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Thermal Analysis of the SAFKEG Package for Long Term Storage

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ABSTRACT

Interim plutonium storage for up to 10 years in the K-reactor building is currently being planned at Savannah River Site (SRS). SAFKEG package could be used to store Pu metal and oxide (PuO_2) in the K-reactor complex with other packagings like 9975. The SAFKEG is designed for carrying Type-B materials across the DOE complex and meets the 10CFR71 requirements. Thermal analyses were performed to ensure that the temperatures of the SAFKEG components will not exceed their temperature limits under the K-reactor storage conditions. Thermal analyses of the SAFKEG packaging with three content configurations using BNFL 3013 outer container (Rocky Flats, SRS bagless transfer cans, and BNFL inner containers) were performed for storage of PuO_2 and plutonium metal.

INTRODUCTION

SAFKEG package is designed by Los Alamos National Laboratory to meet 10CFR71 requirements [1]. The work in this paper consists of steady-state thermal analyses of the SAFKEG package when used to store Pu metal and oxide for long term under ambient temperature conditions different from the SAFKEG SARP [1]. The ambient conditions are calculated in a detailed HVAC analysis of the K-reactor building complex. The purpose of this analysis is to determine the temperatures of the SAFKEG packaging and its plutonium contents for different storage conditions. The storage conditions include allowance for storing the SAFKEG in a lattice configuration with stacking. The ambient temperature within the storage facility was assumed to be 120°F (48.9°C) during normal storage conditions, and 200°F (93.3°C) during accident (small remote fire) conditions. Thermal analyses were performed for three 3013 container storage configurations only, namely, Rocky Flats for Pu metal, and BNFL and SRS Can for Pu oxide. The configurations were analyzed under the normal storage and the accident storage conditions

INPUTS

Geometry

Table 1 identifies all the three SAFKEG content configurations. Dimensions of the containers/cans are shown in Table 2. A schematic of the contents of the SAFKEG package with the 3013 containers and the SRS Can containers is shown in Figure 1. The BNFL and Rocky Flats configurations consist of three nested containers/cans within the inner containment vessel (ICV) of the SAFKEG while the SRS Can configuration consists of double nested container/cans. PuO_2 is assumed to fill the convenience cans.

Material Properties

The thermal properties of the packaging components used in the analyses are shown in Tables 3 and 4. Conduction heat transfer through helium and air was considered (as appropriate) within the package. 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. Annular spaces between cans are small and therefore, convection heat transfer is neglected in radial spaces. Convection is also ignored inside the Rocky Flats convenience can to yield conservative (higher) component temperatures.

Boundary Conditions

Normal Conditions: The SAFKEG package will be stored in an upright position in bundles on pallets which may be stacked. This implies that the top and bottom surfaces of the package 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 packages. The ambient temperature in the K-reactor storage building will be no greater than 48.9°C during normal conditions. A summary of the boundary conditions for the normal analyses is as follows:

1. The drum is in an upright position.
2. The drum top and bottom surfaces are adiabatic.
3. There is radiative heat transfer from drum sides to the ambient.
4. There is natural convection heat transfer from the drum sides to the ambient.
5. The ambient temperature is 48.9°C.
6. No insolation (solar flux).
7. Undamaged insulation properties [1] are applied to all the insulation in the drum.
8. 19 watts total decay power.

The natural convection coefficients used are based on the temperature difference between the drum surfaces and the ambient temperature. The correlation $Nu = 0.59\ R_a^{.25}$ is used to calculate the heat transfer coefficient. This correlation is good for the Rayleigh number in the range $10^8 < Ra < 10^9$ [2].

