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Model 9975 SAR Submittal Meeting 2

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Model 9975 SAR Pre-submittal Meeting

SRNL-L4500-2012-00085

EM Environmental Management

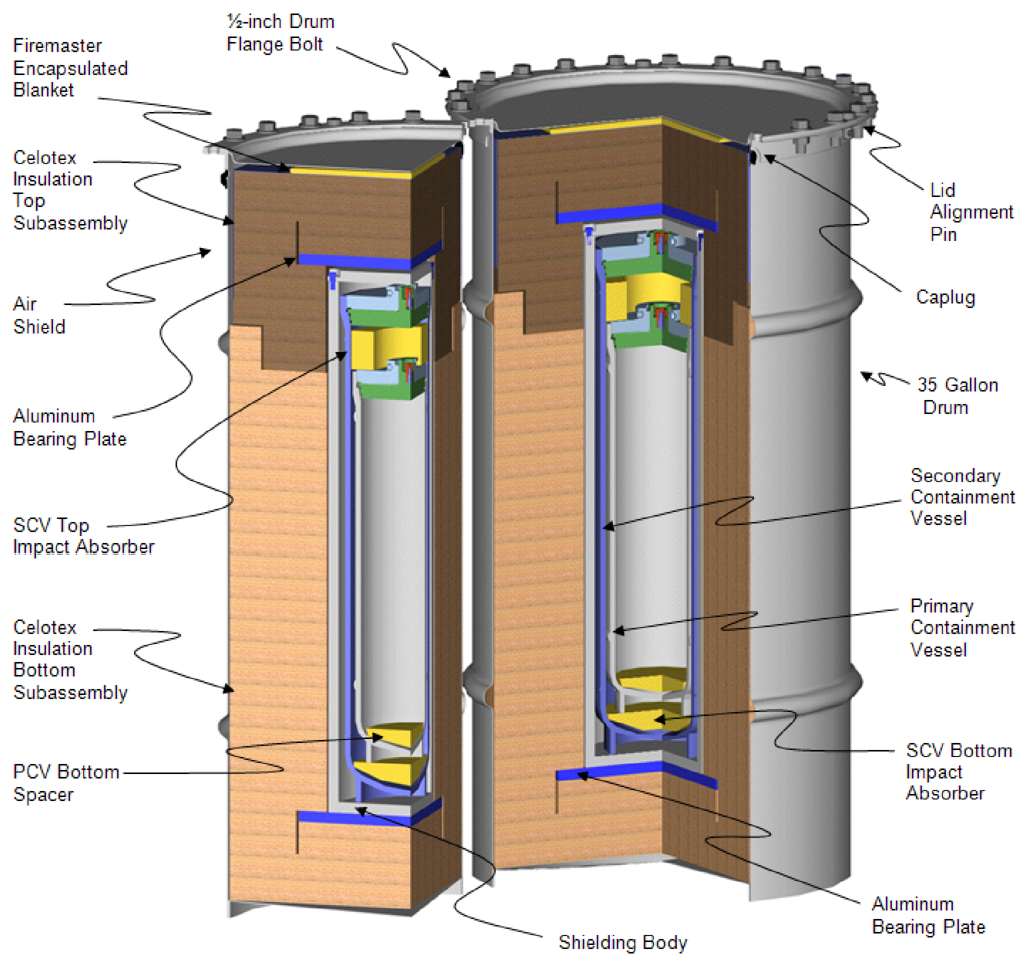
safety ❖ performance ❖ cleanup ❖ closure

DOE Packaging Certification Program

Agenda

- Introductions
- Changes since last meeting
- Description of new content envelope
- Corrosion Test Results
- Thermal Analysis Results
- Shielding/ Criticality Analysis Results
- Path Forward

Model 9975 Shipping Package



Strategy Changes Since Last Meeting

- Content envelope has been changed significantly. C.11 was too broad in impurity allowance
  - Content envelope split into weapons grade and fuels grade oxides
  - Impurity limits taken from actual 3013 data
- License drawings will be included in the submittal
- Lead shield bodies without an outer stainless skin will be part of this submittal (Previously Excluded)

Major analyses since last meeting

- **New NCT thermal analysis has been performed using FLUENT software**
  - FLUENT results benchmarked against PThermal results
  - Results show lower NCT temperatures than HAC temperatures
- **Shielding Analyses Preliminary Results**
  - Maximum amount for Be & F
  - Still defining the content table
- **Criticality Analysis**
  - Flooded, damaged HAC array analysis has been performed
  - Effects of Be and C included

Proposed Content Envelopes

- **Content envelopes have not been finalized**
- **Two preliminary content envelopes**
  - C.12 Weapons Grade Isotopics
    - Less than 7% Pu-240
    - Less than 0.05% Pu-238
  - C.13 Fuels Grade Isotopics
    - Between 7% and 15% Pu-240
    - Less than 0.1% Pu-238

Proposed Content Envelopes

- **C.12 & C.13 Impurities**
  - Based on known Be/F 3013 population Be & light element values.
  - Actual dose rate measurements are within non-exclusive use limits for the 9975 package even though shipped exclusive use
  - Calculated theoretical dose rates at full loading > non-exclusive use dose rate limit with perfect mixing
  - Bounding criticality shows all contents less than k_{safe}

