Enclosure 5

AREVA Calculation

TN40HT-0513, Revision 1
Non-Proprietary

Evaluation of the Potential for the Buildup of Flammable Gases in the TN-40 Dry Cask System

35 pages follow

Non-Proprietary Version

AREVA	Form 3.2-1 Calculation Cover Sheet TIP 3.2 (Revision 6)	Calculation No.	TN40HT-0513
		Revision No.	1
			Page 1 of 35
DCR NO (if applicable): 10427-35	**PROJECT NAME:**	TN-40HT High Burnup Storage and Transport Cask Design	
PROJECT NO: 10427	**CLIENT:**	Xcel Energy	

CALCULATION TITLE:
Evaluation of the potential for the buildup of flammable gases in the TN-40 dry cask system

SUMMARY DESCRIPTION:

1) Calculation Summary

The calculation documents the evaluation of the potential for the buildup of flammable gases due to radiation degradation of the neutron resin in enclosed spaces of the TN-40 and the TN-40HT dry cask systems in the boundary scenario. The flammable gas generation from the TN-40HT cask bounds the amount from the TN-40 cask.

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2) Storage Media Description

Secure network initially, then redundant tape backup.

If original issue, is licensing review per TIP 3.5 required?
Yes ☐ **No** ☒ **(explain below)** **Licensing Review No.:**
The calculation is performed to support a RAI for the Prairie Island license renewal application that will be reviewed and approved by the NRC. Therefore, a 10 CRF72.48 licensing review per TIP 3.5 is not applicable.

Software utilized (subject to test requirements of TIP 3.3):	**Version:**
MCNP5 v1.4 SCALE 5.0 (SAS2H, CSAS25) ANSYS	C730MNYCP01 C00725MNYCP00 10.0
Calculation is complete Originator Name and Signature: Philippe Pham	**Date:** **7/3/14**
Calculation has been checked for consistency, completeness, and correctness Checker Name and Signature: William Casino	**Date:** **7/3/14**
Calculation is approved for use Project Engineer Name and Signature: Girish Patel	**Date:** **7/3/14**

REVISION SUMMARY

REV.	DESCRIPTION	AFFECTED PAGES	AFFECTED DISKS
0	Initial Issue	All	N/A
1	Evaluation of the percentage of hydrogen potentially loss, Section 11	2, 6, 24, 25, 34 and 35	N/A

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1 PURPOSE

The purpose of this calculation is to evaluate the potential for the buildup of flammable gases due to the radiation degradation of the neutron absorbing material in enclosed spaces of the dry cask system (TN-40 and TN-40HT) during the 60 years of normal condition service.

The TN-40HT cask configuration is used as the basis of the models developed in this calculation. The amount of flammable gases generated from the TN-40HT cask bounds flammable gases generated from the TN-40 cask as discussed in section 6.2.

Revision 1 evaluates the percentage of hydrogen lost from the resin due to radiation induced degradation in Section 11.

2 REFERENCES

2.1 Transnuclear Calculation TN-40HT-0501, Rev. 1, "TN-40HT Near Field Shielding Calculation"

2.2 Transnuclear Calculation TN-1043-10, Rev. 0, "TN-40 MCNP Near Field Neutron Dose Rates"

2.3 Transnuclear Calculation TN-1043-11, Rev. 0, "TN-40 Decay Heat"

2.4 NUREG/CR-6673, May 2000, "Hydrogen Generation in TRU Waste Transportation Packages"

2.5 Transnuclear Calculation TN-40HT-0412, Rev. 1, "Thermal Evaluation of TN-40HT Cask with 1" Maximum Cutout Length on Each End of Aluminum/Poison Basket Plates and 0.2" Total Axial Thermal Expansion Gap"

2.6 "MCNP/MCNPX – Monte Carlo N-Particle Transport Code System Including MCNP5 1.40 and MCNPX 2.5.0 and Data Libraries," CCC-730, Oak Ridge National Laboratory, RSICC Computer Code Collection, January 2006

2.7 Transnuclear Drawing 1042-70-1 Rev 8

2.8 Transnuclear Drawing 1042-70-2 Rev 6

2.9 Transnuclear Drawing TN40HT-72-3 Rev 2

2.10 Transnuclear Calculation TN40HT-0402, Rev.3, "TN40HT Normal and Off-Normal Storage Conditions, Thermal Analysis"

2.11 Transnuclear Calculation TN-40HT-0512, Rev. 0, "Dose Rates and Occupational Exposure Estimates for Prairie Island ISFSI Comprised with TN40HT Casks Loaded with WE 14X14 STD Fuel Assemblies"