<u>Accident Conditions</u>: A small fire corresponding to 2 packages burning simultaneously in the material storage area is analyzed in Ref. 2. Such a fire would result in a short duration increase in the ambient temperature (assumed isothermal) away from the fire and thus will impact all the packages. This ambient temperature during a small fire is expected to remain below 93.3°C. Additional steady-state analyses were performed with an ambient temperature 93.3°C to determine the response of the SAFKEG packaging and its contents. For all analyses, a 19 watts total decay power was uniformly distributed over the volume of the Pu metal and/or oxide as an internal heat source. A summary of the boundary conditions for the normal analyses is as follows:

1. The drum top and bottom surfaces are adiabatic.
2. There is radiative heat transfer from drum sides to the ambient.
3. There is natural convection heat transfer from the drum sides to the ambient.
4. The ambient temperature is 93.3°C.
5. No insolation (solar flux).
6. Undamaged insulation properties [1] are applied to all the insulation in the drum.
7. 19 watts total decay power.

During the accident, the ambient temperature of 93.3°C is assumed to persist for sufficiently long time to reach steady-state conditions. The natural convection coefficients used are based on the temperature difference between the drum surfaces and the ambient temperature. The correlation $Nu = 0.59\ R_a^{.25}$ is used to calculate the heat transfer coefficient. This correlation is good for the Rayleigh number in the range $10^8 < Ra < 10^9$ [2].

ANALYSIS METHODOLOGY

Based on the SAFKEG package geometry, axisymmetric models were developed in PATRAN [3] and run with MSC/Thermal [3]. Figure 2 shows a detailed finite element (FE) axisymmetric model of the SAFKEG packaging with the BNFL configuration for Pu oxide contents. The three axisymmetric SAFKEG models (two 3013 and one SRS Can) contain roughly 3800 nodes each. Metal thicknesses of the SAFKEG components and 3013 containers are modeled in the FE model. However, the convenience cans are modeled only as metal surfaces.

RESULTS

Results of the analyses include temperatures of the SAFKEG packaging and the plutonium contents. The results of the computations are presented in Tables 5 and 6 for the three configurations. The maximum temperatures at key locations are reported for each configuration. In addition, color fringe plots of the six cases are provided in Figures 3 through 8.

<u>Normal Conditions</u>: The following are noteworthy for the normal (48.9°C ambient) case.

1. The maximum predicted temperature for the cork insulation is approximately 107ºC and occurs with the Pu oxide in the SRS Can configuration. The maximum for the TISAF insulation is approximately 73.3°C. The maximum occurs close to the bottom for both the cases. The limiting temperatures for cork and TISAF insulation materials are 180°C and 140°C [1].

2. The maximum outer containment vessel (OCV) temperature is 111°C and the maximum inner containment vessel (ICV) temperature is 130°C both of which are close to the maximum temperatures, 117°C and 128°C [1]. In any case these temperatures are well below the acceptable limits for SS 304L material. The maximum temperatures occur with Pu oxide case in the SRS Can configuration.

3. Maximum Pu metal temperature is 160°C. The maximum temperature for the Pu oxide is 228°C and occurs in the SRS Can configuration.

4. The maximum seal temperature for ICV is 112°C. This is well below the safe operating limit of 160°C [1].

5. Sufficient radial and axial clearances exist in the design that thermal stresses are not a concern for the operating conditions encountered here [1].

<u>Accident Conditions</u>: The following temperatures are noteworthy for the accident (93.3°C ambient) case.

1. The maximum predicted temperature for the cork insulation is approximately 147ºC and occurs with the Pu oxide in the SRS Can configuration. The maximum for the TISAF insulation is approximately 116°C. The maximum occurs close to the bottom for both the cases. The limiting temperatures for cork and TISAF insulation materials are 180°C and 140°C [1].

2. The maximum outer containment vessel (OCV) temperature is 151°C and the maximum inner containment vessel (ICV) temperature is 165°C. These temperatures are well below the ASME acceptable limits for the SS 304L material. The maximum temperatures occur with Pu oxide case in the SRS Can configuration.

3. Maximum Pu metal temperature is 194°C. The maximum temperature for the Pu oxide is 265°C and occurs in the SRS Can configuration.

