3.584E\text{-}03*10.73*762.6/0.1986 = 147.7$ psia = 133.0 psig

4.3 Sensitivity Analyses

4.3.1 Mesh Size

A mesh sensitivity analysis was performed to assess the impact of finer finite element mesh on the package temperatures. For the P/Thermal analyses, the number of elements was increased from about 5800 to 12,000. The maximum content temperature was found to be same for both models. The results reported in this report are based on models with about 12,000 elements.

For the analysis, FLUENT models are based on 25,000 nodes, which were established by the mesh sensitivity analysis such that numerical solutions were independent of mesh sizes. Final number of the mesh nodes was established when maximum content temperature was changed less than 0.5°F at the finer meshes and energy residual reached less than 0.001 watts.

4.3.2 Drum Surface Properties

A second sensitivity analysis was performed to evaluate the impact of variation in drum surface finish on the package temperatures during NCT. Table 14 lists the drum surface finishes evaluated in Reference [4]. The drum surface finish evaluated in the analyses in this report is the *as received (medium)* finish. The two cases evaluated in the sensitivity analysis are the *asreceived (polished)* and the *as received (very dull surface)* finishes to cover the range of surface finishes for the drums. It should be noted that the drum surface is not ground, machined, sandblasted or lapped during fabrication and therefore these finishes were not evaluated. The drums are fabricated by rolling, bending and welding of the stainless steel plates. The finished surface is smooth but not shinny.

Table 14: Drum Surface Finishes[4]

Case	Description	Solar Absorptance	Emittance (400ºK)
1	303 stainless ground rough	0.485	0.168
2	303 stainless lapped	0.347	0.108
3	303 stainless machined fine	0.545	0.162
4	303 stainless lapped	0.385	0.107
5	303 stainless sandblasted lightly	0.612	0.343
6	Stainless as received (close to polished)	0.391	0.124
7	Stainless as received (medium)	0.498	0.210
8	Stainless as received (very dull surface)	0.570	0.296

The component temperatures for the surface finishes in Cases 6 and 8 are summarized in Table 15. Surface finish in Case 7 has been assumed in the analyses in this report.

Table 15: Maximum Component Temperatures

Case	Description	PCV (°F)	O-rings (°F)	Insulation (°F)
6	Stainless as received (close to polished)	234	214	210
7	Stainless as received (medium)	239	219	214
8	Stainless as received (very dull surface)	239	219	214

A review of the Case 8 results in Table 14 shows that although the solar thermal loading increased from the baseline Case 7 values, the component temperatures did not change. This is because the package temperatures depend both on solar absorptivity and thermal emissivity of the drum surface. Higher solar absorptivity results in higher temperatures provided the emissivity remains same. While an increase in emissivity results in lower temperatures for the same absorptivity. The analyses show that the Case 7 analyzed in this report provides realistic results.

The radiation surface properties used in this report are compared with data published in a NASA publication.[17] Additional analyses are performed to compare the results with the temperatures in Table 16. Table 16 shows the comparison of solar absorptivity (•) and thermal emittance (•) data used in this report and the data from the NASA publication. As indicated above, the drums are fabricated by rolling the steel plates and therefore Machine Rolled surface is included. The comparison shows that the rolled surface is actually close to the polished surface and, therefore, the chosen Reference Surface is conservative. Table 17 shows a comparison of the component temperatures for the two sets of data.

Table 16 – Comparison of Absorptivity (•) and Emissivity (•)

SRNS Data			NASA Data (Reference [16])		
Surface	•	•	Surface	•	•
Stainless as received (close to polished)	0.391	0.124	Machine Rolled	0.39	0.11
Stainless as received (medium) **Reference Surface**	0.498	0.210	Machined	0.47	0.14
Stainless as received (very dull surface)	0.570	0.296	Sandblasted	0.58	0.38

Table 17: Maximum Component Temperatures

Description	PCV (°F)	O-rings (°F)	Insulation (°F)
Data Used in This Report			
Stainless as received (close to polished)	234	214	210
Stainless as received (medium) **Reference Surface**	**239**	**219**	**214**
Stainless as received (very dull surface)	239	219	215
NASA Data			
Machine rolled	235	215	211
Machined	241	221	217
Sandblasted	234	214	210

A comparison of the results in Table 17 shows that the temperatures for the **Reference Surface** (*as received*) in this report represent true and credible temperatures for the range of surface conditions that might be found for the actual drum packages. In addition, it should also be noted that the solar flux is applied all around the cylindrical surface of the drum which is very conservative considering the directional nature of the solar radiation.

4.3.3 Insulation Thermal Conductivity

A sensitivity analysis was performed to evaluate the impact of uncertainty in the insulation thermal conductivity. The radial thermal conductivity of the fabricated insulation assembly, which is formed by gluing ½" insulation discs, was found to be about twice as much as the axial thermal conductivity. This was based on testing of the assembly samples and also benchmarking of the NCT thermal tests. Since lower thermal conductivity results in higher insulation temperature, as an extreme case, a sensitivity analysis was performed assuming uniform thermal conductivity (lower thermal conductivity) in all directions. The NCT/Solar results are summarized in Table 18.

Table 18: Maximum Component Temperatures for NCT/Solar

Component	Temperature (°F)	Limit (°F)
PCV	273	300
PCV O-rings	254	400
Insulation	250	250
PCV Gas (Average)	304	313

A review of the results in Table 18 shows that all temperatures are within their design limits. The average gas temperature limit of 313°F is the basis for the current MNOP documented in Reference [1].

Table 19 shows sensitivity results for maximum steady state temperatures of key components during HAC post-fire. The results show that when 1.4 inch char layer is replaced by air cavity region with no convection and no radiation cooling, PCV temperature increases at maximum 29°F due to less conductance through the layer. Higher temperatures are used for SAR documentation.

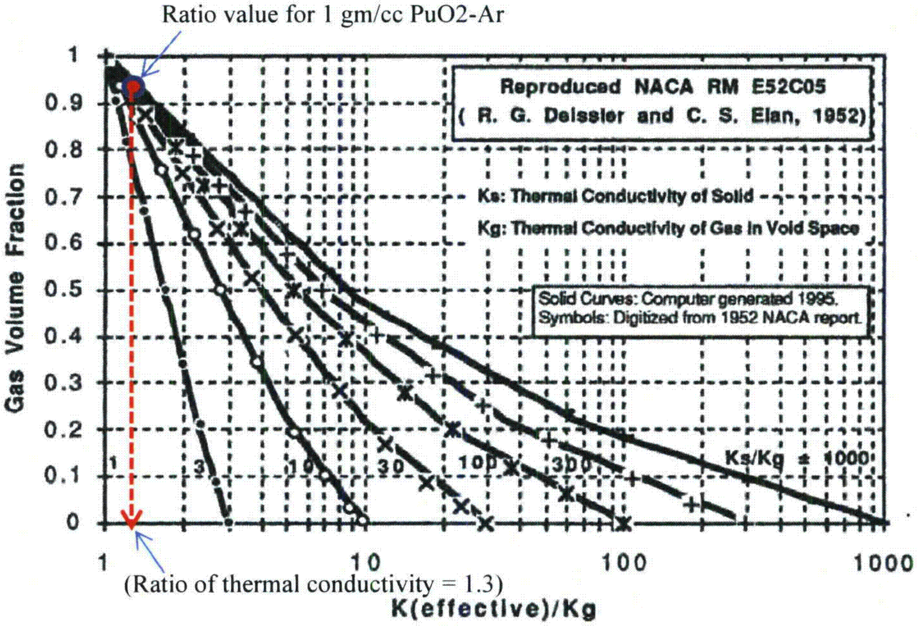
Table 19: Maximum Component Temperatures for HAC Postfire Steady State Results

Description	PCV (°F)	PCV O-rings (°F)	Contents (°F)
1.4" char region	231	212	458
1.4" insulation char region replaced by air cavity	260	241	486

4.3.4 Source Density

The nominal analyses in this report are based on a source having a density of 2 g/cc and a heat rate of 19 watts. Only about 3 kg of 2g/cc source can be put in a 3013 container analyzed in this report. A 3 kg source will normally have heat rate well below 19 watts and, therefore, the analyses in this report are bounding. A higher density source weighing up to 5 kg will have higher thermal conductivity resulting in lower component temperatures. A lower density source will most likely have heat rate even lower than the 2 g/cc source and therefore lower temperatures. In addition, argon fill gas within the 3013 containers is evaluated as a worst case condition.

When the source density is reduced from 2 g/cc to 1 g/cc assuming the same amount of heat rate 19 watts for the regulatory purpose, the thermal calculations were performed by using the NCT model with insolation. For the sensitivity analysis for a lower source density, thermal conductivity for the 1 gm/cc source density of PuO2 was obtained by interpolating the ratio values of effective PuO2 thermal conductivity to gas thermal conductivity (Ratio of $k_{Puo2solid}/k_{Ar}$ = 194, Volume fraction = 0.91) as shown in Figure 19. The corresponding effective thermal conductivity for the 1 gm/cc PuO2 powder filled with argon gas was found to be 1.3 times higher than the argon thermal conductivity (0.0169 Btu/hr-F). The NCT calculations for the argon-filled product can were performed for a conservative estimate since argon gas has thermal conductivity about 30% lower than air. An unlikely low density Pu oxide content which fills the container as shown in Figure 7 and has a heat rate of 19 watts was analyzed as shown in Table 20. This scenario results in higher maximum content temperatures but an average gas temperature less than 313°F. Therefore, such an unlikely case is bounded by existing analyses in terms of average PCV gas temperature and resulting MNOP.


Ratio value for 1 gm/cc PuO2-Ar

(Ratio of thermal conductivity = 1.3)

Figure 19. Effective thermal conductivity ratios of PuO2 powder to gas [SRT-MTS-96-2000]

Table 20: Maximum Component Temperatures for NCT Solar Results

Description	PCV (°F)	PCV O-rings (°F)	PCV gas (°F)	Contents (°F)
3 kg source (2 gm/cc, 19 watts heat rate)	239	219	271	466
1.5 kg source (1 gm/cc, 19 watts heat rate)*	239	219	299	686
1.5 kg source (2 gm/cc, 19 watts heat rate)	244	217	261	550

Note:*The source container filled with argon gas

5.0 Conclusions

1. The analyses show that the maximum temperatures of the package components are below their design limits during NCT and HAC.
2. The maximum pressures during NCT and HAC are lower than their corresponding values in the current safety analysis report (SARP) of 9975 (Reference [1]) and, therefore, there is no impact on the existing structural analyses of PCV and SCV components.
3. ANSYS FLUENT can be used in place of P/Thermal for package thermal analysis, but the existing P/Thermal results are also valid.

6.0 References

1. S-SARP-G-00003 Rev. 0, Safety Analysis Report for Packaging Model 9975 Type B(M)F-96, WSRC, (2008).
2. MSC.PATRAN THERMAL 2008 r1, Online Manual, MSC Software Company, Santa Ana, California.
3. ANSYS FLUENT 6.3 ANSYS, Inc. (2011).
4. Safety Analysis Report for Packaging, Model 9975, S-SARP-G-00003, Rev. 0: Appendix 3.13; *Solar Absorptance and Emittance of Stainless Steel at 400°K* (2008).
5. Solar Absorptance and Thermal Emittance of Some Common Spacecraft Control-Surface Coatings, John H. Henninger, NASA Reference Publication 1121, page 11, April 1984.
6. Drawings
   - R-R2-F-0026, Rev.5, Drum with Flange Closure Assembly
   - R-R2-F-0025, Rev.6, Flange Closure Subassembly Details
   - R-R2-F-0019, Rev.8, Insulation Assembly details
   - R-R2-F-0015, Rev.6, Air Shield Weldment
   - R-R2-F-0018, Rev. 10, Containment Vessel Subassemblies
   - R-R2-F-0016, Rev.13, Containment Vessel Weldments
   - R-R4-F-0054, Rev.13, Containment Vessel Component Details
   - R-R2-F-0020, Rev.11, Shielding
   - R-R4-F-0055, Rev.5, 3013 Top Spacer
   - M-PV-F-0017, Rev. 0, 3013 Outer Can
   - M-PV-F-0016, Rev. 0, Rocky Flats Inner Can
   - M-PV-F-0015, Rev. 0, Rocky Flats Convenience Can
7. Parker O-ring Handbook ORD-5700a, The Parker Seal Group, Parker Hannifin Corp., Cleveland OH (2001).
8. J. Davis, et al., *Metals Handbook, Vol. 2, 10th ed.*, ASM International (1990).
9. ASME Boiler and Pressure Vessel Code, Pressure Vessels, Section VIII, Division 2,.
10. Kaowool Blanket, Thermal Ceramics Datasheet – www.thermalceramics.com, Kaowool Bulk Fiber, Foundry Services & Supplies, Santa Fe Springs, CA.
11. J.E. Evans and A.A. Gates, *Safety Analysis Report - Packages - 238Pu Oxide Shipping Cask*, DPSPU 74-124-1, Savannah River Plant, Aiken, SC, p. 40 (1975).

12. Theory and Problems of Heat Transfer, by D. R. Pitts and L. E. Sissom, Schaum's Outline Series, McGraw-Hill Book Co., 1977
13. P. S. Lam, "Effective Thermal Conductivity of PuO2 Powder (U)", SRT-MTS-96-2000, January 17, 1996.
14. Packaging and Transportation of Radioactive Materials. Code of Federal Regulations Title 10, Part 71, Washington, DC (2006).
15. NRC Regulatory Guide 7.8 Rev. 1, Load Combinations for the Structural Analysis of Shipping Casks for Nuclear Materials, 1989.
16. Design and Development Guide for NNSA Type B Packages, Safety Guide 100, Chapter 3, Thermal Aspects, 2005.
17. 1) G-SQP-A-00004 Rev. 1, *Software Quality Assurance Plan for MSC/PATRAN/THERMAL* (2009). 2) B-STP-A-00023 Rev. 0, *MSC/PATRAN/THERMAL Version 2008 Software Test Documentation* (2009).
18. FLUENT Test & Verification Doc., WSRC-TR-2005-00563, Rev 2 (2009).
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20. Mark's Standard Handbook for Mechanical Engineers, by E. A. Avallone and T. Baumeister III, 9th Edition, Table 4.3.2, McGraw-Hill Co., (1987).
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APPENDIX 5.3

SHIELDING CODES

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The radiation source terms were characterized using RASTA [1, 2], and the MCNP [3, 4] code package was used for subsequent three dimensional Monte Carlo transport calculations to determine absorbed dose rates outside the 9975 shipping container. The calculations performed are grouped into two sets: Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC).

The following are excerpts from the reference documentation for each of the codes that are used in the calculations. These excerpts are selected to provide general descriptions of the analytical methods employed.

> **RASTA** (RAdiation Source Term Analysis) is a code that computes neutron and photon source terms arising from (α,n) events, spontaneous fission, bremsstrahlung, and decay. The code was written to consolidate existing capabilities into a single, easy to use code with flexible, extensive output edits, while also adding new capabilities. Specifically, the gamma decay calculation from the GAMSRC code, bremsstrahlung production calculations from the BREMRAD code, and the (α,n) and spontaneous fission neutron calculations from the SOURCES code have been incorporated into RASTA. These three codes require different inputs and output their results on different bases. RASTA provides a single, easy to use input and output for these modules. In addition, RASTA provides calculational routines to find the photon source arising from decay of the product isotope resulting from an (α,n) calculation, and to find the photon source arising from both prompt and delayed spontaneous fission events. Finally, RASTA incorporates a methodology similar to that used in KMULT to account for subcritical neutron multiplication.
>
> **MCNP:** MCNP treats an arbitrary three-dimensional configuration of materials in geometric cells bounded by first- and second-degree surfaces and some special fourth-degree surfaces. Point-wise continuous-energy cross section data are used, although multi-group data may also be used. Fixed-source adjoint calculations may be made with the multi-group data option. For neutrons, all reactions in a particular cross-section evaluation are accounted for. Both free gas and S(alpha, beta) thermal treatments are used. Criticality sources as well as fixed and surface sources are available. For photons, the code takes account of incoherent and coherent scattering with and without electron binding effects, the possibility of fluorescent emission following photoelectric absorption, and absorption in pair production with local emission of annihilation radiation. A very general source and tally structure is available. The tallies have extensive statistical analysis of convergence. Rapid convergence is enabled by a wide variety of variance reduction methods. Energy ranges are 0-60 MeV for neutrons (data generally only available up to 20 MeV) and 1 keV - 1 GeV for photons and electrons.

The RASTA and MCNP calculations were performed on the SRNS Criticality Safety Analysis Computer Cluster, using code and libraries verified on that system [2, 4].

References

1. Nathan, S. J., *Radiation Source Term Analysis Code RASTA User Guide*, SRNS-RP-2009-00275, Revision 0, Savannah River Nuclear Solutions, Aiken, SC., March 2009.

2. Nathan, S. J., *RASTA Validation Report for SRNS Personal Computers*, SRNS-RP-2009-00277, Revision 0, Savannah River Nuclear Solutions, Aiken, S. C., March 2009.
3. X-5 Monte Carlo Team, *MCNP – A General Monte Carlo N Particle Transport Code, Version 5*, LA-UR-03-1987, Los Alamos National Laboratory, Los Alamos, NM, April 2004.
4. Nathan, S. J., *Monte Carlo N-Particle Transport Code System MCNP5 Shielding Validation Report*, SRNS-RP-2009-00285, Revision 0, Savannah River Nuclear Solutions, Aiken, SC, April 2009.

APPENDIX 5.4

MODELING DETAILS

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1. MODELING DETAILS

The available engineering drawings along with assumptions about material loading were used to create a 3-D model within MCNP for the 9975 shipping cask.

The following engineering drawings were used:

Title	Old Drawing used	Regulatory Drawing
9975 Shipping Package Containment Vessel Weldments (U),	R-R3-F-0016, Rev. 6, 12/13/00.	R-R3-G-00063
9975 Shipping Package Primary and Secondary Containment Vessel Subassemblies (U),	R-R2-F-0018, Rev. 3, 7/24/00.	R-R2-G-00081
9975 Shipping Package Insulation Assembly, Subassemblies and Details (U),	R-R2-F-0019, Rev. 4, 7/24/00.	R-R2-G-00083
9975 Shipping Package Drum with Flange Closure Assembly (U),	R-R2-F-0026, Rev. 0, 7/24/00.	R-R2-G-00078
9975 Drum with Flange Closure Subassembly and Details (U),	R-R2-F-0025, Rev. 0, 7/24/00.	R-R2-G-00080
9975 Shipping Package Shielding (U),	R-R2-F-0020, Rev. 4, 7/24/00.	R-R2-G-00079
PUSPS, Plutonium Stabilization and Packaging System, Assembly and Details, Convenience Can PI NO. V4001,	M-PV-F-0015, Rev. B, 2/24/99.	
PUSPS, Plutonium Stabilization and Packaging System, Assembly and Details, Inner Can PI NO. V4002,	M-PV-F-0016, Rev. B, 2/24/99.	
PUSPS, Plutonium Stabilization and Packaging System, Assembly and Details, Outer Can PI NO. V4003,	M-PV-F-0017, Rev. B, 2/24/99.	

The following additional geometry details are considered:

1. thicknesses of the drum walls, tops, and bottoms (from 49 CFR 178.115-6).
2. minimum and maximum standard pipe dimensions (from ASTM A 312/A 312M - 01a).

2. DEVELOPMENT OF COMPONENT MODELS

Normal Conditions of Transport

Normal conditions of transport are defined as conditions in which the package integrity is maintained throughout the intended operation. During NCT, all of the shielding materials will remain in place and the package will be transported in its assumed upright position. The geometric model for the NCT case is shown in Figures1.

The 9975 package consists of a Primary Containment Vessel (PCV) inside of a Secondary Containment Vessel (SCV). The SCV is surrounded on the sides and bottom by one-half inch of lead shielding. Low-density cane fiberboard (Celotex®) surrounds the shield to fill the remainder of the 35-gallon drum. Other components of the package include:

- Aluminum plates -- one below the lead shield and two above;
- Aluminum honeycomb spacers inside the PCV and SCV, and on top of the PCV;
- 3013 Container (see Figure 1)
- Plutonium Metal and Beryllium uniformly distributed in a convenience can in a 3013 container.

It is also considered a normal condition for the Plutonium and Beryllium mixture to form a compacted sphere or cylinder and move from location to location within the convenience can during transportation.

- Complex PCV/SCV closure geometry

Simplifications made to the package geometry include:

- Uniform PCV and SCV wall thickness (ignoring the flaring and, hence, the increased thickness at the vessel closures),
- Simplified PCV and SCV vessel bottoms (both approximated as a 14.732 cm IR sphere),
- Ignoring the "legs' on the bottom of the PCV and SCV,
- Modeling the gland nut's hexagonal outer surface as a cylinder having the equivalent cross-sectional area,
- Modeling the Celotex as a single component, ignoring seams that exist between the different pieces of Celotex, and
- Ignoring the rolling hoops and the drum lid closure.

Dimensions of the various components are given below. References for all dimensions are from the drawings.

- PCV – 6.491605 cm Inner Radius, 7.06501 cm Outer Radius, 41.5925 cm height from outer (bottom) surface of the PCV to the bottom of the primary cone seal plug; outer (bottom) surface is 17.4027 cm above the outer (bottom) surface of the 35 gallon drum.
- SCV – 7.840345 cm Inner Radius, 8.41375 cm Outer Radius, 55.2323 cm height from outer (bottom) surface of the PCV to the bottom of the primary cone seal plug; outer (bottom) surface is 13.3929 cm above the outer (bottom) surface of the 35 gallon drum.
- Aluminum honeycomb above PCV – 4.572 cm high, 4.6725 cm Inner Radius, 7.46125 cm Outer Radius.
- Inner Shield liner – 9.2075 cm Inner Radius and 9.29894 cm Outer Radius.
- Lead shield – 9.29894 cm Inner Radius and 10.4013 cm Outer Radius; 62.738 cm high (outer dimensions) – bottom is 11.12214 cm above the outer (bottom) surface of the 35 gallon drum.
- Outer Shield liner – 10.4013 cm Inner Radius and 10.49274 cm Outer Radius – bottom is 11.0307 cm above the outer (bottom) surface of the 35 gallon drum.
- Lower aluminum anti-rotation plate – 14.224 cm radius, 1.27 cm thick; bottom is 9.7607 cm above the outer (bottom) surface of the 35 gallon drum.
- Upper aluminum plate – 10.7823 cm radius, 1.27 cm thick; bottom rests on top of the lead shield and is 73.6417 cm above the outer (bottom) surface of the 35 gallon drum.
- Upper aluminum anti-rotation plate – 14.224 cm radius, 1.27 cm thick; bottom rests on the other aluminum plate and is 75.5467 cm above the outer (bottom) surface of the 35 gallon drum.
- Celotex – 10.7315 cm Inner Radius for bottom Celotex sections, 10.8585 cm Inner Radius for top section; 22.987 cm Outer Radius for bottom Celotex sections, 22.479 cm Outer Radius for top section; the change in inner radii between top and bottom sections occurs at 62.8467 cm above the drum's outer (bottom) surface, and the change in outer radii occurs at 67.9267 cm above the drum's outer surface; top of Celotex at 86.2147 cm above the drum's outer (bottom) surface.
- Drum – 23.1775 cm Inner Radius and 23.2989 cm Outer Radius; 0.1087 cm bottom thickness; inner height 84.9376 cm; external height 85.167712 cm.

Hypothetical Accident Conditions

The HAC geometry is depicted in Figure 2. This model was developed from the NCT model by deleting all regions outside the secondary containment vessel (SCV).

3. NUCLEAR MATERIAL GEOMETRIC MODELS

The plutonium oxide powder was modeled as a compressed powder at 7 g/cc filling the bottom portion of the inner convenience can with height determined as:

$$h = \frac{V}{\pi r^2}$$

$$V = \frac{M}{\rho}$$

Where:

h	is the height of the oxide (8.185 cm)
r	is the radius of the inner convenience can (5.2705 cm)
V	is the volume of the oxide powder (cc)
M	is the mass of the oxide powder (5000 g)
ρ	is the density of the oxide powder (7 g/cc)

The convenience cans were not included in the model. This is a minor conservatism since the convenience cans are thin walled and the dose rate outside the package is predominantly due to neutrons.

4. Differences in Modeling

The reduced lead thickness due to 50 years of hypothesized corrosion used a slightly revised model shown in Figure 3. The changes are listed below.

- PCV – 6.57098 cm Inner Radius and 7.02564 cm Outer Radius. The PVC bottom is approximated as a 10.97534 cm IR sphere.
- SCV – 7.87019 cm Inner Radius and 8.37438 cm Outer Radius
- Shield liner – 9.3846 cm Inner Radius and 9.5377 cm Outer Radius.
- Lead shield – 9.29894 cm Inner Radius and 10.1473 cm Outer Radius; 62.738 cm high (outer dimensions) – bottom is 11.37614 cm above the outer (bottom) surface of the 35 gallon drum.
- Outer Shield liner – 10.4013 cm Inner Radius and 10.49274 cm Outer Radius – bottom is 11.0307 cm above the outer (bottom) surface of the 35 gallon drum.
- Lower aluminum anti-rotation plate – 14.288 cm radius, 1.2446 cm thick; bottom is 10.0147 cm above the outer (bottom) surface of the 35 gallon drum.
- Upper aluminum plate –1.2446 cm thick
- Upper aluminum anti-rotation plate – 14.288 cm radius, 1.2446 cm thick; bottom rests on the other aluminum plate and is 74.8863 cm above the outer (bottom) surface of the 35 gallon drum.
- Celotex – 10.922 cm Inner Radius for bottom Celotex sections, 11.049 cm Inner Radius for top section; 22.86 cm Outer Radius for bottom Celotex sections; the change in inner radii between top and bottom sections occurs at 62.1863 cm above the drum's outer (bottom) surface, and the change in outer radii occurs at 67.5203 cm above the drum's outer surface; top of Celotex at 85.0463 cm above the drum's outer (bottom) surface.

Figure 1. 9975 NCT Model

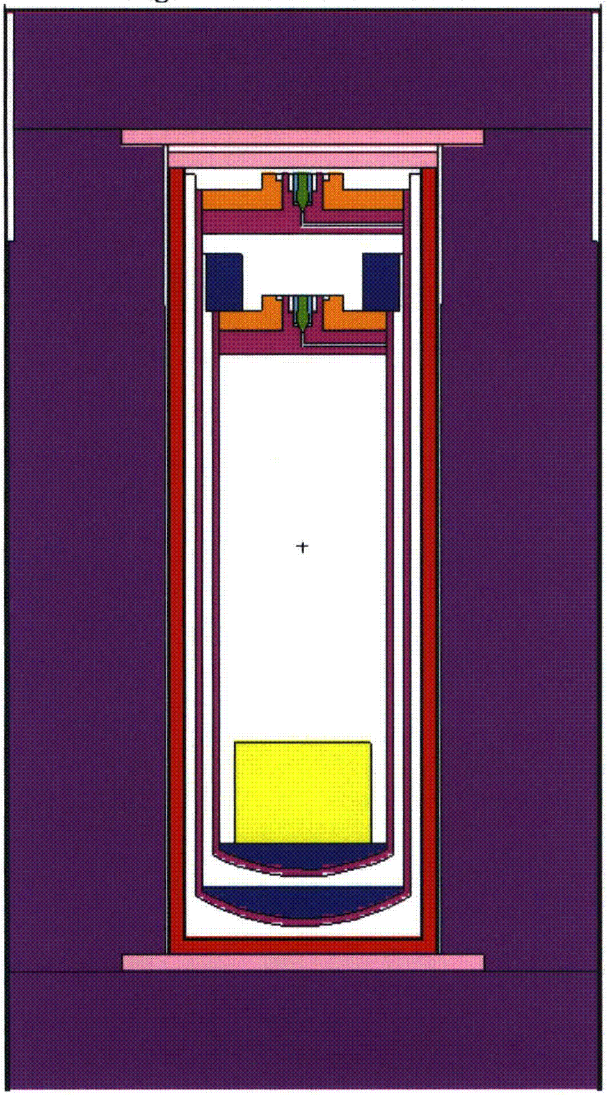


Figure 2. HAC Model

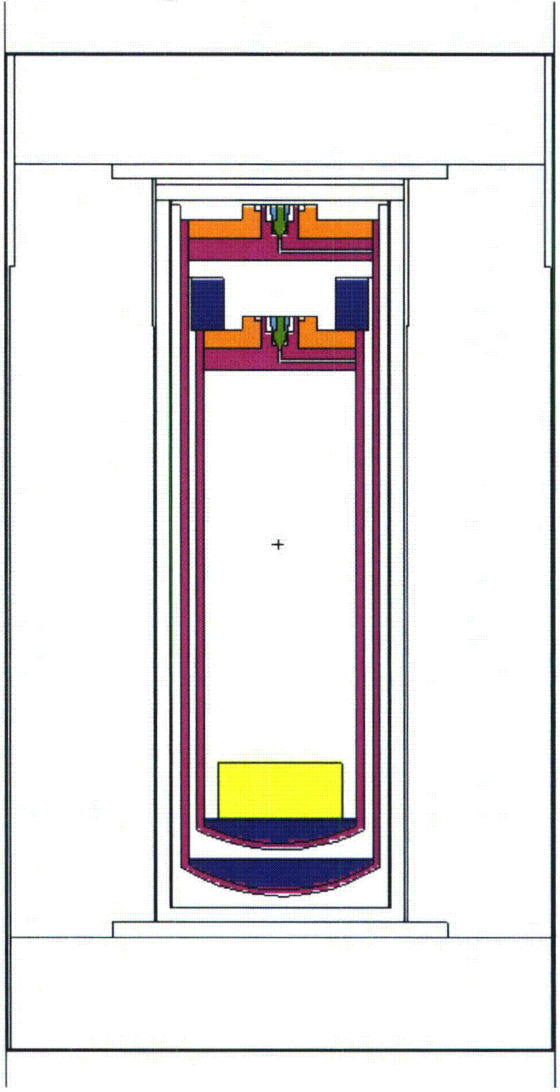
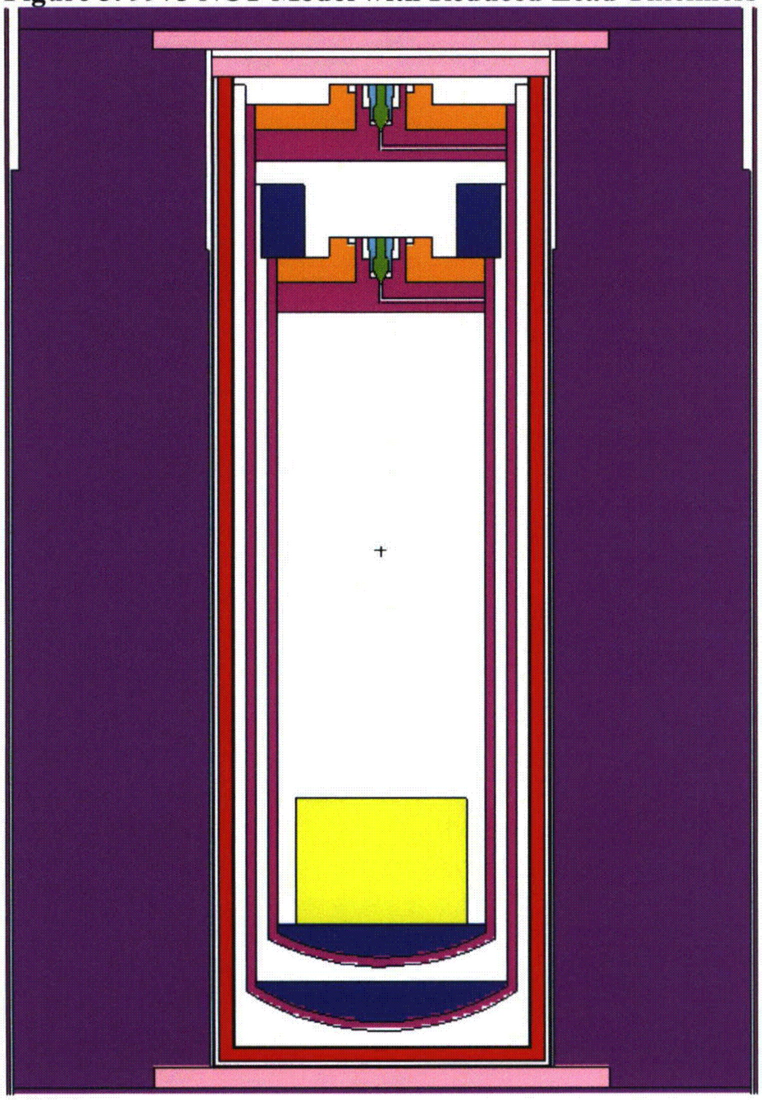


Figure 3. 9975 NCT Model with Reduced Lead Thickness



APPENDIX 5.5

MATERIAL PROPERTIES

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1.0 Introduction

This section describes the determination of isotopic splits for the non-nuclear package materials and gives the composition and density for each.

2.0 DETERMINATION OF ISOTOPIC SPLITS OF NON-NUCLEAR MATERIALS

For each of the following materials, the ASTM standards [1] or stated reference were consulted for the isotopic breakdown.

2.1 Steels

The composition of the steels used in the calculations is given in Table 1. [2] 316-SS and 304L-SS do not include Phosphorus and Sulfur, though they are given in the reference. Phosphorus and sulfur are given a very low maximum weight percent, and their exclusion does not impact shielding calculations.

TABLE 6. Elemental Composition (in weight fractions) of Steels[2]

	316-SS	**304L-SS**	**410-SS**	**Nitronic-60**
Iron	0.6917	0.7117	0.8603	0.655
Nickel	0.1	0.08	0.005	0.08
Molybdenum	0.02	0	0	0
Chromium	0.16	0.18	0.115	0.16
Silicon	0.0075	0.0075	0.0075	0.035
Carbon	0.0008	0.0008	0.0015	0.001
Manganese	0.02	0.02	0.01	0.07
Phosphorus	0	0	0.0004	0
Sulfur	0	0	0.0003	0

2.2 Cane Fiberboard ASTM Spec C-208-72

According to ASTM standard C-208-72, the material is made of ligno-cellulose (wood or cane) fibers ($C_6H_{10}O_5$).

2.3 Aluminum 1100 ASTM B-209

The standard gives some impurity information but states that the material should be 99% aluminum. Therefore, the impurities were ignored.

2.4 Lead ASTM B-749

The standard gives some impurity information but states that the material should be 99.9% lead. Therefore, the impurities were ignored.

3.0 DETERMINATION OF MATERIAL DENSITIES OF NON-NUCLEAR MATERIALS

Material densities were determined from References 1 and 2 and are given in Table 2. All steels were assumed to be the same density.

Table 3. Densities (g/cm^3)

Material	Density
Lead	11.29
Aluminum	2.70
Steels	7.895
Al honeycomb	0.28
Cane fiberboard	0.20

Several comparison values for the fiberboard were obtained from a Radiological Engineering Computation Sheet (ESH-HPT-93-0170). They rounded the density of 0.24 g/cm^3 down to 0.20, which accounts for the differences seen.

9.0 REFERENCES

1. 1992 Annual Book of ASTM Standards.

2. Mechanical and Physical Properties of Steels for Nuclear Applications, United States Steel, 525 William Penn Place, Pittsburgh, PA 15230 (1967).

APPENDIX 5.6

INPUT/OUTPUT COMPUTER FILES

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Listed below are the input file names used in this calculation.
Copies of the input and output files are provided on a CD.

File name	**Description**
	RASTA Input Files
rasta_c.12.in*	Content Envelope C.12 with Be and F only
	MCNP Input Files
hac_n.12.in	Content Envelope C.12 with Be and F only HAC neutron case
hac_p.12.in*	Content Envelope C.12 with Be and F only HAC photon case
nct_n.12.in*	Content Envelope C.12 with Be and F only NCT 0.434 INCH LEAD neutron case
nct_p.12.in	Content Envelope C.12 with Be and F only NCT 0.434 INCH LEAD photon case
nct_n.12.50.in*	Content Envelope C.16 with Be and F only NCT 0.334 INCH LEAD neutron case
nct_p.12.50.in	Content Envelope C.16 with Be and F only NCT 0.334 INCH LEAD photon case
	ORIGEN-S Input Files
c.12.inp*	Content Envelope C.12 heat generation calculation

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APPENDIX 5.7

SHIELDING ANALYSIS OF THE 9975 CONTAINER

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Calculation No. N-CLC-G-00148
Sheet No. **1 of 43**

Shielding Analysis of Plutonium Oxide in 9975 for NRC SAR

Project/Task 9975 NRC SAR	Calculation No: N-CLC-G-00148	Project /Task No: N/A
Title Shielding Analysis of Plutonium Oxide in 9975 for NRC SAR	Functional Classification: GS	Sheet **1 of 43**
	Discipline: Nuclear	
Calc Type ☒ Type 1 ☐ Type 2	Type 1 Calc Status ☐ Preliminary ☒ Confirmed	
Computer Program No.: ORIGENS RASTA MCNP EXCEL ☐ N/A	Version/release No: SCALE 5.0 RASTA Version 6 MCNP 5.1.40 Microsoft Office Professional Plus 2010	

Purpose and Objective:

This Engineering Calculation analyzes the dose rates outside the package associated with shipment of plutonium oxide in the 9975 shipping package in support of the Safety Analysis Report (SAR) being submitted to the U.S. Nuclear Regulatory Commission (NRC).

DC/RO
Reviewed and determined to be

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DC &
Reviewing
Official: Steven J. Nathan, SRNS/N&CSE

Date:

Summary of Conclusion:
The peak dose rate at the surface of the 9975 shipping package under NCT is below the limit for non-exclusive use shipment (200 mrem/hr). The dose rate at 1 meter from the surface of the damaged 9975 shipping package under HAC is below the regulatory limit (1000 mrem/hr).

The thinning of the lead shield corresponding to 50 years of corrosion at 2 mils/year (100 mils) does not have any impact on the dose rate outside the 9975 shipping package.

Revisions

Rev #	Revision Description
0	Original Issue

Sign Off

Rev #	Originator (Print) Sign/Date	Verification/ Checking Method (see form instructions)	Verifier/Checker (Print) Sign/Date	Manager (Print) Sign/Date
0	S. J. Nathan	☐ Design Check (GS/PS only) ☒ Document Review ☐ Alternate Calculation ☐ Operational Testing	J. Reyes-Jimenez	J. Brotherton
		☐ Design Check (GS/PS only) ☒ Document Review ☐ Alternate Calculation ☐ Operational Testing		

Additional Reviewer (Print) N/A	Signature	Date
Design Authority – (Print) D. R. Leduc	Signature	Date
Release to Outside Agency – (Print) N/A	Signature	Date

Security Classification of the Calculation

UNCLASSIFIED

DOES NOT CONTAIN UNCLASSIFIED CONTROLLED NUCLEAR INFORMATION

RECORD OF REVISION					
Project: 9975 NRC SAR				Calculation No: N-CLC-G-00148	
Subject: Shielding Analysis of Plutonium Oxide in 9975 for NRC SAR				Sheet No: 2 of 43	
Originator: S. J. Nathan		Date: 3/14/13	Checker: J. Reyes-Jimenez	Date:	Rev. No:
REV. NO.	PAGES REPLACED	PAGES ADDED	PAGES DELETED	PAGES REVISED	DESCRIPTION OF REVISIONS
0		All			Original Issue

Keywords:

9975 SAR

Plutonium Oxide

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COMPUTER PROGRAMS USED

NAME	**Version**	**Configuration Control**	**If NO Description on page/in reference**
RASTA	6	Yes	
MCNP	5	Yes	
ORIGEN	SCALE 5.0	Yes	
Excel	2010	No	Commercial Software

1 INTRODUCTION

This Engineering Calculation analyzes the dose rates outside the package associated with shipment of plutonium oxide in the 9975 shipping package in support of the Safety Analysis Report (SAR) being submitted to the U.S. Nuclear Regulatory Commission (NRC).

2 INPUT

The isotopic content of plutonium analyzed listed in Table 1 is taken from SRNL-L4500-2013-00025, (*9975 SAR Content Envelope C.12*).

Table 1 Isotopic Composition of Radioactive Material

	Material	**C.12**	**MCNP Model**
Radioisotope (Radioactive Material Mass - grams)	^{238}Pu	2.2	1.224
	^{239}Pu	4400	2266.724
	^{240}Pu	264	
	^{241}Pu	50	27.813
	^{242}Pu	8.8	4.895
	^{241}Am + ^{241}Pu	50	146.850
	^{243}Am	1.00	
	^{244}Cm	0.0044	
	^{237}Np	220	
	^{232}U	0.00044	
	^{233}U	427	
	^{234}U	4400	
	^{235}U	4400	
	^{236}U	2640	
	^{238}U	4400	
	^{232}Th	4400	
Impurities (grams)	Al	290	290
	Mg	1620	1620
	Na	315	315
	F	0	
	Be	0	
	C	1000	
Total Mass (kg)	Radioactive Materials	4.4	2.448
	Impurities	3.08	2.225
	Oxygen		0.327
	All Contents	5	5.000

The geometric model of the 9975 shown in Figure 1 was taken from N-CLC-G-00122, Revision 1 (*Shielding Analysis of the 9975 Shipping Container with U-233 Metal*) and is used as the basis for this analysis.

