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Thermal Analysis of the 9975 Package as a Plutonium Storage Container

by

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S. J. Hensel

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Abstract

Thermal analysis of the 9975 package with three configurations of the BNFL 3013 outer container (with Rocky Flats, SRS, and BNFL inner containers) and two configurations with food pack cans have been analyzed for storage of plutonium oxide and metal. The storage conditions include allowance for storing up to five packages on a pallet which are stacked two pallets high. The ambient temperature within the storage facility was assumed to be 110°F (43.3 °C) during normal storage conditions.

The Rocky and SRS 3013 configurations with Pu metal contents result in similar packaging temperatures, however the plutonium metal temperatures are lower for the SRS design (SRS has helium fill gas whereas Rocky is essentially air filled). Similarly, the BNFL configuration for Pu oxide contents result in a lower maximum Pu temperature than the food pack cans even though the 9975 packaging temperatures are very similar.

For all of the cases analyzed the 3013 pressure is less than 500 psig and the 9975 PCV pressure is less than 300 psig. In general, pressures within the 9975 PCV and the BNFL 3013 vessel are acceptable provided the moisture is 0.5% or less as required in DOE-STD-3013-96. Gas species in the pressure computations include air, helium and hydrogen from complete radiolysis of the moisture. The oxygen generated from the radiolysis of the water is not included as a pressure contributor because it combines chemically with the plutonium oxide.

1.0 Introduction

Plutonium storage is currently being planned for K-reactor and in a new Actinide Package Storage Facility (APSF) at SRS. The present work consists of steady-state thermal analyses of the 9975 package when used to store Pu metal and oxide. In addition, pressures in the 3013 container and PCV are computed. This work does not evaluate the computed temperatures or pressures in terms of their impact on safety.

Several BNFL 3013 container storage configurations utilizing the 9975 package are contemplated. A schematic of the storage configurations with the BNFL 3013 container is presented in Figure 1. A similar schematic in Figure 2 illustrates the food can configurations. Table 1 identifies all of the configurations currently considered and the respective contents. The BNFL and Rocky configurations consist of three nested containers/cans within the primary containment vessel of the 9975. The food can configuration consists of double nested cans within an outer food can. The SRS configuration is the only double nested configuration. Dimensions of the containers/cans are provided in Tables 2 and 3. Three thermal loadings for the food pack can configurations (stacked two high) are illustrated in Figure 2. Although the 9975 package is currently certified for transportation purposes at only 19 watts, 30 watts of Pu was evaluated for comparison purposes.

The 9975 packages shall be stored in an upright position in bundles of five on pallets which may be stacked two high. This implies the top and bottom surfaces of the 9975 outer drum will be nearly adiabatic for the lower package. Furthermore, the middle package on the pallet will not radiate heat to the surroundings as it is surrounded by other 9975 packages. The ambient temperature in K-reactor and APSF is assumed to be no greater than 110°F (43.3 °C) during normal operations.