4. The maximum seal temperature for ICV is 151°C. This is well below the short term safe operating limit of 205°C [1].

5. The estimate for thermal stresses is addressed in the SAFKEG SARP [1]. It is concluded that even if the package is put in 1000°C fire for 43 minutes, thermal stresses are not a concern due to sufficient radial and axial clearances between the ICV and OCV.
6. Table 3.6 (Section 3.5.6) of the SAFKEG SARP [1] estimates the maximum allowable ICV temperature to be 172°C. This is

higher than the maximum temperature of 165°C calculated for the accident steady state analysis. Section 3.5.6 of the SARP [1] concludes that the SAFKEG package is structurally safe for the thermal conditions that result in a 172°C ICV temperature. It can therefore be concluded that the SAFKEG packaging is safe for 93.3°C ambient conditions.

CONCLUSION

The SAFKEG temperatures are found to be very similar for all three configurations. The highest Pu metal temperatures are lower than the Pu oxide case when the oxide is packed in one container. The SAFKEG packaging temperatures for all three configurations during normal storage conditions are well below the limiting values identified in the SAFKEG SARP. For the remote fire accident conditions, the SAFKEG temperatures are also below the limiting temperatures.

ACKNOWLEDGMENTS

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2. Theory and Problems of Heat Transfer, by Pitts, D. R. and Sissom, L. E., McGraw-Hill Book Company, 1977.
3. MSC/Thermal, MacNeal-Schwendler Corporation, Los Angeles, CA 90041.
4. Safety Analysis Report for Packaging Model 9975 B(M)F-85, WSRC-SA-2002-00008, 2003.

Table 1: SAFKEG Configurations

Name	Outer Container	Inner Container	Convenience Container
BNFL	BNFL 3013	BNFL	BNFL
Rocky Flats	BNFL 3013	BNFL	Rocky Flats
SRS	BNFL 3013	SRS cans	No

Table 2: Content Can Dimensions

Container	Diameter X Height (in.)
BNFL Outer 3013	4.92 X 10.0
BNFL Inner Container	4.61 X 9.095 (top of lip) 4.61 X 8.80 (top of plug)
BNFL /Rocky Can	4.29 X 8.435
SRS Inner Container	4.6 X 4.625

Table 3: Emissivity of Different Materials

Component	Emissivity
Insulation	0.50
Drum Outer Surface	0.21
3013 Container	0.30
BNFL Middle Can	0.30
BNFL Convenience Can	0.30
Pu Oxide	0.90
Pu Metal	0.90
Rocky Convenience Can	0.30

Table 4: Constitutive Properties of Packaging Materials

Material	Density (kg/m^3) @ T(°K)	Conductivity (W/m - °K) @ T(°K)	Sp. Heat (J/kg- °K) @ T(°K)
Helium [2]	0.2435 @ 200.2 0.1906 @ 255.2 0.1328 @ 366.2 0.1020 @ 477.2 0.0828 @ 589.2 0.0703 @ 700.2 0.0602 @ 811.2	0.1176 @ 200.2 0.1356 @ 255.2 0.1690 @ 366.2 0.1972 @ 477.2 0.2248 @ 589.2 0.2508 @ 700.2 0.2750 @ 811.2	5196.5 @ 200.2 5196.5 @ 255.2 5196.5 @ 366.2 5196.5 @ 477.2 5196.5 @ 589.2 5196.5 @ 700.2 5196.5 @ 811.2
Air [2]	100 @ 3.6 200 @ 1.77 300 @ 1.18 400 @ 0.783 500 @ 0.642 600 @ 0.543 700 @ 0.471 800 @ 0.415	100 @ 9.40 E-3 200 @ 18.4 E-3 300 @ 26.2 E-3 400 @ 33.3 E-3 500 @ 39.7 E-3 600 @ 45.7 E-3 700 @ 52.3 E-3 800 @ 57.8 E-3	1046 @ all temp.
Cork (Insulation) [1]	290 @ 293.15	0.068 @ 293.15 0.079 @ 343.15 0.087 @ 381.15	1650 @ 293.15 1650 @ 343.15 1650 @ 381.15
TISAF (Insulation) [1]	400 @ 293.15	0.072 @ 293.15 0.088 @ 343.15 0.102 @ 381.15	850 @ 293.15 850 @ 343.15 850 @ 381.15
Stainless steel (304, 316) [1]	7900 @ 293.15	14.90 @ 293.15 17.00 @ 422.15 18.00 @ 477.15	460 @ 293.15 460 @ 422.15 460 @ 477.15
Pu oxide [4]	1999 @ 293.15	0.0796 @ all temp.	92.05 @ all temp.
Pu metal [4]	19200 @ 293.15	1.6736 @ 83.8 3.3472 @ 191.8 4.6024 @ 227.8 7.9496 @ 335.8 10.042 @ 407.8 12.552 @ 479.8 13.389 @ 515.8 15.899 @ 539.8	133.9 @ 305.2 137.2 @ 485.2 729.7 @ 530.2 123.0 @ 575.2 123.0 @ 620.2 302.9 @ 665.2 166.9 @ 710.2 1115.2@ 166.9