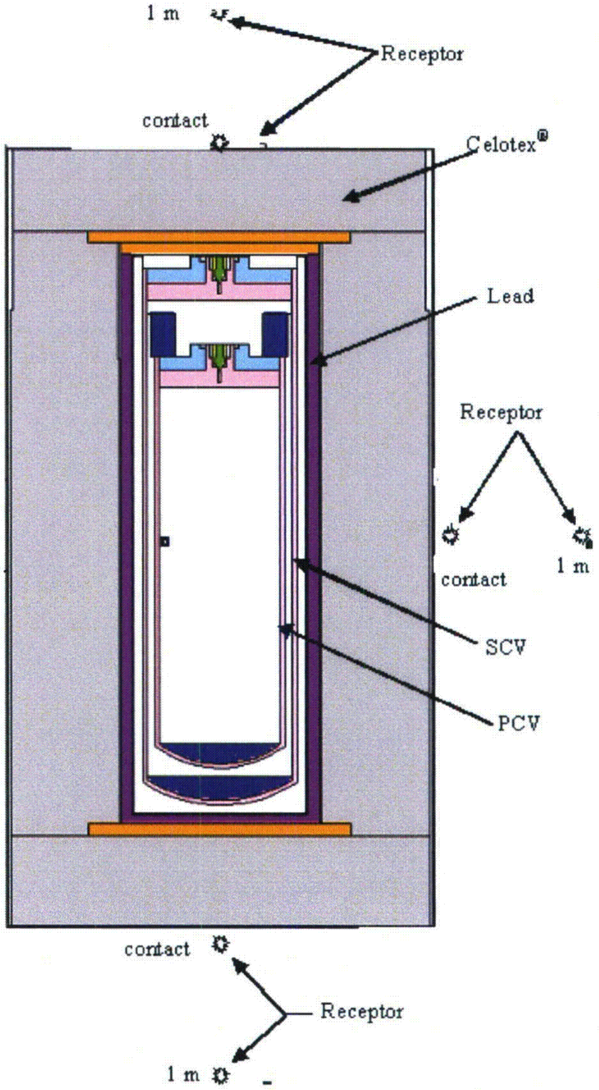

Figure 1 9975 Model from N-CLC-G-00122

The dimensions of the convenience can (Table 2) are taken from drawings R-R4-F-0143, Revision 0 (*3013 Container Surveillance and Storage Capability 235-F, Hanford Convenience Can Lid Detail*) and R-R4-F-0144, Revision 0 (*3013 Container Surveillance and Storage*

Capability 235-F, Hanford Convenience Can Detail). The convenience can is not modeled explicitly. The inner radius of the convenience can is used to define the source region.

Table 2 Convenience Can Dimensions

	Diameter		**Radius**	**Length**	
	in	**cm**	**cm**	**in**	**cm**
Inside	4.15	10.541	5.271	7.661	19.459
Outside	4.27	10.846	5.423	8.031	20.399
Top Thickness				0.12	0.305
Bottom Thickness				0.25	0.635
Material	SS 304/304L				

3 OPEN ITEMS

There are no Open Items associated with this Engineering Calculation.

4 ASSUMPTIONS

The isotopic composition of the Content Envelope (Table 1) lists a combined mass for Pu-241 and its daughter Am-241. This mass is assumed to be all Am-241.

5 ANALYTICAL METHODS

The dose rate outside the 9975 shipping package was calculated under Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC).

The radiation source terms were characterized using RASTA (SRNS-RP-2009-00275, Revision 0, *Radiation Source Term Analysis Code RASTA User Guide)*, and the MCNP code package (LA-UR-03-1987, *MCNP — A General Monte Carlo N-Particle Transport Code, Version 5)* was used for subsequent three dimensional Monte Carlo transport calculations to determine absorbed dose rates outside the 9975 shipping container.

The heat generation rate was calculated using the ORIGEN-S (ORNL/TM-2005/39, Revision 5, *ORIGEN-S: Scale System Module to Calculate Fuel Depletion, Actinide Transmutation, Fission Product Buildup and Decay, and Associated Radiation Source Terms*) module of the SCALE Code System.

5.1 Computer Codes

The following are excerpts from the reference documentation for each of the codes that were used in the calculations. These excerpts are selected to provide general descriptions of the analytical methods employed.

RASTA (RAdiation Source Term Analysis) is a code that computes neutron and photon source terms arising from (α,n) events, spontaneous fission, bremsstrahlung, and decay. The code was written to consolidate existing capabilities into a single, easy to use code with flexible, extensive output edits, while also adding new capabilities. Specifically, the gamma decay calculation from the GAMSRC code, bremsstrahlung production calculations from the BREMRAD code, and the (α,n) and spontaneous fission neutron calculations from the SOURCES code have been incorporated into RASTA. These three codes require different inputs and output their results on different bases. RASTA provides a single, easy to use input and output for these modules. In addition, RASTA provides calculational routines to find the photon source arising from decay of the product isotope resulting from an (α,n) calculation, and to find the photon source arising from both prompt and delayed spontaneous fission events. Finally, RASTA incorporates a methodology similar to that used in KMULT to account for subcritical neutron multiplication.

MCNP treats an arbitrary three-dimensional configuration of materials in geometric cells bounded by first- and second-degree surfaces and some special fourth-degree surfaces. Point-wise continuous-energy cross section data are used, although multi-group data may also be used. Fixed-source adjoint calculations may be made with the multi-group data option. For neutrons, all reactions in a particular cross-section evaluation are accounted for. Both free gas and S(alpha, beta) thermal treatments are used. Criticality sources as well as fixed and surface sources are available. For photons, the code takes account of incoherent and coherent scattering with and without electron binding effects, the possibility of fluorescent emission following photoelectric absorption, and absorption in pair production with local emission of annihilation radiation. A very general source and tally structure is available. The tallies have extensive statistical analysis of convergence. Rapid convergence is enabled by a wide variety of variance reduction methods. Energy ranges are 0-60 MeV for neutrons (data generally only available up to 20 MeV) and 1 keV - 1 GeV for photons and electrons.

ORIGEN-S computes time-dependent concentrations and source terms of a large number of isotopes, which are simultaneously generated and depleted through neutronic transmutation, fission, radioactive decay, input feed rates, and physical or chemical removal rates. The matrix exponential model of the ORIGEN code is unaltered in ORIGEN-S. The version of ORIGEN applied in the SCALE system, ORIGEN-S, has several improvements over the original program. The code has been modified to include dynamic storage allocation, free-form input processing, and flexible dimensioning.

The RASTA, MCNP, and ORIGEN-S calculations were performed on the SRNS Criticality Safety Analysis Computer Cluster, using code and libraries verified on that system (SRNS-RP-2009-00277, Revision 0, *RASTA Validation Report for SRNS Personal Computers*; SRNS-RP-2009-00285, Revision 0, *Monte Carlo N-Particle Transport Code System MCNP5 Shielding Validation Report;* and SRNS-RP-2008-00151, Revision 1, *SCALE Test Report for SRS Personal Computers*). Appendix A lists the files used in these analyses.

5.2 Geometric Models

The 9975 shipping container consists of two concentric cylindrical stainless steel containment vessels, two metal product cans, a 35-gallon steel drum, cane fiberboard insulation, bearing plates, lead shield, and aluminum honeycomb spacers. Neither the materials nor the geometry is specifically designed to provide significant neutron shielding. However, some attenuation is provided by the vessels, lead, cane fiberboard, and the drum. Neutron attenuation is primarily provided by the distance between the source and points external to the package, whereas photons are significantly absorbed by the lead shield.

5.2.1 Normal Conditions of Transport

Normal conditions of transport are defined as conditions in which the package integrity is maintained throughout the intended operation. During NCT, all of the shielding materials will remain in place and the package will be transported in its assumed upright position. Figure 2 shows the geometric model for the NCT case with the lead shield modeled as 0.434" thick with 0.036" thick steel liners on the inside and outside. Figure 3 shows a special case to evaluate the effect of lead thinning based on 50 years of lead loss at 2 mils/year.

The 9975 package consists of a primary containment vessel (PCV) inside of a secondary containment vessel (SCV). The SCV is surrounded on the sides and bottom by one-half inch of lead shielding. Low-density cane fiberboard (Celotex®) surrounds the shield to fill the remainder of the 35-gallon drum. Other components of the package include:

- Aluminum plates – one below the lead shield and two above.
- Aluminum honeycomb spacers inside the PCV and SCV, and on top of the PCV.
- Plutonium oxide and impurities uniformly distributed in a 3013 convenience can.
- Complex PCV/SCV closure geometry.

Simplifications made to the package geometry include:

- Uniform PCV and SCV wall thickness (ignoring the flaring and, hence, the increased thickness at the vessel closures)
- Simplified PCV and SCV vessel bottoms (both approximated as a 14.732 cm inner radius sphere)
- Ignoring the "legs" on the bottom of the PCV and SCV
- Modeling the gland nut's hexagonal outer surface as a cylinder having the equivalent cross-sectional area
- Modeling the Celotex® as a single component, ignoring seams that exist between the different pieces of Celotex®

- Ignoring the rolling hoops and the drum bolted lid closure
- Modeling thicknesses at their minimum value

Dimensions of the various components are given below.

- PCV – 6.491605 cm inner radius, 7.06501 cm outer radius, 41.5925 cm height from outer (bottom) surface of the PCV to the bottom of the primary cone seal plug; outer (bottom) surface is 17.4027 cm above the outer (bottom) surface of the 35-gallon drum.
- SCV – 7.840345 cm inner radius, 8.41375 cm outer radius, 55.2323 cm height from outer (bottom) surface of the PCV to the bottom of the primary cone seal plug; outer (bottom) surface is 13.3929 cm above the outer (bottom) surface of the 35-gallon drum.
- Aluminum honeycomb above PCV – 4.572 cm high, 4.6725 cm inner radius, 7.46125 cm outer radius.
- Inner shield liner – 9.2075 cm inner radius and 9.29894 cm outer radius.
- Lead shield – 9.29894 cm inner radius and 10.4013 cm outer radius; 62.738 cm high (outer dimensions) – bottom is 11.12214 cm above the outer (bottom) surface of the 35-gallon drum.
- Outer shield liner – 10.4013 cm inner radius and 10.49274 cm outer radius – bottom is 11.0307 cm above the outer (bottom) surface of the 35-gallon drum.
- Lower aluminum anti-rotation plate – 14.224 cm radius, 1.27 cm thick; bottom is 9.7607 cm above the outer (bottom) surface of the 35-gallon drum.
- Upper aluminum plate – 10.7823 cm radius, 1.27 cm thick; bottom rests on top of the lead shield and is 73.6417 cm above the outer (bottom) surface of the 35-gallon drum.
- Upper aluminum anti-rotation plate – 14.224 cm radius, 1.27 cm thick; bottom rests on the other aluminum plate and is 75.5467 cm above the outer (bottom) surface of the 35-gallon drum.
- Celotex® – 10.7315 cm inner radius for bottom Celotex® sections, 10.8585 cm inner radius for top section; 22.987 cm outer radius for bottom Celotex® sections, 22.479 cm outer radius for top section; the change in inner radii between top and bottom sections occurs at 62.8467 cm above the drum's outer (bottom) surface, and the change in outer radii occurs at 67.9267 cm above the drum's outer surface; top of Celotex® at 86.2147 cm above the drum's outer (bottom) surface.
- Drum – 23.1775 cm inner radius and 23.2989 cm outer radius; 0.1087 cm bottom thickness; inner height 84.9376 cm; external height 85.167712 cm.

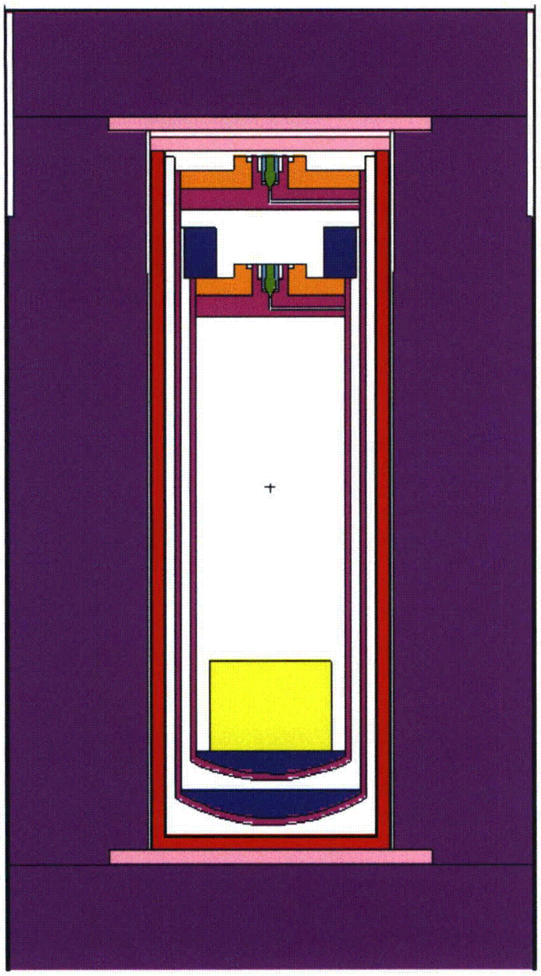

Figure 2 MCNP Model for NCT

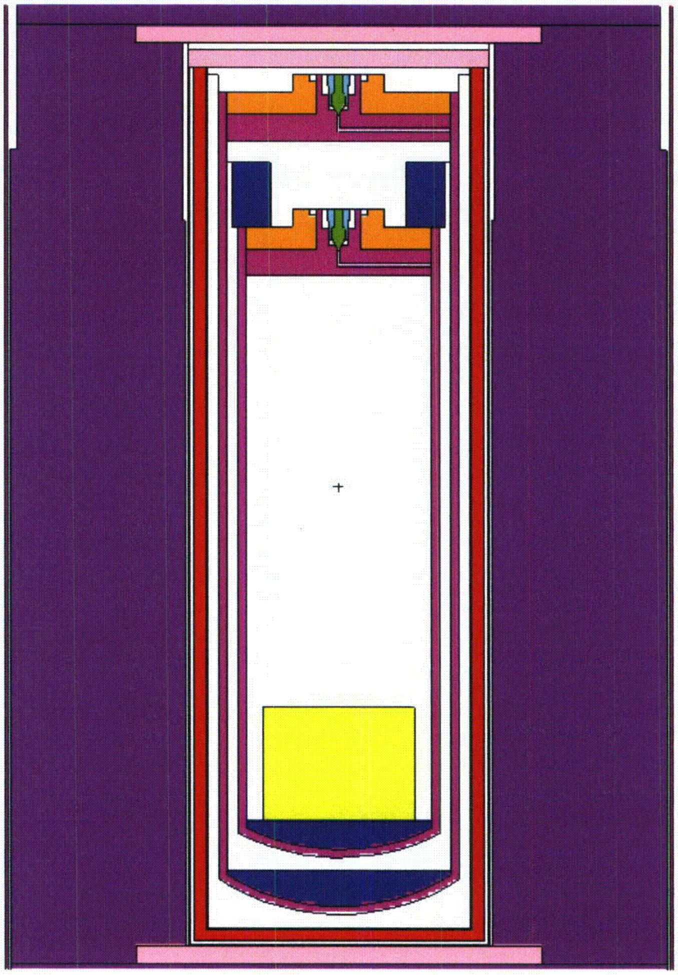

Figure 3 9975 Shipping Package with Reduced Lead Thickness

5.2.2 Hypothetical Accident Conditions

For the purpose of this analysis, Hypothetical Accident Conditions are defined as a complete loss of all material outside the SCV. Figure 4 depicts the HAC geometry. This model was developed from the NCT model by setting the material in all regions outside the SCV to void.

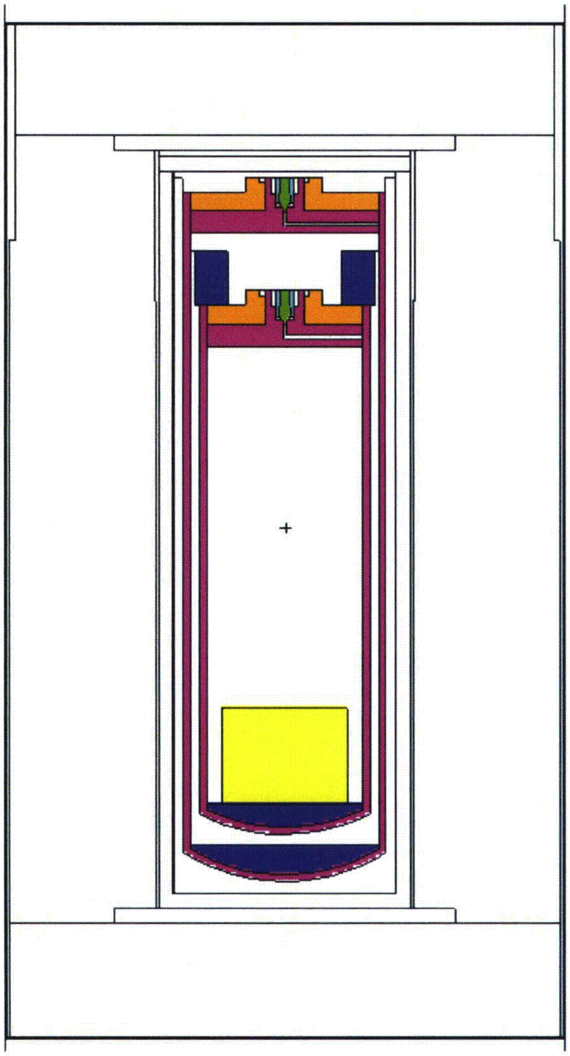

Figure 4 MCNP Model for HAC with Source Height Based on 7 g/cc

5.2.3 Nuclear Material Geometric Models

The plutonium oxide powder was modeled as a compressed powder at 7 g/cc filling the bottom portion of the inner convenience can with height determined as:

$$h = \frac{V}{\pi r^2}$$

$$V = \frac{M}{\rho}$$

Where:

h	is the height of the oxide (8.185 cm)
r	is the radius of the inner convenience can (5.2705 cm)
V	is the volume of the oxide powder (cc)
M	is the mass of the oxide powder (5000 g)
ρ	is the density of the oxide powder (7 g/cc)

The convenience cans were not included in the model. This is a minor conservatism since the convenience cans are thin walled and the dose rate outside the package is predominantly due to neutrons.

5.3 Materials

Eight material compositions (Table 3) were used to model the 9975 shipping container. Compositions of the various steels used in the calculations are taken from *Mechanical and Physical Properties of Steels for Nuclear Applications*. The lead shield was modeled as 100% lead at 11.29 g/cc. The aluminum honeycomb spacers and aluminum plate were modeled as 100% aluminum at 0.28 and 2.7 g/cm^3, respectively. The Celotex® was modeled as cellulose, $C_6H_{10}O_5$, at 0.20 g/cm^3 (LA-12827-M, *Criticality Calculations with MCNP: A Primer*). [The cane fiberboard (Celotex®) insulation has a nominal density of 15 ± 1 lb/ft^3, resulting in a minimum density of 0.224 g/cm^3. For conservatism, 0.20 g/cm^3 was used.]

Table 3 Material Compositions

	Lead	**Al honeycomb**	**316-SS**	**410-SS**	**304L-SS**	**Nitronic-60**	**Aluminum**	**Celotex®**
Density (g/cc)	11.29	0.28	7.895	7.895	7.895	7.895	2.7	0.2
Element	**Weight Fraction**							**No. of Atoms**
Hydrogen								10
Beryllium								
Carbon			8.00E-04	1.50E-03	8.00E-04	1.00E-03		6
Oxygen								5
Sodium								
Fluorine								
Aluminum		1.00E+00					1.00E+00	
Silicon			7.50E-03	7.50E-03	7.50E-03	3.50E-02		
Phosphorous				4.00E-04				
Sulfur				3.00E-04				
Chromium			1.60E-01	1.15E-01	1.80E-01	1.60E-01		
Manganese			2.00E-02	1.00E-02	2.00E-02	7.00E-02		
Iron			6.92E-01	8.60E-01	7.12E-01	6.55E-01		
Nickel			1.00E-01	5.00E-03	8.00E-02	8.00E-02		
Lead	1.00E+00		2.00E-02					

5.4 Source Term

The effect of impurities was analyzed by mixing a specified mass of each of five light elements (aluminum, beryllium, fluorine, magnesium, and sodium) with the plutonium oxide while maintaining the mass of material at 5000 grams. The formulas used are:

$$M_{PuO_2} = min\left(\left(5000 - \sum M_{im}\right), 4400 * \frac{A_{Pu} + 2 * A_O}{A_{Pu}}\right)$$

$$M_{Pu} = M_{PuO_2} * \frac{A_{Pu}}{A_{Pu} + 2 * A_O}$$

$$M_O = M_{PuO_2} - M_{Pu}$$

$$M_O^i = M_O * wf^i$$

$$M_{im}^j = M_{im} * wf^j$$

Where:

M_{im}	is the mass of the impurity (grams)
M_{Pu}	is the mass of plutonium (grams)
M_O	is the mass of oxygen (grams)
M_O^i	is the mass of isotope "i" of oxygen (grams)
A_{Pu}	is the atomic weight of plutonium (239.1213)
A_O	is the atomic weight of oxygen (15.9994)
wf^i	is the weight fraction of the ith isotope of oxygen
wf^j	is the weight fraction of the jth isotope of the impurity

5.4.1 Photon Source

The contributing mechanisms for photon (gamma) production include (1) nuclide decay, (2) decay of daughters, (3) (α, n) reaction photons, (4) spontaneous fission, (5) bremsstrahlung, (6) neutron interaction (n, γ) in the stainless steel containers (treated within MCNP), and (7) alpha interaction with light nuclides (α, n) reactions. Alpha and beta particles are insignificant outside the package for all practical purposes. Table 4 shows the spectrum and total source strength (photons/sec).

The RASTA code was used to calculate the energy dependent decay source terms in the BUGLE-80 (NUREG/CR 7045, ORNL/TM-2011/12, *Production and Testing of the VITAMIN-B7 Fine Group and BUGLE B7 Broad Group Coupled Neutron/Gamma Cross Section Libraries Derived from ENDF/B VII.0 Nuclear Data*) twenty group structure. The source spectrum was input to MCNP as a histogram and the total source was used as a tally multiplier to convert the dose rates from units of per source particle to total dose rate.

5.4.2 Neutron Source

Neutrons are produced by spontaneous fission and by alpha particle interaction with light nuclides (α,n), which is the dominant source for these Content Envelopes. The neutron source strength was calculated in the BUGLE-80 forty-seven group structure using RASTA. The effect of subcritical multiplication was not included in the source strength, but accounted for during the radiation transport calculations. Table 5 shows the total source strength (neutrons/sec) of each Content Envelope.

5.5 Radiation Transport

Radiation transport calculations were performed using MCNP5. The normalized photon and neutron source spectra (Tables 4 and 5) were input into MCNP as histograms. The source strengths were used as a multiplier, internal in MCNP, to convert the MCNP-calculated dose rates from units of rem/hr per source particle started to total dose rate (rem/hr).

Table 4 Photon Spectra

Group	Energy Bound (MeV)		Photon Spectrum					
No.	Upper	Lower	(alpha, n)	(Prompt S.F.)	(Delayed S.F)	(Decay)	Total	Normalized
1	1.40E+01	1.00E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	1.00E+01	8.00E+00	0.00E+00	1.49E+02	3.62E-02	0.00E+00	1.49E+02	3.28E-11
3	8.00E+00	7.00E+00	1.37E+00	7.44E+01	7.10E-01	0.00E+00	7.64E+01	1.69E-11
4	7.00E+00	6.00E+00	3.28E+04	8.10E+02	3.32E+01	0.00E+00	3.36E+04	7.42E-09
5	6.00E+00	5.00E+00	4.81E+04	1.74E+03	2.33E+02	0.00E+00	5.00E+04	1.10E-08
6	5.00E+00	4.00E+00	1.71E+05	4.13E+03	1.49E+03	0.00E+00	1.77E+05	3.90E-08
7	4.00E+00	3.00E+00	6.85E+04	1.18E+04	9.25E+03	0.00E+00	8.95E+04	1.97E-08
8	3.00E+00	2.00E+00	1.76E+06	3.44E+04	3.55E+04	0.00E+00	1.83E+06	4.04E-07
9	2.00E+00	1.50E+00	2.18E+06	3.81E+04	3.63E+04	0.00E+00	2.25E+06	4.96E-07
10	1.50E+00	1.00E+00	1.40E+06	8.86E+04	7.36E+04	1.36E+04	1.58E+06	3.48E-07
11	1.00E+00	8.00E-01	1.07E+05	6.56E+04	6.13E+04	3.38E+05	5.72E+05	1.26E-07
12	8.00E-01	7.00E-01	1.59E+05	3.28E+04	4.16E+04	9.32E+06	9.56E+06	2.11E-06
13	7.00E-01	6.00E-01	4.01E+04	4.88E+04	4.16E+04	8.22E+06	8.35E+06	1.84E-06
14	6.00E-01	4.00E-01	5.52E+05	1.03E+05	1.04E+05	8.86E+07	8.93E+07	1.97E-05
15	4.00E-01	2.00E-01	2.68E+05	9.56E+04	1.03E+05	4.04E+08	4.05E+08	8.92E-05
16	2.00E-01	1.00E-01	0.00E+00	4.89E+04	4.92E+04	1.28E+09	1.28E+09	2.82E-04
17	1.00E-01	6.00E-02	0.00E+00	6.49E+03	1.97E+04	2.31E+09	2.31E+09	5.11E-04
18	6.00E-02	3.00E-02	1.10E+02	1.33E+04	1.48E+04	1.68E+12	1.68E+12	3.70E-01
19	3.00E-02	2.00E-02	0.00E+00	7.42E+03	4.92E+03	3.47E+11	3.47E+11	7.64E-02
20	2.00E-02	1.00E-02	0.00E+00	5.74E+03	4.92E+03	2.51E+12	2.51E+12	5.53E-01
		Total	6.79E+06	6.08E+05	6.02E+05	4.53E+12	4.53E+12	

Table 5 Neutron Spectra

Group	Energy Bound (MeV)		Neutron Spectrum			
No.	Upper	Lower	(alpha, n)	(S. F.)	Total	Normalized
1	1.73E+01	1.42E+01	0.00E+00	1.45E+00	1.45E+00	2.04E-07
2	1.42E+01	1.22E+01	0.00E+00	9.00E+00	9.00E+00	1.26E-06
3	1.22E+01	1.00E+01	0.00E+00	7.31E+01	7.31E+01	1.03E-05
4	1.00E+01	8.61E+00	0.00E+00	2.16E+02	2.16E+02	3.02E-05
5	8.61E+00	7.41E+00	1.30E+04	5.76E+02	1.36E+04	1.90E-03
6	7.41E+00	6.07E+00	1.58E+05	1.92E+03	1.60E+05	2.24E-02
7	6.07E+00	4.97E+00	3.68E+05	4.19E+03	3.73E+05	5.22E-02

8	4.97E+00	3.68E+00	9.94E+05	1.23E+04	1.01E+06	1.41E-01
9	3.68E+00	3.01E+00	4.60E+05	1.24E+04	4.73E+05	6.63E-02
10	3.01E+00	2.73E+00	2.72E+05	6.98E+03	2.79E+05	3.92E-02
11	2.73E+00	2.47E+00	3.41E+05	7.62E+03	3.48E+05	4.89E-02
12	2.47E+00	2.37E+00	1.49E+05	3.25E+03	1.52E+05	2.13E-02
13	2.37E+00	2.35E+00	3.12E+04	6.71E+02	3.19E+04	4.47E-03
14	2.35E+00	2.23E+00	1.97E+05	4.18E+03	2.01E+05	2.82E-02
15	2.23E+00	1.92E+00	5.66E+05	1.21E+04	5.78E+05	8.11E-02
16	1.92E+00	1.65E+00	5.10E+05	1.21E+04	5.22E+05	7.32E-02
17	1.65E+00	1.35E+00	5.87E+05	1.51E+04	6.02E+05	8.44E-02
18	1.35E+00	1.00E+00	7.48E+05	1.94E+04	7.68E+05	1.08E-01
19	1.00E+00	8.21E-01	3.90E+05	1.04E+04	4.00E+05	5.61E-02
20	8.21E-01	7.43E-01	1.65E+05	4.54E+03	1.69E+05	2.37E-02
21	7.43E-01	6.08E-01	2.72E+05	7.79E+03	2.80E+05	3.92E-02
22	6.08E-01	4.98E-01	2.02E+05	6.18E+03	2.08E+05	2.92E-02
23	4.98E-01	3.69E-01	2.12E+05	6.87E+03	2.19E+05	3.07E-02
24	3.69E-01	2.97E-01	1.03E+05	3.56E+03	1.07E+05	1.49E-02
25	2.97E-01	1.83E-01	1.34E+05	5.01E+03	1.39E+05	1.94E-02
26	1.83E-01	1.11E-01	5.85E+04	2.60E+03	6.11E+04	8.57E-03
27	1.11E-01	5.74E-02	2.76E+04	1.51E+03	2.91E+04	4.08E-03
28	5.74E-02	4.09E-02	5.42E+03	3.63E+02	5.78E+03	8.11E-04
29	4.09E-02	3.18E-02	2.33E+03	1.73E+02	2.51E+03	3.52E-04
30	3.18E-02	2.61E-02	1.22E+03	9.72E+01	1.32E+03	1.85E-04
31	2.61E-02	2.42E-02	3.68E+02	3.03E+01	3.98E+02	5.58E-05
32	2.42E-02	2.19E-02	4.18E+02	3.51E+01	4.53E+02	6.35E-05
33	2.19E-02	1.50E-02	1.07E+03	9.43E+01	1.17E+03	1.64E-04
34	1.50E-02	7.10E-03	8.79E+02	8.35E+01	9.63E+02	1.35E-04
35	7.10E-03	3.35E-03	2.71E+02	2.73E+01	2.98E+02	4.18E-05
36	3.35E-03	1.58E-03	8.57E+01	8.87E+00	9.46E+01	1.33E-05
37	1.58E-03	4.54E-04	3.44E+01	3.60E+00	3.80E+01	5.33E-06
38	4.54E-04	2.14E-04	4.22E+00	4.43E-01	4.66E+00	6.54E-07
39	2.14E-04	1.01E-04	1.37E+00	1.43E-01	1.51E+00	2.12E-07
40	1.01E-04	3.73E-05	5.07E-01	5.33E-02	5.60E-01	7.85E-08
41	3.73E-05	1.07E-05	1.24E-01	1.31E-02	1.37E-01	1.93E-08
42	1.07E-05	5.04E-06	1.52E-02	1.60E-03	1.68E-02	2.35E-09
43	5.04E-06	1.86E-06	5.49E-03	5.95E-04	6.08E-03	8.53E-10
44	1.86E-06	8.76E-07	1.26E-03	1.16E-04	1.37E-03	1.93E-10
45	8.76E-07	4.14E-07	4.07E-04	3.75E-05	4.45E-04	6.23E-11
46	4.14E-07	1.00E-07	1.22E-04	1.59E-05	1.38E-04	1.94E-11
47	1.00E-07	1.00E-11	1.17E-05	2.14E-06	1.38E-05	1.94E-12
		Total	6.97E+06	1.62E+05	7.13E+06	

The flux-to-dose-rate conversion factors used were those recommended by ANSI/ANS-6.1.1-1977 (*Neutron and Gamma-Ray Flux-to-Dose-Rate Factors).* Table 6 lists the conversion factors. The values from the 1977 version of the standard were used rather than those from the 1991 version of the standard because the neutron dose conversion factors in the 1977 version more closely reflect those provided in 49 CFR 173.403, and the photon dose conversion factors in the 1977 version more closely correspond to the response measured by instrumentation.

The sources were modeled as uniformly distributed in the volume of the convenience can occupied by plutonium oxide powder with a density of 7 g/cc. The 3013 containers and the convenience can are not modeled. The source was modeled as resting at the bottom of the PCV.

Point and surface detectors were modeled adjacent to the package and 1 meter from the surface of the package for NCT MCNP cases:

- On the source centerline at the top
- Vertically centered on the source at the side
- On the source centerline at the bottom

Table 6 Flux to Dose Rate Conversion Factors

Neutron		**Photon**	
Energy (MeV)	**Factor (rem/hr per $n/cm^2/sec$)**	**Energy (MeV)**	**Factor (rem/hr per $p/cm^2/sec$)**
2.50E-08	3.67E-06	1.00E-02	3.96E-06
1.00E-07	3.67E-06	3.00E-02	5.82E-07
1.00E-06	4.46E-06	5.00E-02	2.90E-07
1.00E-05	4.54E-06	7.00E-02	2.58E-07
1.00E-04	4.18E-06	1.00E-01	2.83E-07
1.00E-03	3.76E-06	1.50E-01	3.79E-07
1.00E-02	3.56E-06	2.00E-01	5.01E-07
1.00E-01	2.17E-05	2.50E-01	6.31E-07
5.00E-01	9.26E-05	3.00E-01	7.59E-07
1.00E+00	1.32E-04	3.50E-01	8.78E-07
2.50E+00	1.25E-04	4.00E-01	9.85E-07
5.00E+00	1.56E-04	4.50E-01	1.08E-06
7.00E+00	1.47E-04	5.00E-01	1.17E-06
1.00E+01	1.47E-04	5.50E-01	1.27E-06
1.40E+01	2.08E-04	6.00E-01	1.36E-06
2.00E+01	2.27E-04	6.50E-01	1.44E-06
		7.00E-01	1.52E-06
		8.00E-01	1.68E-06
		1.00E+00	1.98E-06
		1.40E+00	2.51E-06
		1.80E+00	2.99E-06
		2.20E+00	3.42E-06
		2.60E+00	3.82E-06
		2.80E+00	4.01E-06
		3.25E+00	4.41E-06
		3.75E+00	4.83E-06
		4.25E+00	5.23E-06
		4.75E+00	5.60E-06
		5.00E+00	5.80E-06
		5.25E+00	6.01E-06
		5.75E+00	6.37E-06
		6.25E+00	6.74E-06
		6.75E+00	7.11E-06
		7.50E+00	7.66E-06
		9.00E+00	8.77E-06
		1.10E+01	1.03E-05
		1.30E+01	1.18E-05
		1.50E+01	1.33E-05

The dose rate plus three standard deviations (D_{Total}) reported in mrem/hr was calculated as follows:

$$D_{Total} = 1000 \, {}^{mrem}\!/_{rem} * \sum D^i$$

$$D^i = D^i_m * (1 + 3 * fsd)$$

D^i_m is the mean dose rate for contribution from MCNP in rem/hr from radiation type i (neutron, secondary photon, primary photon)

fsd is the fractional standard deviation

ENDF/B-VI cross-section sets for transport calculations were used. Appendix A describes the MCNP input files.

6 RESULTS AND DISCUSSIONS

6.1 Dose Rate Outside the 9975 Shipping Package

Dose rates were calculated at the surface of the 9975 shipping package and 1 meter from the surface for Content Envelope C.12. An additional NCT case was analyzed with the outer 100 mils of lead replaced by void to assess the effect of lead corrosion. The MCNP results are presented in Tables 7 (NCT) and 8 (HAC).

Table 7 NCT MCNP Results

filename	x	y	z	mean (rem/hr)	fsd	mean (rem/hr)	fsd	mean (rem/hr)	fsd
				Neutron		Secondary Photon		Primary Photon	
Content Envelope C.12									
nct_n.12	0.0000	0.0000	-0.1000	1.77E-01	0.0022	7.19E-04	0.0044	8.02E-04	0.0059
nct_n.12	0.0000	0.0000	86.4400	1.02E-02	0.0087	4.57E-05	0.0168	2.65E-05	0.0312
nct_n.12	0.0000	23.3989	24.0340	1.84E-01	0.0021	7.03E-04	0.0047	8.57E-04	0.0074
nct_n.12	0.0000	0.0000	-100.0000	5.30E-03	0.0004	2.05E-05	0.0011	2.65E-05	0.0036
nct_n.12	0.0000	0.0000	186.3400	6.73E-04	0.0009	2.90E-06	0.0026	2.43E-06	0.0044
nct_n.12	0.0000	123.3990	24.0340	6.13E-03	0.0004	2.39E-05	0.0010	2.86E-05	0.0035
Content Envelope C.12 Lead Thinned									
nct_n.12.50	0.0000	0.0000	-0.1000	1.76E-01	0.0020	7.78E-04	0.0033	1.00E-03	0.0071
nct_n.12.50	0.0000	0.0000	86.4400	1.00E-02	0.0072	4.45E-05	0.0133	2.61E-05	0.0235
nct_n.12.50	0.0000	23.3989	24.0340	1.83E-01	0.0019	7.71E-04	0.0032	1.08E-03	0.0087
nct_n.12.50	0.0000	0.0000	-100.0000	5.33E-03	0.0004	2.27E-05	0.0010	3.29E-05	0.0034
nct_n.12.50	0.0000	0.0000	186.3400	6.80E-04	0.0009	2.99E-06	0.0023	2.69E-06	0.0168
nct_n.12.50	0.0000	123.3990	24.0340	6.11E-03	0.0004	2.64E-05	0.0009	3.57E-05	0.0030

The dose rates are summarized in Table 9, which presents the results in the format required for Chapter 5 of the Safety Analysis Report.

Table 8 HAC MCNP Results 1 meter from SCV

filename	x	y	z	mean (rem/hr)	fsd	mean (rem/hr)	fsd	mean (rem/hr)	fsd
				Neutron		Secondary Photon		Primary Photon	
Content Envelope C.12									
hac_n.12	0.0000	0.0000	-86.7200	7.75E-03	0.0002	4.27E-05	0.0005	1.83E-04	0.0026
hac_n.12	0.0000	0.0000	173.2800	7.30E-04	0.0004	2.20E-06	0.0021	3.26E-06	0.0058
hac_n.12	0.0000	108.4100	24.0340	8.55E-03	0.0002	4.85E-05	0.0005	2.05E-04	0.0108

Table 9 Summary of Dose Rates Outside 9975 Shipping Package

	C.12	C.12 50 year lead thinning
NCT at Surface (mrem/hour)		
SIDE		
Neutrons	184.75	183.77
Photons	1.59	1.88
Total[a]	186.34	185.66
TOP		
Neutrons	10.47	10.24
Photons	0.08	0.07
Total[a]	10.54	10.32
BOTTOM		
Neutrons	178.40	176.87
Photons	1.54	1.81
Total[a]	179.95	178.68
NCT 1 meter away (mrem/hour)		
SIDE		
Neutrons	6.14	6.12
Photons	0.05	0.06
Total[a]	6.19	6.18
TOP		
Neutrons	0.67	0.68
Photons	0.01	0.01
Total[a]	0.68	0.69
BOTTOM		
Neutrons	5.31	5.34
Photons	0.05	0.06
Total[a]	5.36	5.39
HAC 1 meter away (mrem/hour)		
SIDE		Not Analyzed Lead Shield is not present under HAC
Neutrons	8.55	
Photons	0.26	
Total[a]	8.81	
TOP		
Neutrons	0.73	
Photons	0.01	
Total[a]	0.74	
BOTTOM		
Neutrons	7.76	
Photons	0.23	
Total[a]	7.99	

[a] Total may differ from sum of neutron and photon due to round off

MCNP performs ten statistical checks. Not all calculations passed all ten checks. However, the neutron responses passed all statistical checks. In all cases where the statistical checks were not passed, the mean was well behaved. Since the dose rate outside the 9977 is predominately (more than 99%) from neutrons, the results of the MCNP calculations are judged to be acceptable.

6.2 Heat Generation Rates

The heat generation rate in the 9975 shipping package with Content Envelope C.12 is 16.7 watts.

7 CONCLUSIONS

The peak dose rate at the surface of the 9975 shipping package under NCT is below the limit for non-exclusive use shipment (200 mrem/hr). The dose rate at 1 meter from the surface of the damaged 9975 shipping package under HAC is below the regulatory limit (1000 mrem/hr).

The thinning of the lead shield corresponding to 50 years of corrosion at 2 mils/year (100 mils) does not have any impact on the dose rate outside the 9975 shipping package.

8 REFERENCES

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APPENDIX A INPUT FILES

The following table lists the input files used in this calculation. Output files have the same root name (e.g., hac_n.1) but with the suffix ".out." All input and output files will be archived in the SRNS electronic files on \\Wg01\CRIT\. Those files marked with an * are presented following the table.