2.12 Oak Ridge National Laboratory, RSIC Computer Code Collection, "SCALE: A Modular Code System for Performing Standardized Computer Analysis for Licensing Evaluations", ORNL/TM-2005/39, Version 5, April 2005

2.13 Transnuclear Calculation 10421-040, Rev. 0, "Burnup Credit Criticality Analysis for Responses to RAI-1"

2.14 ANSYS Computer Code and On-line User's Manuals, Rev. 8.0 and 10.0

2.15 Transnuclear Calculation TN40HT-0600, Rev. 1, "TN-40HT Criticality Evaluation"

2.16 Rohensow, W.M., et al., "Handbook of Heat Transfer Fundamentals," 2nd Edition, 1991

2.17 Sandia National Lab 8100, "Technical Reference on Hydrogen Compatibility of Materials-Nonmetals: Polymers (code 8100)"

2.18 Transnuclear, "Commercial Grade Dedication Report Item: Radial Neutron Shield", CGDR No. 10426-04

3 METHODOLOGY

The resin is used as the neutron shield in the TN-40 and TN-40HT casks [2.1, 2.2]. In the TN-40HT cask, a 4 in thick disk of polypropylene (Top Resin) is attached to the outside of the cask lid to provide neutron shielding during storage on the top and a 5 in thick polyester resin surrounding the body (Side Resin) provides neutron shielding on the side.

Hydrogen and other flammable gases may be generated from the resin due to the radiation degradation or radiolysis as a result of exposure to radiation such as alpha particles, beta particles, or gamma rays from radioactive isotope decay [2.4, page 4].

When the neutrons react with the resin, the energy transferred from the neutrons to the resin, or the reactions caused by the neutrons in the resin, will eventually cause release of gamma ray and other charged particles. For example, B-10 (n,alpha) reaction releases alpha particle and most time with 0.48 MeV gamma ray. Therefore, the energy deposited from both the gamma source and the neutron source is considered.

3.1 G-value

Radiolytic G-value for flammable gas generation is the molecules of flammable gas per 100 ev of radiation energy absorbed. The G-values for polypropylene and polyester at temperature of 298 K can be retrieved from the reference [2.4]. The G-value for different temperature can be calculated from the G-value at 298 K based on the equation 2.2 from the reference [2.4, page 6]:

$$G_{T_2} = G_{T_1}\exp[(\frac{E_a}{R})(\frac{T_2-T_1}{T_2T_1})] \quad (3\text{-}1)$$

Where T_1 and T_2 are two different temperature in [K]

G_{T_1} and G_{T_2} are the G-value in [molecules/100 eV] at temperature T_1 and T_2, respectively

E_a is the activation energy for radiolytic gas generation (assumed to be 3 kcal/mol [2.4, page 5])

R is the gas constant (1.986e-3 kcal/K/mole)

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Table 3-3 Mass Inventory and Number Density

Isotopes	Mass (grams/FA)	Scaling Factor [2.13]	Number Density after Correction (atoms/bn-cm)
u234	6.65E+01	0.98	3.78E-06
u235	1.34E+03	1.02	7.87E-05
u236	1.99E+03	1.00	1.14E-04
u238	3.79E+05	1.00	2.16E-02
np237	3.23E+02	0.94	1.74E-05
pu238	1.41E+02	1.00	8.02E-06
pu239	2.43E+03	1.02	1.41E-04
pu240	1.29E+03	1.00	7.30E-05
pu241	3.29E+02	1.02	1.89E-05
pu242	5.48E+02	0.98	3.01E-05
am241	4.56E+02	1.00	2.57E-05
am243	1.75E+02	1.00	9.75E-06
mo95	4.86E+02	0.94	6.52E-05
tc99	5.02E+02	0.93	6.39E-05
ru101	5.31E+02	0.96	6.85E-05
rh103	3.11E+02	0.89	3.64E-05
ag109	6.01E+01	0.47	3.51E-06
cs133	7.09E+02	0.97	7.01E-05
nd143	4.32E+02	0.97	3.97E-05
nd145	4.10E+02	1.00	3.83E-05
sm147	1.13E+02	1.00	1.04E-05
sm149	3.60E+00	0.85	2.79E-07
sm150	2.38E+02	0.90	1.94E-05
sm151	8.22E+00	0.78	5.76E-07
eu151	1.22E+00	1.00	1.10E-07
sm152	8.27E+01	0.80	5.90E-06
eu153	9.12E+01	0.99	8.00E-06
gd155	4.38E+00	1.00	3.83E-07

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9 APPENDIX B: VOLUME OF RESINS

The volumes of all resin parts are calculated based on the geometries used in the MCNP model. All figures are generated by using MCNP tool VISED [2.6] and Microsoft software Paint.