Table 5: Steady State Temperatures (°C) for Normal Conditions

Location	BNFL	Rocky Flats	SRS Cans
Drum Top	61.8	61.9	63.1
OCV O-ring	87.8	87.7	93.0
ICV O-ring	98.6	97.5	112.0
OCV	101.0	107.0	111.0
ICV	115.0	126.0	126.0
Pu or PuO_2 Centerline	214.0	160.0	228.0
TISAF, Insulation	69.3	71.1	73.3
Cork, Inner Insulation	97.4	103.0	107.0

Table 6: **Steady State Temperatures (ºC) for Accident Conditions**

Location	BNFL	Rocky Flats	SRS Cans
	°C	°C	°C
Drum Top	106	106	107
Drum Bottom	104	105	106
Drum Side	101	101	102
OCV O-ring	129	129	134
ICV O-ring	139	138	151
OCV	141	146	151
ICV	153	163	164
Pu or PuO_2 Centerline	251	194	265
TISAF, Insulation	112	114	116
Cork, Inner Insulation	137	143	147

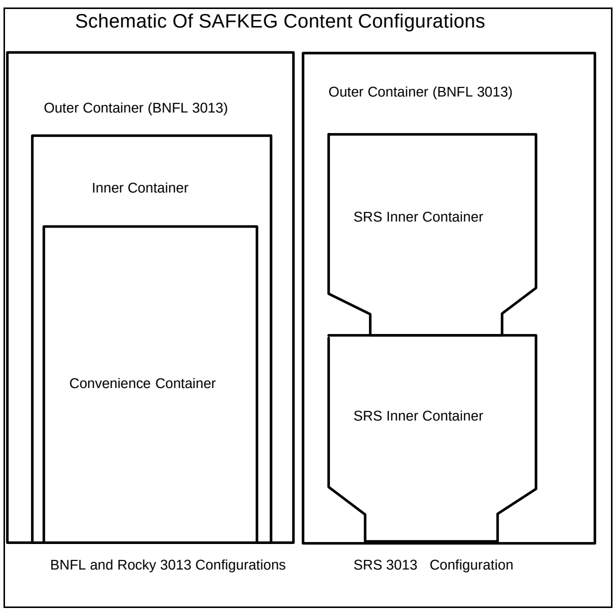

Figure 1 – Content Can Configuration

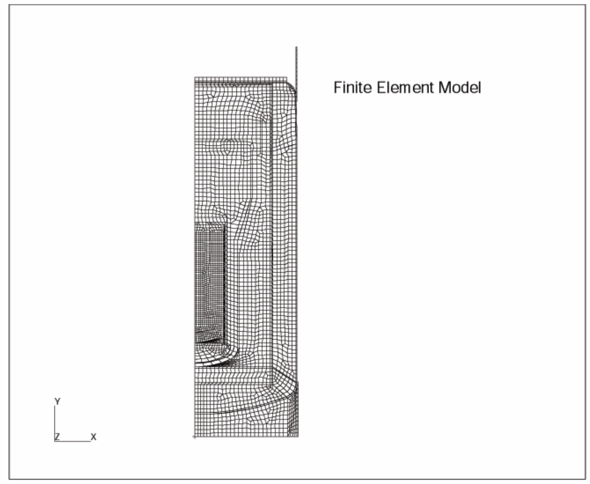

Figure 2 – Finite Element Model for SAFKEG

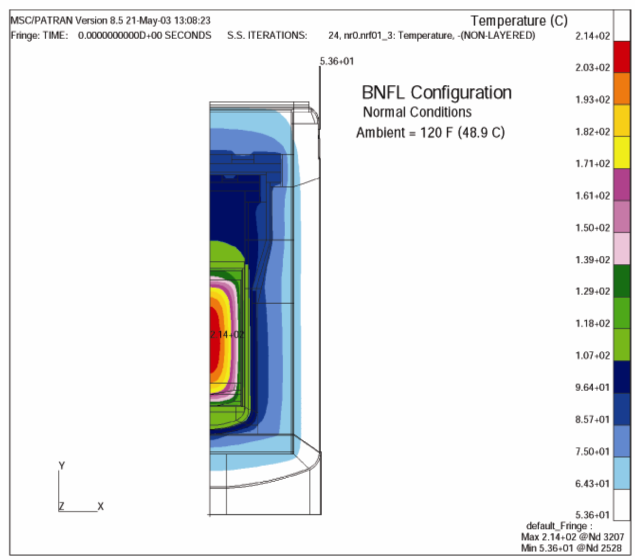

Figure 3 – Temperature Contours for BNFL Configuration for Normal Conditions

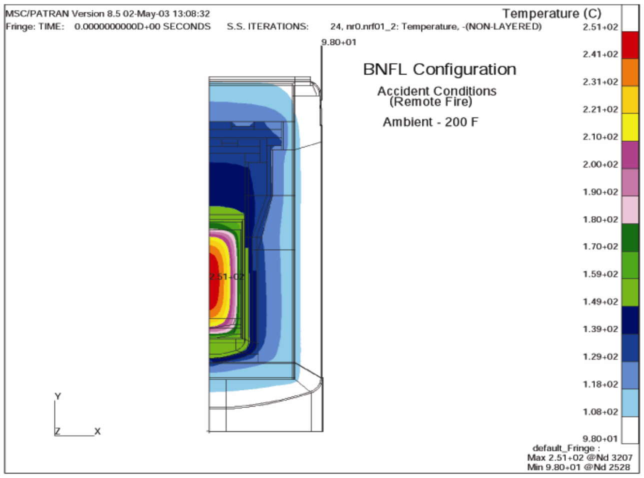

Figure 4 - Temperature Contours for BNFL Configuration for Accident Conditions

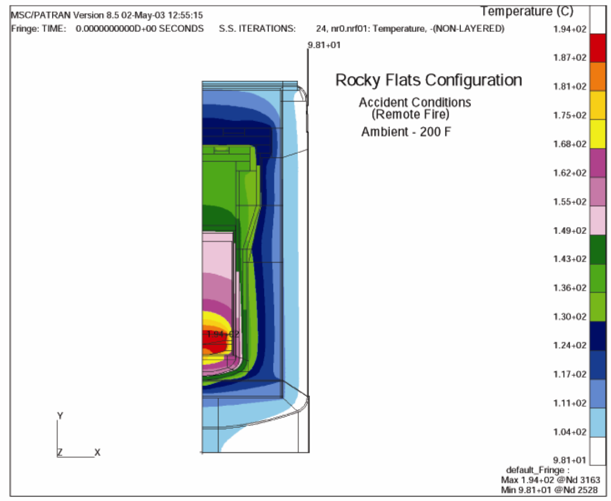

Figure 6 – Temperature Contours for Rocky Flats Configuration for Accident Conditions