File name	Description
RASTA Input Files	
rasta_c.12.in*	Content Envelope C.12 with Be and F only
MCNP Input Files	
hac_n.12.in	Content Envelope C.12 with Be and F only HAC neutron case
hac_p.12.in*	Content Envelope C.12 with Be and F only HAC photon case
nct_n.12.in*	Content Envelope C.12 with Be and F only NCT 0.434 INCH LEAD neutron case
nct_p.12.in	Content Envelope C.12 with Be and F only NCT 0.434 INCH LEAD photon case
nct_n.12.50.in*	Content Envelope C.16 with Be and F only NCT 0.334 INCH LEAD neutron case
nct_p.12.50.in	Content Envelope C.16 with Be and F only NCT 0.334 INCH LEAD photon case
ORIGEN-S Input Files	
c.12.inp*	Content Envelope C.12 heat generation calculation

RASTA Input File rasta_c.12.in

```
rasta_C.12  75 g Be and 390 g F in 5000 grams fuel grade oxide
5000 g of Plutonium oxide
/nng  npg  cmf  wsbi  keff  sog  ebeam  idd
-1   -1    1     1     0    0     0     1
/ni   iu
 5    2
     942380     0.909038353
     942390     3734.511363
     942400     239.9861252
     952410     16.36269036
     942420     7.999537508
/ni   iu
5    2
     80160     533.7807837
     80170     0.216096404
     80180     1.234365286
     40090     75
     90190     390
```

MCNP Input File hac_p.12.in

```
9975 HAC C.12  290 Al, 315 Na, & 1620 Mg - Photons
c 9975 Primary containment vessel.
c    Gland Plug (316-SS)
1     5    -7.895      (-29 -4 -49 32):(-3 20 -23):(-50 49 -20)      u=1
c    Gland Nut  (410-SS)
2     6    -7.895      (4 -5  17 -49):(50 -5 49 -20):(3 -5  20 -19):
                                          (3 -6  19 -23)     u=1
c    Cone Seal Plug (304L-SS)
3     7    -7.895      (7 -8  18 -23):(5 -8  16 -18):
                      ((29 1 -8 32 -16):(1 -10 32 -15)):
                      ((14 -32 -10) (1:-30) (28:-31))                 u=1
4     0                (29 16 -17 -5):(29 -4 17)                      u=1
5     0               ((-1 29  32):(-1 30 -32)):(-28 31 -10)          u=1
c    Cone Seal Nut (Nitronic-60 SST)
6     8    -7.895      (15 -21  8 -10):(21 -22 8 24 -25 26 -27):
                                 (22 -23 9 24 -25 26 -27)     u=1
7     0                22 -23 8 -9                                    u=1
8     0                (18 -19 5 -7):(19 -23 6 -7)                    u=1
c    PCV wall (304L-SS)
9     7    -7.895      (10 -11 35 -21):(-33 34 -35):(-10 34 35 -36)  u=1
c    Contents of PCV
11    0                 -10  36 -14 130             u=1
c    Al honeycomb spacer at bottom
12    2    -0.28        -10 -34 -36                                   u=1
13    0               ((21 -23 -46) (-24:25:-26:27)):(-46 23):48     u=1
c    Al honeycomb spacer at top
14    2    -0.28        46 -47  21 -48                                u=1
15    0                 (11 -21):(-11 33 -35):(21 47 -48)            u=1
20    5    -7.895      (-29 -4 -49 32):(-3 20 -23):(-50 49 -20)      u=2
21    6    -7.895      (4 -5  17 -49):(50 -5 49 -20):(3 -5  20 -19):
                                          (3 -6  19 -23)     u=2
22    7    -7.895      (7 -8  18 -23):(5 -8  16 -18):
                      ((29 1 -8 32 -16):(1 -40 32 -15)):
                      ((51 -32 -40) (1:-30) (28:-31))                 u=2
23    0                (29 16 -17 -5):(29 -4 17)                      u=2
24    0               ((-1 29  32):(-1 30 -32)):(-28 31 -40)          u=2
25    8    -7.895      (15 -21  8 -40):(21 -22 8 24 -25 26 -27):
                                 (22 -23 9 24 -25 26 -27)     u=2
26    0                22 -23 8 -9                                    u=2
27    0                (18 -19 5 -7):(19 -23 6 -7)                    u=2
28    7    -7.895      (40 -41 44 -21):(-42 43 -44):(-40 43 44 -45)  u=2
c  MHB - PCV starts 0.37" above SCV impact absorber
29    0                 -40  55 -51   fill=1 (0.0 0.0 -9.586595)      u=2
30    2    -0.28        -40 -43 -55                                   u=2
```

```
31    0              ((21 -23 -41) (-24:25:-26:27)):23             u=2
32    0              (-41 42 -44):(41 -23)                         u=2
c     MHB - bottom of SCV is 0.38" above SS Liner
40    0                74 -76  -60   fill=2 (0.0 0.0 28.19094)     u=3
 c    Shield liner (304-SS)
41    0       (60 -61 74 -76):(73 -74  -61)              u=3
c    Lead Shield
42    0        (61 -62 73 -76):(72 -73  -62)              u=3
c    Lower Al anti-rotation plate (Al 1100)
43    0           -64  71 -72                              u=3
c    1st of upper Al anti-rotation plate (Al 1100) MHB - changed 77 to 177
44    0         -62  76 -177                               u=3
c    2nd of upper Al anti-rotation plate (Al 1100)
45    0           -64  77 -78                              u=3
c    Celotex Bottom
46    0      (70 -71 -66)                                u=3
c    Celotex Sides
47    0      (71 -72 64 -66):(72 -82  63 -66):
                      (82 -75 81 -66):(75 -77 81 -65):
                      (64 -65 77 -78)                              u=3
c    Celotex Top
48    0      (-65 78 -79)                               u=3
49    0                (72 -82 62 -63):(82 -77 62 -81)           u=3
c MHB - added for space above 1st upper Al plate
149   0               -62 177 -77                                 u=3
50    0               (70 -75 -67 66):(75 -79 65 -67)             u=3
 c    Drum Bottom
51    0         69 -70 -68                               u=3
c    Drum Sides
52    0         67 -68 70 -80                            u=3
c    Drum Top
53    0         79 -80 -67                               u=3
c
91    0  68   u=3
92    0  -68 80    u=3
93    0  -68 -69   u=3
100   0               -52 53 -54                    fill=3
c
1110   4  -7           -130            u=1  $Plutonium oxide in convenience can
999   0                52:-53:54
c    Drum Top

1     cz     0.13891            $Vertical leak test port
3     cz     0.33655            $Top inner component of leak test port plug
4     cz     0.49530            $Lower inner piece   of leak test port plug
5     cz     0.714375           $9/32" bottom hole, leak test port plug
6     cz     0.750814           $Top outer component of leak test port plug
7     cz     1.14300            $0.45" topp   hole, leak test port plug
8     cz     1.58750            $0.625" top OR cone seal
9     cz     2.06375            $0.8125" top IR cone seal nut
10    cz     6.491605           $MHB - PCV IR (5.563" OD, .258" thick at 87.5 %)
11    cz     7.06501            $MHB - PCV OR (5.563" OD nominal)
14    pz    40.32250            $Lower surface of male cone seal PCV
15    pz    42.22750            $Top surface of male cone seal PCV
16    pz    42.54500            $Lowest surface of leak test port plug
17    pz    42.86250            $Lowest tip of outer plug   (0.875" from top)
18    pz    43.66260            $Outer top lip on cone seal (0.56" from top)
19    pz    44.29252            $Extent of top inner component of port plug
20    pz    43.81627            $Extent of leak test port plug
21    pz    43.81500            $Top surface of cone seal nut  (17.25")
22    pz    44.62780            $Lip on cone seal nut of PCV
23    pz    45.08500            $Top Surface of PCV
24    px    -3.175              $Cone seal nut left
25    px     3.175              $Cone seal nut right
26    py    -3.175              $Cone seal nut left
27    py     3.175              $Cone seal nut right
28    c/x    0.0  41.1099  0.13891    $Horiz. Leak test port
29    kz    42.1336553   0.33333333333    $Plug inner tip
30    pz    40.970993           $Bottom of vertical leak test port.
31    px     0.00               $Left tip of horizontal leak test port.
```

```
32    pz     42.1336553         $Plug inner tip
33    sz     14.035405  15.305405  $MHB - Cask Bot. OR (IR + .258" at 82.5%)
34    sz     14.035405  14.732  $MHB - Cask bot IR (5.8" IR)
35    pz      0.458179            $ MHB - change 4/15/02
36    pz      1.335405          $ MHB - PCV bottom spacer (0.8" high)
40    cz      7.840345          $MHB - Max SCV IR (OD - 0.280" at 82.5%)
41    cz      8.41375           $MHB - SCV OR (6.625" OD nominal)
42    sz      0.395605  15.305405  $MHB - SCV Cask Bottom OR (IR + 0.280" at82.5%)
43    sz      0.395605  14.732    $MHB - SCV Cask Bottom IR (5.8")
44    pz    -12.3897            $ MHB - change 4/15/02
45    pz    -11.796395          $ MHB - SCV bot. impact absorber (1" high)
46    cz      4.7625            $IR top honeycomb spacer (3-3/4" ID)
47    cz      7.46125           $OR top honeycomb spacer (5-7/8" OD)
48    pz     48.387             $Top of top spacer on PCV (1.8" tall)
49    pz     43.65752           $Bottom plane plug upper cone
50    kz     44.15282    1.00   $Plug upper cone
51    pz    40.32250            $Same as surface 14 (for SCV)
52    cz   523.0
53    pz  -500.0
54    pz   590.0
55    pz    -11.796395          $MHB - Top surface of SCV honeycomb (1")
60    cz      9.2075            $MHB - IR SS liner of Pb shield
61    cz      9.29894           $MHB - IR Pb shield (20 gauge SS liner 0.036")
62    cz     10.49274           $MHB - OR Pb shield (0.47 inch thick)
63    cz     10.7315            $MHB - IR cane fiberboard (bottom at 8.45" ID)
81    cz     10.8585            $MHB - IR cane fiberboard (top at 8.55" ID)
64    cz     14.224             $MHB - End rotation plate (11.2" OD)
65    cz     22.479             $OR cane fiberboard top     (17.7" OD)
66    cz     22.987             $MHB - OR cane fiberboard bottom(18.1" OD)
67    cz     23.1775            $IR drum
68    cz     23.2989            $OR drum (18 gauge, 0.0478")
69    pz      0.0               $Bottom outside surface drum
70    pz      0.1087            $bottom inside  surface drum
71    pz     9.7607             $MHB - To bottom of rotation plate (+3.8")
72    pz     11.0307            $MHB - To bottom of lead plate (+0.5")
73    pz     12.2245            $MHB - To bottom of lead shield liner (+0.47")
74    pz     12.31594           $MHB - To top of SS liner of lead shield (+0.036")
75    pz     67.9267            $MHB - Top/Bottom Celotex division  (+22.4)
82    pz     62.8467            $MHB - Top/bottom Celotex division (+20.4")
76    pz     73.7687            $MHB - Bottom of top Al rotation plate (24.1" IH)
177   pz     75.0387            $MHB - To top of 1st (top) rotation plate (+0.5")
77    pz     75.5467            $MHB - To bot of 2nd (top) rotation plate
78    pz     76.8167            $MHB - To top of 2nd (top) rotation plate (+0.5")
79    pz     86.2147            $MHB - To top of Celotex
80    pz     86.336112          $MHB - Top outer surface of drum  (+0.0478")
 130  rcc 0  0 1.337 0 0 8.185       5.2705       $PuO2 inside convenience can

m1   82000        1.0       $Lead at 11.29
m2   13000        1.00      $Al honeycomb at 0.28
c    source material Pu-239
m4    94239      1.0  8016 2.0
m5   26000       -0.6917    $316-SS at 7.895
     28000       -0.10
     42000       -0.02
     24000       -0.16
     14000       -0.0075
      6000       -0.0008
     25000       -0.02
m6   26000       -0.8603    $410-SS at 7.895
      6000       -0.0015
     25000       -0.01
     15000       -0.0004
     16000       -0.0003
     14000       -0.0075
     24000       -0.115
     28000       -0.005
m7   26000       -0.7117    $304L-SS at 7.895
     25055       -0.02
     24000       -0.18
     14000       -0.0075
```

```
      6000      -0.0008
     28000      -0.08
m8   26000      -0.655    $Nitronic-60 at 7.895
     28000      -0.08
     24000      -0.16
     14000      -0.035
     25000      -0.07
      6000      -0.001
m9   13000       1.0       $Aluminum at 2.7
m10   6000       6.0       $Celotex at 0.20
      1000      10.0
      8000       5.0
sdef   erg d1   rad d3 ext d2 axs 0 0 1
       pos 0 0 19.941345
si2   0 8.185
si3   0 5.2705
c Photon Groups
si1   1.00000E-02  2.00000E-02  3.00000E-02  6.00000E-02  1.00000E-01
      2.00000E-01  4.00000E-01  6.00000E-01  7.00000E-01  8.00000E-01
      1.00000E+00  1.50000E+00  2.00000E+00  3.00000E+00  4.00000E+00
      5.00000E+00  6.00000E+00  7.00000E+00  8.00000E+00  1.00000E+01
      1.40000E+01
c  Photon source strength -
sp1   0.00000E+00  5.52808E-01  7.64400E-02  3.69845E-01  5.10535E-04
      2.81748E-04  8.92241E-05  1.97057E-05  1.84237E-06  2.10766E-06
      1.26117E-07  3.47943E-07  4.96412E-07  4.04244E-07  1.97476E-08
      3.90319E-08  1.10328E-08  7.42167E-09  1.68615E-11  3.28133E-11
      0.00000E+00
sb1   0.0          0.01         0.01         0.01         0.01
      0.1          0.5          1  12r       0.0
ctme 360
mode p
c point detectors
f15:p 0 0 -86.72      2          $1 meter from bottom surface
      0 0 173.28      2          $1 meter from top surface
      0 108.41 24.034 2          $1 meter from side surface, level with source
c
c dose factors for Photons from ANS 6.1.1-1977, rem/hr
de15 .01 .03 .05 .07 .1 .15 .2 .25 .3 .35 .4 .45 .5 .55 .6 .65 &
    .7 .8 1. 1.4 1.8 2.2 2.6 2.8 3.25 3.75 4.25 4.75 5.0 5.25 &
    5.75 6.25 6.75 7.5 9. 11. 13. 15.
df15 3.96E-6 5.82E-7 2.9E-7 2.58E-7 2.83E-7 3.79E-7 5.01E-7 6.31E-7 &
    7.59E-7 8.78E-7 9.85E-7 1.08E-6 1.17E-6 1.27E-6 1.36E-6 1.44E-6 &
    1.52E-6 1.68E-6 1.98E-6 2.51E-6 2.99E-6 3.42E-6 3.82E-6 4.01E-6 &
    4.41E-6 4.83E-6 5.23E-6 5.6E-6 5.8E-6 6.01E-6 6.37E-6 6.74E-6 &
    7.11E-6 7.66E-6 8.77E-6 1.03E-5 1.18E-5 1.33E-5
fm15 4.53396E+12
c
imp:p 1 46r 0
```

MCNP Input File nct_n.12.in

```
9975 NCT C.12  290 Al, 315 Na, & 1620 Mg - Neutrons
c 9975 Primary containment vessel.
c    Gland Plug (316-SS)
1    5    -7.895      (-29 -4 -49 32):(-3 20 -23):(-50 49 -20)      u=1
c    Gland Nut  (410-SS)
2    6    -7.895      (4 -5  17 -49):(50 -5 49 -20):(3 -5  20 -19):
                                                  (3 -6  19 -23)     u=1
c    Cone Seal Plug (304L-SS)
3    7    -7.895      (7 -8  18 -23):(5 -8  16 -18):
                     ((29 1 -8 32 -16):(1 -10 32 -15)):
                     ((14 -32 -10) (1:-30) (28:-31))                 u=1
4    0                (29 16 -17 -5):(29 -4 17)                      u=1
5    0               ((-1 29  32):(-1 30 -32)):(-28 31 -10)          u=1
c    Cone Seal Nut (Nitronic-60 SST)
6    8    -7.895      (15 -21  8 -10):(21 -22 8 24 -25 26 -27):
```

```
                                        (22 -23 9 24 -25 26 -27)      u=1
7     0                22 -23 8 -9                                    u=1
8     0                (18 -19 5 -7):(19 -23 6 -7)                    u=1
c    PCV wall (304L-SS)
9     7    -7.895      (10 -11 35 -21):(-33 34 -35):(-10 34 35 -36)   u=1
c    Contents of PCV
11    0                 -10  36 -14 130              u=1
c    Al honeycomb spacer at bottom
12    2    -0.28        -10 -34 -36                                   u=1
13    0               ((21 -23 -46) (-24:25:-26:27)):(-46 23):48      u=1
c    Al honeycomb spacer at top
14    2    -0.28        46 -47  21 -48                                u=1
15    0                 (11 -21):(-11 33 -35):(21 47 -48)             u=1
20    5    -7.895      (-29 -4 -49 32):(-3 20 -23):(-50 49 -20)       u=2
21    6    -7.895      (4 -5  17 -49):(50 -5 49 -20):(3 -5  20 -19):
                                                   (3 -6  19 -23)     u=2
22    7    -7.895      (7 -8  18 -23):(5 -8  16 -18):
                      ((29 1 -8 32 -16):(1 -40 32 -15)):
                      ((51 -32 -40) (1:-30) (28:-31))                 u=2
23    0                (29 16 -17 -5):(29 -4 17)                      u=2
24    0               ((-1 29  32):(-1 30 -32)):(-28 31 -40)          u=2
25    8    -7.895      (15 -21  8 -40):(21 -22 8 24 -25 26 -27):
                                        (22 -23 9 24 -25 26 -27)      u=2
26    0                22 -23 8 -9                                    u=2
27    0                (18 -19 5 -7):(19 -23 6 -7)                    u=2
28    7    -7.895      (40 -41 44 -21):(-42 43 -44):(-40 43 44 -45)  u=2
c  MHB - PCV starts 0.37" above SCV impact absorber
29    0                 -40  55 -51    fill=1 (0.0 0.0 -9.586595)     u=2
30    2    -0.28        -40 -43 -55                                   u=2
31    0               ((21 -23 -41) (-24:25:-26:27)):23               u=2
32    0                (-41 42 -44):(41 -23)                          u=2
c     MHB - bottom of SCV is 0.38" above SS Liner
40    0                 74 -76  -60    fill=2 (0.0 0.0 28.19094)      u=3
c    Shield liner (304-SS)
41    7    -7.895      (60 -61 74 -76):(73 -74  -61)                  u=3
c    Lead Shield
42    1   -11.29       (61 -162 73 -76):(172 -73  -162)                 u=3
c    Lower Al anti-rotation plate (Al 1100)
43    9    -2.7         -64  71 -72                                   u=3
c    1st of upper Al anti-rotation plate (Al 1100) MHB - changed 77 to 177
44    9    -2.7         -62  76 -177                                   u=3
c    2nd of upper Al anti-rotation plate (Al 1100)
45    9    -2.7         -64  77 -78                                   u=3
c    Celotex Bottom
46   10    -0.20      (70 -71 -66)                                    u=3
c    Celotex Sides
47   10    -0.20      (71 -72 64 -66):(72 -82  63 -66):
                      (82 -75 81 -66):(75 -77 81 -65):
                      (64 -65 77 -78)                                 u=3
c    Celotex Top
48   10    -0.20       (-65 78 -79)                                   u=3
49    0                (72 -82 62 -63):(82 -77 62 -81)                u=3
c SJN - added for reduced lead thickness
249   7    -7.895      (-62 72 -172):(-62 162 172 -76)                u=3
c MHB - added for space above 1st upper Al plate
149   0                -62 177 -77                                    u=3
50    0                (70 -75 -67 66):(75 -79 65 -67)                u=3
c    Drum Bottom
51    7    -7.895       69 -70 -68                                    u=3
c    Drum Sides
52    7    -7.895       67 -68 70 -80                                 u=3
c    Drum Top
53    7    -7.895       79 -80 -67                                    u=3
c
91   0  68   u=3
92   0  -68 80    u=3
93   0  -68 -69   u=3
100   0                -52 53 -54                     fill=3
c
1110   4  -7             -130               u=1  $Plutonium oxide in convenience can
```

```
999   0              52:-53:54
c    Drum Top

1     cz     0.13891           $Vertical leak test port
3     cz     0.33655           $Top inner component of leak test port plug
4     cz     0.49530           $Lower inner piece   of leak test port plug
5     cz     0.714375          $9/32" bottom hole, leak test port plug
6     cz     0.750814          $Top outer component of leak test port plug
7     cz     1.14300           $0.45" topp   hole, leak test port plug
8     cz     1.58750           $0.625" top OR cone seal
9     cz     2.06375           $0.8125" top IR cone seal nut
10    cz     6.491605          $MHB - PCV IR (5.563" OD, .258" thick at 87.5 %)
11    cz     7.06501           $MHB - PCV OR (5.563" OD nominal)
14    pz    40.32250           $Lower surface of male cone seal PCV
15    pz    42.22750           $Top surface of male cone seal PCV
16    pz    42.54500           $Lowest surface of leak test port plug
17    pz    42.86250           $Lowest tip of outer plug   (0.875" from top)
18    pz    43.66260           $Outer top lip on cone seal (0.56" from top)
19    pz    44.29252           $Extent of top inner component of port plug
20    pz    43.81627           $Extent of leak test port plug
21    pz    43.81500           $Top surface of cone seal nut  (17.25")
22    pz    44.62780           $Lip on cone seal nut of PCV
23    pz    45.08500           $Top Surface of PCV
24    px    -3.175             $Cone seal nut left
25    px     3.175             $Cone seal nut right
26    py    -3.175             $Cone seal nut left
27    py     3.175             $Cone seal nut right
28    c/x    0.0  41.1099  0.13891    $Horiz. Leak test port
29    kz    42.1336553   0.33333333333    $Plug inner tip
30    pz    40.970993          $Bottom of vertical leak test port.
31    px     0.00              $Left tip of horizontal leak test port.
32    pz    42.1336553         $Plug inner tip
33    sz     14.035405  15.305405  $MHB - Cask Bot. OR (IR + .258" at 82.5%)
34    sz     14.035405  14.732  $MHB - Cask bot IR (5.8" IR)
35    pz      0.458179            $ MHB - change 4/15/02
36    pz      1.335405         $ MHB - PCV bottom spacer (0.8" high)
40    cz      7.840345         $MHB - Max SCV IR (OD - 0.280" at 82.5%)
41    cz      8.41375          $MHB - SCV OR (6.625" OD nominal)
42    sz      0.395605  15.305405  $MHB - SCV Cask Bottom OR (IR + 0.280" at82.5%)
43    sz      0.395605  14.732    $MHB - SCV Cask Bottom IR (5.8")
44    pz    -12.3897           $ MHB - change 4/15/02
45    pz    -11.796395         $ MHB - SCV bot. impact absorber (1" high)
46    cz      4.7625           $IR top honeycomb spacer (3-3/4" ID)
47    cz      7.46125          $OR top honeycomb spacer (5-7/8" OD)
48    pz     48.387            $Top of top spacer on PCV (1.8" tall)
49    pz     43.65752          $Bottom plane plug upper cone
50    kz     44.15282    1.00  $Plug upper cone
51    pz    40.32250           $Same as surface 14 (for SCV)
52    cz   523.0
53    pz  -500.0
54    pz   590.0
55    pz   -11.796395          $MHB - Top surface of SCV honeycomb (1")
60    cz     9.2075            $MHB - IR SS liner of Pb shield
61    cz     9.29894           $MHB - IR Pb shield (20 gauge SS liner 0.036")
62    cz    10.49274           $MHB - OR SS liner of Pb shield (20 gauge SS liner 0.036")
162   cz    10.4013            $MHB - OR Pb shield (0.434 inch thick)
63    cz    10.7315            $MHB - IR cane fiberboard (bottom at 8.45" ID)
81    cz    10.8585            $MHB - IR cane fiberboard (top at 8.55" ID)
64    cz    14.224             $MHB - End rotation plate (11.2" OD)
65    cz    22.479             $OR cane fiberboard top     (17.7" OD)
66    cz    22.987             $MHB - OR cane fiberboard bottom(18.1" OD)
67    cz    23.1775            $IR drum
68    cz    23.2989            $OR drum (18 gauge, 0.0478")
69    pz     0.0               $Bottom outside surface drum
70    pz     0.1087            $bottom inside  surface drum
71    pz     9.7607            $MHB - To bottom of rotation plate (+3.8")
72    pz    11.0307            $MHB - To bottom of lead plate (+0.5")
172   pz    11.12214           $SJN - bottom of lead shield (surf 73 - 0.434")
73    pz    12.2245            $MHB - To bottom of lead shield liner (+0.47")
74    pz    12.31594           $MHB - To top of SS liner of lead shield (+0.036")
```

```
75    pz    67.9267              $MHB - Top/Bottom Celotex division  (+22.4)
82    pz    62.8467              $MHB - Top/bottom Celotex division (+20.4")
76    pz    73.7687              $MHB - Bottom of top Al rotation plate (24.1" IH)
177   pz    75.0387              $MHB - To top of 1st (top) rotation plate (+0.5")
77    pz    75.5467              $MHB - To bot of 2nd (top) rotation plate
78    pz    76.8167              $MHB - To top of 2nd (top) rotation plate (+0.5")
79    pz    86.2147              $MHB - To top of Celotex
80    pz    86.336112            $MHB - Top outer surface of drum  (+0.0478")
 130  rcc 0 0 1.337 0 0 8.185        5.2705        $PuO2 inside convenience can

m1   82000       1.0       $Lead at 11.29
m2   13027       1.00      $Al honeycomb at 0.28
c     source material Pu-239
m4   94239      1.0  8016 2.0
m5   26000      -0.6917    $316-SS at 7.895
     28000      -0.10
     42000      -0.02
     24000      -0.16
     14000      -0.0075
      6000      -0.0008
     25055      -0.02
m6   26000      -0.8603    $410-SS at 7.895
      6000      -0.0015
     25055      -0.01
     15031      -0.0004
     16000      -0.0003
     14000      -0.0075
     24000      -0.115
     28000      -0.005
m7   26000      -0.7117    $304L-SS at 7.895
     25055      -0.02
     24000      -0.18
     14000      -0.0075
      6000      -0.0008
     28000      -0.08
m8   26000      -0.655    $Nitronic-60 at 7.895
     28000      -0.08
     24000      -0.16
     14000      -0.035
     25055      -0.07
      6000      -0.001
m9   13027       1.0       $Aluminum at 2.7
m10   6000       6.0       $Celotex at 0.20
      1001      10.0
      8016       5.0
sdef   erg d1   rad d3 ext d2 axs 0 0 1
       pos 0 0 19.941345
si2   0 8.185
si3   0 5.2705
c  Neutron
si1   1.00000E-11  1.00000E-07  4.14000E-07  8.76000E-07  1.86000E-06
      5.04000E-06  1.07000E-05  3.73000E-05  1.01000E-04  2.14000E-04
      4.54000E-04  1.58000E-03  3.35000E-03  7.10000E-03  1.50000E-02
      2.19000E-02  2.42000E-02  2.61000E-02  3.18000E-02  4.09000E-02
      5.74000E-02  1.11000E-01  1.83000E-01  2.97000E-01  3.69000E-01
      4.98000E-01  6.08000E-01  7.43000E-01  8.21000E-01  1.00000E+00
      1.35000E+00  1.65000E+00  1.92000E+00  2.23000E+00  2.35000E+00
      2.37000E+00  2.47000E+00  2.73000E+00  3.01000E+00  3.68000E+00
      4.97000E+00  6.07000E+00  7.41000E+00  8.61000E+00  1.00000E+01
      1.22000E+01  1.42000E+01  1.73000E+01
c  Neutron source
sp1   0.00000E+00  1.94076E-12  1.93536E-11  6.23463E-11  1.92739E-10
      8.52796E-10  2.35345E-09  1.92513E-08  7.85490E-08  2.11548E-07
      6.53943E-07  5.33161E-06  1.32647E-05  4.18118E-05  1.35012E-04
      1.63597E-04  6.35119E-05  5.58070E-05  1.85372E-04  3.51527E-04
      8.10692E-04  4.08411E-03  8.56898E-03  1.94492E-02  1.49417E-02
      3.06984E-02  2.91735E-02  3.91976E-02  2.37254E-02  5.60683E-02
      1.07660E-01  8.43683E-02  7.31993E-02  8.10691E-02  2.82381E-02
      4.47152E-03  2.13095E-02  4.88523E-02  3.91684E-02  6.62805E-02
      1.41081E-01  5.22465E-02  2.23748E-02  1.90416E-03  3.02404E-05
```

```
      1.02548E-05  1.26141E-06  2.03704E-07
ctme 420
mode n p
c secondary photon point detectors
f15:p 0 0 -0.1           2   $bottom surface
      0 0 86.44          2   $top surface
      0 23.3989 24.034   2   $side surface, level with source
      0 0 -100           2   $1 meter from bottom surface
      0 0 186.34         2   $1 meter from top surface
      0 123.3989 24.034  2   $1 meter from side surface, level with source
c
c dose factors for Photons from ANS 6.1.1-1977, rem/hr
de15 .01 .03 .05 .07 .1 .15 .2 .25 .3 .35 .4 .45 .5 .55 .6 .65 &
    .7 .8 1. 1.4 1.8 2.2 2.6 2.8 3.25 3.75 4.25 4.75 5.0 5.25 &
    5.75 6.25 6.75 7.5 9. 11. 13. 15.
df15 3.96E-6 5.82E-7 2.9E-7 2.58E-7 2.83E-7 3.79E-7 5.01E-7 6.31E-7 &
    7.59E-7 8.78E-7 9.85E-7 1.08E-6 1.17E-6 1.27E-6 1.36E-6 1.44E-6 &
    1.52E-6 1.68E-6 1.98E-6 2.51E-6 2.99E-6 3.42E-6 3.82E-6 4.01E-6 &
    4.41E-6 4.83E-6 5.23E-6 5.6E-6 5.8E-6 6.01E-6 6.37E-6 6.74E-6 &
    7.11E-6 7.66E-6 8.77E-6 1.03E-5 1.18E-5 1.33E-5
fm15 7.13212E+06
c
c neutron point detectors
f25:n 0 0 -0.1           2   $bottom surface
      0 0 86.44          2   $top surface
      0 23.3989 24.034   2   $side surface, level with source
      0 0 -100           2   $1 meter from bottom surface
      0 0 186.34         2   $1 meter from top surface
      0 123.3989 24.034  2   $1 meter from side surface, level with source
c
c dose factors for Neutrons from ANS 6.1.1-1977, rem/hr
de25  2.5e-08 1.0e-07 1.0e-06 1.0e-05 1.0e-04 1.0e-03 1.0e-02 1.0e-01
      5.0e-01 1.0 2.5 5.0 7.0 10.0 14.0 20.0
df25  3.67e-6 3.67e-6 4.46e-6 4.54e-6 4.18e-6 3.76e-6 3.56e-6 2.17e-5
      9.26e-5 1.32e-4 1.25e-4 1.56e-4 1.47e-4 1.47e-4 2.08e-4 2.27e-4
fm25 7.13212E+06
c
imp:p 1 47r 0
imp:n 1 47r 0
c cut off low energy photons
phys:p 0.0000001
```

MCNP Input File nct_n.12.50.in

```
9975 NCT NCT C.12  290 Al, 315 Na, & 1620 Mg - Neutrons Pb thinned 100 mills
c 9975 Primary containment vessel.
c    Gland Plug (316-SS)
1     5    -7.895      (-29 -4 -49 32):(-3 20 -23):(-50 49 -20)      u=1
c    Gland Nut  (410-SS)
2     6    -7.895      (4 -5  17 -49):(50 -5 49 -20):(3 -5  20 -19):
                                                  (3 -6  19 -23)    u=1
c    Cone Seal Plug (304L-SS)
3     7    -7.895      (7 -8  18 -23):(5 -8  16 -18):
                      ((29 1 -8 32 -16):(1 -10 32 -15)):
                      ((14 -32 -10) (1:-30) (28:-31))                u=1
4     0                (29 16 -17 -5):(29 -4 17)                     u=1
5     0               ((-1 29  32):(-1 30 -32)):(-28 31 -10)         u=1
c    Cone Seal Nut (Nitronic-60 SST)
6     8    -7.895      (15 -21  8 -10):(21 -22 8 24 -25 26 -27):
                                       (22 -23 9 24 -25 26 -27)      u=1
7     0                22 -23 8 -9                                   u=1
8     0                (18 -19 5 -7):(19 -23 6 -7)                   u=1
c    PCV wall (304L-SS)
9     7    -7.895      (10 -11 35 -21):(-33 34 -35):(-10 34 35 -36)  u=1
c    Contents of PCV
11    0                 -10  36 -14 130             u=1
c    Al honeycomb spacer at bottom
```

```
12    2    -0.28        -10 -34 -36                                   u=1
13    0               ((21 -23 -46) (-24:25:-26:27)):(-46 23):48      u=1
c    Al honeycomb spacer at top
14    2    -0.28        46 -47  21 -48                                u=1
15    0                 (11 -21):(-11 33 -35):(21 47 -48)             u=1
20    5    -7.895      (-29 -4 -49 32):(-3 20 -23):(-50 49 -20)       u=2
21    6    -7.895      (4 -5  17 -49):(50 -5 49 -20):(3 -5  20 -19):
                                                (3 -6  19 -23)        u=2
22    7    -7.895      (7 -8  18 -23):(5 -8  16 -18):
                       ((29 1 -8 32 -16):(1 -40 32 -15)):
                       ((51 -32 -40) (1:-30) (28:-31))                u=2
23    0                (29 16 -17 -5):(29 -4 17)                      u=2
24    0                ((-1 29  32):(-1 30 -32)):(-28 31 -40)         u=2
25    8    -7.895      (15 -21  8 -40):(21 -22 8 24 -25 26 -27):
                                   (22 -23 9 24 -25 26 -27)           u=2
26    0                 22 -23 8 -9                                   u=2
27    0                (18 -19 5 -7):(19 -23 6 -7)                    u=2
28    7    -7.895      (40 -41 44 -21):(-42 43 -44):(-40 43 44 -45)   u=2
c  MHB - PCV starts 0.37" above SCV impact absorber
29    0                 -40  55 -51    fill=1 (0.0 0.0 -9.586595)     u=2
30    2    -0.28        -40 -43 -55                                   u=2
31    0                ((21 -23 -41) (-24:25:-26:27)):23              u=2
32    0                (-41 42 -44):(41 -23)                          u=2
c    MHB - bottom of SCV is 0.38" above SS Liner
40    0                 74 -76  -60    fill=2 (0.0 0.0 28.19094)      u=3
c    Shield liner (304-SS)
41    7    -7.895      (60 -61 74 -76):(73 -74  -61)                  u=3
c    Lead Shield
42    1   -11.29       (61 -262 73 -76):(272 -73  -262)                 u=3
c    Lower Al anti-rotation plate (Al 1100)
43    9    -2.7         -64  71 -72                                   u=3
c    1st of upper Al anti-rotation plate (Al 1100) MHB - changed 77 to 177
44    9    -2.7         -62  76 -177                                    u=3
c    2nd of upper Al anti-rotation plate (Al 1100)
45    9    -2.7         -64  77 -78                                   u=3
c    Celotex Bottom
46    10   -0.20       (70 -71 -66)                                   u=3
c    Celotex Sides
47    10   -0.20       (71 -72 64 -66):(72 -82  63 -66):
                       (82 -75 81 -66):(75 -77 81 -65):
                       (64 -65 77 -78)                                u=3
c    Celotex Top
48    10   -0.20       (-65 78 -79)                                   u=3
49    0                (72 -82 62 -63):(82 -77 62 -81)                u=3
c SJN - added for reduced lead thickness
349   0                (-162 172 -272):(-162 262 272 -76)              u=3
249   7    -7.895      (-62 72 -172):(-62 162 172 -76)                u=3
c MHB - added for space above 1st upper Al plate
149   0                -62 177 -77                                    u=3
50    0                (70 -75 -67 66):(75 -79 65 -67)                u=3
c    Drum Bottom
51    7    -7.895       69 -70 -68                                    u=3
c    Drum Sides
52    7    -7.895       67 -68 70 -80                                 u=3
c    Drum Top
53    7    -7.895       79 -80 -67                                    u=3
c
91    0  68   u=3
92    0  -68 80    u=3
93    0  -68 -69   u=3
100   0                -52 53 -54                    fill=3
c
1110   4  -7            -130              u=1  $Plutonium oxide in convenience can
999   0                 52:-53:54
c    Drum Top

1     cz     0.13891           $Vertical leak test port
3     cz     0.33655           $Top inner component of leak test port plug
4     cz     0.49530           $Lower inner piece   of leak test port plug
5     cz     0.714375          $9/32" bottom hole, leak test port plug
```

```
6      cz     0.750814          $Top outer component of leak test port plug
7      cz     1.14300           $0.45" topp  hole, leak test port plug
8      cz     1.58750           $0.625" top OR cone seal
9      cz     2.06375           $0.8125" top IR cone seal nut
10     cz     6.491605          $MHB - PCV IR (5.563" OD, .258" thick at 87.5 %)
11     cz     7.06501           $MHB - PCV OR (5.563" OD nominal)
14     pz    40.32250           $Lower surface of male cone seal PCV
15     pz    42.22750           $Top surface of male cone seal PCV
16     pz    42.54500           $Lowest surface of leak test port plug
17     pz    42.86250           $Lowest tip of outer plug   (0.875" from top)
18     pz    43.66260           $Outer top lip on cone seal (0.56" from top)
19     pz    44.29252           $Extent of top inner component of port plug
20     pz    43.81627           $Extent of leak test port plug
21     pz    43.81500           $Top surface of cone seal nut  (17.25")
22     pz    44.62780           $Lip on cone seal nut of PCV
23     pz    45.08500           $Top Surface of PCV
24     px    -3.175             $Cone seal nut left
25     px     3.175             $Cone seal nut right
26     py    -3.175             $Cone seal nut left
27     py     3.175             $Cone seal nut right
28     c/x    0.0  41.1099  0.13891    $Horiz. Leak test port
29     kz    42.1336553   0.33333333333    $Plug inner tip
30     pz    40.970993          $Bottom of vertical leak test port.
31     px     0.00              $Left tip of horizontal leak test port.
32     pz    42.1336553         $Plug inner tip
33     sz    14.035405  15.305405  $MHB - Cask Bot. OR (IR + .258" at 82.5%)
34     sz    14.035405  14.732  $MHB - Cask bot IR (5.8" IR)
35     pz     0.458179            $ MHB - change 4/15/02
36     pz     1.335405          $ MHB - PCV bottom spacer (0.8" high)
40     cz     7.840345          $MHB - Max SCV IR (OD - 0.280" at 82.5%)
41     cz     8.41375           $MHB - SCV OR (6.625" OD nominal)
42     sz     0.395605  15.305405  $MHB - SCV Cask Bottom OR (IR + 0.280" at82.5%)
43     sz     0.395605  14.732    $MHB - SCV Cask Bottom IR (5.8")
44     pz   -12.3897            $ MHB - change 4/15/02
45     pz   -11.796395          $ MHB - SCV bot. impact absorber (1" high)
46     cz     4.7625            $IR top honeycomb spacer (3-3/4" ID)
47     cz     7.46125           $OR top honeycomb spacer (5-7/8" OD)
48     pz    48.387             $Top of top spacer on PCV (1.8" tall)
49     pz    43.65752           $Bottom plane plug upper cone
50     kz    44.15282    1.00   $Plug upper cone
51     pz    40.32250           $Same as surface 14 (for SCV)
52     cz   523.0
53     pz  -500.0
54     pz   590.0
55     pz   -11.796395          $MHB - Top surface of SCV honeycomb (1")
60     cz     9.2075            $MHB - IR SS liner of Pb shield
61     cz     9.29894           $MHB - IR Pb shield (20 gauge SS liner 0.036")
62     cz    10.49274           $MHB - OR SS liner of Pb shield (20 gauge SS liner 0.036")
162    cz    10.4013            $MHB - OR Pb shield (0.434 inch thick)
262    cz    10.1473            $MHB - OR Pb shield (0.434 inch thick)
63     cz    10.7315            $MHB - IR cane fiberboard (bottom at 8.45" ID)
81     cz    10.8585            $MHB - IR cane fiberboard (top at 8.55" ID)
64     cz    14.224             $MHB - End rotation plate (11.2" OD)
65     cz    22.479             $OR cane fiberboard top     (17.7" OD)
66     cz    22.987             $MHB - OR cane fiberboard bottom(18.1" OD)
67     cz    23.1775            $IR drum
68     cz    23.2989            $OR drum (18 gauge, 0.0478")
69     pz     0.0               $Bottom outside surface drum
70     pz     0.1087            $bottom inside  surface drum
71     pz     9.7607            $MHB - To bottom of rotation plate (+3.8")
72     pz    11.0307            $MHB - To bottom of lead plate (+0.5")
172    pz    11.12214           $SJN - bottom of lead shield (surf 73 - 0.434")
272    pz    11.37614           $SJN - bottom of lead shield (surf 73 - 0.434")
73     pz    12.2245            $MHB - To bottom of lead shield liner (+0.47")
74     pz    12.31594           $MHB - To top of SS liner of lead shield (+0.036")
75     pz    67.9267            $MHB - Top/Bottom Celotex division  (+22.4)
82     pz    62.8467            $MHB - Top/bottom Celotex division (+20.4")
76     pz    73.7687            $MHB - Bottom of top Al rotation plate (24.1" IH)
177    pz    75.0387            $MHB - To top of 1st (top) rotation plate (+0.5")
77     pz    75.5467            $MHB - To bot of 2nd (top) rotation plate
```

```
78    pz    76.8167            $MHB - To top of 2nd (top) rotation plate (+0.5")
79    pz    86.2147            $MHB - To top of Celotex
80    pz    86.336112          $MHB - Top outer surface of drum  (+0.0478")
 130  rcc 0 0 1.337 0 0 8.185        5.2705        $PuO2 inside convenience can

m1   82000       1.0      $Lead at 11.29
m2   13027       1.00     $Al honeycomb at 0.28
c     source material Pu-239
m4    94239     1.0  8016 2.0
m5   26000      -0.6917   $316-SS at 7.895
     28000      -0.10
     42000      -0.02
     24000      -0.16
     14000      -0.0075
      6000      -0.0008
     25055      -0.02
m6   26000      -0.8603   $410-SS at 7.895
      6000      -0.0015
     25055      -0.01
     15031      -0.0004
     16000      -0.0003
     14000      -0.0075
     24000      -0.115
     28000      -0.005
m7   26000      -0.7117   $304L-SS at 7.895
     25055      -0.02
     24000      -0.18
     14000      -0.0075
      6000      -0.0008
     28000      -0.08
m8   26000      -0.655   $Nitronic-60 at 7.895
     28000      -0.08
     24000      -0.16
     14000      -0.035
     25055      -0.07
      6000      -0.001
m9   13027       1.0      $Aluminum at 2.7
m10   6000       6.0      $Celotex at 0.20
      1001      10.0
      8016       5.0
sdef   erg d1   rad d3 ext d2 axs 0 0 1
       pos 0 0 19.941345
si2   0 8.185
si3   0 5.2705
c  Neutron
si1   1.00000E-11  1.00000E-07  4.14000E-07  8.76000E-07  1.86000E-06
      5.04000E-06  1.07000E-05  3.73000E-05  1.01000E-04  2.14000E-04
      4.54000E-04  1.58000E-03  3.35000E-03  7.10000E-03  1.50000E-02
      2.19000E-02  2.42000E-02  2.61000E-02  3.18000E-02  4.09000E-02
      5.74000E-02  1.11000E-01  1.83000E-01  2.97000E-01  3.69000E-01
      4.98000E-01  6.08000E-01  7.43000E-01  8.21000E-01  1.00000E+00
      1.35000E+00  1.65000E+00  1.92000E+00  2.23000E+00  2.35000E+00
      2.37000E+00  2.47000E+00  2.73000E+00  3.01000E+00  3.68000E+00
      4.97000E+00  6.07000E+00  7.41000E+00  8.61000E+00  1.00000E+01
      1.22000E+01  1.42000E+01  1.73000E+01
c  Neutron source
sp1   0.00000E+00  1.94076E-12  1.93536E-11  6.23463E-11  1.92739E-10
      8.52796E-10  2.35345E-09  1.92513E-08  7.85490E-08  2.11548E-07
      6.53943E-07  5.33161E-06  1.32647E-05  4.18118E-05  1.35012E-04
      1.63597E-04  6.35119E-05  5.58070E-05  1.85372E-04  3.51527E-04
      8.10692E-04  4.08411E-03  8.56898E-03  1.94492E-02  1.49417E-02
      3.06984E-02  2.91735E-02  3.91976E-02  2.37254E-02  5.60683E-02
      1.07660E-01  8.43683E-02  7.31993E-02  8.10691E-02  2.82381E-02
      4.47152E-03  2.13095E-02  4.88523E-02  3.91684E-02  6.62805E-02
      1.41081E-01  5.22465E-02  2.23748E-02  1.90416E-03  3.02404E-05
      1.02548E-05  1.26141E-06  2.03704E-07
ctme 420
mode n p
c secondary photon point detectors
f15:p 0 0 -0.1           2   $bottom surface
```