Proposed Content Envelopes

	Material	C.12	C.13
		Pu/U Oxides grams	Pu/U Oxides grams
Radioisotope (Radioactive Material Mass)	^{236}Pu		
	^{238}Pu	2.2	4.4
	^{239}Pu	4114	3789
	^{240}Pu	264	528
	^{241}Pu	18	70.4
	^{242}Pu	2.2	8.8
	$^{241}Am + ^{241}Pu$	18	70.4
	^{243}Am	1.00	1.00
	^{244}Cm	0.0044	0.0044
	^{237}Np	220	220
	^{232}U	0.00044	0.00044
	^{233}U	427	427
	^{234}U	4400	4400
	^{235}U	4400	4400
	^{236}U	2640	2640
	^{238}U	4400	4400
	^{232}Th	4400	4400
Impurities (grams)	Al	3000	500
	Mg	3000	2000
	Na	3000	600
	F	400	400
	Be	150	150
	C	1000	1000
Total Mass (kilograms)	Radioactive Materials	4.4	4.4
	Impurities	3.08	3.08
	All Contents	5	5

Proposed Content Envelopes Impurities

- **C.12 & C.13 Impurities**
- **Based on known Be/F 3013 population Be & light element values**
  - Highest Be and F wt% not from same 3013
  - Be, F, Na, Mg, & Al impurity values based on wt% of maximum (5 kg) material mass

Beryllium and Fluorine Content by Prompt Gamma

- **SRS has over 5,000 3013s in Storage**
- **Beryllium**
  - Maximum Be concentration in a container is 2.4% of material mass
  - 40 containers between 1.0% and 2.4%
  - 90 containers between 0.1% and 1.0%
  - Remainder less than 0.1%
- **Fluorine**
  - Maximum F concentration in a container is 7.2% of material mass
  - 160 containers between 1.0% and 7.2%
  - 400 containers between 0.1% and 1.0%
  - Remainder less than 0.1%

Dose Rates Measured by Shipper ($\gamma + n$)

- **At surface of bare 3013 Container**
  - Maximum container dose rate was 900 mrem/hr
  - 15 containers between 500 and 900 mrem/hr
  - 185 containers between 200 and 500 mrem/hr
  - Remainder less than 200 mrem/hr
- **30 cm from surface of bare 3013 Container**
  - Maximum container rate was 230 mrem/hr
  - 5 containers between 200 and 230 mrem/hr
  - Remainder less than 200 mrem/hr

Dose Rates Measured by Shipper ($\gamma + n$) (Continued)

- **At surface of loaded 9975 Shipping Package**
  - Maximum shipping package dose rate was 180 mrem/hr (less than non-exclusive dose rate limit of 200mrem/hr)
  - 15 shipping package between 100 and 180 mrem/hr
  - Remainder less than 100 mrem/hr

Sampling of Highest Beryllium Items

- Item A: 2.4% Be, 0% F
- Item B: 1.8% Be, 0% F
- Item C: 1.5% Be, 0% F
- Item D: 1.5% Be, 0% F
- Item E: 1.4% Be, 0% F
- Item F: 1.3% Be, 0.08% F
- Item G: 1.3% Be, 0% F
- Item H: 1.3% Be, 0% F
- Item I: 1.2% Be, 0% F
- Item J: 1.2% Be, 0% F

Sampling of Highest Fluorine Items

- Item K: 0% Be, 7.2% F
- Item L: 0% Be, 6.0% F
- Item M: 0.03% Be, 5.7% F
- Item N: 0% Be, 4.9% F
- Item O: 0% Be, 4.6% F
- Item P: 0% Be, 4.3% F
- Item Q: 0.03% Be, 4.0% F
- Item R: 0% Be, 3.8% F
- Item S: 0% Be, 3.4% F
- Item T: 0.08% Be, 3.3% F

License drawing development

- **Existing 9975 drawings are both fabrication and license drawings**
- **Feedback from last meeting was to develop license drawings**
- **License drawings are under development**
  - Drawings will be checked against all previous deviation approvals
  - Drawings will retain material lists, specifications, codes & Standards information
  - Information not related to licensing will be removed

DOE-STD-3013 Container Set

Corrosion Issues

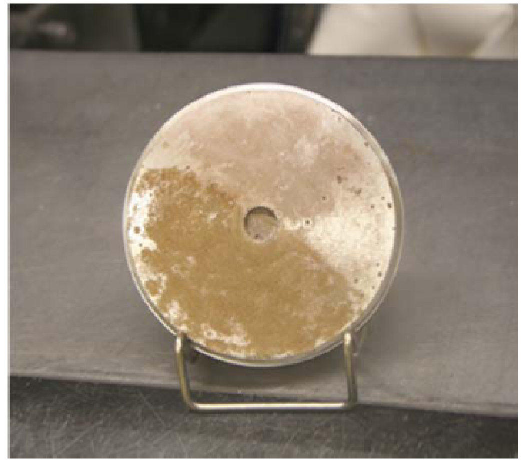
- The double seal welded 3013 containers are designed to contain 5kg of Pu oxide for 50 years
- Pu Oxide is never in contact with the 9975 containment vessel
- 3013 containers are required to be 300 stainless steel
- Although 3013 vessels are <u>NOT</u> credited in the 9975 transport package, extensive corrosion studies have been performed on 3013 vessels in service
- 3013 barrier is defense in depth