Schematic Of 3013 Configurations

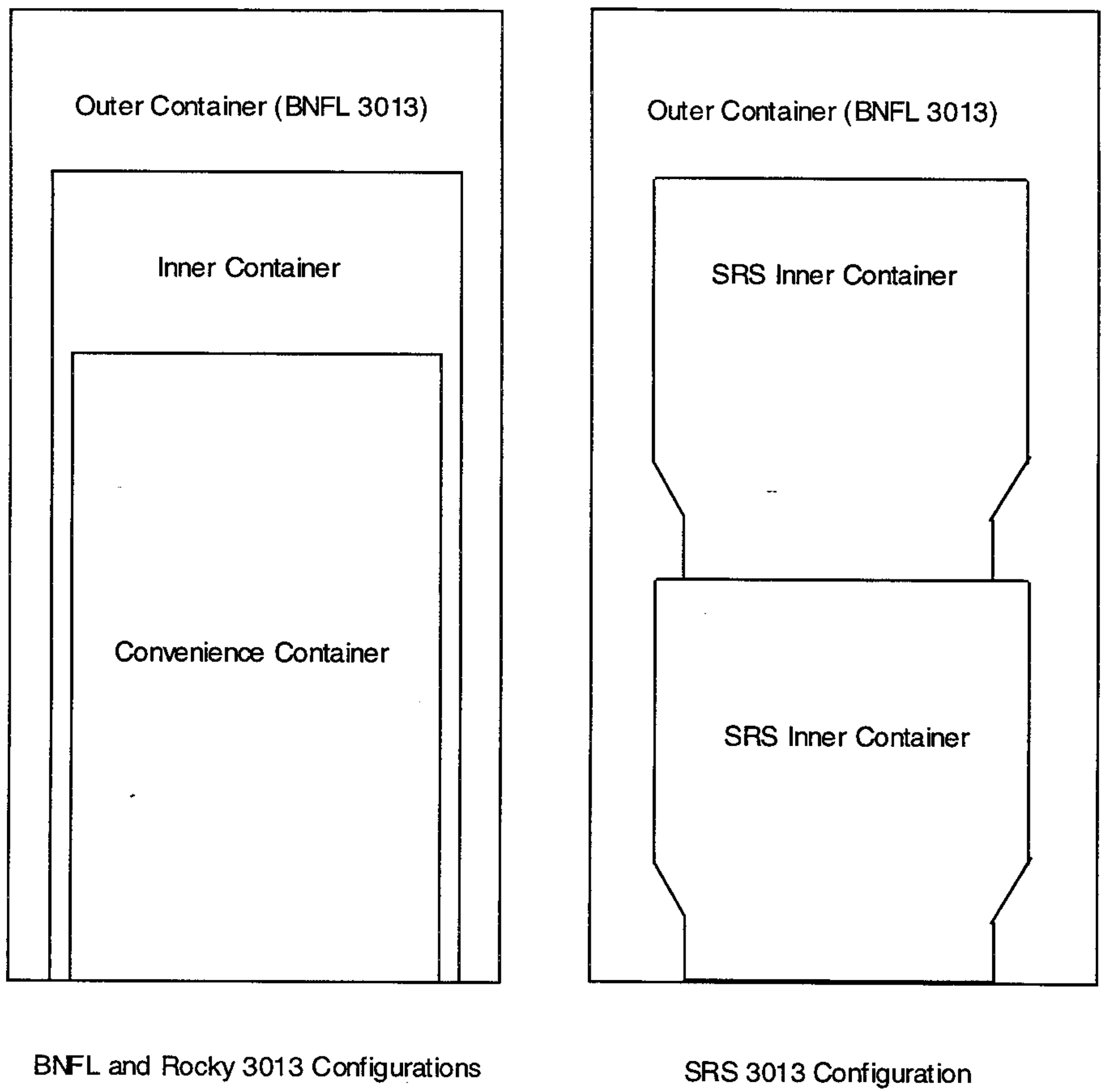
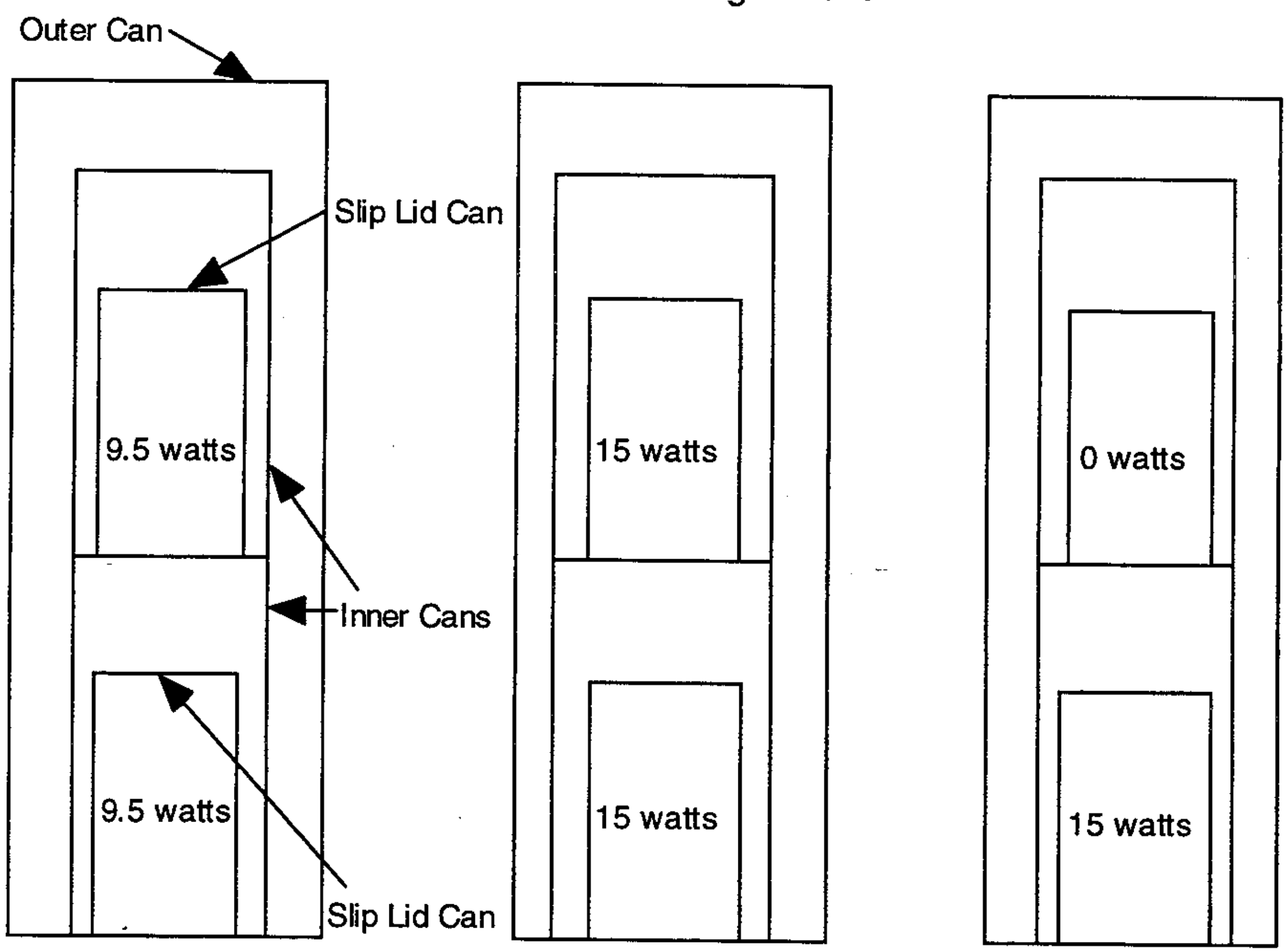