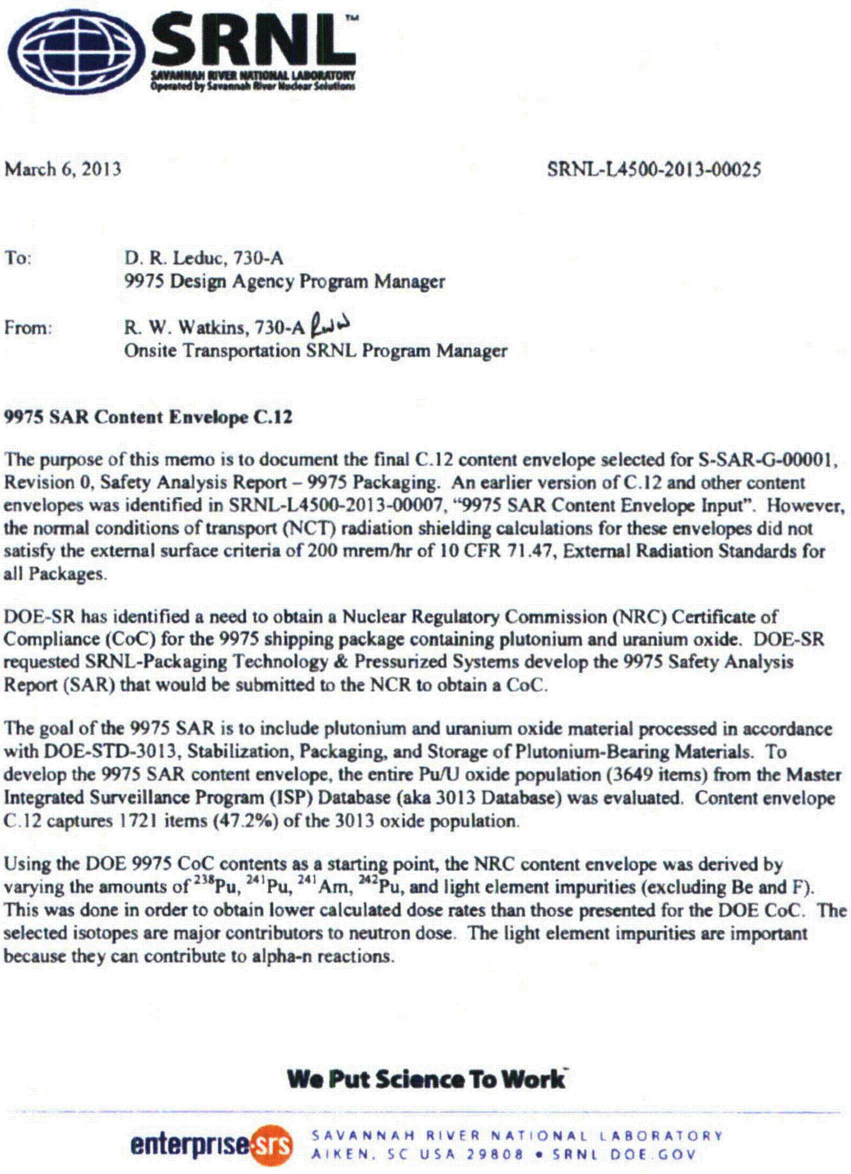
```
      0 0 86.44          2    $top surface
      0 23.3989 24.034   2    $side surface, level with source
      0 0 -100           2    $1 meter from bottom surface
      0 0 186.34         2    $1 meter from top surface
      0 123.3989 24.034  2    $1 meter from side surface, level with source
c
c dose factors for Photons from ANS 6.1.1-1977, rem/hr
de15 .01 .03 .05 .07 .1 .15 .2 .25 .3 .35 .4 .45 .5 .55 .6 .65 &
    .7 .8 1. 1.4 1.8 2.2 2.6 2.8 3.25 3.75 4.25 4.75 5.0 5.25 &
    5.75 6.25 6.75 7.5 9. 11. 13. 15.
df15 3.96E-6 5.82E-7 2.9E-7 2.58E-7 2.83E-7 3.79E-7 5.01E-7 6.31E-7 &
    7.59E-7 8.78E-7 9.85E-7 1.08E-6 1.17E-6 1.27E-6 1.36E-6 1.44E-6 &
    1.52E-6 1.68E-6 1.98E-6 2.51E-6 2.99E-6 3.42E-6 3.82E-6 4.01E-6 &
    4.41E-6 4.83E-6 5.23E-6 5.6E-6 5.8E-6 6.01E-6 6.37E-6 6.74E-6 &
    7.11E-6 7.66E-6 8.77E-6 1.03E-5 1.18E-5 1.33E-5
fm15 7.13212E+06
c
c neutron point detectors
f25:n 0 0 -0.1           2    $bottom surface
      0 0 86.44          2    $top surface
      0 23.3989 24.034   2    $side surface, level with source
      0 0 -100           2    $1 meter from bottom surface
      0 0 186.34         2    $1 meter from top surface
      0 123.3989 24.034  2    $1 meter from side surface, level with source
c
c dose factors for Neutrons from ANS 6.1.1-1977, rem/hr
de25  2.5e-08 1.0e-07 1.0e-06 1.0e-05 1.0e-04 1.0e-03 1.0e-02 1.0e-01
      5.0e-01 1.0 2.5 5.0 7.0 10.0 14.0 20.0
df25  3.67e-6 3.67e-6 4.46e-6 4.54e-6 4.18e-6 3.76e-6 3.56e-6 2.17e-5
      9.26e-5 1.32e-4 1.25e-4 1.56e-4 1.47e-4 1.47e-4 2.08e-4 2.27e-4
fm25 7.13212E+06
c
imp:p 1 48r 0
imp:n 1 48r 0
c cut off low energy photons
phys:p 0.0000001
```

ORIGEN-S Input File c.12.inp

```
'This SCALE input file was generated by
'OrigenArp Version  5.01  June 9, 2005
#origens
0$$ a11 71 e t
Decay Case
3$$ 21 1 1 0 a16 2 a33 0 e t
35$$ 0 t
54$$ a8 1 a11 0  e
56$$ a2 10 a10 0 a13 9 a15 3 a17 4 e
57** 0 a3 1e-05 e
95$$ 1 t
Case 1
0 MTU
60** 0.001 0.003 0.01 0.03 0.1 0.3 1 3 5 7
61** f1e-20
65$$
'Gram-Atoms   Grams   Curies   Watts-All   Watts-Gamma
 3z   1   0   0   3z   1   0   0   3z   6z
 3z   1   0   0   3z   1   0   0   3z   6z
 3z   1   0   0   3z   1   0   0   3z   6z
73$$ 942380 942390 942400 952410 942420 80000 120000 130000 110000
74** 2.2 4075 264 50 8.8 588.8 1620 290 315
75$$ 2 2 2 2 2 4 4 4 4
t
54$$ a8 1 a11 0  e
56$$ a2 10 a10 10 a15 3 a17 4 e
57** 7 a3 1e-05 e
95$$ 1 t
Case 2
0 MTU
60** 8 10 15 20 25 30 35 40 45 50
```

```
61** f1e-20
65$$
'Gram-Atoms   Grams   Curies   Watts-All   Watts-Gamma
 3z   1   0   0   3z   1   0   0   3z   6z
 3z   1   0   0   3z   1   0   0   3z   6z
 3z   1   0   0   3z   1   0   0   3z   6z
t
54$$ a8 1 a11 0  e
56$$ a2 10 a10 10 a15 3 a17 4 e
57** 50 a3 1e-05 e
95$$ 1 t
Case 3
0 MTU
60** 55 60 65 70 75 80 85 90 95 100
61** f1e-20
65$$
'Gram-Atoms   Grams   Curies   Watts-All   Watts-Gamma
 3z   1   0   0   3z   1   0   0   3z   6z
 3z   1   0   0   3z   1   0   0   3z   6z
 3z   1   0   0   3z   1   0   0   3z   6z
t
56$$ f0 t
end
```

APPENDIX B MEMO SRNL-L4500-2013-00025



SRNL
SAVANNAH RIVER NATIONAL LABORATORY
Operated by Savannah River Nuclear Solutions

March 6, 2013 SRNL-L4500-2013-00025

To: D. R. Leduc, 730-A
9975 Design Agency Program Manager

From: R. W. Watkins, 730-A Rww
Onsite Transportation SRNL Program Manager

9975 SAR Content Envelope C.12

The purpose of this memo is to document the final C.12 content envelope selected for S-SAR-G-00001, Revision 0, Safety Analysis Report – 9975 Packaging. An earlier version of C.12 and other content envelopes was identified in SRNL-L4500-2013-00007, "9975 SAR Content Envelope Input". However, the normal conditions of transport (NCT) radiation shielding calculations for these envelopes did not satisfy the external surface criteria of 200 mrem/hr of 10 CFR 71.47, External Radiation Standards for all Packages.

DOE-SR has identified a need to obtain a Nuclear Regulatory Commission (NRC) Certificate of Compliance (CoC) for the 9975 shipping package containing plutonium and uranium oxide. DOE-SR requested SRNL-Packaging Technology & Pressurized Systems develop the 9975 Safety Analysis Report (SAR) that would be submitted to the NCR to obtain a CoC.

The goal of the 9975 SAR is to include plutonium and uranium oxide material processed in accordance with DOE-STD-3013, Stabilization, Packaging, and Storage of Plutonium-Bearing Materials. To develop the 9975 SAR content envelope, the entire Pu/U oxide population (3649 items) from the Master Integrated Surveillance Program (ISP) Database (aka 3013 Database) was evaluated. Content envelope C.12 captures 1721 items (47.2%) of the 3013 oxide population.

Using the DOE 9975 CoC contents as a starting point, the NRC content envelope was derived by varying the amounts of ^{238}Pu, ^{241}Pu, ^{241}Am, ^{242}Pu, and light element impurities (excluding Be and F). This was done in order to obtain lower calculated dose rates than those presented for the DOE CoC. The selected isotopes are major contributors to neutron dose. The light element impurities are important because they can contribute to alpha-n reactions.

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The C.12 content envelope is presented in Table 1: Content Envelope. The radioisotope and impurities values listed are maximum individual material amounts.

Table 1 - Content Envelope

	Material	C.12
		Pu/U Oxides
Radioisotope (Radioactive Material Mass - grams)	^{238}Pu	2.2
	^{239}Pu	4400
	^{240}Pu	264
	^{241}Pu	50
	^{242}Pu	8.8
	^{241}Am + ^{241}Pu	50
	^{243}Am	1.00
	^{244}Cm	0.0044
	^{237}Np	220
	^{232}U	0.00044
	^{233}U	427
	^{234}U	4400
	^{235}U	4400
	^{236}U	2640
	^{238}U	4400
	^{232}Th	4400
Impurities (grams)	Al	290
	Mg	1620
	Na	315
	F	0
	Be	0
	C	1000
Total Mass (kilograms)	Radioactive Materials	4.4
	Impurities	3.08
	All Contents	5

cc: G. A. Abramczyk, 730-A
J. S. Bellamy, 730-A
J. Brotherton, 707-C
L. F. Gelder, 730-A
M. D. Harris, 707-C
J. L. Lawson, 704-K
B. M. Loftin, 730-A
S.J. Nathan, 730-A
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APPENDIX 6.1

NUCLEAR CRITICALITY SAFETY EVALUATION: 9975 SHIPPING PACKAGE WITH PLUTONIUM OXIDE CONTENTS FOR NRC SAFETY ANALYSIS REPORT

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SAVANNAH RIVER NUCLEAR SOLUTIONS, LLC
NUCLEAR & CRITICALITY SAFETY ENGINEERING

N-NCS-A-00029
Rev. 0
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March 2013

Reviewed and determined to be
UNCLASSIFIED.
This review does not constitute clearance for public release.
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(Name/personal identifier and position title)
Date: 3/21/13

KEYWORDS:
Criticality
9975 Shipping Package
Plutonium
Oxide

RETENTION:
Lifetime

Nuclear Criticality Safety Evaluation:

9975 Shipping Package with Plutonium Oxide Contents for NRC Safety Analysis Report

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ACRONYMS AND ABBREVIATIONS

AEG	Average Energy Group
AOA	Area of Applicability
CC	Convenience Can
CSACC	Criticality Safety Advanced Computing Center
CSI	Criticality Safety Index
HAC	Hypothetical Accident Condition
MSM	Minimum Subcritical Margin
NCSE	Nuclear Criticality Safety Evaluation
NCT	Normal Condition of Transport
NRC	Nuclear Regulatory Commission
PCV	Primary Containment Vessel
SARP	Safety Analysis Report for Packaging
SCV	Secondary Containment Vessel
SRNS	Savannah River Nuclear Solutions
SS	Stainless Steel

1.0 INTRODUCTION

This Nuclear Criticality Safety Evaluation (NCSE) demonstrates the safe configurations of the 9975 shipping package for plutonium oxide material loading under various conditions in support of the Nuclear Regulatory Commission (NRC) Safety Analysis Report.

Criticality safety analysis of the 9975 shipping package in support of the Safety Analysis Report for Packaging (SARP) was previously documented in N-NCS-F-00087, Rev. 2, *9975 Shipping Container Analysis with Revised Contents for SARP, Revision 0.* The previous evaluation demonstrated that contents up to 4.4 kg of plutonium as metal, which was described as a bounding material, with up to 100 grams of plastics could be safely shipped in the 9975 shipping package. This evaluation performs an explicit analysis for the Plutonium Oxide (PuO_2) material shipped in a convenience can.

The evaluation in this NCSE demonstrates that the 9975 shipping package is subcritical with adherence to the design features, limits, and controls specified in Section 7.0.

2.0 DESCRIPTION

The following sections describe the geometry and materials of construction of the 9975 shipping package and the convenience can/3013 configuration.

2.1 9975 SHIPPING PACKAGES

The 9975 shipping package consists of two concentric stainless steel cylindrical containment vessels, a 35-gallon stainless steel drum, cane fiberboard insulation (Celotex®), aluminum bearing plates, lead shield, and aluminum honeycomb spacers. The inner containment vessel is called the primary containment vessel (PCV), and the outer containment vessel is called the secondary containment vessel (SCV). The SCV is surrounded on the sides and the bottom by ½ inch of lead shielding. Low-density cane fiberboard (Celotex®) surrounds the shield to fill the remainder of the 35-gallon drum. Other components of the package include a ½-inch thick aluminum lid to cover the lead shield and two ½-inch thick aluminum bearing plates – one below the lead shield and one on top of the aluminum lid. Nuclear fuel material contained in product cans (3013 and convenience can) is loaded into the PCV, which is sealed with a stainless steel plug and locking nut.

Table 1 lists dimensions of various components of the 9975 shipping package and the as-modeled dimensions of each component. The "Specification" column of Table 1 indicates the nominal dimensions of each component.

Per ASTM A312, *Specification for Seamless and Welded Austenitic Stainless Steel Pipes*, there is a tolerance of +22.5% / -12.5% on the wall thickness and a tolerance on the outer diameter of +1/16 / -1/32 inch for the PCV and the SCV. A sensitivity study (as shown in Appendix 1) was performed on the variation of dimensional tolerances of the PCV and the SCV. It was determined that there was statistically no significant variations among the k_{eff} values calculated with nominal, minimum, and maximum wall thicknesses. Table 1 also gives the tolerance on drum radius.

The base KENO model was developed from the component specifications listed in Table 1 (see Section 6.1 for description of the KENO models).

Table 1. Geometric Specifications for the 9975 Shipping Packages

Component	Parameter	Specification Inch (cm)	KENO Model (cm)
PCV	Internal Height	18.63 – 1.88 – 0.37 – 0.258 = 16.122 (40.95 cm)	40.95
PCV	Bottom Thickness	0.258 (0.655 cm)	0.655
PCV	Top Thickness	1.88 – 0.5 = 1.38 (3.505 cm)	3.505
PCV	Top Nut Height (top portion)	0.5 (1.27 cm)	1.270
PCV	Leg Height	0.37 (0.94 cm)	0.94
PCV	Inner Radius	5.047*0.5 (6.410 cm)	6.410
PCV	Outer Radius	5.563*0.5 (7.065 cm)	7.065
SCV	Top Aluminum Spacer Height	1.80 (4.572 cm)	4.572
SCV	Void Space Height	24.0 – 1.88 – 0.38 – 0.28-1.0 – 18.63 + 0.5 – 1.8 = 0.53 (1.35 cm)	1.35
SCV	Top Thickness	1.88 – 0.5 = 1.38 (3.505 cm)	3.505
SCV	Top Nut Height (top portion)	0.5 (1.27 cm)	1.27
SCV	Bottom Aluminum Honeycomb Spacer Height	1.0 (2.54 cm)	2.54
SCV	Bottom Thickness	0.28 (0.711 cm)	0.711
SCV	Leg Height	0.38 (0.965 cm)	0.965
SCV	Inner Radius	6.065*0.5 (7.7026 cm)	7.703

Component	**Parameter**	**Specification Inch (cm)**	**KENO Model (cm)**
SCV	Outer Radius	6.625*0.5 (8.414 cm)	8.414
SCV Spacer	Inner/Outer Radius	3.7*0.5/5.8*0.5 (4.699/7.366 cm)	4.699/7.366
Drum	Inner Radius	(18.25 ± 0.06)*0.5 18.19 *0.5, min = 9.095 (23.101 cm)	21.466 (calculated NCT value)
Drum	Outer Radius	(23.101 + 0.122) cm (23.223 cm)	23.223*.93 =21.597 (NCT Value)
Drum	Top Void Thickness (nominal)	34.75 – 33.90 = 0.85 (2.16 cm)	2.16
Drum	Top Wall Thickness	0.048 (0.122 cm)	0.122
Drum	Bottom Void Thickness	0 (0 cm)	0
Drum	Bottom Wall Thickness	0.048 (0.122 cm)	0.122
Drum	Top Wall Thickness	0.048 (0.122 cm)	0.122
Aluminum Lid for Lead Shield	Thickness	0.5 (1.27 cm)	1.27
Drum	Inner Height	34.75 (88.265 cm)	Used to calculate top void thickness in drum
Lead Shield	Thickness	0.506, min (1.285 cm) (lead thickness includes two 0.036" SS304 liners)	1.285
Lead Shield	Inner Radius	7.25*0.5 = 3.625 (9.208 cm)	9.208
Lead Shield	Outer Radius	3.625+0.506 = 4.131 (10.493 cm)	10.493
Aluminum Plate	Outer Radius	5.6 (14.224 cm)	14.224
Aluminum Bearing Plate, Top	Height	0.5 (1.27 cm)	1.27

Component	Parameter	Specification Inch (cm)	KENO Model (cm)
Aluminum Bearing Plate, Bottom	Height	0.5 (1.27 cm)	1.27
Celotex®	Top Thickness	3.7 (9.398 cm)	9.398
Celotex®	Bottom Thickness	3.8 (9.652cm)	9.652
Celotex®	Outer Radius	18.1*0.5 = 9.05 (22.987 cm)	22.987 (Single Unit Model) 21.466 (NCT Model) (used 21.466 to match inner diameter of drum)

2.2 PLUTONIUM CONTENT ENVELOPE

The fissile material evaluated to be shipped in a 9975 shipping package consists of a maximum of 5.0 kg plutonium oxide contained within a convenience can. The plutonium isotopic composition is conservatively chosen as 100% ^{239}Pu. Beryllium and carbon are analyzed assuming up to 500 grams of beryllium or 1,000 grams of carbon as a moderator mixed with the fissile material. When beryllium or carbon are added to the model the mass of the PuO_2 is decreased to maintain the 5.0 kg net weight of the contents. Beryllium metal has a density of 1.85 g/cc, and the carbon has a density of 2.3 g/cc. See Table 2 for contents.

Table 2. Plutonium Oxide Contents

Material	Mass (kg)
PuO_2	5.0
Beryllium	0.5
Carbon	1.0

This evaluation, based on 100% ^{239}Pu, also bounds contents with mixtures of plutonium and uranium of the same total mass.

2.3 3013 AND CONVENIENCE CAN

A convenience can is used to contain the fissile material. The convenience can is housed in the 3013 containers of the 9975 during transport. The 3013 container consists of two nested and sealed containers which isolate the fissile material. The 3013 containers and the convenience cans are fabricated of stainless steel. Table 3 lists three types of convenience cans with their associated 3013 containers, along with their dimensions, used for shipment of oxide powder.

The bounding dimensions for the reference convenience can and 3013 containers developed for the KENO model are also shown in Table 3. The KENO model used in this analysis has dimensions consistent with the volume of the Rocky Flats configuration due to its slightly larger volume.

Table 3. Types of Convenience Cans and 3013 Containers

Parameter	Nominal Dimensions (cm)	Rocky Flats	Hanford	SRS	Reference Dimension for KENO Model
Convenience Can	Outer Diameter	11.00	10.85	11.16	11.00
	Outer Diameter – Inner Diameter Difference	0.05	0.31	0.21	0.05
	Top Lid /Bottom Thickness	0.025/ 0.025	0.305/ 0.635	0.163/ 0.152	0.025/ 0.025
	External Height	20.75	20.40	18.80	20.75
	Internal Height	20.70	19.46	18.48	20.70
	Material	SS 316	SS 304/304L	SS 304/304L	
	Reference	M-PV-F-0015	R-R4-F-0144	R-R1-F-0098	
Inner Can	Outer Diameter	11.35	11.68	11.16	11.35
	Outer Diameter – Inner Diameter Difference	0.30	0.30	0.21	0.30
	Top Lid /Bottom Thickness	0.20/0.15	0.152/0.635	0.163/152	0.20/0.15
	External Height	23.10	22.00	18.80	23.10
	Inner Height	22.75	21.21	18.48	22.75
	Material	SS 316	SS 304L	SS 304L	
	Reference	M-PV-F-0016	R-R4-F-0107	R-R4-F-0107	
Outer Can	Outer Diameter	25.40	25.40	25.40	25.40
	Outer Diameter – Inner Diameter Difference	0.62	0.62	0.62	0.62
	Top Lid /Bottom Thickness	1.91/0.90	1.91/0.90	1.91/0.90	1.91/0.90
	External Height	25.40	25.40	25.40	25.40
	Internal Height	22.59	22.59	22.59	22.59
	Material	SS 316	SS 316	SS 316	
	Reference	M-PV-F-0017 M-PV-F-0017	M-PV-F-0017 M-PV-F-0017	M-PV-F-0017 M-PV-F-0017	

2.4 9975 AND 3013 MATERIALS OF CONSTRUCTION AND FISSILE MATERIAL COMPOSITION

The convenience can, 3013 containers, PCV, SCV, and the drum are made of 304L or 316 stainless steel (SS). However, the analysis used a standard stainless steel, SS 304 with a density of 7.92 g/cc. The small difference in composition between SS 304, SS 304L, and SS 316 will have a negligible effect on reactivity (see the sensitivity study in Appendix 1).

As described in Appendix 1, Celotex® insulation with a nominal density of 0.22 to 0.26 g/cc has the elemental composition of cellulose ($C_6H_{10}O_5$). In addition, Appendix 1 shows that k_{eff} increases as the Celotex® density is decreased. Thus, to account for void spaces between layers, this analysis will use a Celotex® density of 0.20 g/cc. See sensitivity studies documented in Appendix 1.

Water density is conservatively taken as 1.0 g/cc instead of a nominal value of 0.9982 g/cc at 20°C to cover temperatures as low as 0°C.

Aluminum honeycomb spacer density is selected as 0.28 g/cc (estimated density using simplistic calculations). Any variation of aluminum honeycomb spacer density will have a negligible effect on the system reactivity. Standard material densities of lead and aluminum bearing plates are used (see Table 4).

Table 4. Material Specifications for the 9975 and 3013 Containers

Components	Material	Density(g/cc) (as-modeled)*	Reference
Water	H_2O	0.9982 at 20°C 0.99998 at 4°C used 1.0 g/cc	
PCV	304L-Stainless Steel (used SS 304)	7.92	ORNL/TM-2005/39
SCV	304L-Stainless Steel (used SS 304)	7.92	ORNL/TM-2005/39
Drum	304L-Stainless Steel (used SS 304)	7.92	ORNL/TM-2005/39
Aluminum Lid & Plates	Aluminum	2.70	
Lead Shield	Lead	11.34	ORNL/TM-2005/39
Celotex®	$C_6H_{10}O_5$	(0.22 – 0.26 g/cc) (used 0.20 g/cc)	Appendix 1
3013, Outer Can	316L-SS (used SS 304)	7.92	ORNL/TM-2005/39
3013, Inner Can	316-SS (used SS 304)	7.92	ORNL/TM-2005/39
Convenience Can	316-SS / 304L-SS (used SS-304)	7.92	ORNL/TM-2005/39

3.0 REQUIREMENTS DOCUMENTATION

This NCSE is prepared in accordance with SCD-3, Revision 26, *Nuclear Criticality Safety Manual*; SRNS-IM-2009-00035, Revision 2, *Criticality Safety Methods Manual*; and 10 CFR Part 71, *Packaging and Transportation of Radioactive Material.*

NUREG/CR-5661, *Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packages,* for criticality safety evaluation of transportation packages was also followed.

4.0 METHODOLOGY

The following sections provide a high level overview of the criticality safety computer codes used in this analysis, justify the lower tolerance limit and the minimum subcritical margin (MSM), define the area of applicability (AOA), and justify a value for k_{safe} for this analysis. Other sections address material compositions and various analysis methods utilized in this analysis.

4.1 COMPUTER CODES

The SCALE 5 code system, ORNL/TM-2005/39, Version 5, *SCALE: A Modular Code System for Performing Standardized Computer Analysis for Licensing Evaluation,* operating on the SRNS Criticality Safety Advanced Computing Center (CSACC) was used to calculate k_{eff} values for this study. The SCALE system is under configuration control, SRNS-RP-2008-00150, Revision 1, *Software Configuration and Control Guidance for SCALE on SRS Personal Computers (U)*, and SRNS-RP-2008-00151, Revision 1, *SCALE Test Report for SRS Personal Computers (U).* The CSAS26 driver was used. It calls the BONAMI and CENTRM modules for the generation of a problem-dependent cross sections library (accounting for resonance self-shielding) and then calls the KENO-VI module to perform the Monte Carlo k_{eff} calculations. All calculations used the 238-group ENDF/B-V cross section set (ORNL/TM-12370, *The LAW-238 Library – A Multigroup Cross-Section Library for Use in Radioactive Waste Analysis Calculations*). Calculations were performed using numbers of generations and neutrons per generation to achieve a calculated statistical uncertainty (σ) less than 0.002.

4.2 CODE VALIDATION AND BIAS

SCALE 5 has been validated for Pu solution and Pu oxide systems (SRNS-RP-2008-00153, Rev. 0, *SCALE 5.0 Validation for SRNS Personal Computers (U)*) on the SRNS CSACC system. No critical experiments similar to the 9975 shipping package systems with Pu/U metal/oxide are available. Therefore a wide set of validation experiments was chosen for this study. Table 5 shows the bias and k_{safe} values for different systems. NUREG/CR-5661 specifies a minimum required margin of subcriticality of 0.05 for packaging applications. Because a large MSM has been used for the 9975 analysis using common fissile materials and drum components, no additional margin due to 'areas of applicability' is necessary.

SCD-3 provides guidance to determine an upper bound of system reactivity, called k_{safe}, which is determined using the following equation:

$$k_{safe} = 1 - B - AOA - MSM \quad (1)$$

Where:

k_{safe} is a conservative upper bound for which a system can be said to be safely subcritical.

B is an upper bound for the bias. This term accounts for the bias and its uncertainty and is generally dependent on the system being evaluated.

AOA is a margin associated with the area of applicability for the system being evaluated. This term is used to compensate for relevant differences that may be encountered between the system being evaluated and the selected set of validation studies used in determining B. This term is called the area of applicability margin.

MSM is a minimum subcritical margin, an arbitrary margin that is used to ensure subcriticality and, unlike AOA, is independent of the fissile configuration, but rather its magnitude relies in part on the complexity of the entire process being evaluated. This term provides a buffer that is judged to be sufficient to compensate for relevant uncertainties or lack of confidence in understanding the entire process.

In the validation studies documented in SRNS-RP-2008-00153, the bias and its uncertainty are provided in terms of the lower tolerance band (LTB), and are related to B by the following:

$$LTB = 1 - B \quad (2)$$

Using the definition for LTB from Equation (2) with Equation (1) and removing the AOA per above discussion yields the following equation for k_{safe}:

$$k_{safe} = LTB - MSM \quad (3)$$

4.2.1 Plutonium Solution

For the plutonium solution fuels, the validation in SRNS-RP-2008-00153, Revision 0, utilized critical experiments involving plutonium nitrate solution. The biased k_{eff} values were taken from the validation reference and were based on LTB for the system(s) considered. The LTB values recommended are based on Equation (4) for which the values of $H/^{239}Pu$ atom ratio is calculated from the multiple calculations performed.

$$LTB\ (PuSol) = 0.99341 + [0.0000053803 * H/^{239}Pu] + [-0.0000000009576 * (H/^{239}Pu)^2] \quad (4)$$

Where $H/^{239}Pu$ is the hydrogen to ^{239}Pu atom ratio and the constants are those provided by the quoted reference. The lowest calculated LTB value for plutonium solution is 0.9934.

4.2.2 Plutonium Oxide

For the plutonium oxide fuels, the validation in SRNS-RP-2008-00153, Revision 0, utilized critical experiments involving plutonium oxide. The biased k_{eff} values were taken from the validation reference and were based on LTB for the system(s) considered. The LTB values recommended are based on Equation (5) for which the values of AEG (Average Energy Group) are taken from the multiple calculations performed.

$$\text{LTB } (PuO_2) = 0.99529 + [0.000086341 * \text{AEG}] + [-0.00000069867 * (\text{AEG})^2] \quad (5)$$

Where AEG is the energy of a neutron causing fission and the constants are those provided by the quoted reference. The lowest calculated LTB value plutonium oxide is 0.9953.

Table 5. k_{safe} Values for Plutonium

System	Lower Tolerance Band	MSM	= k_{safe}
Plutonium Solution	0.99340	0.05	0.943
Plutonium Oxide, dry	0.99530	0.05	0.945

The validations for the plutonium oxide and plutonium solution critical experiments in SRNS-RP-2008-00153 are used to determine the k_{safe} value applicable to this analysis. Table 5 shows that the k_{safe} value of 0.943 derived for plutonium solution experiments is bounding.

4.3 MATERIAL COMPOSITIONS

Table 4 provides a specification of materials used in this analysis and the material density as modeled. The following is a brief discussion of the modeling choices made for this analysis.

- Plutonium oxide was modeled as Pu with 100% by weight ^{239}Pu.

  ANSI/ANS-8.1 ^{239}Pu limits apply to isotopic mixtures of plutonium provided that the concentration of ^{240}Pu exceeds that of ^{241}Pu and all isotopes are considered to be ^{239}Pu. The package contents meet this restriction. Therefore, the content envelope is conservatively modeled as 100% ^{239}Pu.

- The compositions of lead, aluminum, SS 304, and water used the "Standard Composition Library" in SCALE.

- Aluminum used the standard composition library except in the case of the honeycomb spacer, which uses a lower density per Section 2.4.

5.0 DISCUSSION OF CONTINGENCIES

10 CFR 71 specifies the contingencies that are to be considered in the shipping package criticality analysis. Specifically, the objective of this evaluation is to demonstrate compliance with the performance requirements for each content envelope as specified in:

a) 10 CFR 71.55 – General requirements for fissile material packages

b) 10 CFR 71.59 – Standards for arrays of fissile material packages

The requirements of 10 CFR 71 are thorough and ensure that the maximum value of k_{eff} is found in the analysis based on prescribed configurations. These configurations are related to and are bounding of the conditions (including accident scenarios) a shipping package may be subjected to during its use. 10 CFR 71 requires that the system k_{eff} remains less than k_{safe} for each of the prescribed configurations. Thus, 10 CFR 71 does not require a contingency analysis.

The following specific scenarios are analyzed based on the requirements:

i) Single unit – dry and flooded

ii) Normal condition of transport (NCT) array

iii) Hypothetical accident condition (HAC) array

6.0 EVALUATIONS AND RESULTS

Calculations and evaluations were performed to demonstrate that the 9975 shipping packages evaluated with 5 kg of PuO_2 with no more than 500 grams of beryllium and 1,000 grams of carbon can be safely transported.

6.1 MODEL DESCRIPTIONS

6.1.1 Modeling Approximations

The KENO models for single unit, NCT arrays, and HAC arrays include the following simplifications:

- PCV and SCV are approximated as right circular cylinders.
- Aluminum honeycomb spacer inside the PCV is neglected.
- Rolling hoops and the drum lid closure are ignored.
- The two SS 304 sleeves in the lead shield are modeled as lead and included in the lead thickness.

Per Table 1, nominal 9975 component dimensions (except the drum diameter) were used, since the dimensional tolerances were small and their effects on reactivity were shown to be insignificant. But the lower tolerance value was used for the drum diameter to conservatively estimate the array pitch and, thus, to maximize the interaction effect among the fissile units in different packages. In this analysis, the two rolling hoops and bolted ring closure of the 9975 containers were neglected. Neglecting these geometric details reduces the effective drum diameter, which in turn conservatively models the array pitch.

6.1.2 Single Unit, NCT, and HAC Dimensions

Table 6 shows the 9975 drum and Celotex® dimensions used for the single unit, NCT, and HAC model.

The single unit model used the base shipping package dimensions, which are shown in Table 6.

For the NCT array model (rectangular pitch), the outer nominal drum radius is reduced by 7%. NUREG/CR-5661 shows that a rectangular pitch drum array, with the drum radius reduced by 7%, is equivalent to a triangular pitch drum array. To preserve the drum wall mass, the drum wall thickness was adjusted (see Table 6).

For the HAC array model, the drum radius was decreased corresponding to a specified amount due to the damage from a prescribed drop, and then was further reduced by 7% to simulate a triangular pitch array. A triangular pitch array model places fissile material units (drums) as close as possible, maximizing the areal density of fissile units, and thereby increasing the reactivity effect due to interaction.

Table 6. Drum and Celotex® Dimensions for Different KENO Models

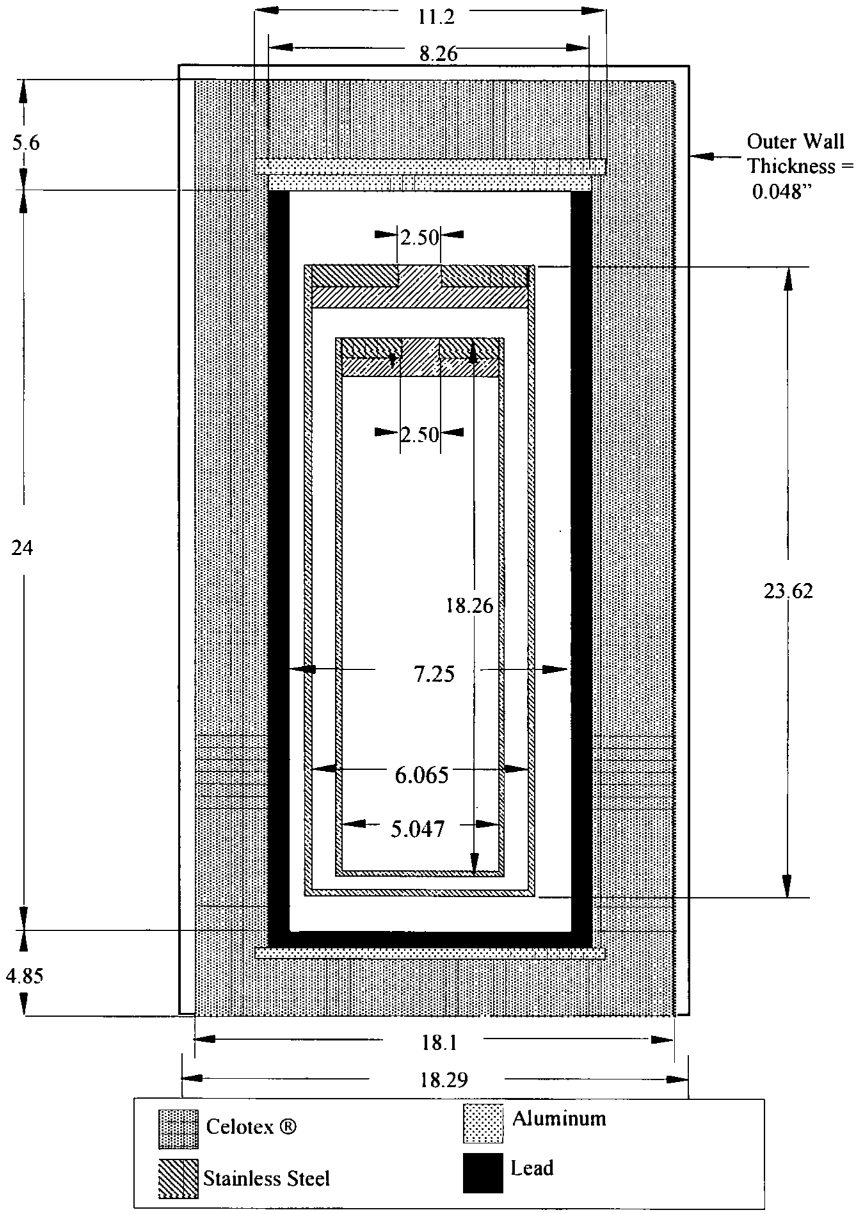
Dimension	Specification (cm)	Single Unit Model (cm)	NCT Model (cm)	HAC Model (cm)
Drum Outer Radius	23.101+0.122 =23.223 cm	23.101 + 0.122 =23.223 cm	23.223 *0.93 = 21.597	19.235 (23.223-2.54)*0.93 Note: 1.0 inch (2.54 cm) drum radial reduction due to impact (see Table 7)
Drum Wall Thickness	(0.048 inch) 0.122 cm	0.122 cm	0.131 ** (** 0.122 cm thickness is changed to 0.131 cm to conserve mass of drum wall)	0.147
Drum Inner Radius	(18.25±0.06)*0.5 inches (cm)	(18.19*0.5 = 9.095 inches) 23.101cm	21.597-0.131 =21.466	19.088
Celotex® Outer Radius	18.1*0.5 = 9.05 inches 22.987 cm	22.987 cm	21.466 to match the inner diameter of drum	22.987 - 6.35 =16.637 Note: 2.5 inches (6.35 cm) of Celotex® loss due to fire (see Table 7)

6.1.3 Single Unit Model

Figure 1 shows a schematic of the 9975 shipping package (convenience can/3013 containers not shown), and Figure 2 shows the corresponding KENO model. The 9975 drum overall size is about 34 inches in height and 18 inches in diameter. The base case model analyzed the fissile material as a mixture of plutonium oxide and 0.5% of water to account for moisture content. The fissile material is configured as a right circular cylinder, inside a convenience can, with a height/diameter ratio equal to 1 to maximize reactivity since formation of a perfectly spherical configuration is not credible for oxide material. This base case 9975 model assumed no additional water or flooding with the 3013, PCV, and SCV remaining dry.

10 CFR 71.55 requires single unit analysis to account for the most reactive configurations, including moderation by water to the most reactive credible extent. Therefore, to simulate water inleakage, subsequent variations of the base case modeled water flooding into the convenience can and ultimately filling it while keeping the amount of fissile material constant. This parametric study included variations of water flooding into the 3013, PCV, and SCV. However, the 3013, PCV, and SCV containers remained free of fissile material as the convenience can is a sealed container and it is considered not credible for fissile material to leak out of these cans. For single unit cases, the outer container (drum) was reflected with 30 cm of water on all sides.

Therefore, a conservative single unit model was developed for a homogenized fissile material/water mixture, with water reflection.



All dimensions in inches (Not to Scale)

Figure 1. General Schematic of the 9975 Shipping Package (convenience can not shown)

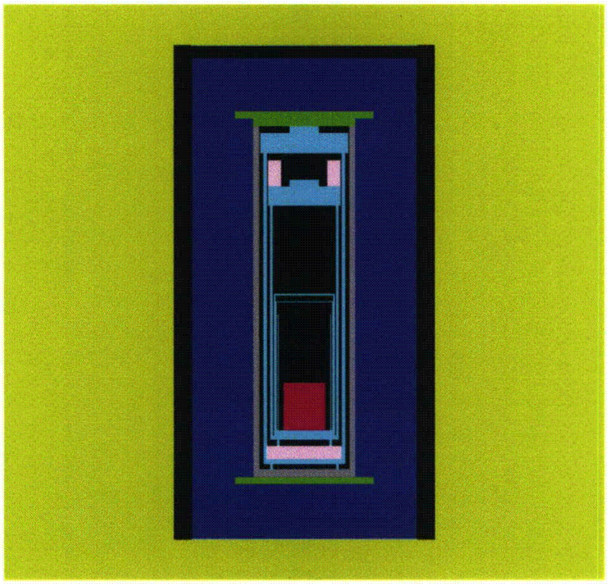


Figure 2. **9975 Single Unit with Convenience Can/3013 Combination**

6.1.4 NCT Model

10 CFR 71.55 requires the NCT analysis to address undamaged packages in an array. Therefore, for the NCT model, an infinite array of undamaged 9975 shipping packages was analyzed with the convenience can containing the plutonium oxide, in dry conditions (the 0.5% for moisture content is included as dry conditions). This model is similar to the base case single unit model but with an infinite array of 9975 drums containing fissile material.