Surveillance Program Destructive Examination

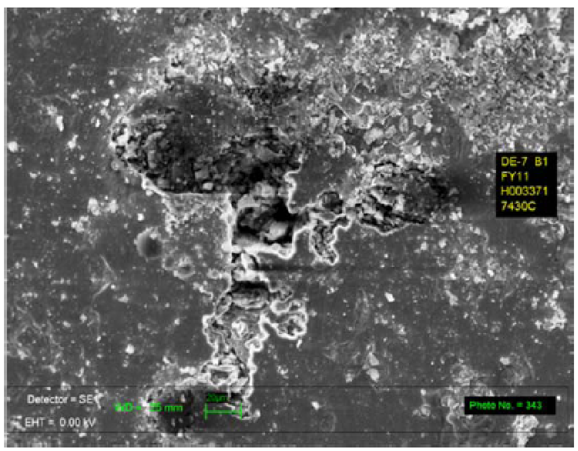
- **3013 containers are binned for corrosion concerns (high Cl, F and water content)**
- **More than 70 3013 containers have been destructively examined**
- **DE cans must be a minimum of five years in service**
  - Some selected at random
  - Some selected based on engineering judgment (pressure/corrosion)

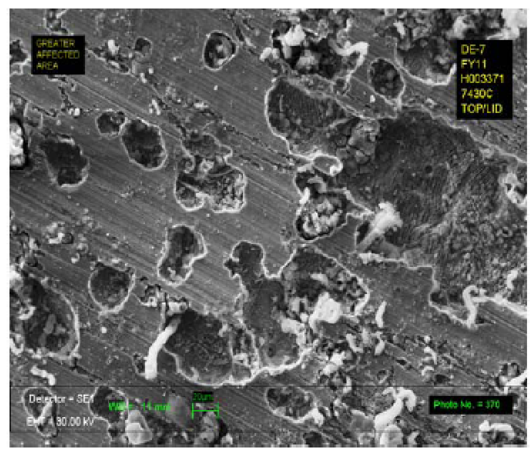
Typical convenience can examination

Convenience can



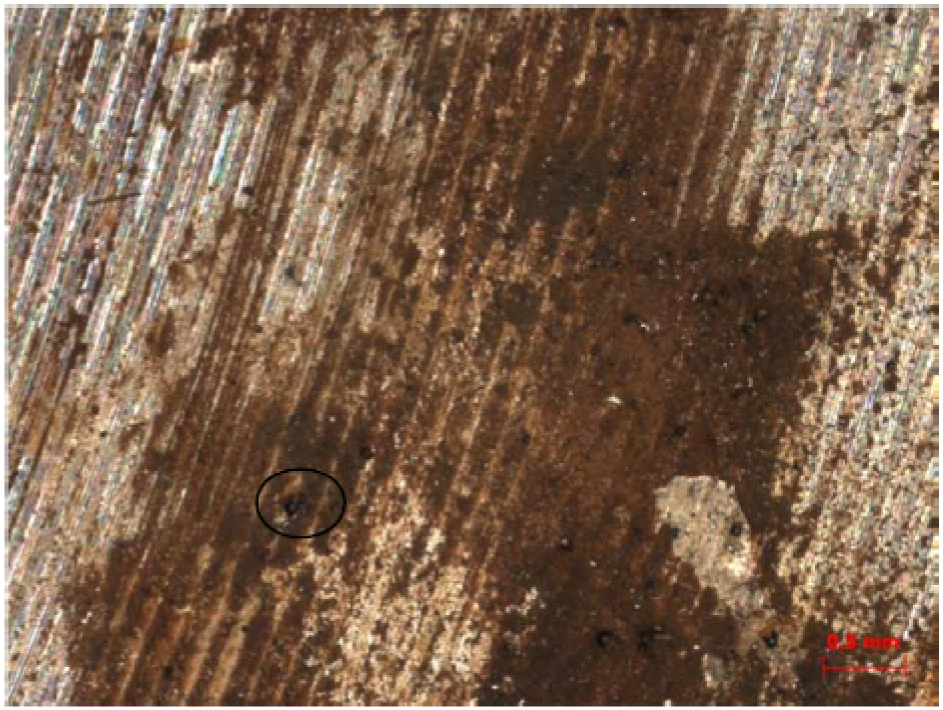
Convenience lid





SEM Photomicrograph of convenience can and l id

Largest Inner can Pit



Inner can bottom (25X, uncleaned, circled pit largest measured)

Surveillance Program Destructive Examination Results

- Localized pitting corrosion has been found on convenience containers (Particularly on threads)
- No penetration of the convenience container wall has been found
- Gas phase corrosion has been found on inner can with a few localized pits
- Pit depths found thus far do not challenge the container integrity
- Multiple barriers and slow corrosion rate prevent corrosion concerns for 9975 Vessel

Lead thinning from carbonate corrosion

- Lead thinning/loss of lead from carbonate corrosion of shield bodies without an outer stainless steel skin is a recognized possibility in the current SARP
- Maximum corrosion rate is 2 mils per years
- Minimum initial lead thickness is 470 mils
- For Pu Oxide contents proposed, loss of 100 mils of lead (50 year shield life) does not raise package dose rates (neutron dominated)
- For conservatism, a shield body service life of 30 years will be applied