Figure 1

Food Can Configurations



1800 g Pu oxide per can

0.8 liter slip lid cans

1800 g Pu oxide per can

0.8 liter slip lid cans

1000 g Pu oxide

0.5 liter slip lid cans

Figure 2

Table 1: Storage Configurations

Name	Outer Container	Inner Container	Convenience Container	Fill Gasses	Contents
BNFL	Yes BNFL 3013	Yes BNFL	Yes BNFL	Helium between Inner container and 3013, all other is air	low density Pu Oxide (19 W or 30 W)
Rocky	Yes BNFL 3013	Yes BNFL	Yes Rocky Flats	Helium between Inner container and 3013, all other is air	2 Pu metal buttons stacked directly on top of each other (19 W total)
SRS	Yes BNFL 3013	Yes SRS cans stacked two high	No	Helium within 3013 container and Inner container	2 Pu metal buttons (19 W total divided between 2 containers)
Food Cans (triple nested cans stacked two high)	Yes food can	Yes food can	Yes slip lid food cans (0.5 liter or 0.8 liter)	Air	Low density Pu oxide, 9.5 W per can or 15 W per can

Table 2: External Dimensions Of Containers (in.)

Container	Diameter X Height (in.)	Drawing Number
BNFL 3013	4.92 X 10.0	BNFL Drawing M-4-20-1-245 Mod C
BNFL Inner Container	4.61 X 9.45	BNFL Drawing M-4-20-1-244 Mod D
BNFL Convenience Container	4.29 X 8.91	BNFL Drawing M-4-20-1-243 Mod C
Rocky Convenience Container	4.11 X 5.96	Dynamic Machine Works 1509-02
SRS Inner Container	4.6 X 4.625	WSRC Drawing R-R1-F-0039 rev. 2

Table 3: Food Can External Dimensions (Diameter X Height in inches)

Food Can	Small Slip Lid Can Configuration (0.5 liter)	Large Slip Lid Can Configuration (0.8 liter)
Inner Slip Lid Convenience Can	3.5 X 3.5	3.4375 X 5.625
Inner Can	4.167 X 4.625	4.167 X 6.25
Outer Can	4.25 X 7.0	4.25 X 7.0

The general purpose conduction-radiation computer code MSC/Thermal (also known as P/Thermal) was used to perform the computations [1]. This computer code meets site nuclear safety QA requirements [2], and work was performed in accordance with the WSRC E-7 manual [3].

2.0 Thermal Models And Analysis

The thermal models of the storage configurations were created using the general purpose finite element pre and post processor Patran [4].

2.1 Models

Axisymmetric models of the 9975 drum package used in the preparation of the 9975 SARP were modified to accommodate the proposed configurations and storage boundary conditions [5]. A schematic of the axisymmetric model of the 9975 packaging with the BNFL configuration is shown in Figure 3. Models for the other configurations are very similar except for the containers within the PCV and the metal contents. Metal buttons are modeled as disks 0.75 in. thick with flat tops and 5.125 in. radius of curvature bottoms (curved side down) as shown in Figure 4 [6]. The axisymmetric models contain roughly 5500 nodes. Heat is transferred to the ambient by conduction through the 9975 components and radiation and conduction across the air gaps. Within the primary containment vessel conduction heat transfer is modeled, but natural convection is neglected. Radiation within the primary containment vessel is considered as listed in Table 4. The contribution of radiation heat transfer between the inner and outer containers for the BNFL and Rocky configurations is relatively small and therefore neglected. For the food can configuration the model is identical to previous analyses where radiation within the cans was neglected [5]. Natural convection within the packaging is also conservatively neglected. Contact resistances are neglected as is the conduction through the food can rims.

Fringe plots of the axisymmetric models used to analyze the Rocky and BNFL configurations are presented in Figures 5 and 6. The package materials are represented by the fringe colors.