In the infinite models, there is no leakage from the system (the 3013, PCV, and SCV remain dry), and reflection is irrelevant. Thus, a single 9975 package was modeled inside a tight fitting cuboid with mirror boundary conditions defined for the four x and y faces. In addition, periodic boundary conditions were defined for the z faces of the cuboid using standard KENO options (Figure 3). These boundary conditions reflected all incident neutrons back into the system, thus simulating an infinite square pitch array of packages.

Although the NCT analysis evaluates undamaged packages, cases were analyzed to account for water being present in the Celotex®.

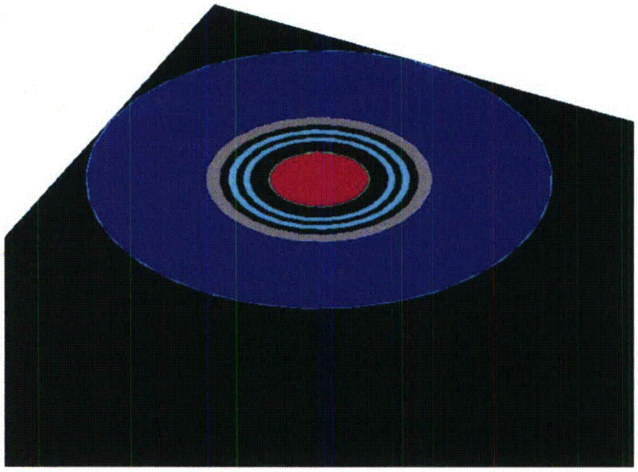


Figure 3. Normal Condition Transport Infinite Array

6.1.5 HAC Model

The HAC model is required per 10 CFR 71.55 to address the most credible configuration of damaged packages, thus a 2x2x2 infinite array of damaged 9975 packages was used in this analysis. The 2x2x2 array configuration was modeled inside a tight fitting cuboid with mirror boundary conditions defined for the four x and y faces. In addition, periodic boundary conditions were defined for the z faces of the cuboid using standard KENO options (Figure 4).

The damaged HAC array model used conservative assumptions regarding the radial and axial reduction of drum dimensions to address a drop and the amount of Celotex® charred due to fire, as shown in Table 7. Additional reduction factors were added to the burn and drop test data for conservatism, also shown in Table 7. As previously stated and as documented in Appendix 1, Celotex® inhibits neutronic interaction between packages and removing the outer layers of Celotex® increases the k_{eff} for array calculations; thus, modeling less Celotex® is conservative.

Table 7. Fire and Drop Test Data for the HAC Model

Dimension	Celotex® Burn Test Data (inch)	HAC Model (inch)	Drop Test Data (inch)	HAC Model (inch)
Radial	2.3	2.5	0.5	1.0
Axial (top/bottom)	1.4/2.0	2.0/2.0	1 ⅛ (total)	1.0/1.0
Reference	WSRC-SA-7, Revision 14, Safety Analysis Report - Packages 9965, 9968, 9972 – 9975 Packages (U), Appendix 3.7, Thermal Test.		WSRC-SA-7, Chapter 2.0.	

This section describes the basic HAC model, shown in Figure 4. Section 6.5 discusses the variations of the basic model.

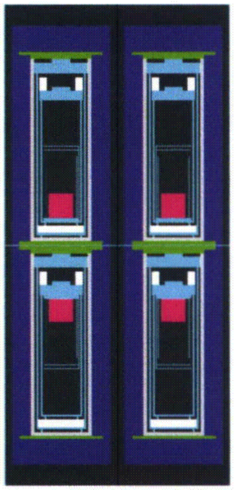


Figure 4. 2x2x2, Hypothetical Accident Condition

The drum dimensions are reduced based on the test data, as shown in Table 6. The Celotex® outer dimensions are also reduced based on fire data. Charred Celotex® is assumed to be completely vaporized.

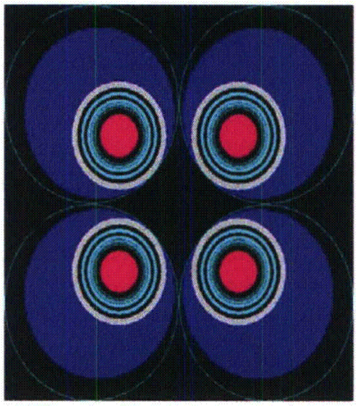


Figure 5. **HAC Array (2x2x2) Model, Plan View**

To address the fissile units at close contact, a conservative HAC model is constructed by assuming maximum movement of the inner containment vessels (Figure 5). The Celotex® has also moved and is off-center. The fissile material is in the dry configuration of the single unit base case model, which is contained in the volume of the convenience can. This is shown in Figure 5, as indicated in red.

6.2 PLUTONIUM OXIDE CONTENT ENVELOPE

The fissile material evaluated to be shipped in a 9975 shipping package consists of a maximum of 5.0 kg plutonium oxide contained within a convenience can. The plutonium isotopic composition is conservatively chosen as 100% ^{239}Pu. Beryllium and carbon are analyzed assuming up to 500 grams of beryllium or 1000 grams of carbon as a moderator mixed with the fissile material. As indicated in Section 2, when beryllium or carbon are added to the model the mass of the PuO_2 is decreased to maintain the 5.0 kg net weight of the contents. Beryllium metal has a density of 1.85 g/cc, and the carbon has a density of 2.3 g/cc.

6.3 SINGLE UNIT ANALYSES

10 CFR 71.55 contains the following requirements for single package analyses:

> (b) Except as provided in paragraph (c) or (g) of this section, a package used for the shipment of fissile material must be so designed and constructed and its contents so limited that it would be subcritical if water were to leak into the containment system, or liquid contents were to leak out of the containment system so that, under the following conditions, maximum reactivity of the fissile material would be attained:
>
> > (1) The most reactive credible configuration consistent with the chemical and physical form of the material;
> > (2) Moderation by water to the most reactive credible extent; and
> > (3) Close full reflection of the containment system by water on all sides, or such greater reflection of the containment system as may additionally be provided by the surrounding material of the packaging.

6.3.1 Convenience Can Intact

The single unit base case model was developed with a maximum of 5.0 kg plutonium oxide and 0.5% water fissile mixture contained in the convenience can. The convenience can and 3013 containers are assumed to be leak tight, thus the fissile material remains dry. Cases were modeled with and without the 3013 container. Table 8 summarizes the resultant k_{eff} values. Figure 2 shows the fissile material and convenience can/3013 combination in the 9975 shipping package.

6.3.2 Convenience Can Damaged

To address damage to the convenience can and flooding, a parametric study was performed filling the convenience can with water while maintaining the fissile material constant at 5.0 kg plutonium oxide. As discussed earlier, the height/diameter ratio is equal to 1 to maximize reactivity until the fissile cylinder fills the diameter of the inner container. Then the height of the cylinder will be increased until the inner container is full. Therefore, the fissile solution fills the entire width of the convenience can and the water level is varied (Table 9).

Tables 8 through 17 presents the single unit results.

Table 8. Base Case Single Unit Cases Without Flooding

Case No.	File ID	Description	k_{eff}	σ	$k_{eff}+2\sigma$
1.	nrc_su.cyl3013.out:	Base Case with 3013, dry oxide	0.59217	0.00099	0.595
2.	nrc_su.cyl3013be.out:	Base Case with 3013 and mixed with beryllium, dry oxide	0.48049	0.00089	0.483
3.	nrc_su.cylno3013.out:	Base Case with no 3013, dry oxide	0.57962	0.00099	0.582
4.	nrc_su.cylno3013be.out:	Base Case with no 3013 and mixed with beryllium, dry oxide	0.46685	0.00094	0.469
5.	nrc_su.cyl3013c12.out:	Base Case with 3013 and mixed with carbon, dry oxide	0.38802	0.00067	0.390

As seen in Table 8, the base case (Case 1) with a convenience can containing dry plutonium oxide, with the 3013 containers in place, yields a maximum k_{eff} value of 0.595. In addition, Table 8 shows that the addition of beryllium or carbon does not cause an increase in k_{eff} above the base case with dry plutonium oxide in an intact convenience can/3013 configuration (Case 1).

Table 9. Single Unit Cases Flooding the Convenience Can

Case No.	File ID	Description	k_{eff}	σ	k_{eff} +2σ
1.	nrc_su.cyl3013_100.out:	Base Case with 3013, dry oxide – 0.1 liter water added	0.56020	0.00100	0.563
2.	nrc_su.cyl3013_200.out:	Same as #1 – 0.2 liter water added	0.55130	0.00100	0.554
3.	nrc_su.cyl3013_300.out:	Same as #1 – 0.3 liter water added	0.55410	0.00100	0.557
4.	nrc_su.cyl3013_400.out:	Same as #1 – 0.4 liter water added	0.56370	0.00100	0.566
5.	nrc_su.cyl3013_400w.out:	Same as #1 – 0.4 liter water added, diameter of convenience can (CC)	0.56570	0.00100	0.568
6.	nrc_su.cyl3013_500w.out:	Same as #5 – 0.5 liter water added	0.56920	0.00110	0.572
7.	nrc_su.cyl3013_750w.out:	Same as #5 – 0.75 liter water added	0.58970	0.00130	0.593
8.	nrc_su.cyl3013_1000w.out:	Same as #5 – 1.0 liter water added	0.60170	0.00110	0.604
9.	nrc_su.cyl3013_1100w.out:	Same as #5 – 1.1 liters water added	0.60620	0.00120	0.609
10.	nrc_su.cyl3013_1200w.out:	Same as #5 – 1.2 liters water added	0.60980	0.00110	0.612
11.	nrc_su.cyl3013_ccfull.out	Same as #5 CC full	0.62600	0.00130	0.629

Table 10. Single Unit Cases Flooding the Convenience Can – Beryllium

Case No.	File ID	Description	keff	σ	keff +2σ
1.	nrc_su.cyl3013be_100.out:	Base Case with 3013 and mixed with beryllium, dry oxide – 0.1 liter water added	0.47699	0.00096	0.479
2.	nrc_su.cyl3013be_200.out:	Same as #1 – 0.2 liter water added	0.48880	0.00100	0.491
3.	nrc_su.cyl3013be_200w.out:	Same as #1 – 0.2 liter water added, diameter of CC	0.48911	0.00091	0.491
4.	nrc_su.cyl3013be_300w.out:	Same as #3 – 0.3 liter water added	0.50090	0.00110	0.504
5.	nrc_su.cyl3013be_500w.out:	Same as #3 – 0.5 liter water added	0.52280	0.00120	0.526
6.	nrc_su.cyl3013be_750w.out:	Same as #3 – 0.75 liter water added	0.54480	0.00120	0.548
7.	nrc_su.cyl3013be_1000w.out	Same as #3 – 1.0 liter water added	0.55860	0.00110	0.561
8.	nrc_su.cyl3013be_1100w.out:	Same as #3 – CC full	0.56700	0.00130	0.570

Table 11. Single Unit Cases Flooding the Convenience Can – No 3013 Containers

Case No.	File ID	Description	k_{eff}	σ	$k_{eff}+2\sigma$
1.	nrc_su.cylno3013_100.out:	Base Case with no 3013, dry oxide – 0.1 liter water added	0.54699	0.00099	0.549
2.	nrc_su.cylno3013_200.out:	Same as #1 – 0.2 liter water added	0.53380	0.00100	0.536
3.	nrc_su.cylno3013_300.out:	Same as #1 – 0.3 liter water added	0.53481	0.00093	0.537
4.	nrc_su.cylno3013_400.out:	Same as #1 – 0.4 liter water added	0.54180	0.00110	0.544
5.	nrc_su.cylno3013_400w.out:	Same as #1 – 0.4 liter water added, diameter of CC	0.53910	0.00120	0.542
6.	nrc_su.cylno3013_500w.out:	Same as #5 – 0.5 liter water added	0.54930	0.00100	0.552
7.	nrc_su.cylno3013_750w.out:	Same as #5 – 0.75 liter water added	0.56180	0.00120	0.565
8.	nrc_su.cylno3013_1000w.out:	Same as #5 – 1.0 liter water added	0.57170	0.00120	0.575
9.	nrc_su.cylno3013_1100w.out:	Same as #5 – 1.1 liters water added	0.57820	0.00120	0.581
10.	nrc_su.cylno3013_1200w.out:	Same as #5 – 1.2 liters water added	0.57900	0.00110	0.582
11.	nrc_su.cylno3013_1300w.out:	Same as #5 – 1.3 liters water added	0.58700	0.00110	0.59
12.	nrc_su.cylno3013_ccfull.out	Same as #5 – CC full	0.61900	0.00120	0.622

Table 12. Single Unit Cases Flooding the Convenience Can with Beryllium - No 3013

Case No.	File ID	Description	k_{eff}	σ	$k_{eff}+2\sigma$
1.	nrc_su.cylno3013be_100.out:	Base Case with no 3013 and mixed with beryllium, dry oxide – 0.1 liter water added	0.46322	0.00086	0.465
2.	nrc_su.cylno3013be_200.out:	Same as #1 – 0.2 liter water added	0.46845	0.00095	0.471
3.	nrc_su.cylno3013be_200w.out:	Same as #1 – 0.2 liter water added, diameter of CC	0.46949	0.00089	0.472
4.	nrc_su.cylno3013be_300w.out:	Same as #3 – 0.3 liter water added	0.47950	0.00100	0.482
5.	nrc_su.cylno3013be_500w.out:	Same as #3 – 0.5 liter water added	0.49590	0.00110	0.499
6.	nrc_su.cylno3013be_750w.out:	Same as #3 – 0.75 liter water added	0.51720	0.00120	0.520
7.	nrc_su.cylno3013be_1000w.out:	Same as #3 – 1.0 liter water added	0.53200	0.00100	0.534

Case No.	File ID	Description	k_{eff}	σ	$k_{eff}+2\sigma$
8.	nrc_su.cylno3013be_1100w.out:	Same as #3 – CC full	0.53750	0.00120	0.540

Table 13. Single Unit Cases Flooding the Convenience Can with Carbon

Case No.	File ID	Description	k_{eff}	σ	$k_{eff}+2\sigma$
1.	nrc_su.cyl3013c12_100.out:	Base Case with 3013 and mixed with carbon, dry oxide – 0.1 liter water added	0.40333	0.00086	0.406
2.	nrc_su.cyl3013c12_100w.out:	Same as #1 – 0.1 liter water added, diameter of CC	0.40028	0.00086	0.402
3.	nrc_su.cyl3013c12_200w.out:	Same as #2 – 0.2 liter water added	0.40934	0.00088	0.412
4.	nrc_su.cyl3013c12_300w.out:	Same as #2 – 0.3 liter water added	0.42274	0.00095	0.425
5.	nrc_su.cyl3013c12_400w.out:	Same as #2 – 0.4 liter water added	0.44060	0.00100	0.443
6.	nrc_su.cyl3013c12_500w.out:	Same as #2 – 0.5 liter water added	0.45490	0.00140	0.458
7.	nrc_su.cyl3013c12_750w.out:	Same as #2 – 0.75 liter water added	0.47860	0.00120	0.481
8.	nrc_su.cyl3013c12_1000w.out:	Same as #2 – 1.0 liter water added	0.50120	0.00110	0.504

As shown above, Tables 9 through 13 compare the k_{eff} values for a single unit to examine the effects of flooding the convenience can while forming a homogenized solution, with or without the 3013 container in place. As shown in Table 9, the highest k_{eff} of 0.629 is achieved when the convenience can is completely full of fissile solution (plutonium oxide plus flooding water) in a convenience can/3013 combination (Case 11).

Based on Tables 8 through 13, the most reactive cases are achieved with the convenience cans fully flooded with water. Thus, additional cases were run varying water flooding into the various compartments (PCV, SCV, Celotex®) of the 9975 shipping package. Tables 14 through 17 list this comparison.

Table 14. Single Unit Cases Flooding the PCV, SCV, and Celotex® – Inner 3013 Flooded

Case No.	File ID	Description	k_{eff}	σ	$k_{eff}+2\sigma$
1.	nrc_su.cyl3013_ccfull_3013inn.out:	CC – full of solution 3013 – inner flooded with water	0.65980	0.00140	0.663
2.	nrc_su.cyl3013_ccfull_3013inner_PCV.out:	Same as #1 – PCV contains water	0.66330	0.00130	0.666
3.	nrc_su.cyl3013_ccfull_3013inner_PCVSCV.out :	Same as #1 – PCV/SCV contains water	0.69790	0.00120	0.701
4.	nrc_su.cyl3013_ccfull_3013inner_SCV.out:	Same as #1 – SCV contains water	0.68490	0.00120	0.688

Table 15. Single Unit Cases Flooding the PCV, SCV, and Celotex® – Outer 3013 Flooded

Case No.	File ID	Description	k_{eff}	σ	$k_{eff}+2\sigma$
1.	nrc_su.cyl3013_ccfull_3013outer.out:	CC – full of solution 3013 – outer flooded with water	0.63520	0.00130	0.638
2.	nrc_su.cyl3013_ccfull_3013outer_PCV.out:	Same as #1 – PCV contains water	0.64900	0.00130	0.652
3.	nrc_su.cyl3013_ccfull_3013outer_PCVSCV.out :	Same as #1 – PCV/SCV contains water	0.67820	0.00130	0.681
4.	nrc_su.cyl3013_ccfull_3013outer_SCV.out:	Same as #1 – SCV contains water	0.66540	0.00140	0.669

Table 16. Single Unit Cases Flooding the PCV, SCV, and Celotex® – Both 3013 Containers Flooded

Case No.	File ID	Description	k_{eff}	σ	$k_{eff}+2\sigma$
1.	nrc_su.cyl3013_ccfull_3013both.out:	CC – full of solution 3013 – inner/outer flooded with water	0.66930	0.00130	0.672
2.	nrc_su.cyl3013_ccfull_3013both_PCV.out:	Same as #1 – PCV contains water	0.68340	0.00140	0.687
3.	nrc_su.cyl3013_ccfull_3013both_PCVSCV.out:	Same as #1 – PCV/SCV contains water	0.70490	0.00140	0.708
4.	nrc_su.cyl3013_ccfull_3013both_SCV.out:	Same as #1 –SCV contains water	0.69200	0.00120	0.695
5.	nrc_su.cyl3013_ccfull_3013both_PCV_Celo.out:	Same as #1 – PCV/ Celotex® as water	0.71580	0.00130	0.719
6.	nrc_su.cyl3013_ccfull_3013both_ALL.out:	Same as #1 – PCV/SCV/ Celotex® as water	0.73250	0.00150	0.736

Table 17. Single Unit Cases Flooding the PCV, SCV, and Celotex® – No 3013 Containers

Case No.	File ID	Description	k_{eff}	σ	$k_{eff}+2\sigma$
1.	nrc_su.cylno3013_ccfull.out:	CC – full of solution No 3013	0.62040	0.00120	0.623
2.	nrc_su.cylno3013_ccfull_PCV.out:	Same as #1 – PCV contains water	0.68470	0.00150	0.688
3.	nrc_su.cylno3013_ccfull_PCVSCV.out:	Same as #1 – PCV/SCV contains water	0.70970	0.00130	0.713
4.	nrc_su.cylno3013_ccfull_SCV.out:	Same as #1 –SCV contains water	0.62190	0.00150	0.625
5.	nrc_su.cylno3013_ccfull_PCVSCV_ALL.out:	Same as #1 – PCV/SCV/ Celotex® as water	0.73530	0.00130	0.738

Tables 14 through 17 show that a 9975 shipping package with a convenience can containing plutonium oxide, with or without the 3013 container, with water flooding in all compartments of the 9975 shipping package is subcritical. The highest $k_{eff} + 2\sigma$ of 0.738 was achieved for the case with a homogenized fissile cylinder modeled the width of the convenience can, no 3013 containers, with the PCV, SCV, and Celotex® regions fully flooded with water (Table 17, Case 5).

Therefore all $k_{eff} + 2\sigma$ values in Tables 8 through 17 are below the k_{safe} of 0.943, which satisfies the 10 CFR 71.55(b) requirements related to a flooded single package.

6.4 NORMAL CONDITIONS OF TRANSPORT ARRAY ANALYSES

10 CFR 71.55 contains the following requirements for NCT criticality safety analyses:

> (d) A package used for the shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in § 71.71 ("Normal conditions of transport") --
>
> (1) The contents would be subcritical;
> (2) The geometric form of the package contents would not be substantially altered;
> (3) There would be no leakage of water into the containment system unless, in the evaluation of undamaged packages under § 71.59(a)(1), it has been assumed that moderation is present to such an extent as to cause maximum reactivity consistent with the chemical and physical form of the material; and
> (4) There will be no substantial reduction in the effectiveness of the packaging, including:
>
> (i) No more than 5 percent reduction in the total effective volume of the packaging on which nuclear safety is assessed;
> (ii) No more than 5 percent reduction in the effective spacing between the fissile contents and the outer surface of the packaging;

In the NCT undamaged drum array analysis, no water enters the PCV, 3013, or convenience can. Thus, an infinite array of drums was analyzed with the convenience can containing dry plutonium oxide and 0.5% water fissile mixture, with or without the 3013 containers and additional cases with the Celotex® flooded. As mentioned earlier, all array analyses were performed using the 7% reduced drum radius to utilize an equivalent rectangular array configuration.

Table 18 presents the NCT results.

Table 18. 9975 Array Model – NCT Cases

Case No.	File ID	Description	k_{eff}	σ	k_{eff} $+2\sigma$
1.	nrc_nct.cyl3013.out	Infinite drum array, dry fissile material	0.65200	0.00110	0.655
2.	nrc_nct.cyl3013_celofld.out	Same as #1 water as Celotex®	0.60990	0.00098	0.612
3.	nrc_nct.cyl3013_h2orefl.out	Same as #1 w/water between drums	0.61019	0.00094	0.613
4.	nrc_nct.cyl3013_h2orefl_celofld.out	Same as #1 w/water between drums, water as Celotex®	0.60990	0.00100	0.612

Case No.	File ID	Description	k_{eff}	σ	k_{eff} +2σ
5.	nrc_nct.cylno3013.out	Infinite drum array, dry fissile material, no 3013 containers	0.65240	0.00110	0.655
6.	nrc_nct.cylno3013_celofld.out	Same as #5, water as Celotex®	0.60460	0.00100	0.607
7.	nrc_nct.cylno3013_h2orefl.out	Same as #5, w/water between drums	0.60490	0.00120	0.608
8.	nrc_nct.cylno3013_h2orefl_celofld.out	Same as #5 w/water between drums, water as Celotex®	0.60424	0.00098	0.607

The cases in Table 18 demonstrate that the 9975 with plutonium oxide in convenience can, with and without the 3013 container, in dry conditions, is subcritical with the highest $k_{eff} + 2\sigma$ of 0.655 for a dry system (Cases 1 and 5). As the water is added to the Celotex® and in between the shipping packages in an array, interaction is reduced, thus reducing the k_{eff} of the system as indicated in Table 18. Thus, water flooding of the Celotex® is subcritical.

Therefore all $k_{eff} + 2\sigma$ values in Table 18 are below the k_{safe} of 0.943, which satisfies the 10 CFR 71.55(d) and 71.59(a)(1) requirements related to NCT analyses.

6.5 HYPOTHETICAL ACCIDENT CONDITIONS ANALYSES

10 CFR 71.55 contains the following requirements for HAC criticality safety analyses:

> (e) A package used for the shipment of fissile material must be so designed and constructed and its contents so limited that under the tests specified in § 71.73 ("Hypothetical accident conditions"), the package would be subcritical. For this determination, it must be assumed that:
>
> (1) The fissile material is in the most reactive credible configuration consistent with the damaged condition of the package and the chemical and physical form of the contents;
> (2) Water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents; and
> (3) There is full reflection by water on all sides, as close as is consistent with the damaged condition of the package.

In the HAC analysis, damaged units are arranged in various configurations to demonstrate a most reactive configuration. The damaged HAC array model used a conservative radial and axial drum dimension reduction to address a drop and the amount of Celotex® charred due to fire, see Table 7. A conservative infinite array, modeled as 2x2x2, was developed where the fissile material was moved together as close as possible. This model brought a cluster of four drums, stacked two high (eight packages total), to its closest contact position. In other words, although not credible, the radial movement is such that four drums together form the closest configuration (a quadrupole arrangement), as shown in Figure 6.

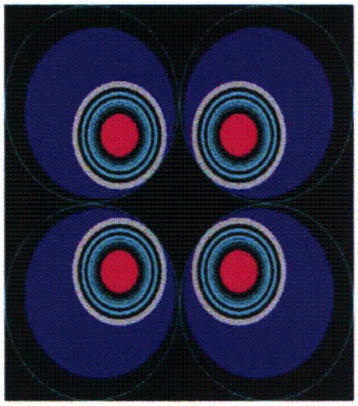


Figure 6. 2x2x2 Closest Contact Model (Case 1)

These models assume that the Celotex® loss is localized around the periphery of the drum, and the 9975 is dropped during the accident. The inner containment (convenience can/3013/PCV/SCV) is moved inside the Celotex® (keeping the Celotex® volume constant) such that the lead shield is touching the drum at one point.

Although the close contact HAC model (Figure 6, Case 1) minimizes fissile spacing between the payloads in as many as eight packages, it increases fissile spacing between those packages and the packages surrounding them. Thus, it is not entirely obvious that a HAC model that only accounts for the destruction of Celotex® but includes none of the material movements, is less reactive or not. Therefore, an additional symmetrical model was also developed (Figure 7, Case 5) to help determine the most reactive configuration. Case 5 (symmetrical model) is a damaged array scenario with the Celotex®, containment, and fissile material in its normal, centered orientation, but the destruction of Celotex® due to fire and reduction of drum diameter due to impact are included.

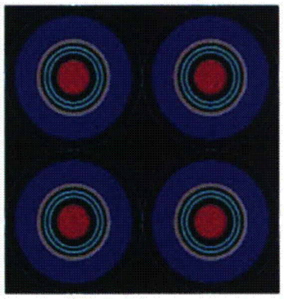


Figure 7. 2x2x2 Symmetrical Model (Case 5)

Table 19 presents the HAC results.

Table 19. 9975 Array Model – HAC Cases

Case No.	File ID	Description	k_{eff}	σ	$k_{eff}+2\sigma$
1.	nrc_hac.cyl3013_2x2x2.out	2x2x2 array inifinite array Fissile at closest position	0.73460	0.00110	0.737
2.	nrc_hac.cyl3013_2x2x2_PCVfl.out	Same as #1, PCV flooded	0.72090	0.00120	0.724
3.	nrc_hac.cyl3013_2x2x2_PCVSCVfl.out	Same as #1, PCV/SCV flooded	0.71200	0.00100	0.714
4.	nrc_hac.cyl3013_2x2x2_SCVfl.out	Same as #1, SCV flooded	0.71440	0.00110	0.717
5.	nrc_hac.cyl3013_2x2x2_symm.out	2x2x2 array inifinite array Fissile at centered position	0.72870	0.00100	0.731
6.	nrc_hac.cyl3013_2x2x2_PCVfl_symm.out	Same as #5, PCV flooded	0.71350	0.00100	0.716
7.	nrc_hac.cyl3013_2x2x2_PCVSCVfl_symm.out	Same as #5, PCV/SCV flooded	0.70080	0.00110	0.703
8.	nrc_hac.cyl3013_2x2x2_SCVfl_symm.out	Same as #5, SCV flooded	0.70650	0.00130	0.710

Table 19 shows that all $k_{eff} + 2\sigma$ values are less than k_{safe} for the damaged array cases. This demonstrates that moving the fissile units closer together (Case 1, the bounding closest position case) only produces a slightly higher k_{eff} than when all of the fissile units are centered within the 9975 shipping package (Case 5, the bounding centered position case), on the order of 1.6% difference. Thus, the infinite 2x2x2 base HAC array model with the fissile material units closest together (Case 1) within the array has the highest $k_{eff} + 2\sigma$ of 0.737.

Table 20. 9975 Array Model – Flooded Convenience Can HAC Cases

Case No.	File ID	Description	k_{eff}	σ	$k_{eff}+2\sigma$
1.	nrc_hac.cyl_CCfl_2x2x2.out:	Convenience can flooded Fissile at closest position	0.91490	0.00140	0.918
2.	nrc_hac.cyl_CCfl_3013fl.out:	Same as #1, 3013 flooded	0.93490	0.00130	0.938
3.	nrc_hac.cyl_CCfl_allfl.out:	Same as #1, 3013, PCV, SCV, water as Celotex®	0.78750	0.00130	0.791
4.	nrc_hac.cyl_CCfl_3013dry_PCVSCVfl.out:	Same as #1, 3013 dry, PCV, SCV flooded	0.84430	0.00150	0.848
5.	nrc_hac.cyl_CCfl_3013dry_allfl.out:	Same as #1, 3013 dry, PCV, SCV, water as Celotex®	0.76470	0.00140	0.768
6.	nrc_hac.cyl_CCL_2x2x2_symm.out:	Convenience can flooded Fissile at centered position	0.90380	0.00160	0.907

A conservative analysis was performed, with the results provided in Table 20, flooding the 9975 shipping package to the fullest extent while modeled as an infinite array. Various models were developed that flooded the different compartments (i.e., 3013, PCV, SCV, Celotex®) of the 9975 shipping package, while flooding the convenience can containing the fissile solution. As seen in Table 19, for the base HAC analysis, the configuration with the fissile units at their closest position (Table 19, Case 1) yields the highest $k_{eff} + 2\sigma$ which also hold true for the cases with the convenience can flooded. Thus, the study on flooding the 9975 shipping package compartments, Table 20, used this as the base case configuration. As shown in Table 20, the case where the convenience can/3013 configuration was flooded while the remainder of the 9975 shipping package remains dry (Case 2) yields a $k_{eff} + 2\sigma$ of 0.938.

Therefore all $k_{eff} + 2\sigma$ values for the HAC array analysis as shown in Table 19 and Table 20 are below the k_{safe} of 0.943, which satisfies the 10 CFR 71.55(e) and 71.59(a)(2) requirements related to HAC analyses.

6.6 CRITICALITY SAFETY INDEX

The calculation of the Criticality Safety Index (CSI) for the 9975 shipping package is required to follow the explicit equations specified in 10 CFR 71.59:

> (a) A fissile material package must be controlled by either the shipper or the carrier during transport to assure that an array of such packages remains subcritical. To enable this control, the designer of a fissile material package shall derive a number "N" based on all the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close full reflection on all sides of the stack by water:
>
> > (1) Five times "N" undamaged packages with nothing between the packages would be subcritical;
> > (2) Two times "N" damaged packages, if each package were subjected to the tests specified in § 71.73 ("Hypothetical accident conditions") would be subcritical with optimum interspersed hydrogenous moderation; and
> > (3) The value of "N" cannot be less than 0.5.
>
> (b) The CSI must be determined by dividing the number 50 by the value of "N" derived using the procedures specified in paragraph (a) of this section. The value of the CSI may be zero provided that an unlimited number of packages are subcritical, such that the value of "N" is effectively equal to infinity under the procedures specified in paragraph (a) of this section. Any CSI greater than zero must be rounded up to the first decimal place.
> (c) For a fissile material package which is assigned a CSI value--
>
> > (1) Less than or equal to 50, that package may be shipped by a carrier in a nonexclusive use conveyance, provided the sum of the CSIs is limited to less than or equal to 50.
> > (2) Less than or equal to 50, that package may be shipped by a carrier in an exclusive use conveyance, provided the sum of the CSIs is limited to less than or equal to 100.
> > (3) Greater than 50, that package must be shipped by a carrier in an exclusive use conveyance, provided the sum of the CSIs is limited to less than or equal to 100.

The CSI is conservatively computed for both the NCT and HAC, with the CSI calculation shown in Table 21.

Table 21. CSI Calculation

Calculate the value of N for NCT:	Calculate the value of N for HAC:
5*N = ∞ (infinite), so N = ∞/5 = ∞	2*N = ∞ (infinite), so N = ∞/2 = ∞
The CSI is defined by 10 CFR 71.59 as,	The CSI is defined by 10 CFR 71.59 as,
CSI ≡ 50/N = 50/∞ = 0.0	CSI ≡ 50/N = 50/∞ = 0.0
Rounding up to the first decimal we get,	Rounding up to the first decimal we get,
CSI = 0.0	CSI = 0.0

The CSI calculation in Table 21 derives a CSI in the infinite array NCT and HAC configurations equal to 0.0 for the 9975 package with the plutonium oxide content envelope, as specified in Section 2.2.

7.0 ADMINISTRATIVELY CONTROLLED LIMITS AND REQUIREMENTS

The following limits apply to the 9975 shipping packages evaluated in this analysis:

1. The 9975 shipping package shall be used to transport the plutonium oxide material which has the content envelope described in Table 2 and shown again in Table 22.

Table 22. Plutonium Oxide Contents

Material	Mass (kg)
^{239}Pu	4.4
Beryllium	0.5
Carbon	1.0
Total Content	5.0

*The 5.0 kg is the maximum payload for the shipping package. The addition of the Beryllium or Carbon reduces the fissile content.

8.0 SUMMARY AND CONCLUSIONS

An evaluation was performed to address shipping the plutonium oxide content envelope, as specified in Section 2.2, in the 9975 shipping package.

Based on the analysis performed in Section 6.0, an infinite array of 9975 shipping packages with a 5.0 kg plutonium oxide content envelope is subcritical provided the limits and controls in Section 7.0 are maintained.

This NCSE has demonstrated that 9975 shipping packages can be safely shipped carrying the plutonium oxide contents as described in Table 2, with a CSI of 0.0.

9.0 REFERENCES

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APPENDIX 1 SENSITIVITY STUDIES

1. Variation of k_{eff} with Celotex® density

Celotex® density is varied to determine the effect of Celotex® density on k_{eff}. The density may vary substantially (WSRC-TR-2000-00444). Table A1.1 shows that k_{eff} increases significantly with a reduction in Celotex® density in the array scenario. This nominal density of Celotex® is 0.24 g/cc and the density variation ranges from 0.22 g/cc to 0.26 g/cc (WSRC-TR-2000-00444). Therefore, a conservative Celotex® density of 0.20 g/cc is chosen for this analysis.

Table A1.1. Variation of k_{eff} with Celotex® Density

Case No.	File ID	Celotex® Density (g/cc)	k_{eff}	σ	$k_{eff}+2\sigma$
1.	nrc_nct.cyl_celo_den_0.02.out:	NCT case, No 3013, Dry, Infinite array – 0.02 Density	0.97670	0.00120	0.980
2.	nrc_nct.cyl_celo_den_0.04.out:	Same as #1, Density 0.04	0.83600	0.00120	0.839
3.	nrc_nct.cyl_celo_den_0.06.out:	Same as #1, Density 0.06	0.76810	0.00110	0.771
4.	nrc_nct.cyl_celo_den_0.08.out:	Same as #1, Density 0.08	0.73130	0.00120	0.734
5.	nrc_nct.cyl_celo_den_0.10.out:	Same as #1, Density 0.10	0.70720	0.00110	0.710
6.	nrc_nct.cyl_celo_den_0.12.out:	Same as #1, Density 0.12	0.68970	0.00100	0.692
7.	nrc_nct.cyl_celo_den_0.14.out:	Same as #1, Density 0.14	0.67591	0.00097	0.678
8.	nrc_nct.cyl_celo_den_0.16.out:	Same as #1, Density 0.16	0.66620	0.00120	0.669
9.	nrc_nct.cyl_celo_den_0.18.out:	Same as #1, Density 0.18	0.65730	0.00100	0.660
10.	nrc_nct.cyl_celo_den_0.20.out:	Same as #1, Density 0.20	0.65240	0.00100	0.655
11.	nrc_nct.cyl_celo_den_0.22.out:	Same as #1, Density 0.22	0.64870	0.00100	0.651
12.	nrc_nct.cyl_celo_den_0.24.out:	Same as #1, Density 0.24	0.64330	0.00100	0.646
13.	nrc_nct.cyl_celo_den_0.26.out:	Same as #1, Density 0.26	0.63763	0.00097	0.640

2. Variation of Stainless Steel Composition

Several kinds of stainless steel are used in the 9975/3013 system. To simplify the analysis, a standard composition of stainless steel corresponding to SS 304 from ORNL/TM-2005/39 is used. Table A1.2 shows the composition of several different types of stainless steel used in 9975/3013 components. It should be noted that there is a small variation of elemental compositions and density for each type of stainless steel. Table A1.3 shows the k_{eff} results for the base case of a NCT scenario using different stainless steel composition and another case with a variation in stainless steel density.

Table A1.2. Stainless Steel Composition

Element	SCALE ID	SS 304 (wt. %)	SS 304L (wt. %)	SS-316 (wt. %)
Fe	26304	68.375	67.895	65.375
Cr	24304	19.00	19.00	17.00
Ni	28304	9.50	10.00	12.00
Mo	42000	-		2.50
Mn	25055	2.00	2.00	2.00
Si	14000	1.00	1.00	1.00
C	6012	0.08	0.030	0.08
P	15031	0.045	0.045	0.045
S	16000	0.03	0.03	-
total		100.00	100.00	100.00
Density g/cc		7.92++	7.90	8.03

++Note: ORNL/TM-2005/39 specifies the density of SS 304 as 7.94 g/cc. A density value of 7.92 g/cc was used in this analysis. The variation in steel density is shown to be negligible in Table A1.3.

Table A1.3. Variation of k_{eff} with Stainless Steel Composition

Case No.	File ID	Description	k_{eff}	σ	$k_{eff}+2\sigma$
1.	nrc_nct.cylno3013.out:	NCT case, No 3013, Dry, Infinite array – SS 304 (7.92 g/cc)	0.65240	0.00110	0.655
2.	nrc_nct.cylno3013_SS304_0.94.out:	Same as #1, SS 304 (7.94 g/cc)	0.65030	0.00120	0.653
3.	nrc_nct.cylno3013_SS304L.out:	Same as #1, SS 304L	0.65200	0.00100	0.654
4.	nrc_nct.cylno3013_SS316.out:	Same as #1, SS 316	0.64960	0.00100	0.652

Table A1.3 shows that the variation in k_{eff} by using different types of stainless steel is insignificant (within 1σ). It should be noted that for each of the models, it is assumed that all steel components are made of one kind of stainless steel.

3. Variation of Dimensional Tolerances on PCV and SCV

The effect of uncertainties in the thickness of the PCV and SCV on the calculated k_{eff} was also considered in this analysis. The ASTM A312 standard indicates a tolerance of +22.5% / -12.5% on the wall thickness and a tolerance of $+^{1}/_{16}$ / $-^{1}/_{32}$ inches on the outer diameter. This evaluation performed an analysis and determined that there is no statistical significance among the k_{eff} values calculated with nominal, minimum, and maximum wall thickness (Table A1.4). Therefore the nominal dimensions of PCV and SCV are used in this analysis.

Table A1.4. Variation of Dimensional Tolerances on PCV and SCV – Single Unit

Case No.	File ID	Description	k_{eff}	σ	$k_{eff}+2\sigma$
1.	nrc_su.cyl3013.out: (From Table 8)	Nominal wall dimensions for PCV/SCV outer diameter	0.59217	0.00099	0.595
2.	nrc_su.pos_PCV_pos_SCV.out:	Upper Tolerance PCV Upper Tolerance SCV	0.59145	0.00094	0.593
3.	nrc_su.pos_PCV_neg_SCV.out:	Upper Tolerance PCV Lower Tolerance SCV	0.59564	0.00099	0.598
4.	nrc_su.neg_PCV_pos_SCV.out:	Lower Tolerance PCV Upper Tolerance SCV	0.59510	0.00100	0.597
5.	nrc_su.neg_PCV_neg_SCV.out:	Lower Tolerance PCV Lower Tolerance SCV	0.59267	0.00091	0.594

4. Stainless Steel Sleeve Sensitivity Calculation

The 9975 Shipping Package has an outer and inner stainless steel sleeve surrounding the lead shield of the package. The sleeves are 20 gage, 0.036 inch thick SS 304. The minimum lead thickness is 0.434 inches. However, the lead shield body is modeled with overall thickness of 0.506 inches with the inner and outer skin of nominal 0.036 inch thickness. As shown in Table A1.5, neglecting the stainless steel sleeves and including the thickness as lead has a negligible effect and thus neglected.

Table A1.5. Stainless Steel Sleeve Sensitivity Calculation

Case No.	File ID	Description	k_{eff}	σ	$k_{eff}+2\sigma$
1.	nrc_su.cyl3013.out:	SS Sleeve thickness included as lead	0.59217	0.00099	0.595
2.	nrc_su.cyl3013_2ss_sleeve.out:	SS Sleeve thicknes modeled as SS 304	0.59406	0.00093	0.596

APPENDIX 2 SAMPLE INPUT FILES

Sample input files: (for the plutonium oxide cases):

1. nrc_su.cyl3013.in – Single unit case (Base Case with 3013, dry oxide) – see Table 8.
2. nrc_su.cylno3013_ccfull_PCVSCV_ALL.in – Single unit case (convenience can flooded with water, PCV/SCV/Celotex® as water) – see Table 17.
3. nrc_nct.cyl3013.in – NCT case (Infinite drum array, dry fissile material) – see Table 18.
4. nrc_hac.cyl_CCfl_3013fl.in – HAC case (2x2x2 array infinite array, convenience can flooded/3013 flooded, fissile units at closest position) – see Table 20.