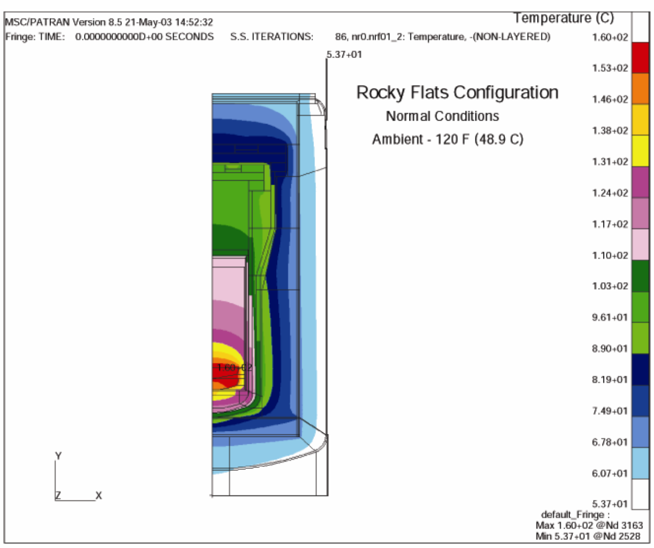

Figure 5 – Temperature Contours for Rocky Flats Configuration for Normal Conditions

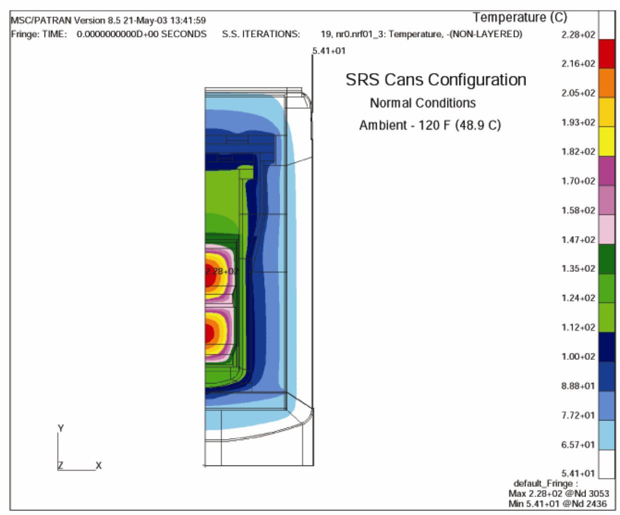

Figure 7 - Temperature Contours for SRS Cans Configuration for Normal Conditions

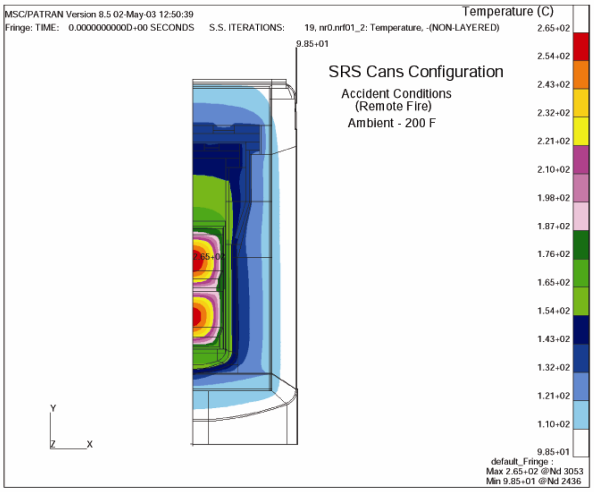

Figure 8 - Temperature Contours for SRS Cans Configuration for Accident Conditions