Schematic of 9975 With BNFL Containers And Pu Oxide Contents

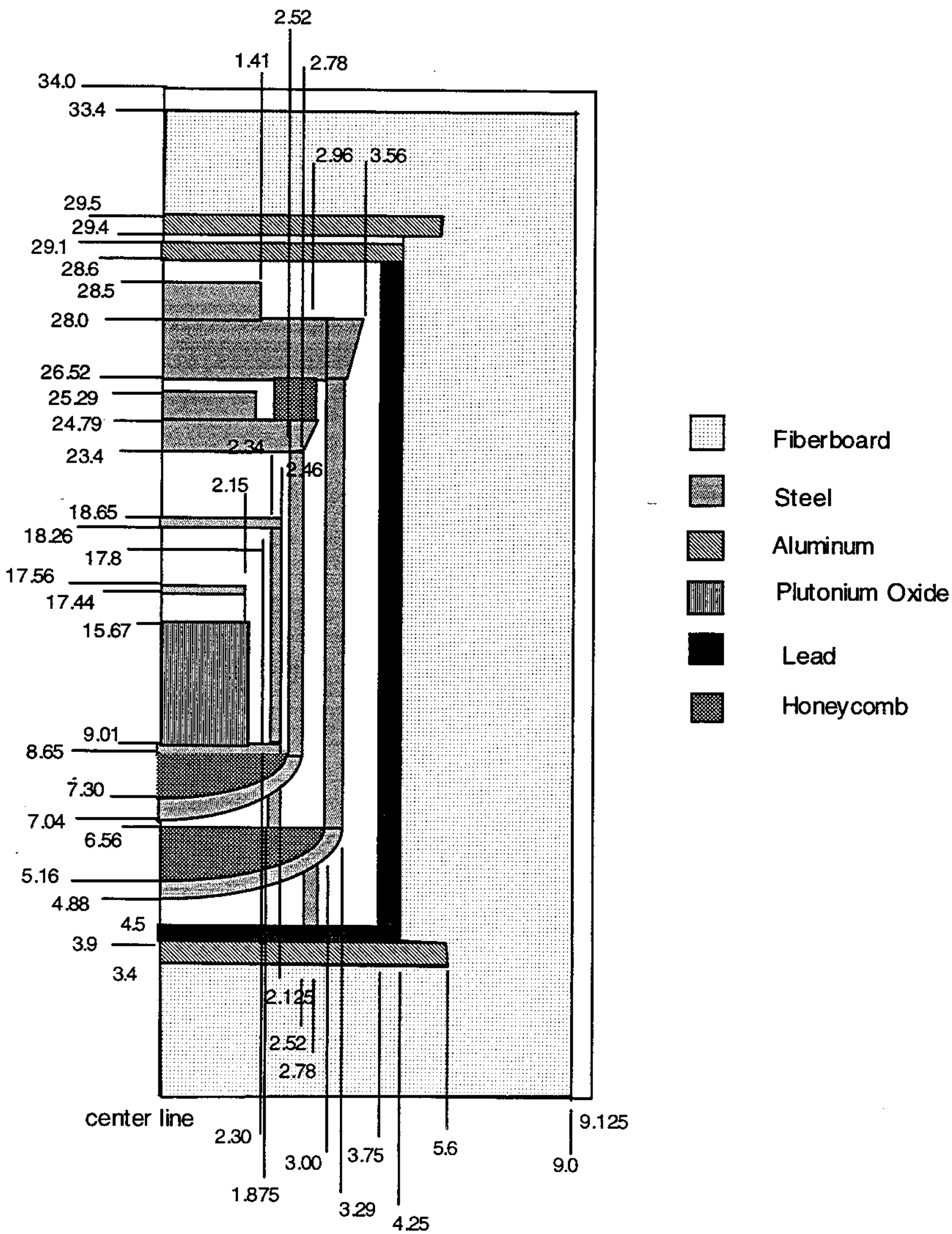


Figure 3

Schematic Of Pu Button