---

1. nrc_su.cyl3013.in

```
'NRC PuO2 Single Unit Case - 12/2012
=csas26   parm=Centrm
nrc_su 9975 - pu oxide – 3013
238groupndf5
read composition
 wtptpuo2      1  10.8921  3
                      94239 87.76187
                       1001  0.055698
                       8016 12.18243
               1 300   end
 atom-celt     2  0.2  3
                      6000 6
                      1001 10
                      8016 5
               1 293   end
 ss304     3 den=7.92 1 293 end
 al        4 den=2.7 1 293 end
 h2o       5 den=1 1 293 end
 pb        8 den=11.34 1 293 end
 al        9 den=0.28 1 293 end
end composition
read parameter
 tme=300
 gen=425
 nsk=25
 plt=no
end parameter
read geometry
unit 1
com="pu cylinder, 5.0 kg PuO2"
 cylinder 1   4.187   -11.005   -19.380
 cylinder 2   5.271     1.320   -19.380
 cylinder 3   5.423     1.345   -19.405
 cylinder 4   5.690     3.335   -19.415
```

```
 cylinder 5   5.842   3.535  -19.565
 cylinder 6   5.948   4.535  -19.575
 cylinder 7   6.255   4.935  -20.475
 cylinder 8   6.410  20.475  -20.475
 cylinder 9   7.065  20.475  -21.130
 cylinder 10   7.703   20.475  -21.130
 cylinder 11   8.414   20.475  -21.130
 cylinder 12   9.208   20.475  -21.130
 cylinder 13  10.493   20.475  -21.130
 cylinder 14  22.987   20.475  -21.130
 cylinder 15  23.101   20.475  -21.130
 cylinder 16  23.223   20.475  -21.130
 cuboid  17  23.223  -23.223   23.223 -23.223  20.475  -21.13
 media 1 1 1
 media 0 1 2 -1
 media 3 1 3 -2
 media 0 1 4 -3
 media 3 1 5 -4 -3
 media 0 1 6 -5 -4
 media 3 1 7 -6 -5
 media 0 1 8 -7 -6
 media 3 1 9 -8 -7
 media 0 1 10 -9 -8
 media 3 1 11 -10 -9
 media 0 1 12 -11 -10
 media 8 1 13 -12 -11
 media 2 1 14 -13 -12
 media 0 1 15 -14 -13
 media 3 1 16 -15 -14
 media 0 1 17 -16 -15
 boundary 17
unit 2
com="top of primary containment"
 cylinder 1   7.455   3.505      0
 cylinder 2   7.703   3.505      0
 cylinder 3   8.414   3.505      0
 cylinder 4   9.208   3.505      0
 cylinder 5  10.493   3.505      0
 cylinder 6  22.987   3.505      0
 cylinder 7  23.101   3.505      0
 cylinder 8  23.223   3.505      0
 cuboid 9  23.223 -23.223  23.223 -23.223   3.505       0
 media 3 1 1
 media 0 1 2 -1
 media 3 1 3 -2 -1
 media 0 1 4 -3 -2
 media 8 1 5 -4 -3
 media 2 1 6 -5 -4
 media 0 1 7 -6 -5
 media 3 1 8 -7 -6
 media 0 1 9 -8 -7
 boundary 9
unit 3
com="primary containment nut and al honeycomb"
 cylinder 1   3.175    1.27      0
```

```
 cylinder 2   4.699   4.572      0
 cylinder 3   7.366   4.572      0
 cylinder 4   7.703   5.922      0
 cylinder 5   8.414   5.922      0
 cylinder 6   9.208   5.922      0
 cylinder 7  10.493   5.922      0
 cylinder 8  22.987   5.922      0
 cylinder 9  23.101   5.922      0
 cylinder 10  23.223   5.922      0
 cuboid 11  23.223  -23.223  23.223  -23.223   5.922       0
 media 3 1 1
 media 0 1 2 -1
 media 9 1 3 -2 -1
 media 0 1 4 -3 -2
 media 3 1 5 -4 -3
 media 0 1 6 -5 -4
 media 8 1 7 -6 -5
 media 2 1 8 -7 -6
 media 0 1 9 -8 -7
 media 3 1 10 -9 -8
 media 0 1 11 -10 -9
 boundary 11
unit 4
com="secondary containment top"
 cylinder 1   9.042   3.505      0
 cylinder 2   9.208   3.505      0
 cylinder 3  10.493   3.505      0
 cylinder 4  22.987   3.505      0
 cylinder 5  23.101   3.505      0
 cylinder 6  23.223   3.505      0
 cuboid 7  23.223  -23.223  23.223  -23.223   3.505       0
 media 3 1 1
 media 0 1 2 -1
 media 8 1 3 -2 -1
 media 2 1 4 -3 -2
 media 0 1 5 -4 -3
 media 3 1 6 -5 -4
 media 0 1 7 -6 -5
 boundary 7
unit 5
com="scv nut and al shield top"
 cylinder 1   3.175    1.27     0
 cylinder 2   9.208    1.27     0
 cylinder 3  10.493    1.27     0
 cylinder 4  10.493    2.54     0
 cylinder 5  22.987    2.54     0
 cylinder 6  23.101    2.54     0
 cylinder 7  23.223    2.54     0
 cuboid 8  23.223  -23.223  23.223  -23.223    2.54       0
 media 3 1 1
 media 0 1 2 -1
 media 8 1 3 -2 -1
 media 4 1 4 -3 -2
 media 2 1 5 -4 -3
 media 0 1 6 -5 -4
```

```
 media 3 1 7 -6 -5
 media 0 1 8 -7 -6
 boundary 8
unit 6
com="pcv legs, al honeycomb and scv bottom"
 cylinder 1   5.113      0   -0.94
 cylinder 2   5.715      0   -0.94
 cylinder 3   7.703      0   -0.94
 cylinder 4   7.703      0   -3.48
 cylinder 5   8.414      0  -4.191
 cylinder 6   9.208      0  -4.191
 cylinder 7  10.493      0  -4.191
 cylinder 8  22.987      0  -4.191
 cylinder 9  23.101      0  -4.191
 cylinder 10  23.223      0  -4.191
 cuboid 11  23.223 -23.223  23.223  -23.223      0  -4.191
 media 0 1 1
 media 3 1 2 -1
 media 0 1 3 -2 -1
 media 9 1 4 -3 -2
 media 3 1 5 -4 -3
 media 0 1 6 -5 -4
 media 8 1 7 -6 -5
 media 2 1 8 -7 -6
 media 0 1 9 -8 -7
 media 3 1 10 -9 -8
 media 0 1 11 -10 -9
 boundary 11
unit 7
com="scv legs and bottom of lead shield"
 cylinder 1    6.41      0  -0.965
 cylinder 2   7.065      0  -0.965
 cylinder 3   9.208      0  -0.965
 cylinder 4  10.493      0   -2.25
 cylinder 5  22.987      0   -2.25
 cylinder 6  23.101      0   -2.25
 cylinder 7  23.223      0   -2.25
 cuboid 8  23.223  -23.223  23.223  -23.223      0   -2.25
 media 0 1 1
 media 3 1 2 -1
 media 0 1 3 -2 -1
 media 8 1 4 -3 -2
 media 2 1 5 -4 -3
 media 0 1 6 -5 -4
 media 3 1 7 -6 -5
 media 0 1 8 -7 -6
 boundary 8
unit 8
com="al top plate and celotex plus top void plus drum"
 cylinder 1  14.224    1.27      0
 cylinder 2  22.987  10.668      0
 cylinder 3  23.101  12.828      0
 cylinder 4  23.223   12.95     0
 cuboid 5  23.223  -23.223  23.223  -23.223   12.95      0
 media 4 1 1
```

```
 media 2 1 2 -1
 media 0 1 3 -2 -1
 media 3 1 4 -3 -2
 media 0 1 5 -4 -3
 boundary 5
unit 9
com="al bottom plate and celotex plus bottom void (zero, new model) plus drum"
 cylinder 1  14.224      0   -1.27
 cylinder 2  22.987      0  -10.922
 cylinder 3  23.101      0  -10.922
 cylinder 4  23.223      0  -11.044
 cuboid 5  23.223  -23.223  23.223  -23.223       0  -11.044
 media 4 1 1
 media 2 1 2 -1
 media 0 1 3 -2
 media 3 1 4 -3
 media 0 1 5 -4
 boundary 5
global unit 10
com="global unit 10 references array 1"
 cuboid 1  46.446      0  46.446      0  87.512      0
 array 1 1  place 1 1 1 23.223 23.223 11.044
 cuboid 2  76.446    -30  76.446    -30  117.512    -30
 media 5 1 2 -1
 boundary 2
end geometry
read array
ara=1 nux=1 nuy=1 nuz=9 typ=square
 com="
 fill
   9
   7
   6
   1
   2
   3
   4
   5
   8  end fill
end array
read plot
 scr=yes
 ttl='plot1 xy slice'
 pic=mixtures
 xul=-10
 yul=60
 zul=39
 xlr=60
 ylr=-10
 zlr=39
 nax=600
 clr=1 200 200 200
    2 0 0 205
    3 0 229 238
    4 0 238 0
```

```
   5 205 205 0
   8 150 150 150
   9 240 200 220
   12 0 255 127
   13 255 255 224
 end color
 uax=1 vdn=-1
  end
end plot
read start
 nst=0
  end start
end data
end
```

---

2. nrc_su.cylno3013_ccfull_PCVSCV_ALL.in

```
'NRC PuO2 Single Unit Case - 12/2012
=csas26   parm=Centrm
nrc_su 9975 - pu oxide - 3013
238groupndf5
read composition
 wtptpuo2      1  3.5862  3
                     94239 69.723859
                     1001 2.345257
                     8016 27.930885
                  1 300   end
 atom-celt      2  0.2  3
                     6000 6
                     1001 10
                     8016 5
                  1 293   end
 ss304      3 den=7.92   1 293   end
 al        4 den=2.7    1 293   end
 h2o        5 den=1.0    1 293   end
 pb        8 den=11.34  1 293   end
 al        9 den=0.28   1 293   end
end composition
read parameter
 tme=300
 gen=425
 nsk=25
 plt=no
end parameter
read geometry
unit 1
com="pu cylinder, 5.0 kg PuO2"
 cylinder 1   5.271   0.275   -20.450
 cylinder 2   5.271   0.275   -20.450
 cylinder 3   5.423   0.275   -20.475
 cylinder 4   6.410  20.475   -20.475
 cylinder 5   7.065  20.475   -21.130
```

```
 cylinder 6    7.703  20.475  -21.130
 cylinder 7    8.414  20.475  -21.130
 cylinder 8    9.208  20.475  -21.130
 cylinder 9   10.493  20.475  -21.130
 cylinder 10  22.987  20.475  -21.130
 cylinder 11  23.101  20.475  -21.130
 cylinder 12  23.223  20.475  -21.130
 cuboid 13   23.223  -23.223   23.223  -23.223  20.475  -21.13
 media 1 1  1
 media 0 1  2 -1
 media 3 1  3 -2
 media 5 1  4 -3
 media 3 1  5 -4 -3
 media 5 1  6 -5 -4
 media 3 1  7 -6 -5
 media 0 1  8 -7 -6
 media 8 1  9 -8 -7
 media 5 1 10 -9 -8
 media 0 1 11 -10 -9
 media 3 1 12 -11 -10
 media 0 1 13 -12 -11
 boundary 13
unit 2
com="top of primary containment"
 cylinder 1   7.455   3.505      0
 cylinder 2   7.703   3.505      0
 cylinder 3   8.414   3.505      0
 cylinder 4   9.208   3.505      0
 cylinder 5  10.493   3.505      0
 cylinder 6  22.987   3.505      0
 cylinder 7  23.101   3.505      0
 cylinder 8  23.223   3.505      0
 cuboid 9  23.223  -23.223  23.223  -23.223   3.505      0
 media 3 1 1
 media 5 1 2 -1
 media 3 1 3 -2 -1
 media 0 1 4 -3 -2
 media 8 1 5 -4 -3
 media 5 1 6 -5 -4
 media 0 1 7 -6 -5
 media 3 1 8 -7 -6
 media 0 1 9 -8 -7
 boundary 9
unit 3
com="primary containment nut and al honeycomb"
 cylinder 1   3.175    1.27      0
 cylinder 2   4.699   4.572      0
 cylinder 3   7.366   4.572      0
 cylinder 4   7.703   5.922      0
 cylinder 5   8.414   5.922      0
 cylinder 6   9.208   5.922      0
 cylinder 7  10.493   5.922      0
 cylinder 8  22.987   5.922      0
 cylinder 9  23.101   5.922      0
 cylinder 10  23.223   5.922      0
```

```
 cuboid 11  23.223  -23.223  23.223  -23.223   5.922     0
 media 3 1 1
 media 5 1 2 -1
 media 9 1 3 -2 -1
 media 5 1 4 -3 -2
 media 3 1 5 -4 -3
 media 0 1 6 -5 -4
 media 8 1 7 -6 -5
 media 5 1 8 -7 -6
 media 0 1 9 -8 -7
 media 3 1 10 -9 -8
 media 0 1 11 -10 -9
 boundary 11
unit 4
com="secondary containment top"
 cylinder 1   9.042   3.505     0
 cylinder 2   9.208   3.505     0
 cylinder 3  10.493   3.505     0
 cylinder 4  22.987   3.505     0
 cylinder 5  23.101   3.505     0
 cylinder 6  23.223   3.505     0
 cuboid 7  23.223  -23.223  23.223  -23.223   3.505     0
 media 3 1 1
 media 0 1 2 -1
 media 8 1 3 -2 -1
 media 5 1 4 -3 -2
 media 0 1 5 -4 -3
 media 3 1 6 -5 -4
 media 0 1 7 -6 -5
 boundary 7
unit 5
com="scv nut and al shield top"
 cylinder 1   3.175    1.27     0
 cylinder 2   9.208    1.27     0
 cylinder 3  10.493    1.27     0
 cylinder 4  10.493    2.54     0
 cylinder 5  22.987    2.54     0
 cylinder 6  23.101    2.54     0
 cylinder 7  23.223    2.54     0
 cuboid 8  23.223  -23.223  23.223  -23.223   2.54     0
 media 3 1 1
 media 0 1 2 -1
 media 8 1 3 -2 -1
 media 4 1 4 -3 -2
 media 5 1 5 -4 -3
 media 0 1 6 -5 -4
 media 3 1 7 -6 -5
 media 0 1 8 -7 -6
 boundary 8
unit 6
com="pcv legs, al honeycomb and scv bottom"
 cylinder 1   5.113     0   -0.94
 cylinder 2   5.715     0   -0.94
 cylinder 3   7.703     0   -0.94
 cylinder 4   7.703     0   -3.48
```

```
 cylinder 5   8.414     0  -4.191
 cylinder 6   9.208     0  -4.191
 cylinder 7  10.493     0  -4.191
 cylinder 8  22.987     0  -4.191
 cylinder 9  23.101     0  -4.191
 cylinder 10  23.223    0  -4.191
 cuboid 11  23.223 -23.223  23.223 -23.223     0  -4.191
 media 5 1 1
 media 3 1 2 -1
 media 5 1 3 -2 -1
 media 9 1 4 -3 -2
 media 3 1 5 -4 -3
 media 0 1 6 -5 -4
 media 8 1 7 -6 -5
 media 5 1 8 -7 -6
 media 0 1 9 -8 -7
 media 3 1 10 -9 -8
 media 0 1 11 -10 -9
 boundary 11
unit 7
com="scv legs and bottom of lead shield"
 cylinder 1   6.41     0  -0.965
 cylinder 2   7.065    0  -0.965
 cylinder 3   9.208    0  -0.965
 cylinder 4  10.493    0   -2.25
 cylinder 5  22.987    0   -2.25
 cylinder 6  23.101    0   -2.25
 cylinder 7  23.223    0   -2.25
 cuboid 8  23.223 -23.223  23.223 -23.223     0  -2.25
 media 0 1 1
 media 3 1 2 -1
 media 0 1 3 -2 -1
 media 8 1 4 -3 -2
 media 5 1 5 -4 -3
 media 0 1 6 -5 -4
 media 3 1 7 -6 -5
 media 0 1 8 -7 -6
 boundary 8
unit 8
com="al top plate and celotex plus top void plus drum"
 cylinder 1  14.224   1.27     0
 cylinder 2  22.987  10.668     0
 cylinder 3  23.101  12.828     0
 cylinder 4  23.223   12.95    0
 cuboid 5  23.223 -23.223  23.223 -23.223   12.95     0
 media 4 1 1
 media 5 1 2 -1
 media 0 1 3 -2 -1
 media 3 1 4 -3 -2
 media 0 1 5 -4 -3
 boundary 5
unit 9
com="al bottom plate and celotex plus bottom void (zero, new model) plus drum"
 cylinder 1  14.224     0  -1.27
 cylinder 2  22.987     0 -10.922
```

```
 cylinder 3  23.101      0 -10.922
 cylinder 4  23.223      0 -11.044
 cuboid 5  23.223  -23.223  23.223  -23.223      0 -11.044
 media 4 1 1
 media 5 1 2 -1
 media 0 1 3 -2
 media 3 1 4 -3
 media 0 1 5 -4
 boundary 5
global unit 10
com="global unit 10 references array 1"
 cuboid 1  46.446      0  46.446      0  87.512      0
 array 1 1  place 1 1 1 23.223 23.223 11.044
 cuboid 2  76.446     -30  76.446     -30  117.512    -30
 media 5 1 2 -1
 boundary 2
end geometry
read array
ara=1 nux=1 nuy=1 nuz=9 typ=square
 com="
 fill
   9
   7
   6
   1
   2
   3
   4
   5
   8  end fill
end array
read plot
 scr=yes
 ttl='plot1 xy slice'
 pic=mixtures
 xul=-10
 yul=60
 zul=39
 xlr=60
 ylr=-10
 zlr=39
 nax=600
 clr=1 200 200 200
    2 0 0 205
    3 0 229 238
    4 0 238 0
    5 205 205 0
    8 150 150 150
    9 240 200 220
    12 0 255 127
    13 255 255 224
 end color
 uax=1 vdn=-1
  end
end plot
```

```
read start
 nst=0
  end start
end data
end
```

---

3. nrc_nct.cyl3013.in

```
'NRC PuO2 NCT Case - 12/2012
=csas26   parm=Centrm
nrc_nct 9975 - pu oxide – 3013
238groupndf5
read comp
 wtptpuo2       1  10.8921  3
                       94239  87.761870
                        1001   0.055698
                        8016  12.182430
                    1 300 end
 atom-celt      2  0.2  3
                       6000 6
                       1001 10
                       8016 5
                    1 293 end
 ss304     3 den=7.92   1 293 end
 al        4 den=2.7    1 293 end
 h2o       5 den=1      1 293 end
 pb        8 den=11.34  1 293 end
 al        9 den=0.28   1 293 end
end comp
read parameter
 tme=300
 gen=425
 nsk=25
 plt=no
end parameter
read geometry
unit 1
com="pu cylinder, 5.0 kg"
 cylinder 1    4.187   -9.225   -17.600
 cylinder 2    5.271    3.100   -17.600
 cylinder 3    5.423    3.125   -17.625
 cylinder 4    5.690    5.115   -17.635
 cylinder 5    5.842    5.315   -17.785
 cylinder 6    5.948    6.315   -17.795
 cylinder 7    6.255    6.705   -18.695
 cylinder 8    6.410   20.475   -20.475
 cylinder 9    7.065   20.475   -21.130
 cylinder 10    7.703   20.475   -21.130
 cylinder 11    8.414   20.475   -21.130
 cylinder 12    9.208   20.475   -21.130
 cylinder 13   10.493   20.475   -21.130
 cylinder 14   21.466   20.475   -21.130
```

```
 cylinder 15  21.466  20.475  -21.130
 cylinder 16  21.597  20.475  -21.130
 cuboid 17  21.597 -21.597  21.597 -21.597  20.475  -21.13
 media 1 1 1
 media 0 1 2 -1
 media 3 1 3 -2
 media 0 1 4 -3
 media 3 1 5 -4 -3
 media 0 1 6 -5 -4
 media 3 1 7 -6 -5
 media 0 1 8 -7 -6
 media 3 1 9 -8 -7
 media 0 1 10 -9 -8
 media 3 1 11 -10 -9
 media 0 1 12 -11 -10
 media 8 1 13 -12 -11
 media 2 1 14 -13 -12
 media 0 1 15 -14 -13
 media 3 1 16 -15 -14
 media 0 1 17 -16 -15
 boundary 17
unit 2
com='top of primary containment'
 cylinder 1  7.455  3.505  0
 cylinder 2  7.703  3.505  0
 cylinder 3  8.414  3.505  0
 cylinder 4  9.208  3.505  0
 cylinder 5  10.493  3.505  0
 cylinder 6  21.466  3.505  0
 cylinder 7  21.466  3.505  0
 cylinder 8  21.597  3.505  0
 cuboid 9  21.597  -21.597  21.597  -21.597  3.505  0
 media 3 1 1
 media 0 1 2 -1
 media 3 1 3 -2
 media 0 1 4 -3
 media 8 1 5 -4
 media 2 1 6 -5
 media 0 1 7 -6
 media 3 1 8 -7
 media 0 1 9 -8
 boundary 9
unit 3
com='primary containment nut and al honeycomb'
 cylinder 1  3.175  1.27  0
 cylinder 2  4.699  4.572  0
 cylinder 3  7.366  4.572  0
 cylinder 4  7.703  5.922  0
 cylinder 5  8.414  5.922  0
 cylinder 6  9.208  5.922  0
 cylinder 7  10.493  5.922  0
 cylinder 8  21.466  5.922  0
 cylinder 9  21.466  5.922  0
 cylinder 10  21.597  5.922  0
 cuboid 11  21.597  -21.597  21.597  -21.597  5.922  0
```

```
 media 3 1 1
 media 0 1 2 -1
 media 9 1 3 -2 -1
 media 0 1 4 -3 -2
 media 3 1 5 -4 -3
 media 0 1 6 -5 -4
 media 8 1 7 -6 -5
 media 2 1 8 -7 -6
 media 0 1 9 -8 -7
 media 3 1 10 -9 -8
 media 0 1 11 -10 -9
 boundary 11
unit 4
com='secondary containment top'
 cylinder 1  9.042  3.505  0
 cylinder 2  9.208  3.505  0
 cylinder 3  10.493  3.505  0
 cylinder 4  21.466  3.505  0
 cylinder 5  21.466  3.505  0
 cylinder 6  21.597  3.505  0
 cuboid 7  21.597  -21.597  21.597  -21.597  3.505  0
 media 3 1 1
 media 0 1 2 -1
 media 8 1 3 -2 -1
 media 2 1 4 -3 -2
 media 0 1 5 -4 -3
 media 3 1 6 -5 -4
 media 0 1 7 -6 -5
 boundary 7
unit 5
com='scv nut and al shield top'
 cylinder 1  3.175  1.27  0
 cylinder 2  9.208  1.27  0
 cylinder 3  10.493  1.27  0
 cylinder 4  10.493  2.54  0
 cylinder 5  21.466  2.54  0
 cylinder 6  21.466  2.54  0
 cylinder 7  21.597  2.54  0
 cuboid 8  21.597  -21.597  21.597  -21.597  2.54  0
 media 3 1 1
 media 0 1 2 -1
 media 8 1 3 -2 -1
 media 4 1 4 -3 -2
 media 2 1 5 -4 -3
 media 0 1 6 -5 -4
 media 3 1 7 -6 -5
 media 0 1 8 -7 -6
 boundary 8
unit 6
com='pcv legs, al honeycomb and scv bottom'
 cylinder 1  5.113  0  -0.94
 cylinder 2  5.715  0  -0.94
 cylinder 3  7.703  0  -0.94
 cylinder 4  7.703  0  -3.48
 cylinder 5  8.414  0  -4.191
```

```
 cylinder 6  9.208  0  -4.191
 cylinder 7  10.493  0  -4.191
 cylinder 8  21.466  0  -4.191
 cylinder 9  21.466  0  -4.191
 cylinder 10  21.597  0  -4.191
 cuboid 11  21.597  -21.597  21.597  -21.597  0  -4.191
 media 0 1 1
 media 3 1 2 -1
 media 0 1 3 -2 -1
 media 9 1 4 -3 -2
 media 3 1 5 -4 -3
 media 0 1 6 -5 -4
 media 8 1 7 -6 -5
 media 2 1 8 -7 -6
 media 0 1 9 -8 -7
 media 3 1 10 -9 -8
 media 0 1 11 -10 -9
 boundary 11
unit 7
com='scv legs and bottom of lead shield'
 cylinder 1  6.41  0  -0.965
 cylinder 2  7.065  0  -0.965
 cylinder 3  9.208  0  -0.965
 cylinder 4  10.493  0  -2.25
 cylinder 5  21.466  0  -2.25
 cylinder 6  21.466  0  -2.25
 cylinder 7  21.597  0  -2.25
 cuboid 8  21.597  -21.597  21.597  -21.597  0  -2.25
 media 0 1 1
 media 3 1 2 -1
 media 0 1 3 -2 -1
 media 8 1 4 -3 -2 -1
 media 2 1 5 -4 -3 -2
 media 0 1 6 -5 -4 -3
 media 3 1 7 -6 -5 -4
 media 0 1 8 -7 -6 -5
 boundary 8
unit 8
com='al top plate and celotex plus top void plus drum'
 cylinder 1  14.224  1.27  0
 cylinder 2  21.466  10.668  0
 cylinder 3  21.466  12.828  0
 cylinder 4  21.597  12.95  0
 cuboid 5  21.597  -21.597  21.597  -21.597  12.95  0
 media 4 1 1
 media 2 1 2 -1
 media 0 1 3 -2
 media 3 1 4 -3
 media 0 1 5 -4
 boundary 5
unit 9
com='al bottom plate and celotex plus bottom void (zero, new model) plus drum'
 cylinder 1  14.224  0  -1.27
 cylinder 2  21.466  0  -10.922
 cylinder 3  21.466  0  -10.922
```

```
 cylinder 4  21.597  0  -11.044
 cuboid 5  21.597  -21.597  21.597  -21.597  0  -11.044
 media 4 1 1
 media 2 1 2 -1
 media 0 1 3 -2
 media 3 1 4 -3
 media 0 1 5 -4
 boundary 5
global unit 10
 cuboid 1  43.194  0  43.194  0  87.512  0
 array 1 1  place 1 1 1 21.597 21.597 11.044
 boundary 1
end geometry
read array
ara=1 nux=1 nuy=1 nuz=9 typ=square
fill 9 7 6 1 2 3 4 5 8
end fill
end array
read plot
 scr=yes
 ttl='plot1 xy slice'
 pic=mixtures
 xul=-10
 yul=60
 zul=39
 xlr=60
 ylr=-10
 zlr=39
 nax=800
 clr=1 200 200 200
    2 0 0 205
    3 0 229 238
    4 0 238 0
    5 205 205 0
    8 150 150 150
    9 240 200 220
    12 0 255 127
    13 255 255 224
 end color
 uax=1 vdn=-1
  end
end plot
read bnds
  body=1
    surface(1)=mirror
    surface(2)=mirror
    surface(3)=mirror
    surface(4)=mirror
    surface(5)=periodic
    surface(6)=periodic
end bnds
read start
 nst=0

  end start
```

```
end data
end
```

---

4. nrc_hac.cyl_CCfl_3013fl.in

```
'NRC PuO2 HAC Case - 12/2012
=csas26  parm=Centrm
nrc_hac 9975 - pu oxide - 3013
238groupndf5
read comp
 wtptpuo2     1  3.7421  3
                   94239   70.843921
                   1001     2.203088
                   8016    26.952992
              1 300   end
 atom-celt    2  0.2  3
                   6000 6
                   1001 10
                   8016 5
              1 293   end
 ss304     3 den=7.92 1 293 end
 al        4 den=2.7 1 293 end
 h2o       5 den=1  1 293 end
 pb        8 den=11.34 1 293 end
 al        9 den=0.28 1 293 end
end comp
read parameter
 tme=300
 gen=425
 nsk=25
 plt=no
end parameter
read geometry
unit 1
com="pu cylinder, 5.0 kg PuO2"
 cylinder 1   5.271   19.380   -1.320   origin  x=6.076 y=-6.076 z=0
 cylinder 2   5.271   19.380   -1.320   origin  x=6.076 y=-6.076 z=0
 cylinder 3   5.423   19.405   -1.345   origin  x=6.076 y=-6.076 z=0
 cylinder 4   5.690   19.415   -3.335   origin  x=6.076 y=-6.076 z=0
 cylinder 5   5.842   19.565   -3.535   origin  x=6.076 y=-6.076 z=0
 cylinder 6   5.948   19.575   -4.535   origin  x=6.076 y=-6.076 z=0
 cylinder 7   6.255   20.475   -4.925   origin  x=6.076 y=-6.076 z=0
 cylinder 8   6.410   20.475  -20.475   origin  x=6.076 y=-6.076 z=0
 cylinder 9   7.065   20.475  -21.130   origin  x=6.076 y=-6.076 z=0
 cylinder 10  7.703   20.475  -21.130   origin  x=6.076 y=-6.076 z=0
 cylinder 11  8.414   20.475  -21.130   origin  x=6.076 y=-6.076 z=0
 cylinder 12  9.208   20.475  -21.130   origin  x=6.076 y=-6.076 z=0
 cylinder 13  10.493  20.475  -21.130   origin  x=6.076 y=-6.076 z=0
 cylinder 14  16.637  20.475  -21.130   origin  x=1.732 y=-1.732 z=0
 cylinder 15  19.088  20.475  -21.130
 cylinder 16  19.235  20.475  -21.130
 cuboid 17  19.235 -19.235  19.235 -19.235  20.475  -21.13
```

```
 media 1 1 1
 media 0 1 2 -1
 media 3 1 3 -2
 media 5 1 4 -3
 media 3 1 5 -4 -3
 media 5 1 6 -5 -4
 media 3 1 7 -6 -5
 media 0 1 8 -7 -6
 media 3 1 9 -8 -7
 media 0 1 10 -9 -8
 media 3 1 11 -10 -9
 media 0 1 12 -11 -10
 media 8 1 13 -12 -11
 media 2 1 14 -13 -12
 media 0 1 15 -14 -13
 media 3 1 16 -15 -14
 media 0 1 17 -16 -15
 boundary 17
unit 2
com='top of primary containment'
 cylinder 1  7.455  3.505  0   origin  x=6.076 y=-6.076 z=0
 cylinder 2  7.703  3.505  0   origin  x=6.076 y=-6.076 z=0
 cylinder 3  8.414  3.505  0   origin  x=6.076 y=-6.076 z=0
 cylinder 4  9.208  3.505  0   origin  x=6.076 y=-6.076 z=0
 cylinder 5  10.493  3.505  0   origin  x=6.076 y=-6.076 z=0
 cylinder 6  16.637  3.505  0   origin  x=1.732 y=-1.732 z=0
 cylinder 7  19.088  3.505  0
 cylinder 8  19.235  3.505  0
 cuboid 9  19.235  -19.235  19.235  -19.235  3.505  0
 media 3 1 1
 media 0 1 2 -1
 media 3 1 3 -2
 media 0 1 4 -3
 media 8 1 5 -4
 media 2 1 6 -5
 media 0 1 7 -6
 media 3 1 8 -7
 media 0 1 9 -8
 boundary 9
unit 3
com='primary containment nut and al honeycomb'
 cylinder 1  3.175  1.27  0   origin  x=6.076 y=-6.076 z=0
 cylinder 2  4.699  4.572  0   origin  x=6.076 y=-6.076 z=0
 cylinder 3  7.366  4.572  0   origin  x=6.076 y=-6.076 z=0
 cylinder 4  7.703  5.922  0   origin  x=6.076 y=-6.076 z=0
 cylinder 5  8.414  5.922  0   origin  x=6.076 y=-6.076 z=0
 cylinder 6  9.208  5.922  0   origin  x=6.076 y=-6.076 z=0
 cylinder 7  10.493  5.922  0   origin  x=6.076 y=-6.076 z=0
 cylinder 8  16.637  5.922  0   origin  x=1.732 y=-1.732 z=0
 cylinder 9  19.088  5.922  0
 cylinder 10  19.235  5.922  0
 cuboid 11  19.235  -19.235  19.235  -19.235  5.922  0
 media 3 1 1
 media 0 1 2 -1
 media 9 1 3 -2
```

```
 media 0 1 4 -3
 media 3 1 5 -4
 media 0 1 6 -5
 media 8 1 7 -6
 media 2 1 8 -7
 media 0 1 9 -8
 media 3 1 10 -9
 media 0 1 11 -10
 boundary 11
unit 4
com='secondary containment top'
 cylinder 1  9.042  3.505  0   origin  x=6.076 y=-6.076 z=0
 cylinder 2  9.208  3.505  0   origin  x=6.076 y=-6.076 z=0
 cylinder 3  10.493  3.505  0   origin  x=6.076 y=-6.076 z=0
 cylinder 4  16.637  3.505  0   origin  x=1.732 y=-1.732 z=0
 cylinder 5  19.088  3.505  0
 cylinder 6  19.235  3.505  0
 cuboid 7  19.235  -19.235  19.235  -19.235  3.505  0
 media 3 1 1
 media 0 1 2 -1
 media 8 1 3 -2
 media 2 1 4 -3
 media 0 1 5 -4
 media 3 1 6 -5
 media 0 1 7 -6
 boundary 7
unit 5
com='scv nut and al shield top'
 cylinder 1  3.175  1.27  0   origin  x=6.076 y=-6.076 z=0
 cylinder 2  9.208  1.27  0   origin  x=6.076 y=-6.076 z=0
 cylinder 3  10.493  1.27  0   origin  x=6.076 y=-6.076 z=0
 cylinder 4  10.493  2.54  0   origin  x=6.076 y=-6.076 z=0
 cylinder 5  16.637  2.54  0   origin  x=1.732 y=-1.732 z=0
 cylinder 6  19.088  2.54  0
 cylinder 7  19.235  2.54  0
 cuboid 8  19.235  -19.235  19.235  -19.235  2.54  0
 media 3 1 1
 media 0 1 2 -1
 media 8 1 3 -2
 media 4 1 4 -3
 media 2 1 5 -4
 media 0 1 6 -5
 media 3 1 7 -6
 media 0 1 8 -7
 boundary 8
unit 6
com='pcv legs, al honeycomb and scv bottom'
 cylinder 1  5.113  0  -0.94   origin  x=6.076 y=-6.076 z=0
 cylinder 2  5.715  0  -0.94   origin  x=6.076 y=-6.076 z=0
 cylinder 3  7.703  0  -0.94   origin  x=6.076 y=-6.076 z=0
 cylinder 4  7.703  0  -3.48   origin  x=6.076 y=-6.076 z=0
 cylinder 5  8.414  0  -4.191   origin  x=6.076 y=-6.076 z=0
 cylinder 6  9.208  0  -4.191   origin  x=6.076 y=-6.076 z=0
 cylinder 7  10.493  0  -4.191   origin  x=6.076 y=-6.076 z=0
 cylinder 8  16.637  0  -4.191   origin  x=1.732 y=-1.732 z=0
```

```
 cylinder 9  19.088  0  -4.191
 cylinder 10  19.235  0  -4.191
 cuboid 11  19.235  -19.235  19.235  -19.235  0  -4.191
 media 0 1 1
 media 3 1 2 -1
 media 0 1 3 -2
 media 9 1 4 -3
 media 3 1 5 -4
 media 0 1 6 -5
 media 8 1 7 -6
 media 2 1 8 -7
 media 0 1 9 -8
 media 3 1 10 -9
 media 0 1 11 -10
 boundary 11
unit 7
com='scv legs and bottom of lead shield'
 cylinder 1  6.41  0  -0.965  origin  x=6.076 y=-6.076 z=0
 cylinder 2  7.065  0  -0.965  origin  x=6.076 y=-6.076 z=0
 cylinder 3  9.208  0  -0.965  origin  x=6.076 y=-6.076 z=0
 cylinder 4  10.493  0  -2.25  origin  x=6.076 y=-6.076 z=0
 cylinder 5  16.637  0  -2.25  origin  x=1.732 y=-1.732 z=0
 cylinder 6  19.088  0  -2.25
 cylinder 7  19.235  0  -2.25
 cuboid 8  19.235  -19.235  19.235  -19.235  0  -2.25
 media 0 1 1
 media 3 1 2 -1
 media 0 1 3 -2
 media 8 1 4 -3
 media 2 1 5 -4
 media 0 1 6 -5
 media 3 1 7 -6
 media 0 1 8 -7
 boundary 8
unit 8
com='al top plate and celotex plus top void plus drum lower'
 cylinder 1  14.224  1.27  0  origin  x=3.438 y=-3.438 z=0
 cylinder 2  16.637  1.27  0  origin  x=1.732 y=-1.732 z=0
 cylinder 3  19.088  1.27  0
 cylinder 4  19.235  1.392  0
 cuboid 5  19.235  -19.235  19.235  -19.235  1.392  0
 media 4 1 1
 media 2 1 2 -1
 media 0 1 3 -2
 media 3 1 4 -3
 media 0 1 5 -4
 boundary 5
unit 9
com='al bottom plate and celotex plus bottom void (zero, new model) plus drum'
 cylinder 1  14.224  0  -1.27  origin  x=3.438 y=-3.438 z=0
 cylinder 2  16.637  0  -10.16  origin  x=1.732 y=-1.732 z=0
 cylinder 3  19.088  0  -17.4
 cylinder 4  19.235  0  -17.522
 cuboid 5  19.235  -19.235  19.235  -19.235  0  -17.522
 media 4 1 1
```

```
 media 2 1 2 -1
 media 0 1 3 -2
 media 3 1 4 -3
 media 0 1 5 -4
 boundary 5
unit 10
 cuboid 1  38.47  0  38.47  0  164.864  0
 array 1 1  place 1 1 1 19.235 19.235 17.522
 boundary 1
unit 13
com="pu cylinder, 5.0 kg PuO2"
 cylinder 1   5.271    1.320   -19.380   origin  x=6.076 y=-6.076 z=0
 cylinder 2   5.271    1.320   -19.380   origin  x=6.076 y=-6.076 z=0
 cylinder 3   5.423    1.345   -19.405   origin  x=6.076 y=-6.076 z=0
 cylinder 4   5.690    3.335   -19.415   origin  x=6.076 y=-6.076 z=0
 cylinder 5   5.842    3.535   -19.565   origin  x=6.076 y=-6.076 z=0
 cylinder 6   5.948    4.535   -19.575   origin  x=6.076 y=-6.076 z=0
 cylinder 7   6.255    4.935   -20.475   origin  x=6.076 y=-6.076 z=0
 cylinder 8   6.410   20.475   -20.475   origin  x=6.076 y=-6.076 z=0
 cylinder 9   7.065   20.475   -21.130   origin  x=6.076 y=-6.076 z=0
 cylinder 10   7.703   20.475   -21.130   origin  x=6.076 y=-6.076 z=0
 cylinder 11   8.414   20.475   -21.130   origin  x=6.076 y=-6.076 z=0
 cylinder 12   9.208   20.475   -21.130   origin  x=6.076 y=-6.076 z=0
 cylinder 13  10.493   20.475   -21.130   origin  x=6.076 y=-6.076 z=0
 cylinder 14  16.637   20.475   -21.130   origin  x=1.732 y=-1.732 z=0
 cylinder 15  19.088   20.475   -21.130
 cylinder 16  19.235   20.475   -21.130
 cuboid 17  19.235  -19.235  19.235  -19.235  20.475  -21.13
 media 1 1 1
 media 0 1 2 -1
 media 3 1 3 -2
 media 5 1 4 -3
 media 3 1 5 -4 -3
 media 5 1 6 -5 -4
 media 3 1 7 -6 -5
 media 0 1 8 -7 -6
 media 3 1 9 -8 -7
 media 0 1 10 -9 -8
 media 3 1 11 -10 -9
 media 0 1 12 -11 -10
 media 8 1 13 -12 -11
 media 2 1 14 -13 -12
 media 0 1 15 -14 -13
 media 3 1 16 -15 -14
 media 0 1 17 -16 -15
 boundary 17
unit 16
com='al top plate and celotex plus top void plus drum upper'
 cylinder 1  14.224  1.27  0   origin  x=3.438 y=-3.438 z=0
 cylinder 2  16.637  10.16  0   origin  x=1.732 y=-1.732 z=0
 cylinder 3  19.088  17.4  0
 cylinder 4  19.235  17.522  0
 cuboid 5  19.235  -19.235  19.235  -19.235  17.522  0
 media 4 1 1
 media 2 1 2 -1
```

```
 media 0 1 3 -2
 media 3 1 4 -3
 media 0 1 5 -4
 boundary 5
unit 17
com="pu cylinder, 5.0 kg PuO2"
 cylinder 1  5.271  19.380  -1.320  origin  x=-6.076 y=-6.076 z=0
 cylinder 2  5.271  19.380  -1.320  origin  x=-6.076 y=-6.076 z=0
 cylinder 3  5.423  19.405  -1.345  origin  x=-6.076 y=-6.076 z=0
 cylinder 4  5.690  19.415  -3.335  origin  x=-6.076 y=-6.076 z=0
 cylinder 5  5.842  19.565  -3.535  origin  x=-6.076 y=-6.076 z=0
 cylinder 6  5.948  19.575  -4.535  origin  x=-6.076 y=-6.076 z=0
 cylinder 7  6.255  20.475  -4.925  origin  x=-6.076 y=-6.076 z=0
 cylinder 8  6.410  20.475  -20.475  origin  x=-6.076 y=-6.076 z=0
 cylinder 9  7.065  20.475  -21.130  origin  x=-6.076 y=-6.076 z=0
 cylinder 10  7.703  20.475  -21.130  origin  x=-6.076 y=-6.076 z=0
 cylinder 11  8.414  20.475  -21.130  origin  x=-6.076 y=-6.076 z=0
 cylinder 12  9.208  20.475  -21.130  origin  x=-6.076 y=-6.076 z=0
 cylinder 13  10.493  20.475  -21.130  origin  x=-6.076 y=-6.076 z=0
 cylinder 14  16.637  20.475  -21.130  origin  x=-1.732 y=-1.732 z=0
 cylinder 15  19.088  20.475  -21.130
 cylinder 16  19.235  20.475  -21.130
 cuboid 17  19.235  -19.235  19.235  -19.235  20.475  -21.13
 media 1 1 1
 media 0 1 2 -1
 media 3 1 3 -2
 media 5 1 4 -3
 media 3 1 5 -4 -3
 media 5 1 6 -5 -4
 media 3 1 7 -6 -5
 media 0 1 8 -7 -6
 media 3 1 9 -8 -7
 media 0 1 10 -9 -8
 media 3 1 11 -10 -9
 media 0 1 12 -11 -10
 media 8 1 13 -12 -11
 media 2 1 14 -13 -12
 media 0 1 15 -14 -13
 media 3 1 16 -15 -14
 media 0 1 17 -16 -15
 boundary 17
unit 18
com='top of primary containment'
 cylinder 1  7.455  3.505  0  origin  x=-6.076 y=-6.076 z=0
 cylinder 2  7.703  3.505  0  origin  x=-6.076 y=-6.076 z=0
 cylinder 3  8.414  3.505  0  origin  x=-6.076 y=-6.076 z=0
 cylinder 4  9.208  3.505  0  origin  x=-6.076 y=-6.076 z=0
 cylinder 5  10.493  3.505  0  origin  x=-6.076 y=-6.076 z=0
 cylinder 6  16.637  3.505  0  origin  x=-1.732 y=-1.732 z=0
 cylinder 7  19.088  3.505  0
 cylinder 8  19.235  3.505  0
 cuboid 9  19.235  -19.235  19.235  -19.235  3.505  0
 media 3 1 1
 media 0 1 2 -1
 media 3 1 3 -2
```

```
 media 0 1 4 -3
 media 8 1 5 -4
 media 2 1 6 -5
 media 0 1 7 -6
 media 3 1 8 -7
 media 0 1 9 -8
 boundary 9
unit 19
com='primary containment nut and al honeycomb'
 cylinder 1  3.175  1.27  0   origin  x=-6.076 y=-6.076 z=0
 cylinder 2  4.699  4.572  0   origin  x=-6.076 y=-6.076 z=0
 cylinder 3  7.366  4.572  0   origin  x=-6.076 y=-6.076 z=0
 cylinder 4  7.703  5.922  0   origin  x=-6.076 y=-6.076 z=0
 cylinder 5  8.414  5.922  0   origin  x=-6.076 y=-6.076 z=0
 cylinder 6  9.208  5.922  0   origin  x=-6.076 y=-6.076 z=0
 cylinder 7  10.493  5.922  0   origin  x=-6.076 y=-6.076 z=0
 cylinder 8  16.637  5.922  0   origin  x=-1.732 y=-1.732 z=0
 cylinder 9  19.088  5.922  0
 cylinder 10  19.235  5.922  0
 cuboid 11  19.235  -19.235  19.235  -19.235  5.922  0
 media 3 1 1
 media 0 1 2 -1
 media 9 1 3 -2
 media 0 1 4 -3
 media 3 1 5 -4
 media 0 1 6 -5
 media 8 1 7 -6
 media 2 1 8 -7
 media 0 1 9 -8
 media 3 1 10 -9
 media 0 1 11 -10
 boundary 11
unit 20
com='secondary containment top'
 cylinder 1  9.042  3.505  0   origin  x=-6.076 y=-6.076 z=0
 cylinder 2  9.208  3.505  0   origin  x=-6.076 y=-6.076 z=0
 cylinder 3  10.493  3.505  0   origin  x=-6.076 y=-6.076 z=0
 cylinder 4  16.637  3.505  0   origin  x=-1.732 y=-1.732 z=0
 cylinder 5  19.088  3.505  0
 cylinder 6  19.235  3.505  0
 cuboid 7  19.235  -19.235  19.235  -19.235  3.505  0
 media 3 1 1
 media 0 1 2 -1
 media 8 1 3 -2 -1
 media 2 1 4 -3 -2
 media 0 1 5 -4 -3
 media 3 1 6 -5 -4
 media 0 1 7 -6 -5
 boundary 7
unit 21
com='scv nut and al shield top'
 cylinder 1  3.175  1.27  0   origin  x=-6.076 y=-6.076 z=0
 cylinder 2  9.208  1.27  0   origin  x=-6.076 y=-6.076 z=0
 cylinder 3  10.493  1.27  0   origin  x=-6.076 y=-6.076 z=0
 cylinder 4  10.493  2.54  0   origin  x=-6.076 y=-6.076 z=0
```

```
 cylinder 5  16.637  2.54  0   origin  x=-1.732 y=-1.732 z=0
 cylinder 6  19.088  2.54  0
 cylinder 7  19.235  2.54  0
 cuboid 8  19.235  -19.235  19.235  -19.235  2.54  0
 media 3 1 1
 media 0 1 2 -1
 media 8 1 3 -2 -1
 media 4 1 4 -3 -2
 media 2 1 5 -4 -3
 media 0 1 6 -5 -4
 media 3 1 7 -6 -5
 media 0 1 8 -7 -6
 boundary 8
unit 22
com='pcv legs, al honeycomb and scv bottom'
 cylinder 1  5.113  0  -0.94   origin  x=-6.076 y=-6.076 z=0
 cylinder 2  5.715  0  -0.94   origin  x=-6.076 y=-6.076 z=0
 cylinder 3  7.703  0  -0.94   origin  x=-6.076 y=-6.076 z=0
 cylinder 4  7.703  0  -3.48   origin  x=-6.076 y=-6.076 z=0
 cylinder 5  8.414  0  -4.191   origin  x=-6.076 y=-6.076 z=0
 cylinder 6  9.208  0  -4.191   origin  x=-6.076 y=-6.076 z=0
 cylinder 7  10.493  0  -4.191   origin  x=-6.076 y=-6.076 z=0
 cylinder 8  16.637  0  -4.191   origin  x=-1.732 y=-1.732 z=0
 cylinder 9  19.088  0  -4.191
 cylinder 10  19.235  0  -4.191
 cuboid 11  19.235  -19.235  19.235  -19.235  0  -4.191
 media 0 1 1
 media 3 1 2 -1
 media 0 1 3 -2 -1
 media 9 1 4 -3 -2
 media 3 1 5 -4 -3
 media 0 1 6 -5 -4
 media 8 1 7 -6 -5
 media 2 1 8 -7 -6
 media 0 1 9 -8 -7
 media 3 1 10 -9 -8
 media 0 1 11 -10 -9
 boundary 11
unit 23
com='scv legs and bottom of lead shield'
 cylinder 1  6.41  0  -0.965  origin  x=-6.076 y=-6.076 z=0
 cylinder 2  7.065  0  -0.965   origin  x=-6.076 y=-6.076 z=0
 cylinder 3  9.208  0  -0.965   origin  x=-6.076 y=-6.076 z=0
 cylinder 4  10.493  0  -2.25   origin  x=-6.076 y=-6.076 z=0
 cylinder 5  16.637  0  -2.25   origin  x=-1.732 y=-1.732 z=0
 cylinder 6  19.088  0  -2.25
 cylinder 7  19.235  0  -2.25
 cuboid 8  19.235  -19.235  19.235  -19.235  0  -2.25
 media 0 1 1
 media 3 1 2 -1
 media 0 1 3 -2 -1
 media 8 1 4 -3 -2
 media 2 1 5 -4 -3
 media 0 1 6 -5 -4
 media 3 1 7 -6 -5
```

```
 media 0 1 8 -7 -6
 boundary 8
unit 24
com='al top plate and celotex plus top void plus drum'
 cylinder 1  14.224  1.27  0   origin  x=-3.438 y=-3.438 z=0
 cylinder 2  16.637  1.27  0   origin  x=-1.732 y=-1.732 z=0
 cylinder 3  19.088  1.27  0
 cylinder 4  19.235  1.392  0
 cuboid 5  19.235  -19.235  19.235  -19.235  1.392  0
 media 4 1 1
 media 2 1 2 -1
 media 0 1 3 -2
 media 3 1 4 -3
 media 0 1 5 -4
 boundary 5
unit 25
com='al bottom plate and celotex plus bottom void plus drum'
 cylinder 1  14.224  0  -1.27   origin  x=-3.438 y=-3.438 z=0
 cylinder 2  16.637  0  -10.16   origin  x=-1.732 y=-1.732 z=0
 cylinder 3  19.088  0  -17.4
 cylinder 4  19.235  0  -17.522
 cuboid 5  19.235  -19.235  19.235  -19.235  0  -17.522
 media 4 1 1
 media 2 1 2 -1
 media 0 1 3 -2
 media 3 1 4 -3
 media 0 1 5 -4
 boundary 5
unit 28
com="pu cylinder, 5.0 kg PuO2"
 cylinder 1   5.271   1.320  -19.380   origin  x=-6.076 y=-6.076 z=0
 cylinder 2   5.271   1.320  -19.380   origin  x=-6.076 y=-6.076 z=0
 cylinder 3   5.423   1.345  -19.405   origin  x=-6.076 y=-6.076 z=0
 cylinder 4   5.690   3.335  -19.415   origin  x=-6.076 y=-6.076 z=0
 cylinder 5   5.842   3.535  -19.565   origin  x=-6.076 y=-6.076 z=0
 cylinder 6   5.948   4.535  -19.575   origin  x=-6.076 y=-6.076 z=0
 cylinder 7   6.255   4.935  -20.475   origin  x=-6.076 y=-6.076 z=0
 cylinder 8   6.410  20.475   -20.475   origin  x=-6.076 y=-6.076 z=0
 cylinder 9   7.065  20.475   -21.130   origin  x=-6.076 y=-6.076 z=0
 cylinder 10   7.703  20.475   -21.130   origin  x=-6.076 y=-6.076 z=0
 cylinder 11   8.414  20.475   -21.130   origin  x=-6.076 y=-6.076 z=0
 cylinder 12   9.208  20.475   -21.130   origin  x=-6.076 y=-6.076 z=0
 cylinder 13  10.493  20.475   -21.130   origin  x=-6.076 y=-6.076 z=0
 cylinder 14  16.637  20.475   -21.130   origin  x=-1.732 y=-1.732 z=0
 cylinder 15  19.088  20.475   -21.130
 cylinder 16  19.235  20.475   -21.130
 cuboid 17  19.235  -19.235  19.235  -19.235  20.475  -21.13
 media 1 1 1
 media 0 1 2 -1
 media 3 1 3 -2
 media 5 1 4 -3
 media 3 1 5 -4 -3
 media 5 1 6 -5 -4
 media 3 1 7 -6 -5
 media 0 1 8 -7 -6
```