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Model 9975 SAR

Chapter 3 - Thermal

Steve Hensel - SRNL

Model 9975 SAR Pre-submital Meeting

EM Environmental Management

safety ❖ performance ❖ cleanup ❖ closure

DOE Packaging Certification Program

Outline

Description of 9975

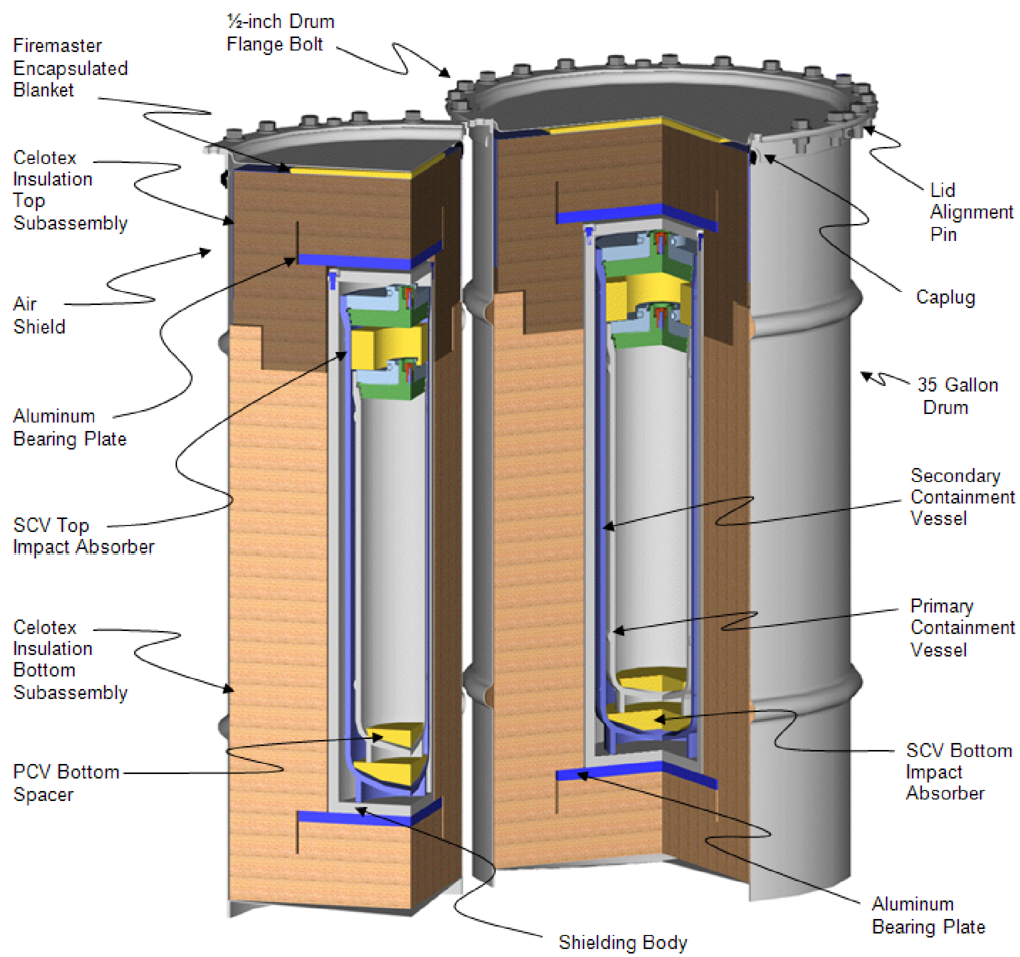
Thermal Design Features

Summary of Thermal Evaluation Results

NCT Thermal Evaluation

HAC Thermal Evaluation

Model 9975 Shipping Package



Model 9975 Shipping Package

Thermal Design Features

- Celotex (Fiberboard) for fire protection
- Air shield for preventing smoldering
- Vent holes to prevent overpack failure during fire
- Thermal blanket in the lid for added fire protection

Summary of Thermal Evaluation Results

Maximum Component Temperatures

	NCT (°F)		HAC (°F)		
Location	Steady State	**Limit**	**Transient**	Steady State	**Limit**
PCV	236	300	206	260	300
PCV O-ring	219	400	187	241	400
SCV	223	300	203	247	300
SCV O-ring	212	400	185	238	400
Shield	216	622	204	237	662
Contents	466	N/S	432	486	N/S
Fiberboard	214	250	N/A	N/A	N/A
Drum	188	N/S	1475	204	2650

N/A – not applicable; N/S – not specified

Observations:

- **Containment vessels design limits are very conservative (low)**
- **HAC temperatures during fire transient are lower than NCT temperatures**

Summary of Thermal Evaluation Results

Maximum Pressures (psig)

	PCV	SCV	Gas Temperature (°F)
NCT	245.1	126.8	271
HAC	251.1	130.1	288
Design Limit	900	800	N/A

Notes:

1. The pressures are based on 3013 configuration (C.11 source) and FLUENT analyses. SCV gas temperatures are conservatively assumed same as the PCV gas temperatures. **These pressures are well below the pressures in the existing safety analysis report (SARP) and therefore there is no impact on the structural analyses.**
2. The pressure estimates are based on radiolysis of 0.5% (25 grams) of moisture, helium production from decay of PuO_2, and heating of fill gases.
3. 3013 containers do not allow plastics. Therefore there is no pressure contribution from off-gassing of plastics.