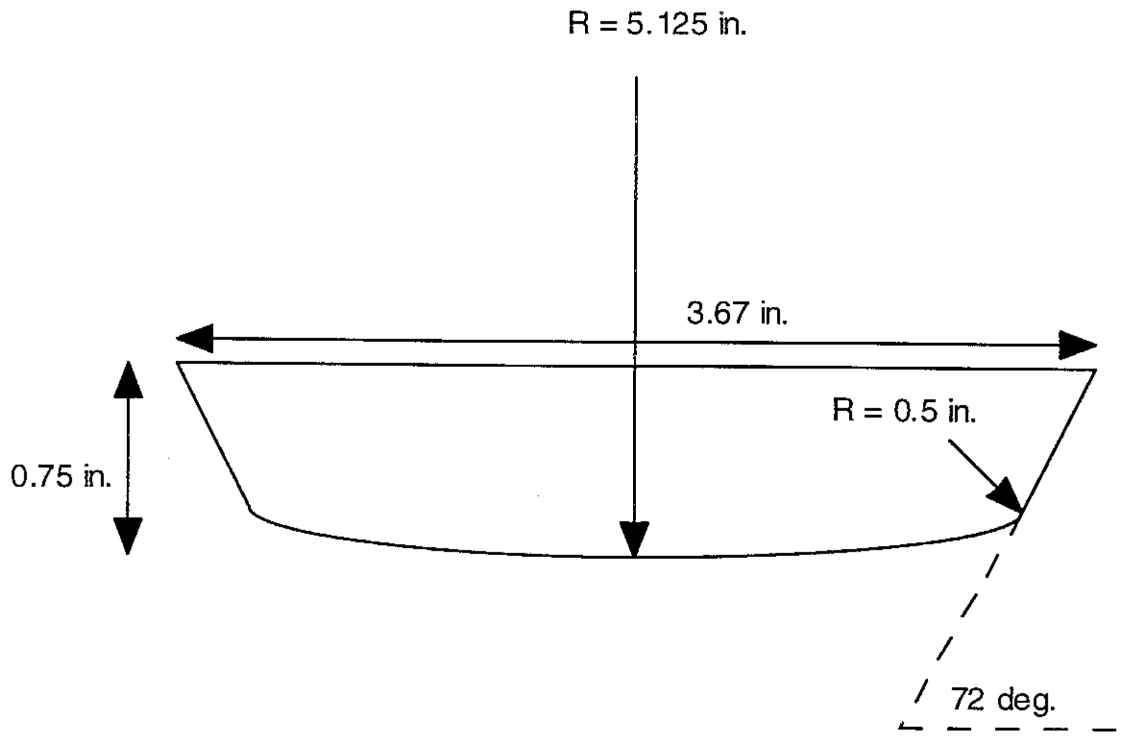


Figure 4

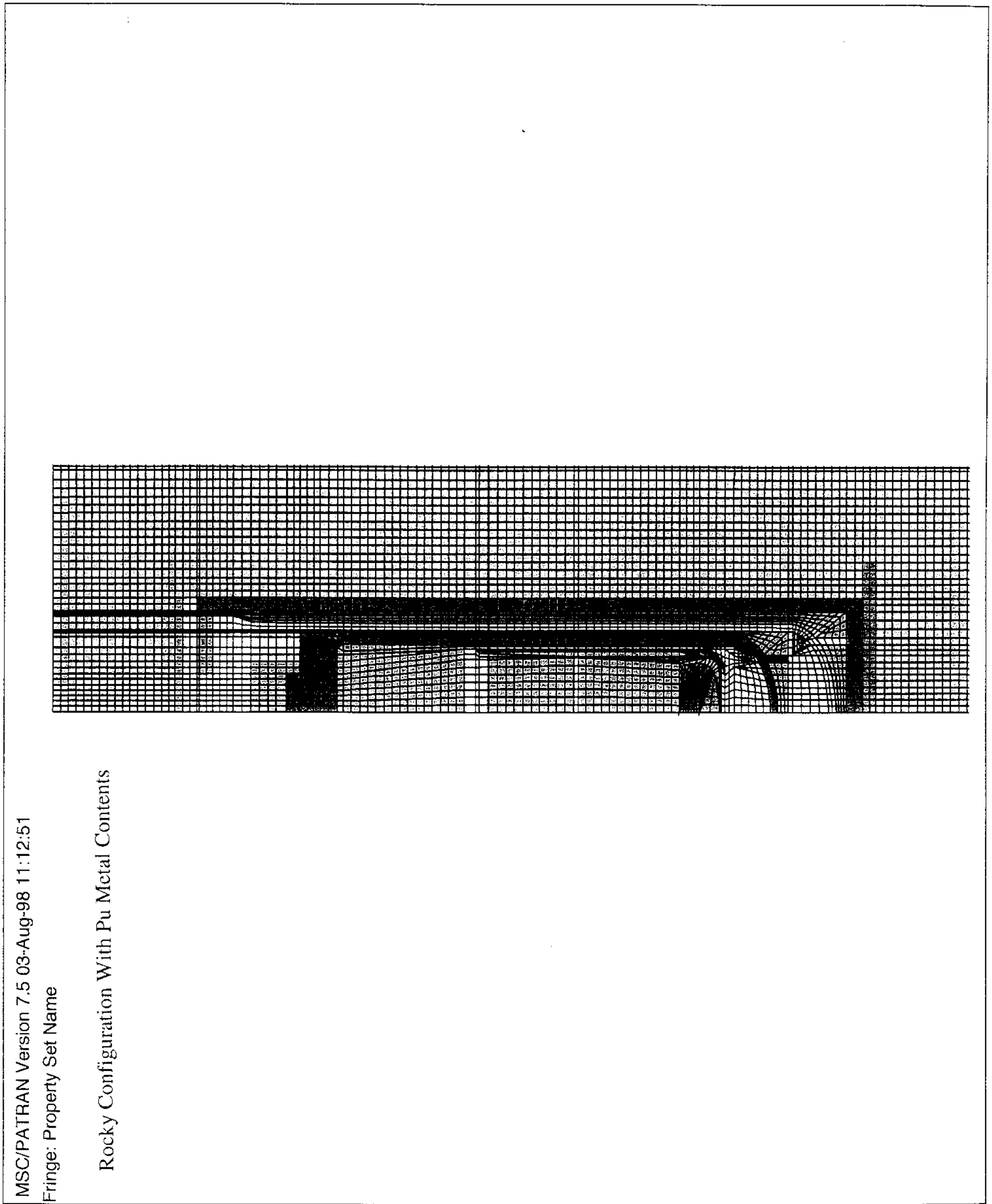
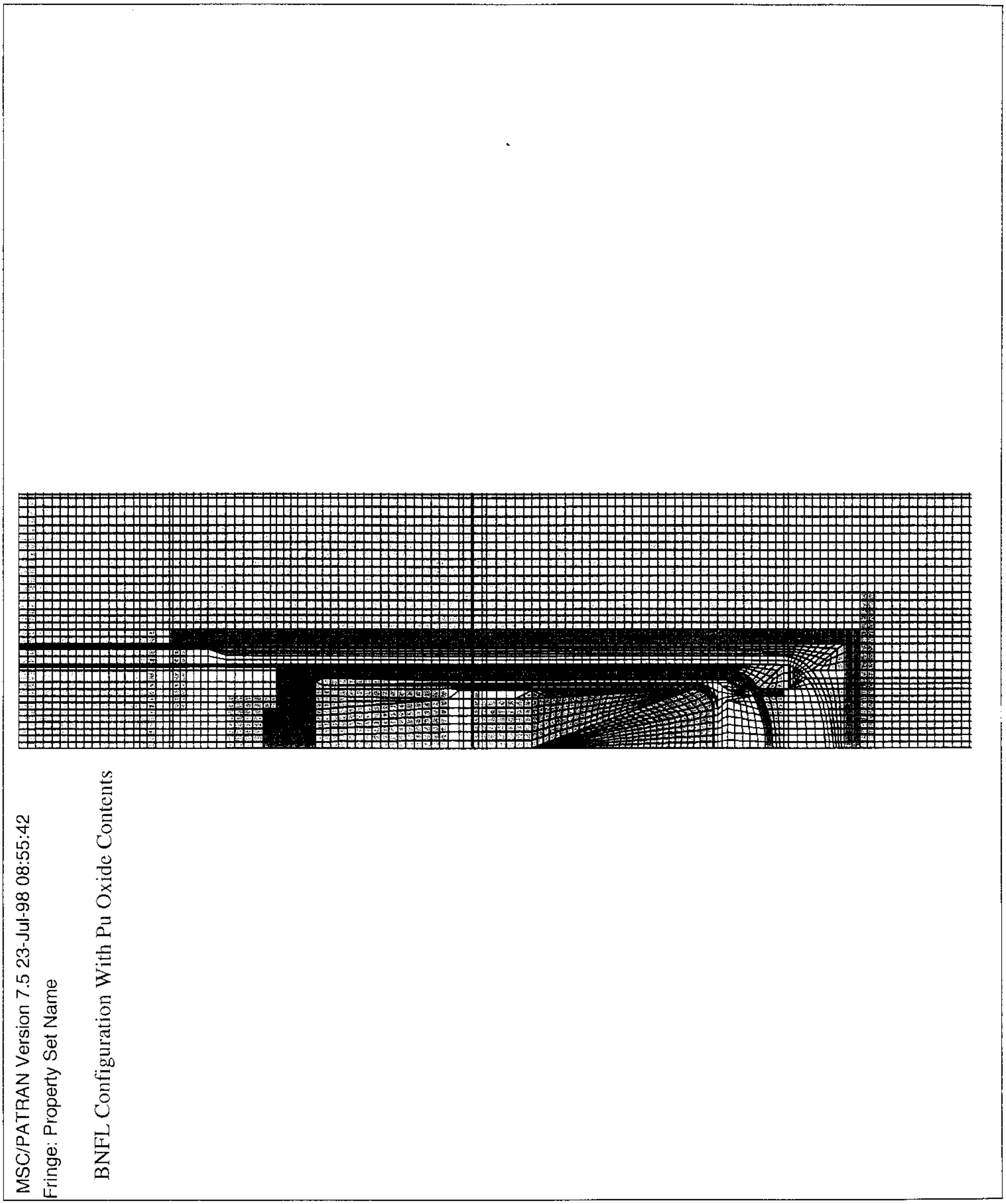