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 media 3 1 9 -8 -7
 media 0 1 10 -9 -8
 media 3 1 11 -10 -9
 media 0 1 12 -11 -10
 media 8 1 13 -12 -11
 media 2 1 14 -13 -12
 media 0 1 15 -14 -13
 media 3 1 16 -15 -14
 media 0 1 17 -16 -15
 boundary 17
unit 31
com='al top plate and celotex plus top void plus drum upper'
 cylinder 1  14.224  1.27  0   origin  x=-3.438 y=-3.438 z=0
 cylinder 2  16.637  10.16  0   origin  x=-1.732 y=-1.732 z=0
 cylinder 3  19.088  17.4  0
 cylinder 4  19.235  17.522  0
 cuboid 5  19.235  -19.235  19.235  -19.235  17.522  0
 media 4 1 1
 media 2 1 2 -1
 media 0 1 3 -2
 media 3 1 4 -3
 media 0 1 5 -4
 boundary 5
unit 32
 cuboid 1  38.47  0  38.47  0  164.864  0
 array 2 1  place 1 1 1 19.235 19.235 17.522
 boundary 1
unit 33
com="pu cylinder, 5.0 kg PuO2"
 cylinder 1    5.271   19.380    -1.320    origin  x=6.076 y=6.076 z=0
 cylinder 2    5.271   19.380    -1.320    origin  x=6.076 y=6.076 z=0
 cylinder 3    5.423   19.405    -1.345    origin  x=6.076 y=6.076 z=0
 cylinder 4    5.690   19.415    -3.335    origin  x=6.076 y=6.076 z=0
 cylinder 5    5.842   19.565    -3.535    origin  x=6.076 y=6.076 z=0
 cylinder 6    5.948   19.575    -4.535    origin  x=6.076 y=6.076 z=0
 cylinder 7    6.255   20.475    -4.925    origin  x=6.076 y=6.076 z=0
 cylinder 8    6.410   20.475   -20.475    origin  x=6.076 y=6.076 z=0
 cylinder 9    7.065   20.475   -21.130    origin  x=6.076 y=6.076 z=0
 cylinder 10   7.703   20.475   -21.130    origin  x=6.076 y=6.076 z=0
 cylinder 11   8.414   20.475   -21.130    origin  x=6.076 y=6.076 z=0
 cylinder 12   9.208   20.475   -21.130    origin  x=6.076 y=6.076 z=0
 cylinder 13  10.493   20.475   -21.130    origin  x=6.076 y=6.076 z=0
 cylinder 14  16.637   20.475   -21.130    origin  x=1.732 y=1.732 z=0
 cylinder 15  19.088   20.475   -21.130
 cylinder 16  19.235   20.475   -21.130
 cuboid 17  19.235  -19.235  19.235  -19.235  20.475  -21.13
 media 1 1 1
 media 0 1 2 -1
 media 3 1 3 -2
 media 5 1 4 -3
 media 3 1 5 -4 -3
 media 5 1 6 -5 -4
 media 3 1 7 -6 -5
 media 0 1 8 -7 -6
 media 3 1 9 -8 -7
```

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 media 0 1 10 -9 -8
 media 3 1 11 -10 -9
 media 0 1 12 -11 -10
 media 8 1 13 -12 -11
 media 2 1 14 -13 -12
 media 0 1 15 -14 -13
 media 3 1 16 -15 -14
 media 0 1 17 -16 -15
 boundary 17
unit 34
com='top of primary containment'
 cylinder 1  7.455  3.505  0   origin  x=6.076 y=6.076 z=0
 cylinder 2  7.703  3.505  0   origin  x=6.076 y=6.076 z=0
 cylinder 3  8.414  3.505  0   origin  x=6.076 y=6.076 z=0
 cylinder 4  9.208  3.505  0   origin  x=6.076 y=6.076 z=0
 cylinder 5  10.493  3.505  0   origin  x=6.076 y=6.076 z=0
 cylinder 6  16.637  3.505  0   origin  x=1.732 y=1.732 z=0
 cylinder 7  19.088  3.505  0
 cylinder 8  19.235  3.505  0
 cuboid 9  19.235  -19.235  19.235  -19.235  3.505  0
 media 3 1 1
 media 0 1 2 -1
 media 3 1 3 -2
 media 0 1 4 -3
 media 8 1 5 -4
 media 2 1 6 -5
 media 0 1 7 -6
 media 3 1 8 -7
 media 0 1 9 -8
 boundary 9
unit 35
com='primary containment nut and al honeycomb'
 cylinder 1  3.175  1.27  0   origin  x=6.076 y=6.076 z=0
 cylinder 2  4.699  4.572  0   origin  x=6.076 y=6.076 z=0
 cylinder 3  7.366  4.572  0   origin  x=6.076 y=6.076 z=0
 cylinder 4  7.703  5.922  0   origin  x=6.076 y=6.076 z=0
 cylinder 5  8.414  5.922  0   origin  x=6.076 y=6.076 z=0
 cylinder 6  9.208  5.922  0   origin  x=6.076 y=6.076 z=0
 cylinder 7  10.493  5.922  0   origin  x=6.076 y=6.076 z=0
 cylinder 8  16.637  5.922  0   origin  x=1.732 y=1.732 z=0
 cylinder 9  19.088  5.922  0
 cylinder 10  19.235  5.922  0
 cuboid 11  19.235  -19.235  19.235  -19.235  5.922  0
 media 3 1 1
 media 0 1 2 -1
 media 9 1 3 -2
 media 0 1 4 -3
 media 3 1 5 -4
 media 0 1 6 -5
 media 8 1 7 -6
 media 2 1 8 -7
 media 0 1 9 -8
 media 3 1 10 -9
 media 0 1 11 -10
 boundary 11
```

```
unit 36
com='secondary containment top'
 cylinder 1  9.042  3.505  0   origin  x=6.076 y=6.076 z=0
 cylinder 2  9.208  3.505  0   origin  x=6.076 y=6.076 z=0
 cylinder 3  10.493  3.505  0   origin  x=6.076 y=6.076 z=0
 cylinder 4  16.637  3.505  0   origin  x=1.732 y=1.732 z=0
 cylinder 5  19.088  3.505  0
 cylinder 6  19.235  3.505  0
 cuboid 7  19.235  -19.235  19.235  -19.235  3.505  0
 media 3 1 1
 media 0 1 2 -1
 media 8 1 3 -2
 media 2 1 4 -3
 media 0 1 5 -4
 media 3 1 6 -5
 media 0 1 7 -6
 boundary 7
unit 37
com='scv nut and al shield top'
 cylinder 1  3.175  1.27  0   origin  x=6.076 y=6.076 z=0
 cylinder 2  9.208  1.27  0   origin  x=6.076 y=6.076 z=0
 cylinder 3  10.493  1.27  0   origin  x=6.076 y=6.076 z=0
 cylinder 4  10.493  2.54  0   origin  x=6.076 y=6.076 z=0
 cylinder 5  16.637  2.54  0   origin  x=1.732 y=1.732 z=0
 cylinder 6  19.088  2.54  0
 cylinder 7  19.235  2.54  0
 cuboid 8  19.235  -19.235  19.235  -19.235  2.54  0
 media 3 1 1
 media 0 1 2 -1
 media 8 1 3 -2 -1
 media 4 1 4 -3 -2
 media 2 1 5 -4 -3
 media 0 1 6 -5 -4
 media 3 1 7 -6 -5
 media 0 1 8 -7 -6
 boundary 8
unit 38
com='pcv legs, al honeycomb and scv bottom'
 cylinder 1  5.113  0  -0.94   origin  x=6.076 y=6.076 z=0
 cylinder 2  5.715  0  -0.94   origin  x=6.076 y=6.076 z=0
 cylinder 3  7.703  0  -0.94   origin  x=6.076 y=6.076 z=0
 cylinder 4  7.703  0  -3.48   origin  x=6.076 y=6.076 z=0
 cylinder 5  8.414  0  -4.191   origin  x=6.076 y=6.076 z=0
 cylinder 6  9.208  0  -4.191   origin  x=6.076 y=6.076 z=0
 cylinder 7  10.493  0  -4.191   origin  x=6.076 y=6.076 z=0
 cylinder 8  16.637  0  -4.191   origin  x=1.732 y=1.732 z=0
 cylinder 9  19.088  0  -4.191
 cylinder 10  19.235  0  -4.191
 cuboid 11  19.235  -19.235  19.235  -19.235  0  -4.191
 media 0 1 1
 media 3 1 2 -1
 media 0 1 3 -2 -1
 media 9 1 4 -3 -2
 media 3 1 5 -4 -3
 media 0 1 6 -5 -4
```

```
 media 8 1 7 -6 -5
 media 2 1 8 -7 -6
 media 0 1 9 -8 -7
 media 3 1 10 -9 -8
 media 0 1 11 -10 -9
 boundary 11
unit 39
com='scv legs and bottom of lead shield'
 cylinder 1  6.41  0  -0.965   origin  x=6.076 y=6.076 z=0
 cylinder 2  7.065  0  -0.965   origin  x=6.076 y=6.076 z=0
 cylinder 3  9.208  0  -0.965   origin  x=6.076 y=6.076 z=0
 cylinder 4  10.493  0  -2.25   origin  x=6.076 y=6.076 z=0
 cylinder 5  16.637  0  -2.25   origin  x=1.732 y=1.732 z=0
 cylinder 6  19.088  0  -2.25
 cylinder 7  19.235  0  -2.25
 cuboid 8  19.235  -19.235  19.235  -19.235  0  -2.25
 media 0 1 1
 media 3 1 2 -1
 media 0 1 3 -2 -1
 media 8 1 4 -3 -2
 media 2 1 5 -4 -3
 media 0 1 6 -5 -4
 media 3 1 7 -6 -5
 media 0 1 8 -7 -6
 boundary 8
unit 40
com='al top plate and celotex plus top void plus drum'
 cylinder 1  14.224  1.27  0   origin  x=3.438 y=3.438 z=0
 cylinder 2  16.637  1.27  0   origin  x=1.732 y=1.732 z=0
 cylinder 3  19.088  1.27  0
 cylinder 4  19.235  1.392  0
 cuboid 5  19.235  -19.235  19.235  -19.235  1.392  0
 media 4 1 1
 media 2 1 2 -1
 media 0 1 3 -2
 media 3 1 4 -3
 media 0 1 5 -4
 boundary 5
unit 41
com='al bottom plate and celotex plus bottom void (zero, new model) plus drum'
 cylinder 1  14.224  0  -1.27   origin  x=3.438 y=3.438 z=0
 cylinder 2  16.637  0  -10.16   origin  x=1.732 y=1.732 z=0
 cylinder 3  19.088  0  -17.4
 cylinder 4  19.235  0  -17.522
 cuboid 5  19.235  -19.235  19.235  -19.235  0  -17.522
 media 4 1 1
 media 2 1 2 -1
 media 0 1 3 -2
 media 3 1 4 -3
 media 0 1 5 -4
 boundary 5
unit 44
com="pu cylinder, 5.0 kg PuO2"
 cylinder 1   5.271   1.320   -19.380   origin  x=6.076 y=6.076 z=0
 cylinder 2   5.271   1.320   -19.380   origin  x=6.076 y=6.076 z=0
```

```
 cylinder 3   5.423   1.345  -19.405  origin  x=6.076 y=6.076 z=0
 cylinder 4   5.690   3.335  -19.415  origin  x=6.076 y=6.076 z=0
 cylinder 5   5.842   3.535  -19.565  origin  x=6.076 y=6.076 z=0
 cylinder 6   5.948   4.535  -19.575  origin  x=6.076 y=6.076 z=0
 cylinder 7   6.255   4.935  -20.475  origin  x=6.076 y=6.076 z=0
 cylinder 8   6.410  20.475  -20.475  origin  x=6.076 y=6.076 z=0
 cylinder 9   7.065  20.475  -21.130  origin  x=6.076 y=6.076 z=0
 cylinder 10  7.703  20.475  -21.130  origin  x=6.076 y=6.076 z=0
 cylinder 11  8.414  20.475  -21.130  origin  x=6.076 y=6.076 z=0
 cylinder 12  9.208  20.475  -21.130  origin  x=6.076 y=6.076 z=0
 cylinder 13  10.493  20.475  -21.130  origin  x=6.076 y=6.076 z=0
 cylinder 14  16.637  20.475  -21.130  origin  x=1.732 y=1.732 z=0
 cylinder 15  19.088  20.475  -21.130
 cylinder 16  19.235  20.475  -21.130
 cuboid 17  19.235  -19.235  19.235  -19.235  20.475  -21.13
 media 1 1 1
 media 0 1 2 -1
 media 3 1 3 -2
 media 5 1 4 -3
 media 3 1 5 -4 -3
 media 5 1 6 -5 -4
 media 3 1 7 -6 -5
 media 0 1 8 -7 -6
 media 3 1 9 -8 -7
 media 0 1 10 -9 -8
 media 3 1 11 -10 -9
 media 0 1 12 -11 -10
 media 8 1 13 -12 -11
 media 2 1 14 -13 -12
 media 0 1 15 -14 -13
 media 3 1 16 -15 -14
 media 0 1 17 -16 -15
 boundary 17
unit 47
com='al top plate and celotex plus top void plus drum upper'
 cylinder 1  14.224  1.27  0   origin  x=3.438 y=3.438 z=0
 cylinder 2  16.637  10.16  0   origin  x=1.732 y=1.732 z=0
 cylinder 3  19.088  17.4  0
 cylinder 4  19.235  17.522  0
 cuboid 5  19.235  -19.235  19.235  -19.235  17.522  0
 media 4 1 1
 media 2 1 2 -1
 media 0 1 3 -2
 media 3 1 4 -3
 media 0 1 5 -4
 boundary 5
unit 48
 cuboid 1  38.47  0  38.47  0  164.864  0
 array 3 1  place 1 1 1 19.235 19.235 17.522
 boundary 1
unit 49
com="pu cylinder, 5.0 kg PuO2"
 cylinder 1   5.271   19.380   -1.320   origin  x=-6.076 y=6.076 z=0
 cylinder 2   5.271   19.380   -1.320   origin  x=-6.076 y=6.076 z=0
 cylinder 3   5.423   19.405   -1.345   origin  x=-6.076 y=6.076 z=0
```

```
 cylinder 4   5.690   19.415    -3.335   origin  x=-6.076 y=6.076 z=0
 cylinder 5   5.842   19.565    -3.535   origin  x=-6.076 y=6.076 z=0
 cylinder 6   5.948   19.575    -4.535   origin  x=-6.076 y=6.076 z=0
 cylinder 7   6.255   20.475    -4.925   origin  x=-6.076 y=6.076 z=0
 cylinder 8   6.410   20.475   -20.475   origin  x=-6.076 y=6.076 z=0
 cylinder 9   7.065   20.475   -21.130   origin  x=-6.076 y=6.076 z=0
 cylinder 10  7.703   20.475   -21.130   origin  x=-6.076 y=6.076 z=0
 cylinder 11  8.414   20.475   -21.130   origin  x=-6.076 y=6.076 z=0
 cylinder 12  9.208   20.475   -21.130   origin  x=-6.076 y=6.076 z=0
 cylinder 13  10.493  20.475   -21.130   origin  x=-6.076 y=6.076 z=0
 cylinder 14  16.637  20.475   -21.130   origin  x=-1.732 y=1.732 z=0
 cylinder 15  19.088  20.475   -21.130
 cylinder 16  19.235  20.475   -21.130
 cuboid 17  19.235  -19.235  19.235  -19.235  20.475  -21.13
 media 1 1 1
 media 0 1 2 -1
 media 3 1 3 -2
 media 5 1 4 -3
 media 3 1 5 -4 -3
 media 5 1 6 -5 -4
 media 3 1 7 -6 -5
 media 0 1 8 -7 -6
 media 3 1 9 -8 -7
 media 0 1 10 -9 -8
 media 3 1 11 -10 -9
 media 0 1 12 -11 -10
 media 8 1 13 -12 -11
 media 2 1 14 -13 -12
 media 0 1 15 -14 -13
 media 3 1 16 -15 -14
 media 0 1 17 -16 -15
 boundary 17
unit 50
com='top of primary containment'
 cylinder 1  7.455  3.505  0   origin  x=-6.076 y=6.076 z=0
 cylinder 2  7.703  3.505  0   origin  x=-6.076 y=6.076 z=0
 cylinder 3  8.414  3.505  0   origin  x=-6.076 y=6.076 z=0
 cylinder 4  9.208  3.505  0   origin  x=-6.076 y=6.076 z=0
 cylinder 5  10.493  3.505  0   origin  x=-6.076 y=6.076 z=0
 cylinder 6  16.637  3.505  0   origin  x=-1.732 y=1.732 z=0
 cylinder 7  19.088  3.505  0
 cylinder 8  19.235  3.505  0
 cuboid 9  19.235  -19.235  19.235  -19.235  3.505  0
 media 3 1 1
 media 0 1 2 -1
 media 3 1 3 -2
 media 0 1 4 -3
 media 8 1 5 -4
 media 2 1 6 -5
 media 0 1 7 -6
 media 3 1 8 -7
 media 0 1 9 -8
 boundary 9
unit 51
com='primary containment nut and al honeycomb'
```

```
 cylinder 1  3.175  1.27  0   origin  x=-6.076 y=6.076 z=0
 cylinder 2  4.699  4.572  0   origin  x=-6.076 y=6.076 z=0
 cylinder 3  7.366  4.572  0   origin  x=-6.076 y=6.076 z=0
 cylinder 4  7.703  5.922  0   origin  x=-6.076 y=6.076 z=0
 cylinder 5  8.414  5.922  0   origin  x=-6.076 y=6.076 z=0
 cylinder 6  9.208  5.922  0   origin  x=-6.076 y=6.076 z=0
 cylinder 7  10.493  5.922  0   origin  x=-6.076 y=6.076 z=0
 cylinder 8  16.637  5.922  0   origin  x=-1.732 y=1.732 z=0
 cylinder 9  19.088  5.922  0
 cylinder 10  19.235  5.922  0
 cuboid 11  19.235  -19.235  19.235  -19.235  5.922  0
 media 3 1 1
 media 0 1 2 -1
 media 9 1 3 -2 -1
 media 0 1 4 -3 -2
 media 3 1 5 -4 -3
 media 0 1 6 -5 -4
 media 8 1 7 -6 -5
 media 2 1 8 -7 -6
 media 0 1 9 -8 -7
 media 3 1 10 -9 -8
 media 0 1 11 -10 -9
 boundary 11
unit 52
com='secondary containment top'
 cylinder 1  9.042  3.505  0   origin  x=-6.076 y=6.076 z=0
 cylinder 2  9.208  3.505  0   origin  x=-6.076 y=6.076 z=0
 cylinder 3  10.493  3.505  0   origin  x=-6.076 y=6.076 z=0
 cylinder 4  16.637  3.505  0   origin  x=-1.732 y=1.732 z=0
 cylinder 5  19.088  3.505  0
 cylinder 6  19.235  3.505  0
 cuboid 7  19.235  -19.235  19.235  -19.235  3.505  0
 media 3 1 1
 media 0 1 2 -1
 media 8 1 3 -2 -1
 media 2 1 4 -3 -2
 media 0 1 5 -4 -3
 media 3 1 6 -5 -4
 media 0 1 7 -6 -5
 boundary 7
unit 53
com='scv nut and al shield top'
 cylinder 1  3.175  1.27  0   origin  x=-6.076 y=6.076 z=0
 cylinder 2  9.208  1.27  0   origin  x=-6.076 y=6.076 z=0
 cylinder 3  10.493  1.27  0   origin  x=-6.076 y=6.076 z=0
 cylinder 4  10.493  2.54  0   origin  x=-6.076 y=6.076 z=0
 cylinder 5  16.637  2.54  0   origin  x=-1.732 y=1.732 z=0
 cylinder 6  19.088  2.54  0
 cylinder 7  19.235  2.54  0
 cuboid 8  19.235  -19.235  19.235  -19.235  2.54  0
 media 3 1 1
 media 0 1 2 -1
 media 8 1 3 -2 -1
 media 4 1 4 -3 -2
 media 2 1 5 -4 -3
```

```
 media 0 1 6 -5 -4
 media 3 1 7 -6 -5
 media 0 1 8 -7 -6
 boundary 8
unit 54
com='pcv legs, al honeycomb and scv bottom'
 cylinder 1  5.113  0  -0.94   origin  x=-6.076 y=6.076 z=0
 cylinder 2  5.715  0  -0.94   origin  x=-6.076 y=6.076 z=0
 cylinder 3  7.703  0  -0.94   origin  x=-6.076 y=6.076 z=0
 cylinder 4  7.703  0  -3.48   origin  x=-6.076 y=6.076 z=0
 cylinder 5  8.414  0  -4.191   origin  x=-6.076 y=6.076 z=0
 cylinder 6  9.208  0  -4.191   origin  x=-6.076 y=6.076 z=0
 cylinder 7  10.493  0  -4.191   origin  x=-6.076 y=6.076 z=0
 cylinder 8  16.637  0  -4.191   origin  x=-1.732 y=1.732 z=0
 cylinder 9  19.088  0  -4.191
 cylinder 10  19.235  0  -4.191
 cuboid 11  19.235  -19.235  19.235  -19.235  0  -4.191
 media 0 1 1
 media 3 1 2 -1
 media 0 1 3 -2
 media 9 1 4 -3
 media 3 1 5 -4
 media 0 1 6 -5
 media 8 1 7 -6
 media 2 1 8 -7
 media 0 1 9 -8
 media 3 1 10 -9
 media 0 1 11 -10
 boundary 11
unit 55
com='scv legs and bottom of lead shield'
 cylinder 1  6.41  0  -0.965  origin  x=-6.076 y=6.076 z=0
 cylinder 2  7.065  0  -0.965   origin  x=-6.076 y=6.076 z=0
 cylinder 3  9.208  0  -0.965   origin  x=-6.076 y=6.076 z=0
 cylinder 4  10.493  0  -2.25   origin  x=-6.076 y=6.076 z=0
 cylinder 5  16.637  0  -2.25   origin  x=-1.732 y=1.732 z=0
 cylinder 6  19.088  0  -2.25
 cylinder 7  19.235  0  -2.25
 cuboid 8  19.235  -19.235  19.235  -19.235  0  -2.25
 media 0 1 1
 media 3 1 2 -1
 media 0 1 3 -2 -1
 media 8 1 4 -3 -2
 media 2 1 5 -4 -3
 media 0 1 6 -5 -4
 media 3 1 7 -6 -5
 media 0 1 8 -7 -6
 boundary 8
unit 56
com='al top plate and celotex plus top void plus drum'
 cylinder 1  14.224  1.27  0   origin  x=-3.438 y=3.438 z=0
 cylinder 2  16.637  1.27  0   origin  x=-1.732 y=1.732 z=0
 cylinder 3  19.088  1.27  0
 cylinder 4  19.235  1.392  0
 cuboid 5  19.235  -19.235  19.235  -19.235  1.392  0
```

```
 media 4 1 1
 media 2 1 2 -1
 media 0 1 3 -2
 media 3 1 4 -3
 media 0 1 5 -4
 boundary 5
unit 57
com='al bottom plate and celotex plus bottom void (zero, new model) plus drum'
 cylinder 1  14.224  0  -1.27   origin  x=-3.438 y=3.438 z=0
 cylinder 2  16.637  0  -10.16   origin  x=-1.732 y=1.732 z=0
 cylinder 3  19.088  0  -17.4
 cylinder 4  19.235  0  -17.522
 cuboid 5  19.235  -19.235  19.235  -19.235  0  -17.522
 media 4 1 1
 media 2 1 2 -1
 media 0 1 3 -2
 media 3 1 4 -3
 media 0 1 5 -4
 boundary 5
unit 60
com="pu cylinder, 5.0 kg PuO2"
 cylinder 1   5.271    1.320   -19.380   origin  x=-6.076 y=6.076 z=0
 cylinder 2   5.271    1.320   -19.380   origin  x=-6.076 y=6.076 z=0
 cylinder 3   5.423    1.345   -19.405   origin  x=-6.076 y=6.076 z=0
 cylinder 4   5.690    3.335   -19.415   origin  x=-6.076 y=6.076 z=0
 cylinder 5   5.842    3.535   -19.565   origin  x=-6.076 y=6.076 z=0
 cylinder 6   5.948    4.535   -19.575   origin  x=-6.076 y=6.076 z=0
 cylinder 7   6.255    4.935   -20.475   origin  x=-6.076 y=6.076 z=0
 cylinder 8   6.410   20.475   -20.475   origin  x=-6.076 y=6.076 z=0
 cylinder 9   7.065   20.475   -21.130   origin  x=-6.076 y=6.076 z=0
 cylinder 10   7.703   20.475   -21.130   origin  x=-6.076 y=6.076 z=0
 cylinder 11   8.414   20.475   -21.130   origin  x=-6.076 y=6.076 z=0
 cylinder 12   9.208   20.475   -21.130   origin  x=-6.076 y=6.076 z=0
 cylinder 13  10.493   20.475   -21.130   origin  x=-6.076 y=6.076 z=0
 cylinder 14  16.637   20.475   -21.130   origin  x=-1.732 y=1.732 z=0
 cylinder 15  19.088   20.475   -21.130
 cylinder 16  19.235   20.475   -21.130
 cuboid 17  19.235  -19.235  19.235  -19.235  20.475  -21.13
 media 1 1 1
 media 0 1 2 -1
 media 3 1 3 -2
 media 5 1 4 -3
 media 3 1 5 -4 -3
 media 5 1 6 -5 -4
 media 3 1 7 -6 -5
 media 0 1 8 -7 -6
 media 3 1 9 -8 -7
 media 0 1 10 -9 -8
 media 3 1 11 -10 -9
 media 0 1 12 -11 -10
 media 8 1 13 -12 -11
 media 2 1 14 -13 -12
 media 0 1 15 -14 -13
 media 3 1 16 -15 -14
 media 0 1 17 -16 -15
```

```
 boundary 17
unit 63
com='al top plate and celotex plus top void plus drum upper'
 cylinder 1  14.224  1.27  0   origin  x=-3.438 y=3.438 z=0
 cylinder 2  16.637  10.16  0   origin  x=-1.732 y=1.732 z=0
 cylinder 3  19.088  17.4  0
 cylinder 4  19.235  17.522  0
 cuboid 5  19.235  -19.235  19.235  -19.235  17.522  0
 media 4 1 1
 media 2 1 2 -1
 media 0 1 3 -2
 media 3 1 4 -3
 media 0 1 5 -4
 boundary 5
unit 64
 cuboid 1  38.47  0  38.47  0  164.864  0
 array 4 1  place 1 1 1 19.235 19.235 17.522
 boundary 1
global unit 65
com=^5 x 5 x 2 damaged array^
cuboid    1
          7.694000E+01  0.000000E+00  7.694000E+01
          0.000000E+00  1.648640E+02  0.000000E+00
array    5      1
           place 1 1 1    0.00000E+00   0.00000E+00   0.00000E+00
boundary    1
unit 71
com='al bot plate and celotex plus top void plus drum lower'
 cylinder 1  14.224  0  -1.27   origin  x=3.438 y=-3.438 z=0
 cylinder 2  16.637  0  -1.27   origin  x=1.732 y=-1.732 z=0
 cylinder 3  19.088  0  -1.27
 cylinder 4  19.235  0  -1.392
 cuboid 5  19.235  -19.235  19.235  -19.235  0  -1.392
 media 4 1 1
 media 2 1 2 -1
 media 0 1 3 -2
 media 3 1 4 -3
 media 0 1 5 -4
 boundary 5
unit 72
com='al bot plate and celotex plus top void plus drum lower'
 cylinder 1  14.224  0  -1.27   origin  x=-3.438 y=-3.438 z=0
 cylinder 2  16.637  0  -1.27   origin  x=-1.732 y=-1.732 z=0
 cylinder 3  19.088  0  -1.27
 cylinder 4  19.235  0  -1.392
 cuboid 5  19.235  -19.235  19.235  -19.235  0  -1.392
 media 4 1 1
 media 2 1 2 -1
 media 0 1 3 -2
 media 3 1 4 -3
 media 0 1 5 -4
 boundary 5
unit 73
com='al bot plate and celotex plus top void plus drum lower'
 cylinder 1  14.224  0  -1.27   origin  x=3.438 y=3.438 z=0
```

```
 cylinder 2  16.637  0  -1.27   origin  x=1.732 y=1.732 z=0
 cylinder 3  19.088  0  -1.27
 cylinder 4  19.235  0  -1.392
 cuboid 5  19.235  -19.235  19.235  -19.235  0  -1.392
 media 4 1 1
 media 2 1 2 -1
 media 0 1 3 -2
 media 3 1 4 -3
 media 0 1 5 -4
 boundary 5
unit 74
com='al bot plate and celotex plus top void plus drum lower'
 cylinder 1  14.224  0  -1.27   origin  x=-3.438 y=3.438 z=0
 cylinder 2  16.637  0  -1.27   origin  x=-1.732 y=1.732 z=0
 cylinder 3  19.088  0  -1.27
 cylinder 4  19.235  0  -1.392
 cuboid 5  19.235  -19.235  19.235  -19.235  0  -1.392
 media 4 1 1
 media 2 1 2 -1
 media 0 1 3 -2
 media 3 1 4 -3
 media 0 1 5 -4
 boundary 5
end geometry
read array
ara=1 nux=1 nuy=1 nuz=18 typ=square
fill 9 7 6 1 2 3 4 5 8 71 7 6 13 2 3 4 5 16
end fill
ara=2 nux=1 nuy=1 nuz=18 typ=square
fill 25 23 22 17 18 19 20 21 24 72 23 22 28 18 19 20 21 31
end fill
ara=3 nux=1 nuy=1 nuz=18 typ=square
fill 41 39 38 33 34 35 36 37 40 73 39 38 44 34 35 36 37 47
end fill
ara=4 nux=1 nuy=1 nuz=18 typ=square
fill 57 55 54 49 50 51 52 53 56 74 55 54 60 50 51 52 53 63
end fill
ara=5 nux=2 nuy=2 nuz=1 fill 48 64
10 32 end fill
end array
read bound xyf=mirror zfc=periodic end bound
read start nst=0 end start
read plot scr=yes lpi=10
ttl='plot1 xy slice'
xul=-10 xlr=100 yul=100 ylr= -10 zul=61 zlr=61
uax=1 vdn=-1 nax=600  end
ttl='plot2 xy slice'
xul=-10 xlr=240 yul=240 ylr= -10 zul=61 zlr=61
uax=1 vdn=-1 nax=600  end
ttl='plot3 xslice'
xul=-5 xlr=100 yul= 27 ylr= 27 zul=190 zlr=-5
uax=1 wdn=-1 nax=600  end
ttl='plot4 xslice'
xul=-5 xlr=300 yul= 19 ylr= 19 zul=190 zlr=-5
uax=1 wdn=-1 nax=800  end
```

```
end plot
end data
end
```

APPENDIX 6.2

INPUT/OUTPUT COMPUTER FILES

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INPUT/OUTPUT COMPUTER FILES

Listed in these tables are the names of input/output files used in support of Chapter 6 of the SAR. Copies of the input and output files are provided on a CD.