NCT Thermal Evaluation

Methodology

- Environmental chamber prototype testing
- Benchmarked computational model. **This model was developed during 90's using computer code P/Thermal.**
- Comparison between FLUENT & P/Thermal models to gain confidence in the FLUENT results. A comparison for a simplified benchmark model is shown below.

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

- Final NCT results using FLUENT are presented.

NCT Thermal Evaluation

Model Parameters

- Upright orientation
- Axisymmetric geometry including all the gaps
- Fill gas as air in the 3013 containers rather than helium
- Temperature dependent material properties
- Surface to surface radiation and conduction in gaps
- 19 watts of heat generation and
- Insolation all around except at the bottom

Boundary Conditions

- Bottom adiabatic
- Convection and radiation heat losses from the drum surface
- Solar heat flux all around except at the bottom

NCT Thermal Evaluation

NCT Results with and without Insolation using FLUENT

Component	Solar (°F)	Shade (°F)	Limit (°F)
PCV	239	181	300
PCV O-rings	219	160	400
SCV	225	166	300
SCV O-rings	216	156	400
Insulation	214	155	250
Drum	187	114	800
Contents	466	411	NA
Shield	216	156	622
PCV Cavity (Average)	271	215	313*

*** Temperature corresponding to the current MNOP values.**

NCT Thermal Evaluation

Conservative Model Parameters

- Adiabatic bottom
- Solar flux all around rather than directional

Conclusions

- Derived temperatures during NCT have good safety margins for all components.
- Average gas temperature (271°F) is less than 313°F (current maximum PCV gas temperature), therefore, the MNOP calculations are not affected.

NCT Thermal Evaluation

Sensitivity Analyses

Sensitivity analyses are performed to address uncertainty in solar absorptance (α) and thermal emittance (ε) of the drum surface. Polished, medium and very dull surface finishes are analyzed. **(Drums are fabricated by rolling, bending and welding operations. No machining or sandblasting operations are performed).** The sensitivity analysis results are shown below.

Surface	α	ε	PCV (°F)	O-rings (°F)	Insulation (°F)
Stainless as received (close to polished)	0.391	0.124	234	214	210
Stainless as received (medium) **Reference Surface**	0.498	0.210	239	219	214
Stainless as received (very dull surface)	0.570	0.296	239	219	215

Note: Solar absorptivity and thermal emittance for the stainless steel surfaces used above have been found to be quite consistent with other (NASA) publications. Surface properties for the rolled plates used in the 9975 drum are close to the polished surface values shown above. Therefore, Reference Surface chosen is conservative.

HAC Thermal Evaluation

Methodology

- Prototype furnace tests
- Benchmarked computational model. **This model was developed during 90's using computer code P/Thermal**.
- Benchmarked model attributes are included in the FLUENT models to get the HAC results.

- An undamaged 9975 prototype with 21 watts heater in the PCV was tested in a controlled environment. The specimen was heated for 120 hours to meet the 10 CFR Part 71 <u>initial condition requirement</u>.
- The package was then exposed to 1500°F or higher furnace environment for nearly 40 minutes including the ramp up/down time of 10 minutes. The component temperatures were monitored during cooldown.
- The benchmarked PATRAN/Thermal model attributes are now duplicated in the FLUENT model for final HAC analyses.

HAC Thermal Evaluation

HAC Analyses included:

- Proper initial conditions, 100°F in shade
- Contents thermal loading, 19 watts
- Proper fire temperature (800°C), fire emissivity (1.0), surface absorptivity 0.9 and forced convection thermal loading
- Postfire phase with natural convective cooling, full insolation (α=1.0) and low drum surface emissivity (0.8).

Conclusions

- The HAC thermal results are based on benchmarked models and represent realistic component temperatures.
- The HAC results have good safety margins.

HAC Thermal Evaluation

HAC Temperatures with Insolation using FLUENT

Component	Transient Maximum (°F)	Steady State (°F)	Limit (°F)
PCV	206	260	300
PCV O-rings	187	241	400
SCV	203	247	300
SCV O-rings	185	238	400
Shield	204	237	622
Contents	432	486	NA
Drum	1475	204	2650
Gas (Average)	< 288	288	NA

- **Maximum temperatures occur during 4 hours of the postfire cooldown. Insolation effect is rather small during this time.**
- **Steady state temperatures are calculated using solar absorptivity of 1.0 and a surface emissivity of 0.8. Solar effect is dominant under steady state conditions.**
- **HAC steady state temperatures are higher than NCT/Solar temperatures.**

Deflagration and Detonation Evaluation

Deflagration and Detonation Considerations

3013 containers packaged in accordance with the 3013 standard must have:

- No more than 0.5% adsorbed moisture in the contents
- No more than 5% oxygen in the fill gases. The remaining gases must be inert gases like helium or nitrogen.

The PCV is diluted to a minimum of 75% CO_2 and the SCV has air. If these conditions are met, a flammable H_2/O_2 mixture will not form to cause deflagration or detonation in the PCV or the SCV.