MSC/PATRAN Version 7.5 03-Aug-98 11:12:51
Fringe: Property Set Name
Rocky Configuration With Pu Metal Contents

Figure 5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Fringe: Property Set Name
BNFL Configuration With Pu Oxide Contents

Figure 6

Table 4: Radiation Heat Transfer Within Primary Containment Vessel

Configuration	Between Outer Container and PCV	Between Inner Container And Outer Container	Between Convenience And Inner Container	Between Contents And Convenience Container
BNFL	Yes	No	Yes	Yes
Rocky	Yes	No	Yes	Yes
SRS	Yes	Yes	N/A	Yes, between contents and inner container
Food Cans	Yes	No	No	No

2.2 Thermal Analysis

All analyses are steady-state without insolation, and the ambient storage temperature is 110°F (43.3 °C). The 9975 drum is assumed to be upright. Both the top and bottom surfaces are adiabatic (to account for stacked storage on pallets), and heat transfer from the drum side to the ambient is via natural convection only (to account for an array of stored packages). The Nusselt number correlation used to determine the natural convection heat transfer coefficient as a function of drum surface temperature is $Nu=0.59Ra^{0.25}$ where Ra is the Rayleigh number [7]. 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 [8]. A summary of the boundary conditions applied in the analyses follows:

1. Drum analyzed in an upright position
2. Adiabatic bottom surface
3. Adiabatic top surface
4. No radiative heat transfer from drum sides

5. Heat is dissipated to the ambient via natural convection from the drum sides
6. Ambient temperature is 110°F (43.3 °C)
7. No insolation

The thermal properties of the packaging components used in the analyses are shown in Tables 5 and 6 and are in general taken from previous analyses [5].

Table 5: Emissivity Of Package Components

Component	Emissivity
aluminum plates, honeycomb	0.25
fiberboard	0.90
lead	0.28
containment vessels	0.30
3013 Container	0.20
BNFL Middle Can	0.20
BNFL Convenience Can	0.20
Pu Oxide	0.90
Pu Metal	0.50
Rocky Çonvenience Can	0.20
SRS Convenience Can	0.20

Table 6 : Thermal Conductivity Of Packaging Materials

Material	Conductivity (Btu/hr.-ft.-°F) @ T(°F)
helium	0.0910 @ 120 0.0985 @ 212 0.1226 @ 392
air	0.1396 @ 32 0.1397 @ 212 0.1398 @ 392 0.02593 @ 572
honeycomb energy absorber (radial)	3.82
honeycomb energy absorber (axial)	7.62
fiberboard (radial)	0.0723
fiberboard (axial)	0.031 @ 77 0.034 @ 187 0.036 @ 295
aluminum	126.0
steel (304)	7.74 @ 32 9.43 @ 212 12.58 @ 932
steel (316)	8.79 @ 261 10.58 @ 621
lead	19.6 @ 209 18.3 @ 400
Pu oxide	0.0460
Pu metal	7.26 @ 207 7.74 @ 243 9.19 @ 266 18.39 @ 1112

3.0 Results

Results of the analyses include both temperatures and pressures.