Table 8. Base Case Single Unit Cases Without Flooding

File ID	Description
nrc_su.cyl3013.out:	Base Case with 3013, dry oxide
nrc_su.cyl3013be.out:	Base Case with 3013 and mixed with beryllium, dry oxide
nrc_su.cylno3013.out:	Base Case with no 3013, dry oxide
nrc_su.cylno3013be.out:	Base Case with no 3013 and mixed with beryllium, dry oxide
nrc_su.cyl3013c12.out:	Base Case with 3013 and mixed with carbon, dry oxide

Table 9. Single Unit Cases Flooding the Convenience Can

File ID	Description
nrc_su.cyl3013_100.out:	Base Case with 3013, dry oxide – 0.1 liter water added
nrc_su.cyl3013_200.out:	Base Case with 3013, dry oxide – 0.2 liter water added
nrc_su.cyl3013_300.out:	Base Case with 3013, dry oxide – 0.3 liter water added
nrc_su.cyl3013_400.out:	Base Case with 3013, dry oxide – 0.4 liter water added
nrc_su.cyl3013_400w.out:	Base Case with 3013, dry oxide – 0.4 liter water added, diameter of convenience can (CC)
nrc_su.cyl3013_500w.out:	Base Case with 3013, dry oxide – 0.5 liter water added, diameter of convenience can (CC)
nrc_su.cyl3013_750w.out:	Base Case with 3013, dry oxide – 0.75 liter water added, diameter of convenience can (CC)
nrc_su.cyl3013_1000w.out:	Base Case with 3013, dry oxide – 1.0 liter water added, diameter of convenience can (CC)
nrc_su.cyl3013_1100w.out:	Base Case with 3013, dry oxide – 1.1 liter water added, diameter of convenience can (CC)
nrc_su.cyl3013_1200w.out:	Base Case with 3013, dry oxide – 1.2 liter water added, diameter of convenience can (CC)
nrc_su.cyl3013_ccfull.out	Base Case with 3013, dry oxide – CC full, diameter of convenience can (CC)

Table 10. Single Unit Cases Flooding the Convenience

Can – Beryllium

File ID	Description
nrc_su.cyl3013be_100.out:	Base Case with 3013 and mixed with beryllium, dry oxide – 0.1 liter water added
nrc_su.cyl3013be_200.out:	Base Case with 3013 and mixed with beryllium, dry oxide – 0.2 liter water added
nrc_su.cyl3013be_200w.out:	Base Case with 3013 and mixed with beryllium, dry oxide – 0.2 liter water added, diameter of CC
nrc_su.cyl3013be_300w.out:	Base Case with 3013 and mixed with beryllium, dry oxide – 0.3 liter water added, diameter of CC
nrc_su.cyl3013be_500w.out:	Base Case with 3013 and mixed with beryllium, dry oxide – 0.5 liter water added, diameter of CC
nrc_su.cyl3013be_750w.out:	Base Case with 3013 and mixed with beryllium, dry oxide – 0.75 liter water added, diameter of CC
nrc_su.cyl3013be_1000w.out	Base Case with 3013 and mixed with beryllium, dry oxide – 1.0 liter water added, diameter of CC
nrc_su.cyl3013be_1100w.out:	Base Case with 3013 and mixed with beryllium, dry oxide – CC full

Table 11. **Single Unit Cases Flooding the Convenience Can – No 3013 Containers**

File ID	Description
nrc_su.cylno3013_100.out:	Base Case with no 3013, dry oxide – 0.1 liter water added
nrc_su.cylno3013_200.out:	Base Case with no 3013, dry oxide – 0.2 liter water added
nrc_su.cylno3013_300.out:	Base Case with no 3013, dry oxide – 0.3 liter water added
nrc_su.cylno3013_400.out:	Base Case with no 3013, dry oxide – 0.4 liter water added
nrc_su.cylno3013_400w.out:	Base Case with no 3013, dry oxide – 0.4 liter water added, diameter of CC
nrc_su.cylno3013_500w.out:	Base Case with no 3013, dry oxide – 0.5 liter water added, diameter of CC
nrc_su.cylno3013_750w.out:	Base Case with no 3013, dry oxide – 0.75 liter water added, diameter of CC
nrc_su.cylno3013_1000w.out:	Base Case with no 3013, dry oxide – 1.0 liter water added, diameter of CC
nrc_su.cylno3013_1100w.out:	Base Case with no 3013, dry oxide – 1.1 liter water added, diameter of CC
nrc_su.cylno3013_1200w.out:	Base Case with no 3013, dry oxide – 1.2 liter water added, diameter of CC
nrc_su.cylno3013_1300w.out:	Base Case with no 3013, dry oxide – 1.3 liter water added, diameter of CC
nrc_su.cylno3013_ccfull.out	Base Case with no 3013, dry oxide – CC full

Table 12. **Single Unit Cases Flooding the Convenience**

Can with Beryllium - No 3013

File ID	Description
nrc_su.cylno3013be_100.out:	Base Case with no 3013 and mixed with beryllium, dry oxide – 0.1 liter water added
nrc_su.cylno3013be_200.out:	Base Case with no 3013 and mixed with beryllium, dry oxide – 0.2 liter water added
nrc_su.cylno3013be_200w.out:	Base Case with no 3013 and mixed with beryllium, dry oxide – 0.2 liter water added, diameter of CC
nrc_su.cylno3013be_300w.out:	Base Case with no 3013 and mixed with beryllium, dry oxide – 0.3 liter water added, diameter of CC
nrc_su.cylno3013be_500w.out:	Base Case with no 3013 and mixed with beryllium, dry oxide – 0.5 liter water added, diameter of CC
nrc_su.cylno3013be_750w.out:	Base Case with no 3013 and mixed with beryllium, dry oxide – 0.75 liter water added, diameter of CC
nrc_su.cylno3013be_1000w.out:	Base Case with no 3013 and mixed with beryllium, dry oxide – 1.0 liter water added, diameter of CC
nrc_su.cylno3013be_1100w.out:	Base Case with no 3013 and mixed with beryllium, dry oxide – CC full

Table 13. Single Unit Cases Flooding the Convenience Can with Carbon

File ID	Description
nrc_su.cyl3013c12_100.out:	Base Case with 3013 and mixed with carbon, dry oxide – 0.1 liter water added
nrc_su.cyl3013c12_100w.out:	Base Case with 3013 and mixed with carbon, dry oxide – 0.1 liter water added, diameter of CC
nrc_su.cyl3013c12_200w.out:	Base Case with 3013 and mixed with carbon, dry oxide – 0.2 liter water added, diameter of CC
nrc_su.cyl3013c12_300w.out:	Base Case with 3013 and mixed with carbon, dry oxide – 0.3 liter water added, diameter of CC
nrc_su.cyl3013c12_400w.out:	Base Case with 3013 and mixed with carbon, dry oxide – 0.4 liter water added, diameter of CC
nrc_su.cyl3013c12_500w.out:	Base Case with 3013 and mixed with carbon, dry oxide – 0.5 liter water added, diameter of CC
nrc_su.cyl3013c12_750w.out:	Base Case with 3013 and mixed with carbon, dry oxide – 0.75 liter water added, diameter of CC
nrc_su.cyl3013c12_1000w.out:	Base Case with 3013 and mixed with carbon, dry oxide – 1.0 liter water added, diameter of CC

Table 14. Single Unit Cases Flooding the PCV, SCV, and

Celotex® – Inner 3013 Flooded

File ID	***Description***
nrc_su.cyl3013_ccfull_3013inn.out:	CC – full of solution, 3013 – inner flooded with water
nrc_su.cyl3013_ccfull_3013inner_PCV.out:	CC – full of solution, 3013 – inner flooded with water – PCV contains water
nrc_su.cyl3013_ccfull_3013inner_PCVSCV.out:	CC – full of solution, 3013 – inner flooded with water – PCV/SCV contains water
nrc_su.cyl3013_ccfull_3013inner_SCV.out:	CC – full of solution, 3013 – inner flooded with water – SCV contains water

Table 15. Single Unit Cases Flooding the PCV, SCV, and Celotex® – Outer 3013 Flooded

File ID	**Description**
nrc_su.cyl3013_ccfull_3013outer.out:	CC – full of solution, 3013 – outer flooded with water
nrc_su.cyl3013_ccfull_3013outer_PCV.out:	CC – full of solution, 3013 – outer flooded with water – PCV contains water
nrc_su.cyl3013_ccfull_3013outer_PCVSCV.out:	CC – full of solution, 3013 – outer flooded with water – PCV/SCV contains water
nrc_su.cyl3013_ccfull_3013outer_SCV.out:	CC – full of solution, 3013 – outer flooded with water – SCV contains water

Table 16. Single Unit Cases Flooding the PCV, SCV, and Celotex® – Both 3013 Containers Flooded

File ID	**Description**
nrc_su.cyl3013_ccfull_3013both.out:	CC – full of solution, 3013 – inner/outer flooded with water
nrc_su.cyl3013_ccfull_3013both_PCV.out:	CC – full of solution, 3013 – inner/outer flooded with water – PCV contains water
nrc_su.cyl3013_ccfull_3013both_PCVSCV.out:	CC – full of solution, 3013 – inner/outer flooded with water – PCV/SCV contains water
nrc_su.cyl3013_ccfull_3013both_SCV.out:	CC – full of solution, 3013 – inner/outer flooded with water – SCV contains water
nrc_su.cyl3013_ccfull_3013both_PCV_Celo.out:	CC – full of solution, 3013 – inner/outer flooded with water – PCV/ Celotex® as water
nrc_su.cyl3013_ccfull_3013both_ALL.out:	CC – full of solution, 3013 – inner/outer flooded with water – PCV/SCV/ Celotex® as water

Table 17. Single Unit Cases Flooding the PCV, SCV, and Celotex® – No 3013 Containers

File ID	Description
nrc_su.cylno3013_ccfull.out:	CC – full of solution, No 3013
nrc_su.cylno3013_ccfull_PCV.out:	CC – full of solution, No 3013 – PCV contains water
nrc_su.cylno3013_ccfull_PCVSCV.out:	CC – full of solution, No 3013 – PCV/SCV contains water
nrc_su.cylno3013_ccfull_SCV.out:	CC – full of solution, No 3013 –SCV contains water
nrc_su.cylno3013_ccfull_PCVSCV_ALL.out:	CC – full of solution, No 3013 – PCV/SCV/ Celotex® as water

Table 18. 9975 Array Model – NCT Cases

File ID	Description
nrc_nct.cyl3013.out	Infinite drum array, dry fissile material
nrc_nct.cyl3013_celofld.out	Infinite drum array, dry fissile material, water as Celotex®
nrc_nct.cyl3013_h2orefl.out	Infinite drum array, dry fissile material, w/water between drums
nrc_nct.cyl3013_h2orefl_celofld.out	Infinite drum array, dry fissile material, w/water between drums, water as Celotex®
nrc_nct.cylno3013.out	Infinite drum array, dry fissile material, no 3013 containers
nrc_nct.cylno3013_celofld.out	Infinite drum array, dry fissile material, no 3013 containers, water as Celotex®
nrc_nct.cylno3013_h2orefl.out	Infinite drum array, dry fissile material, no 3013 containers, w/water between drums
nrc_nct.cylno3013_h2orefl_celofld.out	Infinite drum array, dry fissile material, no 3013 containers, w/water between drums, water as Celotex®

Table 19. 9975 Array Model – HAC Cases

File ID	Description
nrc_hac.cyl3013_2x2x2.out	2x2x2 array inifinite array, Fissile at closest position
nrc_hac.cyl3013_2x2x2_PCVfl.out	2x2x2 array inifinite array, Fissile at closest position, PCV flooded
nrc_hac.cyl3013_2x2x2_PCVSCVfl.out	2x2x2 array inifinite array, Fissile at closest position, PCV/SCV flooded
nrc_hac.cyl3013_2x2x2_SCVfl.out	2x2x2 array inifinite array, Fissile at closest position, SCV flooded
nrc_hac.cyl3013_2x2x2_symm.out	2x2x2 array inifinite array, Fissile at centered position
nrc_hac.cyl3013_2x2x2_PCVfl_symm.out	2x2x2 array inifinite array, Fissile at centered position, PCV flooded
nrc_hac.cyl3013_2x2x2_PCVSCVfl_symm.out	2x2x2 array inifinite array, Fissile at centered position, PCV/SCV flooded
nrc_hac.cyl3013_2x2x2_SCVfl_symm.out	2x2x2 array inifinite array, Fissile at centered position, SCV flooded

Table 20. 9975 Array Model – Flooded Convenience Can HAC Cases

File ID	Description
nrc_hac.cyl_CCfl_2x2x2.out:	Convenience can flooded, Fissile at closest position
nrc_hac.cyl_CCfl_3013fl.out:	Convenience can flooded, Fissile at closest position, 3013 flooded
nrc_hac.cyl_CCfl_allfl.out:	Convenience can flooded, Fissile at closest position, 3013, PCV, SCV, water as Celotex®
nrc_hac.cyl_CCfl_3013dry_PCVSCVfl.out:	Convenience can flooded, Fissile at closest position, 3013 dry, PCV, SCV flooded
nrc_hac.cyl_CCfl_3013dry_allfl.out:	Convenience can flooded, Fissile at closest position, 3013 dry, PCV, SCV, water as Celotex®
nrc_hac.cyl_CCL_2x2x2_symm.out:	Convenience can flooded, Fissile at centered position

APPENDIX 7.1

SPECIAL TOOLS

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SPECIAL TOOLS

Tools for Product Cans

Two commercial vacuum lifting tools were procured by SRS to assist in removing the product cans from the Primary Containment Vessel. The lifting tools were modified slightly (handles swapped) to fit the product cans and containment vessel cavities. Teflon tape was used to reseal the threaded joints on the handles to ensure leakage tightness. The two lifting tools purchased by SRS are a long-reach vacuum lifter (McMaster Model No. 5795 A4) and a lightweight vacuum lifter (McMaster Model No. 6971 A11) from the McMaster Carr Supply Company. These lifting tools are recommended for ease of handling but are not required for unloading operations.

Tools for Lifting the 3013

SRS has an engineered 3013 container lifting tool design available upon request.

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APPENDIX 7.2

PCV CO_2 DILUTION PROCEDURE FOR PLUTONIUM AND/OR URANIUM OXIDE CONTENT ENVELOPE C.12 IN THE 9975 PACKAGE PRIMARY CONTAINMENT VESSEL

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PCV CO_2 DILUTION PROCEDURE FOR PLUTONIUM AND/OR URANIUM OXIDE CONTENT ENVELOPE C.12 IN THE 9975 PACKAGE PRIMARY CONTAINMENT VESSEL

The following procedure is performed to prevent detonation in the package if hydrogen is present in quantities greater than its lower flammability limit.

Diluting the PCV atmosphere with to a minimum 75% CO_2 is a safety measure taken to minimize the effect of a possible combustion of accumulated gases in the PCV and SCV (should the PCV leak). Assurance of getting an adequate concentration of CO_2 (minimum of 75% CO_2) in the PCV is dependent upon following the steps described below in the specified sequence. If alternate PCV content configurations or diluting procedures are used, the Operator shall verify no less than 75% CO_2 at all locations within the PCV.

Carbon dioxide supply shall meet Compressed Gas Association specification G-6.2, Grade H or equivalent. This is considered standard commercial use CO_2.

The dilution procedure below has been validated by testing at the Savannah River National Laboratory (SRNL) for 3013 outer containers packaged in the PCV.[1] Other procedures for CO_2 dilution shall not be used without supporting validation tests. Validation test reports shall be maintained as specified in the SRS QAP.

WARNING: *Introduction of carbon dioxide into the work area may pose a worker asphyxiation hazard. Ensure that all personnel in the work area are protected from the asphyxiation hazard in accordance with approved site/facility procedures.*

1. Connect a purge wand (⅛-inch diameter metal tube of sufficient length) to a CO_2 supply. Place the purge wand within the 3013 top spacer cavity.
2. Using the finger holes, lift the top spacer and position the tip of the wand under the bottom edge of the spacer and against the PCV wall.
3. Cover the open PCV with a temporary purge lid to minimize mixing of ambient air with the PCV atmosphere. The temporary purge lid should:
    - a.) Cover the opening, but not create a seal.
    - b.) Be easy to remove.
    - c.) Be of a shape and size that will not agitate (induce mixing of) the air at the PCV opening when removed.

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[1] R. A. Pierce, *Air Replacement Testing for the 9975 Primary Container Vessel (U),* WSRC-TR-2001-00304, Westinghouse Savannah River Company, Aiken, SC, Rev. 0, (June, 2001).

4. Set the CO_2 purge rate at a minimum of 12 scfh not to exceed 16 scfh and purge for at least 15 minutes at wand location #2 as described in WSRC-TR-2001-00304 Revision 2.

5. Reduce the CO_2 flow to 3 to 5 scfh indicated flow for 3 more minutes of purging (to prevent turbulence in the vessel when removing the wand), then, slowly remove the wand.

NOTE: *Minimize movement of the PCV as the cone-seal closure is installed.*

6. Within 5 minutes of completing the purging, slowly remove purge lid and lower the cone-seal closure assembly into position.
7. Follow the PCV closure procedure in Section 7.2.2.

APPENDIX 8.1

INSPECTION CRITERIA
FOR
ACCEPTANCE OF NEWLY FABRICATED 9975 PACKAGINGS

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INSPECTION CRITERIA
FOR
ACCEPTANCE OF NEWLY FABRICATED 9975 PACKAGINGS

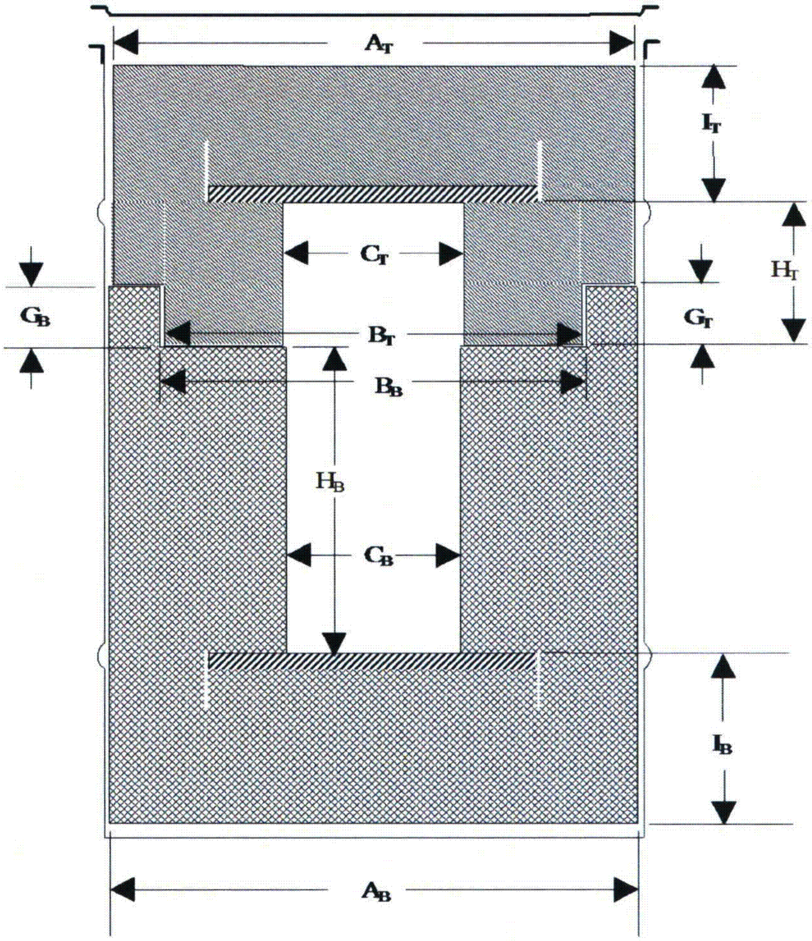
Inspections shall be based solely on those drawings and revisions thereof associated with the currently certified package design. These drawings and revisions are given in Appendix 1.1. All 9975 packagings were fabricated prior to the submittal of this SAR, to the drawings specified in the DOE CoC(s). A cross reference of the DOE to NRC License Drawings is provided in Appendix 1.1.

Prior to delivery to the Owner, the Supplier shall ensure by inspection and documentation that the following criteria are satisfied. The degree of inspection and documentation shall be detailed in the Supplier's Manufacturing and Inspection Plan as agreed between the Design Authority and Supplier. Deviations from the engineering drawings shall be resolved as specified in the procurement agreements; these shall be in agreement with the requirements of SRS QAP.

Packaging Assembly (R-R2-G-00078)

1. Verify that the encapsulated thermal blanket is of the required dimensions.
2. Verify that insertion of the containment vessel assemblies and insulation top assembly is unhindered.
3. Verify that the aluminum shielding lid of the lead shielding body attaches freely and fits freely within the assembly (R-R2-G-00079).
4. Verify that closure of the drum is unhindered when all internal components are in place.
5. Verify that a security seal can be installed freely through the assembled drum closure bolts and pins.
6. Verify and document that the net packaging weight is not greater than 374 pounds.

Insulation Subassemblies (Drawing R-R2-G-00083)



Sketch A – Dimensional References

Overpack Dimension Measurements (Drawings R-R2-G-00083, R-R2-G-00080)

1. Verify that the following dimensions and tolerances for the insulation bottom subassembly are as specified on drawing R-R2-G-00083 (refer to Sketch A for dimension locations):

    - outside diameter (OD), dimension–A_B,
    - inside step diameter, dimension–B_B,
    - inside cavity diameter, dimension–$C_{B,}$
    - step depth, dimension–G_B,
    - inside cavity depth, dimension–H_B,

2. Verify that the following dimensions and tolerances for the insulation top subassembly (below air shield) are as specified on the drawing:
    - OD of fiberboard, dimension–A_T,
    - outside step diameter, dimension–B_T,
    - inside cavity diameter, dimension–C_T,
    - step height, dimension–G_T,
    - inside cavity depth, dimension–H_T,
3. Verify that the aluminum bearing plates are present in both the top and bottom subassemblies.
4. Verify that dimension, I_T, measured from the top of the fiberboard subassembly to the bottom of the aluminum bearing plate, is not less than as specified. Verify this dimension before attachment of the air shield.
5. Verify that dimension, I_B, measured from the bottom of the fiberboard to the top of the aluminum bearing plate is not less than specified.
6. Place the insulation top subassembly on the bottom subassembly and verify that the subassemblies assemble freely.
7. During manufacture, verify that the gap between the installed insulation assembly (without the Air Shield) and the top of the drum flange is less than 0.93 in. as specified on Drawing R-R2-G-00080.
8. Verify that the installed air shield is fully seated on and firmly and permanently attached to the top fiberboard.

Lead Shield (Drawing R-R2-G-00079)

1. Verify that the shielding body subassembly minimum wall thickness is as required.
2. Verify that the shielding body subassembly inside height is as required, and the ID is not less than the minimum allowed.
3. Verify that the shielding body subassembly threaded holes are positioned as required and allow free threading of the specified bolt size.
4. Verify that the lid bolt holes are sized, positioned, and counter bored as required.
5. Verify that the lid thickness and OD are as specified.
6. Verify that the lid and body fit freely and the bolt holes align to allow free bolt threading of all holes.

7. Verify and document that the shielding assembly weighs within tolerance.

Drum (Drawing R-R2-G-00080)

1. Verify and document the drum's inside height with the closure lid removed. Drum height shall be measured from the drum bottom at the internal wall to the top of the drum flange.

2. Verify that the vent holes are sized, positioned, dimpled, and plugged as required (Detail O and Note 6, Drawing R-R2-G-00080). Verify that plugs are BP 1/2-in. Caplug™ as required.

3. Verify that the convexity of the drum's closure lid and bottom are as required (Note 1.A, Drawing R-R2-G-00080,).

4. Verify that the drum has two expanded rolling hoops positioned as shown on Drum Subassembly Drawing R-R2-G-00080-A.

5. Verify that the drum closure is as specified, including lid and flange welded as required.

6. Verify that the identification plate is lettered, positioned, and attached as required.

7. Verify that the drum's ID is as required.

8. Verify that the drum's closure nuts and bolts are as required.

9. Verify that the bar code labeling is attached and is as required.

10. Verify that the drum satisfies DOT 1A2/Y/140/*, per Drawing R-R2-G-00080, Note 1.D. Where the * will be the year the drum was manufactured. (Note: Drum Manufacturer shall provide test documentation to verify that the drum design meets the above DOT specification).

Containment Vessel Subassemblies (Drawing R-R2-G-00081)

1. Verify that the overall height and diameter are as shown on R-R2-G-00081.

2. Verify that all threaded components assemble freely (gland nut, cone-seal nut).

3. Verify that spare O-rings are packaged individually with the O-ring size, material certification (Viton® GLT/GLT-S), cure date, and shelf life specified and labeled on the exterior of the package. Verify that installed O-rings have no nicks, cracks, pits, or flat spots on the O-rings as specified by the O-ring vendor.

4. Verify that the gland nut and leak-test port plug are as required.

5. Verify that the retaining ring is installed and cone-seal plug and cone-seal nut have free relative rotational movement and limited relative axial movement.

6. Verify that the containment vessel is cleaned as required and indicated surfaces are lubricated as required.

Containment Vessel Weldments (Drawing R-R3-G-00063)

1. Verify that the overall height and OD are as required.
2. Verify that the base ring slots are positioned and dimensioned as required.
3. Verify that the markings and serial numbers are as required.
4. Verify that the threading and thread relief are as required and the threading passes gage verification.
5. Verify that the side pressure-release hole is positioned and sized as required.
6. Verify that the internal cone surface upper diameter is as required.
7. Verify that the internal and external cone surfaces are angled as required.
8. Verify that the internal cone surface finish is as required.
9. Verify that the upper surface inside perimeter chamfer is as required.
10. Verify that the pipe surface finish is as required.
11. Verify that the welds have been inspected as required.
12. Verify that the PCV and SCV will accept gauge blocks as required.

Air Shield Weldment (Drawing R-R3-G-00064)

1. Verify that the ID and outside height are as specified on R-R3-G-00064.
2. If of welded construction, verify that the welds have been inspected as specified.
3. Verify that the lifting chain is of the specified size (No. 35), positioned as required, securely tack welded, and free of any sharp protrusions.
4. Verify that warping and deformation are within reasonable bounds such that assembly as part of the top insulation subassembly will not be hindered.

Containment Vessel Details (Drawing R-R2-G-00102)

Verify the following:

1. The cone-seal nut's thread diameter passes the test gage and is perpendicular to the base surface as required.
2. The cone-seal nut's bottom step is dimensioned as required.
3. The cone-seal nut's total height and nut height are as required.
4. The cone-seal nut's flat faces have holes positioned and dimensioned as required.
5. The cone-seal nut's square flat widths are as required.
6. The cone-seal nut's ID and top ID and depth are as required.
7. The cone-seal nut's bottom inside perimeter is chamfered as required.
8. The cone-seal nut is marked as required and the serial number is as required.
9. The cone-seal plug's ODs (dimensions A and B) are as required.
10. The cone-seal plug's total height and base heights are as required.
11. The upper and lower O-ring grooves and leak test groove are positioned and to the depths required and with the corner radii required.
12. The cone-seal plug's face angle is as required.
13. The cone-seal plug's face finish and O-ring groove finishes are as required.
14. The cone-seal plug's leak-test port upper cavity is the diameter and depth required.
15. The cone-seal plug's leak-test port is threaded to the depth required, and with the bottom finish and thread relief required.
16. The cone-seal plug's leak-test port threading passes the gage test required.
17. The cone-seal plug's leak-test port penetrating hole has at the entry the face angle and finish required and is of the depth required.
18. The cone-seal plug's leak-test port radial hole is positioned and dimensioned as required and allows free gas passage form the port to the leak test groove.
19. The cone-seal plug's upper cylinder external groove is positioned and has the width and depth specified.

20. The cone-seal plug's external radius between the upper cylinder and base plate is as required.

21. The cone-seal plug is marked as required and with the required serial number.

22. The SCV's top impact absorber ID and OD and length are as required.

23. The SCV's bottom impact absorber spherical radius is as required, the corner radius is positioned correctly and of the radius required, and the OD and thickness are as required.

24. The impact absorber aluminum honeycomb cell orientation and minimum foil thickness are as required.

25. The aluminum honeycomb impact compressive strength is as required. See Appendix 2.1 Hexcel Tube-Core or equivalent.

26. The PCV's bottom spacer spherical radius is as required, the corner radius is positioned correctly and of the radius required, and the OD and thickness are as required.

27. The SCV's impact absorbers and the PCV's bottom spacer have no edges that could cause injury.

PCV Sleeve and 3013 Spacer (Drawing R-R4-G-00103)

1. Verify that the OD, ID, and height of the PCV sleeve are as specified.

2. Verify that the OD, ID, and height of the 3013 top spacer are as specified.

Shortened 3013 Spacer and Bottom Ring Spacer (Drawing R-R4-G-00082)

1. Verify that the OD, ID, and height of the 3013 shortened top spacer are as specified.

2. Verify that the OD, ID, and height of the bottom ring spacer are as specified.

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APPENDIX 8.2

INDEPENDENT VERIFICATION ITEMS FOR ACCEPTANCE OF NEWLY FABRICATED 9975 PACKAGINGS

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INDEPENDENT VERIFICATION ITEMS
FOR
ACCEPTANCE OF NEWLY FABRICATED 9975 PACKAGINGS

Certain components and features of the 9975 packaging are defined as category A "Q" items (safety-related) in accordance with the SRS QAP. These components and or features require documented evidence that the attributes have been satisfied during packaging fabrication. Table 8.2.1 lists the "Q" items that require independent verification and the basis for designation of the items. The numbered items specifying dimensional, surface feature and material requirements are identified on the engineering drawings given in Chapter 1, Appendix 1.1.

Table 8.2.1 Dimensions/Materials Requiring Independent Verification Records

Number	Quality Item	Basis for Designation	Drawing Number
1	Cone seal face major diameter	Containment	R-R3-G-00063
2	Cone seal face angle	Containment	R-R3-G-00063
3	Cone seal face finish	Containment	R-R3-G-00063
4	Cone seal plug angle	Containment	R-R4-G-00102
5	Test port seat angle	Containment	R-R4-G-00102
6	Test port seat finish	Containment	R-R4-G-00102
7	Test port minor hole diameter	Containment	R-R4-G-00102
8	Lower O-ring gland depth	Containment	R-R4-G-00102
9	Upper O-ring gland depth	Containment	R-R4-G-00102
10	O-ring gland finish	Containment	R-R4-G-00102
11	Upper O-ring gland width	Containment	R-R4-G-00102
12	Lower O-ring gland width	Containment	R-R4-G-00102
13	Cone seal plug minor diameter	Containment	R-R4-G-00102
14	O-ring size and material	Containment	R-R2-G-00081
15	Shielding thickness Lead Shielding Body	Shielding	R-R2-G-00079
16	Reserved	Reserved	Reserved
17	Reserved	Reserved	Reserved

Note: Items 1 through 14 apply to both the primary and secondary containment vessels.

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APPENDIX 8.3

9975 MATERIALS PERFORMANCE

SRNL-L4400-2011-00027

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July 14, 2011 SRNL-L4400-2011-00027

TO: J.S. Bellamy, Packaging Transportation and Pressure Systems

FROM: K.A. Dunn, Materials Science and Technology Directorate
W.L. Daugherty, Materials Science and Technology Directorate

9975 MATERIALS PERFORMANCE

RE: Ql's for the Justification of Extended maintenance with Use of the Radio Frequency Identification (RFID) System – Safety Analysis Report for Packaging Model 9975 S-SARA-G-00008, Revision 1, March 2010, Dated 24 November, 2010

Summary

An extension has been requested for the annual certification for 9975 shipping packages from a one year period to a five year period with the use of the radio frequency identification (RFID) system. A requisite action for justifying this extension is limiting the exterior temperature of the package during the extended 5 year certification to a range of 35 - 130°F and ensuring the axial gap measurement is met at each time of packaging. If the 9975 package has been sealed for shipment and is not unloaded for a period of one year, it is recommended that the axial gap of the loaded package be re-measured before placement in commerce. Data developed within the 9975 Storage and Surveillance Program relative to the fiberboard assembly and corrosion of the drum provide the technical bases to validate the proposed maintenance interval extension.

It is concluded that measurement of the axial gap at the top of the 9975 package provides an adequate and timely indication of degradation of the fiberboard. Also, the axial gap measurement when coupled with an exterior inspection of the drum, provide an adequate and timely indication of drum corrosion significant to package safety. Accordingly, a drum visual exterior inspection for corrosion is proposed as an additional requirement for preparation of each 9975 shipment with extended maintenance as well as any time the axial gap measurement is required.

Background

With approvals in place to install Radio Frequency Identification Devices (RFIDs) on 9975 packages, it is desired that their capabilities be utilized to support a reduction in the maintenance frequency of the packages. Specifically, by monitoring the RFID to ensure that the package temperature remains within a narrower range than allowed for current operation, it is proposed that the maintenance interval be extended from annual to up to 5 years. The package would need to remain between 35°F and 130°F for the entire maintenance interval (if the interval extends beyond 1 year) in order to remain as defined herein.

A Safety Analysis Report for the Package (SARP) Addendum, S-SARA-G-00008, was submitted for review and approval to the 9975 regulator and an independent review team from LLNL provided a list of technical, regulatory questions (Q1s) for the justification. The Q1s, as described in a memo dated 24 November, 2010, are addressed herein by reviewing the available data on the behavior of the 9975 stainless steel drum and fiberboard overpack. Justification for extending the lifetime of the O-rings for a period of five years has been previously accepted by the Lawrence Livermore National Laboratory (LLNL) reviewing authority.

LLNL Q's Discussion

A series of technical questions were posed by the LLNL reviewing authority, dated 24 November, 2010. Specifically, each Q1 is addressed below.

Q1-1, Chapter 7, Section 7.2.1, Preparation for Loading: Please add the appropriate steps to this section to require the measurement of the axial and radial gaps between the fiberboard assemblies and the underside of the drum lid and drum wall, respectively. These steps must be added to the SARPs, and the Certificates of Compliance, for both the Model 9975-85 and Model 9975-96 Packagings, to make them consistent between the two packagings.

A1-1: Data from the 9975 Storage Surveillance Program including field tests, accelerated aging tests, compaction tests, and full scale integrated tests [1-4] show that a primary indicator of significant fiberboard height change is verification of a maximum 1 inch axial gap between the drum flange and upper fiberboard assembly air shield. If the fiberboard height is reduced due to any of the fiberboard degradation mechanisms, this change will be observed directly in the axial gap between the flange and air shield. Thus, the axial gap provides a straight forward method that can be used as a conservative screening tool for fiberboard degradation and is already included in the 9975-85 SARP and the 9975-96 Certificate.

The radial gap measurement is between the air shield (stainless skin) and the drum. Fiberboard shrinkage is not likely to show up as radial gap difference and fiberboard swelling will not result in a change in radial gap without first stretching the air shield. When fiberboard dimensions change, through degradation or change in moisture content, the height will change at a faster rate than the radius. Therefore, the radial gap measurement does not provide the same level confidence as the axial gap measurement and is not warranted.

Q1-2, Chapter 8, Section 8.2.3, Subsystem Maintenance: Please rewrite the information presented in this section to more correctly reflect what is actually happening. As it is currently written, the text of this section states:

> "The geometry (density) of Celotex® is known to change with moisture content. This type of slight geometric fluctuation has no significant affect [*sic*] on the performance of the Celotex® in its function as an impact or thermal insulator. Further, moisture adsorption from or loss to the atmosphere is a normal, benign and reversible Celotex® phenomenon. There are no Celotex® measurement requirements."

A1-2: The 9975 Storage and Surveillance Program has shown that the geometry of fiberboard can change with moisture content and that slight geometric fluctuation has no significant effect on the performance of the fiberboard in its function as an impact absorber or thermal insulator. Slight amounts of moisture adsorption from or loss to the atmosphere is a normal, benign and reversible fiberboard phenomenon. However, the 9975 Storage and Surveillance Program has also shown that a measure of the axial gap will adequately screen the behavior of fiberboard as it degrades. Since axial gap measurement is included in the 9975-85 SARP and 9975-96 Certificate, we suggest that the paragraph be deleted.

Q1-3, Chapter 8, Section 8.2.3, Subsystem Maintenance: Please add additional steps to this section to require the fiberboard assemblies to be removed from the drum as part of the Maintenance Program, so that they can be visually inspected for the build-up of mold and/or other detritus, and so that the dimensions of the fiberboard assemblies can be verified against the original Acceptance Test requirements, as defined in Appendix 8.1 of the SARPs. These requirements must be added to the SARPs, and the Certificates of Compliance, for both the Model 9975-85 and Model 9975-96 Packagings.

A1-3: Measuring the axial gap provides a straight forward method that can be used as a screening tool for fiberboard degradation, rather than removing the fiberboard assembly. Removal of the fiberboard assembly from the drums as part of the Maintenance Program poses several difficult issues for a packaging facility and should only be done if the benefit is deemed worthy. While this operation can be executed safely, any additional operations added to the subsystem maintenance have a risk potential. The nature of the drum design provides for a tight clearance with the fiberboard assembly. The probability of damaging the lower fiberboard assembly increases each time it is removed and handled, especially if it contains regions of elevated moisture content. Additionally, the fiberboard can expand or shrink, depending on moisture and temperature of the package which can make removal of the assembly challenging.

Rather than removing the fiberboard assembly, measuring the axial gap, which is already required, provides a straight forward method that can be used as a conservative screening tool for fiberboard degradation. Excess moisture facilitates two predominate degradation mechanisms for the fiberboard - mold and pyrolysis. Both mechanisms will lead to loss of fiberboard mass, which translates into a reduction in volume within the 9975 package shell and an increase in the axial gap. The rate of mass loss is such that changes in the axial gap would be observed well before any challenge to the fiberboard's function as an impact absorber or thermal insulator.

In a package with typical moisture levels, an internal heat load will create a thermal gradient in the fiberboard, which in turn will create a moisture gradient. The moisture will tend to migrate towards the cooler regions of the fiberboard, which are typically the bottom and outer surfaces [4]. Any areas of liquid moisture (whether from migration, condensation, or other sources) will tend to move downward under the influence of gravity. Once moisture is concentrated towards the bottom of the fiberboard, two things will happen. First, the higher fiberboard elevations which now have reduced moisture levels will shrink due to moisture loss. Second, while the lower fiberboard elevations might tend to swell due to moisture gain, the increased moisture content will reduce the fiberboard compressive strength so that the bottom fiberboard layers will compact under the weight of the package internal components (shield, containment vessels, payload). Both of these effects contribute to an increased axial gap at the top of the package and a failure of the axial gap will occur prior to a problem with package performance.

When an axial gap value of greater than 1 inch is measured, the packaging facility must initiate a non-conformance report (NCR) and then contact the Design Authority (DA) at SRS. The DA will at that time disposition the NCR (past practice has included removing the lower assembly to determine the reason for the axial gap failure).

<u>Q1-4, Chapter 8, Section 8.2.3, Subsystem Maintenance</u>: Please add additional steps to this section to require the appropriate inspections of the inside of the drums as part of the Maintenance Program to look for the onset of localized corrosion. The inspections to be added must be capable of detecting potential defects such as pitting, crevice corrosion, loss of wall thickness, and chloride-induced, stress corrosion cracking. As was noted above, these requirements must also be added to the SARPs, and the Certificates of Compliance, for both the Model 9975-85 and Model 9975-96 Packagings.

<u>A1-4:</u> Moisture is needed to initiate and propagate corrosion phenomena. Localized corrosion has been seen inside the drum in the bounding laboratory tests where moisture migrated to the bottom layers of the fiberboard and resulted in the leaching of the chlorides from the fiberboard and their concentration at the bottom and sides of the drum. The combination of moisture, chlorides, residual stress and moderately elevated temperature can lead to stress corrosion cracking, pitting or other forms of attack of the stainless steel drum. However, concurrent to this migration of moisture, changes in the fiberboard assembly dimensions, particularly the axial gap, are observed. Monitoring of the axial gap will signal potential changes in conditions that could lead to drum corrosion just as it signals changes to the fiberboard properties. Therefore, measuring the axial gap provides a straight forward method that can be used as a screening tool for internal drum corrosion, rather than removing the fiberboard assembly.

For example, during periodic inspections of the first life extension package [1] corrosion of the drum was observed. The drum interior was corroded around most of the weld locations, and the exterior contained spots of corrosion on and near several of the stitch welds around the bottom exterior. Several of these corroded areas were cleaned to examine the underlying steel surface. Most of the attack was general corrosion, with limited evidence of pitting. The testing environment for this drum was in the extreme bounding condition and the axial gap exceeded the 1" criterion after ~5 months. Even after ~20 months at temperature (end of test) with these extreme bounding conditions corrosion was observed but the drum itself was intact and structurally sound.

Additionally, the second life extension package was observed to have a local region of corrosion at the interior bottom crevice. In a subsequent inspection, corrosion at one stitch weld along the exterior bottom edge was also noted. These locations on the second package have not yet been characterized in detail. This life extension package failed the axial gap within two months. In both of these cases, the axial gap measurement provided a conservative screening tool for fiberboard change and the subsequent internal drum corrosion.

Localized corrosion has been noted on at least 2 9975 drums examined in K-Area as a result of a failed axial gap measurement. Package 9975-02130 had corrosion along the outside corner on the underside of the drum exterior [5]. Package 9975-01818 had corrosion on the stitch welds along the bottom exterior surface [6]. Given the observation of limited corrosion on the exterior drum surfaces of several packages (in KAC and in laboratory tests), it is suggested that visual examination of the drum exterior surface, along with the axial gap, would be a meaningful screening tool for the timely identification of corrosion degradation of the drum.

Conclusion

The Celotex® fiberboard is subject to material property changes as a result of elevated humidity and temperature. Data from the 9975 Storage Surveillance Program including accelerated aging tests, compaction tests, and full scale integrated tests show that a primary indicator of significant fiberboard height change is verification of a maximum 1 inch axial gap between the drum flange and upper fiberboard assembly air shield. If the fiberboard height is reduced due to any of the fiberboard degradation mechanisms, this change will be observed directly in the axial gap between the flange and air shield.

The axial gap is a straight forward method that can be used as a conservative screening tool for fiberboard degradation and internal drum corrosion, rather than removing the fiberboard assembly. Therefore, the axial air gap dimension should be measured during pre-use inspections. Any dimensional value outside the established acceptance criteron will require further evaluation prior to use. In addition, it is recommended that visual examination of the drum exterior surface be conducted for further assurance of the continued integrity of the drum.

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5. SRNL-STI-2010-00402, *Examination of Shipping Package 9975-02130*, W.L.

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6. SRNL-STI-2009-00742, *Examination of Shipping Packages 9975-01818, 9975-01903 and 9975-02287*, W.L. Daugherty, November 2009

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