However, as a defense in depth approach to the package safety, the current 9975 SARP does have deflagration and detonation analyses. The SARP assumes:

- Stoichiometric mixture of H_2/O_2
- 3013 container leaking into PCV and PCV leaking into SCV
- Oxygen, helium and CO_2 mixtures in the PCV and the SCV

NCT Thermal Evaluation

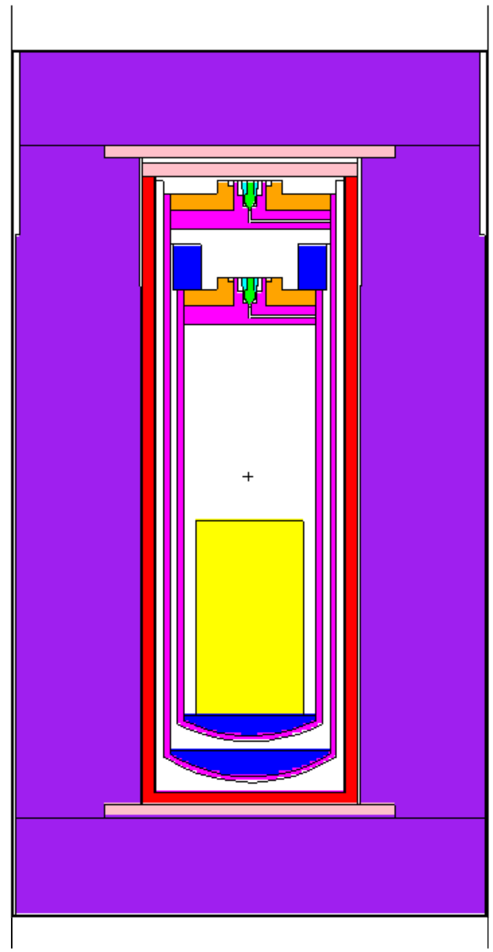
Results of Deflagration and Detonation Analyses

- The deflagration in the PCV is a low-energy event and results in only 1°F increase in PCV gas temperatures. The maximum deflagration pressure is 62 psig.
- If the PCV leaks into SCV, the deflagration pressure is 192 psig.
- Since the deflagration event is not expected, these pressures are not added to the MNOP.
- Deflagration-to-Detonation Transition (DDT) is evaluated using the detonation cell size concepts. The calculated cell sizes are well above the annular spaces in the 3013 configurations and, therefore, no DDT is expected.

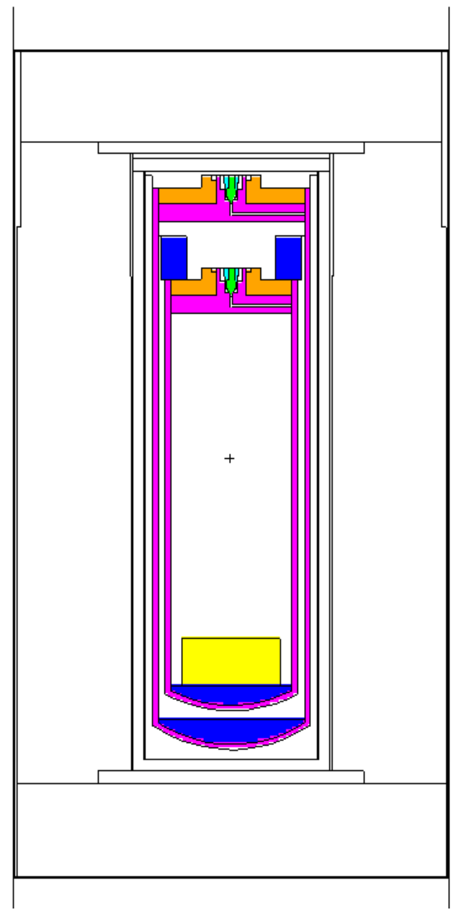
Chapter 5 (Shielding) – General Approach

- **Analyze Two Content Envelopes**
  - Weapon Grade Plutonium Oxide (C.12)
  - Fuel Grade Plutonium Oxide (C.13)
- **Dose Rate with maximum of each impurity**
  - NCT and HAC
- **Analyze Effects of Thinning of Lead Shield**