3.1 Temperatures

The results of the computations are presented in Tables 7 (3013 configurations) and 8 (food pack can configurations). The maximum temperatures at key locations are reported for each configuration and wattage. The following are note worthy:

1. The maximum fiberboard temperature is 197°F (91.7 °C) which is well below the currently acceptable limit of 250°F, and occurs with the 30 watts of Pu oxide in the BNFL configuration or 15 watts in the 0.5 liter food pack convenience can configuration. The maximum occurs at roughly mid height of the contents.

2. The maximum SCV temperature is 220°F and the maximum PCV temperature is 245°F (118.3°C), both of which are well below the current SARP limit of 500°F (260.0 °C). The maximum occurs at roughly mid height of the contents.

2. Maximum Pu metal temperature is 329°F (165.0°C) for the Rocky configuration and only 221°F (105.0°C) for the SRS configuration (19 watts total in two metal buttons).

3. Both primary and secondary container o-rings are below 220°F (104.4°C) for all loadings (including 30 watts of oxide).

4. The maximum temperature of the BNFL 3013 container is 263°F (128.3°C), and it occurs with 30 watts of oxide.

5. The 9975 package temperatures are very similar for the BNFL case with 30 watts of oxide and the 0.8 liter convenience food can configuration with 30 watts.

6. The SRS and Rocky configurations result in very similar 9975 packaging temperatures even though the contents are loaded differently.

The most significant result of these analyses is that there are no obvious temperature problems with storing up to 30 watts of Pu oxide or 19 watts of Pu metal, and there is relatively little temperature difference in the 9975 packaging among the storage configurations. The Rocky and SRS configurations result in similar packaging temperatures, however the plutonium metal temperatures are lower for the SRS design (with helium fill gas). Another reason may be that the SRS design is only a double nested configuration whereas the Rocky is triple nested. Similarly, the BNFL configuration for oxide results in a slightly lower maximum Pu oxide temperature than the food pack can arrangement, although 9975 packaging temperatures are comparable. The heat generation of the plutonium contents is primarily responsible for the packaging and can temperatures. The composition of the plutonium (oxide or metal) significantly impacts its temperature (oxide results in significantly greater maximum Pu temperatures).

Table 7: Temperatures (°F/°C) And Pressures (psig) For 3013 Configuration

Location	19 watts Pu oxide (BNFL)	30 watts Pu oxide (BNFL)	19 watts Pu metal (Rocky)	19 watts Pu metal (SRS)
Drum top	135 / 57.2	149 / 65.0	130 / 54.4	136 / 57.8
Drum bottom	153 / 67.2	177 / 80.6	145 / 62.8	149 / 65.0
Drum side	122 / 50.0	127 / 52.8	123 / 50.6	121 / 49.4
Fiberboard	166 / 74.4	197 / 91.7	155 / 68.3	159 / 70.6
SCV O-ring	172 / 77.8	205 / 96.1	156 / 68.9	165 / 73.9
PCV O-ring	174 / 78.9	208 / 97.8	158 / 70.0	166 / 74.4
SCV side	181 / 82.8	220 / 104.4	167 / 75.0	171 / 77.2
SCV bottom	181 / 82.8	219 / 103.9	169 / 76.1	173 / 78.3
PCV side	198 / 92.2	245 / 118.3	180 / 82.2	184 / 84.4
PCV bottom	195 / 90.6	240 / 115.6	184 / 84.4	186 / 85.6
3013 top	201 / 93.9	249 / 120.6	172 / 77.8	184 / 84.4
3013 bottom	197 / 91.7	243 / 117.2	188 / 86.7	189 / 87.2
3013 side (mid. height of contents)	210 / 98.9	263 / 128.3	186 / 85.6	194 / 90.0
Pu can interface	------------------	------------------	300 / 148.9	215 / 101.7 (top button) 197 / 91.7 (bottom button)
Middle of Pu	445 / 229.4	629 / 331.7	329 / 165 (at interface of buttons)	221 / 105 (top button) 206 / 96.7 (bottom button)
Pressure 3013	404.9	490.2	13.1	9.3
Pressure PCV	217.9	265.2	10.5	7.0

Table 8: Temperatures (°F/°C) And Pressures (psig) For Can Configuration

Location	0.8 liter can (19 W)	0.8 liter can (30 W)	0.5 liter can (15 W)
drum top	142 / 61.1	148 / 64.4	160 / 71.1
drum bottom	153 / 67.2	172 / 77.8	188 / 86.7
drum side	123 / 50.6	127 / 52.8	118 / 47.8
fiberboard	168 / 75.6	191 / 88.3	197 / 91.7
SCV O-ring	183 / 83.9	211 / 99.4	197 / 91.7
PCV O-ring	185 / 85.0	215 / 101.7	198 / 92.2
SCV side	184 / 84.4	214 / 101.1	209 / 98.3
SCV bottom	179 / 81.7	208 / 97.8	210 / 98.9
PCV side	200 / 93.3	239 / 115	227 / 108.3
PCV bottom	187 / 86.1	220 / 104.4	221 / 105
middle Pu oxide:			
top	480 / 248.9	654 / 345.6	-------
bottom	470 / 243.3	644 / 340	738 / 392.2
Pressure PCV	226.9	271.6	293.2

3.2 Pressures

Pressures are also presented in Tables 7 and 8 for the 3013 configurations and the can configurations. The pressures are based upon complete radiolysis of the moisture (0.5% by wt.) in the case of the oxide content, the contribution from 50 years of helium buildup and air expansion. The mass of the content for all pressure calculations is assumed to be 5 Kg of oxide or 4.4 Kg of metal. The gas temperature used to compute the pressures was conservatively assumed to be the maximum in the contents. The PCV pressures are based on all interior containers leaking.

A generic calculation of the pressures within the BNFL 3013 vessel and the 9975 primary containment vessel are presented as a function of Pu oxide moisture content in Figure 7.

The gas temperature is conservatively assumed to be 400°F. Radiolysis of the moisture is presumed, however only hydrogen is produced (oxygen is absorbed into the Pu oxide). Generation of helium, based on 30 watts of Pu oxide, is also accounted for as is the air initially within the vessels. The vessels are taken to be completely empty except for the Pu oxide. Figure 7 is intended to provide basic insight into expected pressures. Clearly, mositure levels near 0.5% pose little concern, however higher levels are a potential problem as pressures exceed 500 psig and approach 1000 psig. The effect of helium on pressure is minimal. Hydrogen is clearly the significant pressure generator. The addition of oxygen would increase the pressures by approximately 50%.

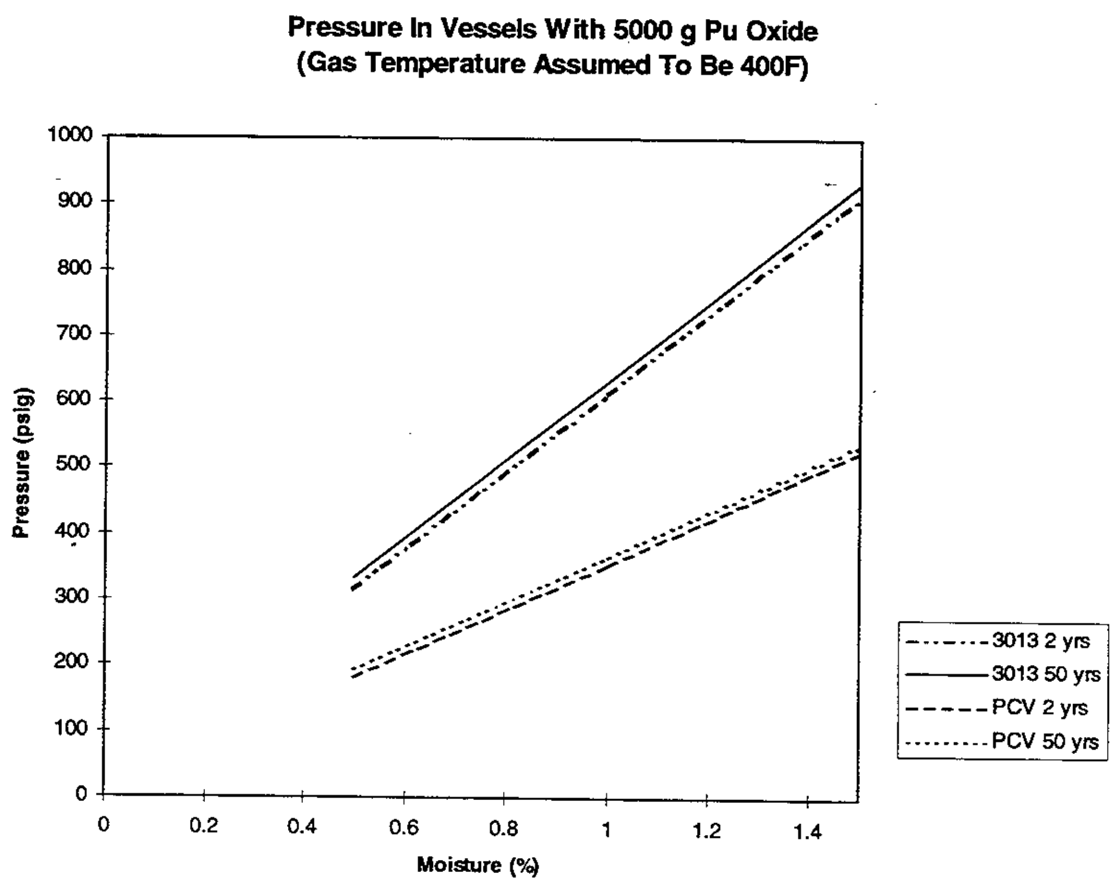

Figure 7

4.0 Conclusions

Thermal analysis of the 9975 package with four configurations of the BNFL 3013 outer container and three configurations with food pack cans have been analyzed for storage of plutonium oxide and metal. The conditions included allowance for storing up to five packages on pallets stacked two high. The ambient within the storage facility was assumed to be 110°F during normal storage conditions. The Rocky and SRS configurations result in similar packaging temperatures, however the plutonium metal temperatures are lower for the SRS design (SRS has helium fill gas whereas Rocky is essentially air filled). Similarly, the BNFL configuration for Pu oxide results in a lower maximum Pu temperature than the food pack cans even though the 9975 package temperatures are very similar. For all of the cases analyzed the 3013 pressure is less than 500 psig and the 9975 PCV pressure is less than 300 psig. In general, pressures within the 9975 PCV and the BNFL 3013 vessel are acceptable provided the moisture is 0.5% or less.

5.0 References

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