Chapter 5 (Shielding) – NCT Model



Chapter 5 (Shielding) – HAC Model



Chapter 5 (Shielding) – Dose Rate with Impurities

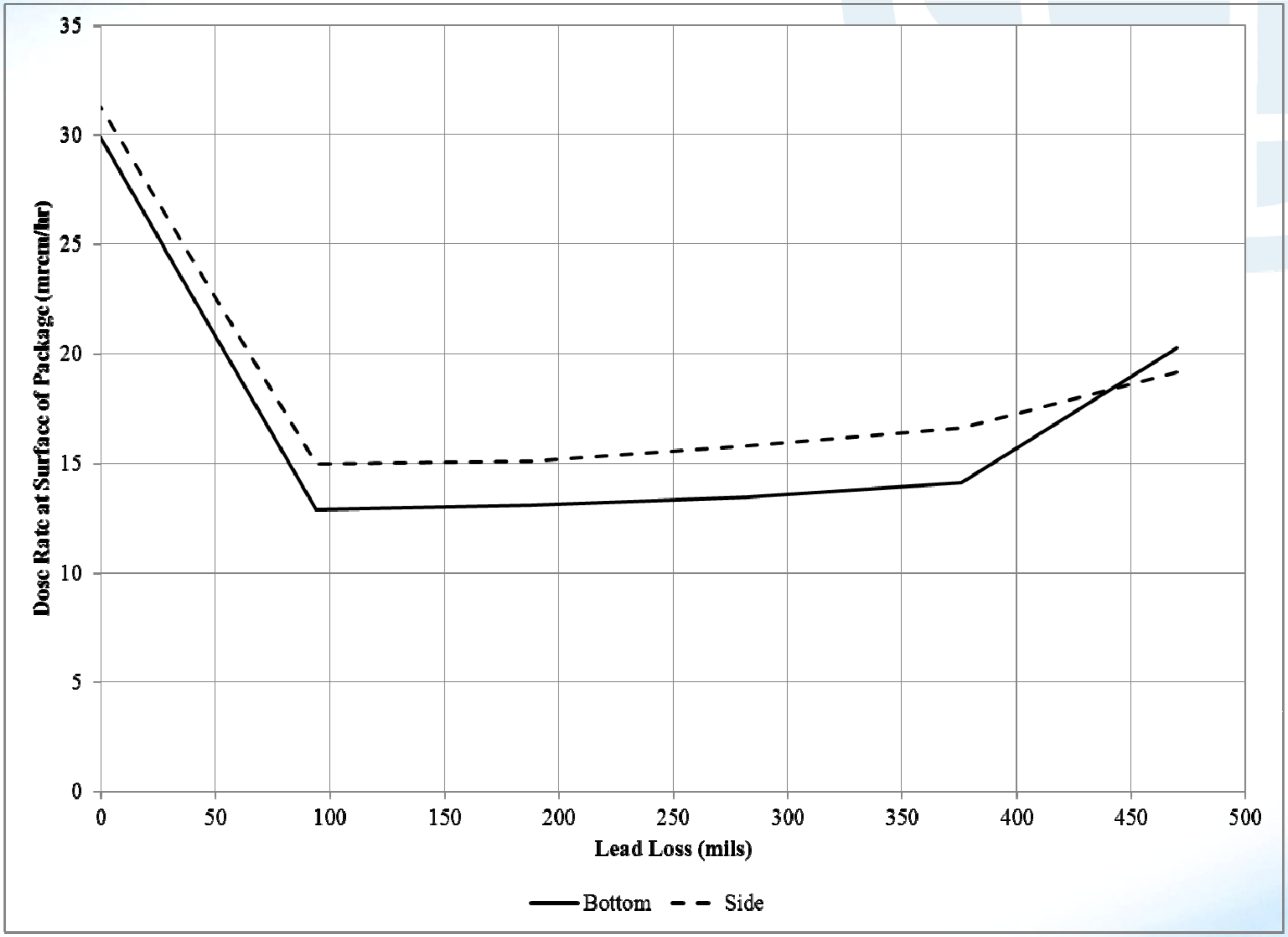
Element	WG			FG		
	Mass (g)	Surface	1 meter	Mass (g)	Surface	1 meter
		Dose Rate (mrem/hr)			Dose Rate (mrem/hr)	
Al	3080	50	2	3000	92	3
Be	150	2101	70	150	3479	116
F	400	442	15	400	764	25
Mg	3080	113	4	2000	235	8
Na	3080	133	4	600	176	6
Be and F	550	2166	72	550	3594	121
Limit		200	10		200	10

Shaded values are above the limit

Chapter 5 (Shielding) – Dose Rate with 150 g Be

Material	Weapon Grade PuO_2	Fuel Grade PuO_2	10CFR71 Limit	Material	Weapon Grade PuO_2	Fuel Grade PuO_2	10CFR71 Limit	Material	Weapon Grade PuO_2	Fuel Grade PuO_2	10CFR71 Limit
NCT at Surface (mrem/hour)				NCT 1 meter away (mrem/hour)				HAC 1 meter away (mrem/hour)			
SIDE				SIDE				SIDE			
Neutrons	2091	3460	—	Neutrons	69.93	115.75	—	Neutrons	95.17	157.64	—
Photons	11	19	—	Photons	0.37	0.64	—	Photons	0.91	1.50	—
Total	2101	3479	200	Total	70.30	116.39	10	Total	96.08	159.14	1000
TOP				TOP				TOP			
Neutrons	122	197	—	Neutrons	8.18	13.58	—	Neutrons	8.08	13.39	—
Photons	1	1	—	Photons	0.05	0.08	—	Photons	0.03	0.06	—
Total	123	198	200	Total	8.22	13.67	10	Total	8.11	13.45	1000
BOTTOM				BOTTOM				BOTTOM			
Neutrons	2002	3310	—	Neutrons	61.19	101.31	—	Neutrons	86.73	143.65	—
Photons	11	20	—	Photons	0.31	0.54	—	Photons	0.78	1.29	—
Total	2014	3330	200	Total	61.49	101.86	10	Total	87.51	144.94	1000

Effect of Lead Thinning



Chapter 5 (Shielding) – Conclusions

- The dose rate with maximum impurities exceeds the 10 CFR 71 limits when conservatively calculated as intimately mixed with 5 kg oxide
- Measured dose rates at the surface of the 9975 shipping package are less than 180 mrem/hr
- This implies that the impurities are not intimately mixed with the plutonium oxide

Chapter 6 (Criticality) – Results

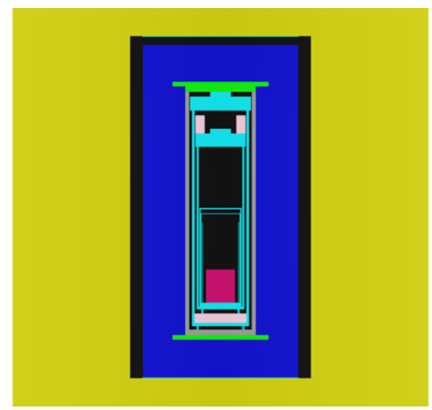
- **Maximum Reactivity**
  - Single Unit Intact 0.632
  - Single Unit Damaged 0.745
  - NCT Infinite Array 0.654
  - HAC Infinite Array 0.742
- **Criticality Safety Index**
  - CSI = 0 (infinite arrays of intact and damaged packages remain subcritical)

Chapter 6 (Criticality) – General Approach

- **Analyze all oxide as pure plutonium-239 for**
  - Single Unit
    - Dry
    - Flooded
  - Normal Conditions of Transport Array
    - Dry
  - Hypothetical Accident Conditions Array
    - Dry
    - Flooded

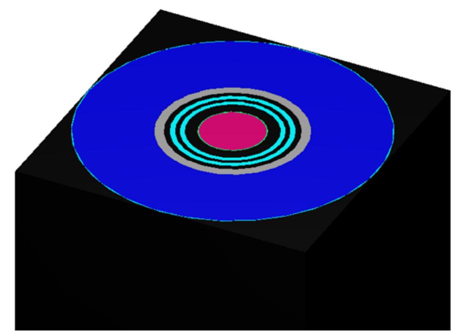
Chapter 6 (Criticality) – Single Unit

- 5 kg of PuO_2
- 0.5 wt% water added
- Up to 500 g Be added
- Fissile material modeled as a cylinder with H/D=1
- Most reactive configuration including moderation by water determined (10 CFR 71.55)



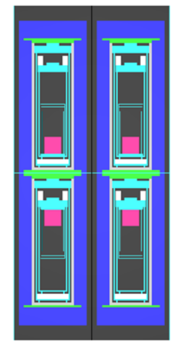
Chapter 6 (Criticality) – NCT Array

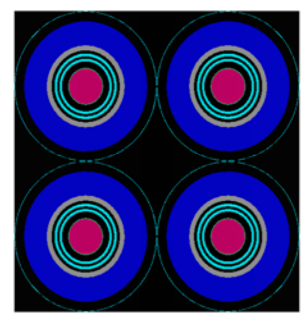
- Infinite array
- 5 kg of PuO_2
- 0.5 wt% water added



Chapter 6 (Criticality) –

- 5 kg of PuO_2
- 0.5 wt% water added
- Drum dimensions reduced based on test data
- Celotex outer dimensions reduced based on fire data
- Flooding of PCV and SCV considered





Chapter 6 (Criticality) – Results

Single Unit Results	
Package calculated to be subcritical under most reactive conditions	Max. $k_{eff} + 2\sigma = 0.745$ (for 9975 flooded condition)
Most reactive configuration	Convenience Can – Filled with Pu water solution (Pu-oxide solution, 3.5862 g/cc – 5.025 kg)
Moderation for most reactive configuration	3013/PCV/SCV/Celotex® - Fully water flooded
Reflection for most reactive configuration (package materials and/or 30 cm water)	30 cm water
Array Results	
NCT Array	Max. $k_{eff} + 2\sigma = 0.655$
Number of packages	Infinite
Water in drum voids	None, dry system
Most reactive fissile content	Dry Pu oxide Dry means 0.5% water content. (5.0 kg) in convenience can (oxide, 10.8921 g/cc)
Reflection surrounding array	Not applicable for infinite array
HAC Array	Max. $k_{eff} + 2\sigma = 0.742$
Number of packages	Infinite
Most reactive fissile content	Dry Pu oxide Dry means 0.5% water content. (5.0 kg) in convenience can (oxide, 10.8921 g/cc)
Moderation to credible extent	None, dry content
Reflection surrounding array	Not applicable for infinite array

$k_{safe} = 0.947$

Chapter 6 (Criticality) – Results

- **Criticality Safety Index**
  - CSI = 0 (infinite arrays of intact and damaged packages remain subcritical)

Normal Conditions of Transport (N = ∞)	
Number of undamaged packages that remain subcritical in array	Infinite
Most reactive credible physical and chemical form of fissile material	Dry Pu oxide*
Most reactive interspersed hydrogenous moderation	None, dry content
Most reactive reflecting material	Not applicable for infinite array
Reflection surrounding the array	Not applicable for infinite array
Hypothetical Accident Conditions (N = ∞)	
Number of damaged packages to remain subcritical	Infinite
Most reactive credible physical and chemical form of fissile material	Dry Pu oxide*
Most reactive interspersed hydrogenous moderation	None, dry content
Most reactive reflecting material	Not applicable for infinite array
Reflection surrounding the array	Not applicable for infinite array

* Dry means 0.5% water content

Conclusion

- Contents envelope is still being defined
- Extensive studies with 3013 material address Cl/F corrosion concerns
- Thermal analyses have been performed using FLUENT addressing staff concerns from first meeting
- License drawings will be included in submittal
- Submission is anticipated in February/March