9.1 Top Resin

The Top Resin is a disk cut at one edge and is shown in Figure 9-1.

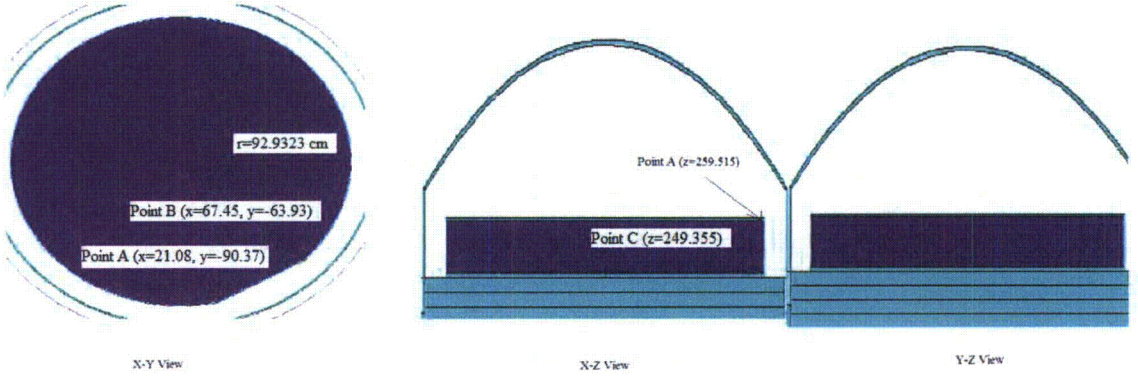

Figure 9-1 Views of Top Resin (not to scale)

The distance between point A and B = $((21.08 - 67.45)^2 - (90.37 - 63.93)^2)^{0.5} = 53.38\ cm$

The angle $\theta = 2 \times \sin^{-1}\left(\frac{0.5 \times 53.38}{92.9323}\right) = 33.38°$

The area from X-Y view = $\pi \times 92.9323^2 \times \frac{360 - 33.38}{360} + 0.5 \times 53.38 \times 92.9323 \times \cos(0.5 \times 33.38) = 26992.18\ cm^2$

The volume = $26992.18 \times (259.515 - 249.355) = 274240.5\ cm^3$

9.2 Side Resin-Middle

The 1/60 of the Side Resin-Middle is shown in Figure 9-2.

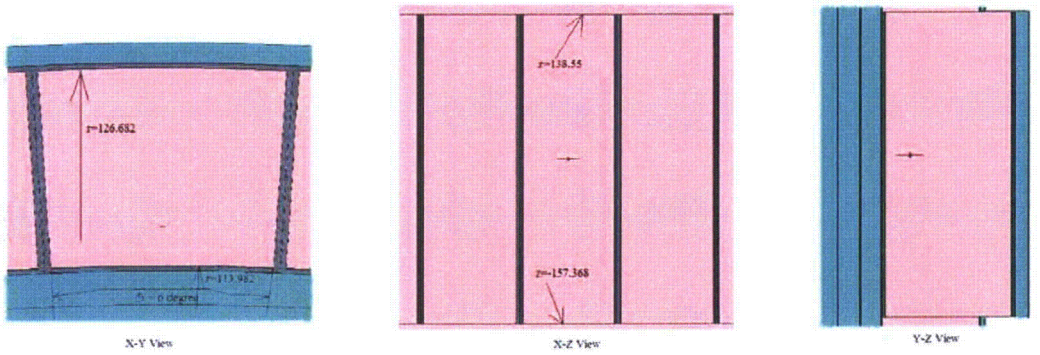

Figure 9-2 Views of Side Resin-Middle (not to scale)

The area from X-Y view= $\pi \times (126.682^2 - 113.982^2) \times \frac{6}{360} = 160.03\ cm^2$

The volume of 1/60 of the Side Resin-Middle = $160.03 \times (138.55 + 157.368) = 47357.07\ cm^3$

The volume of the Side Resin-Middle = $60 \times 47357.07 = 2841424\ cm^3$

9.3 Side Resin-Upper Trunnion

The half of the Side Resin-Upper Trunnion is a cylinder and is shown in Figure 9-3.

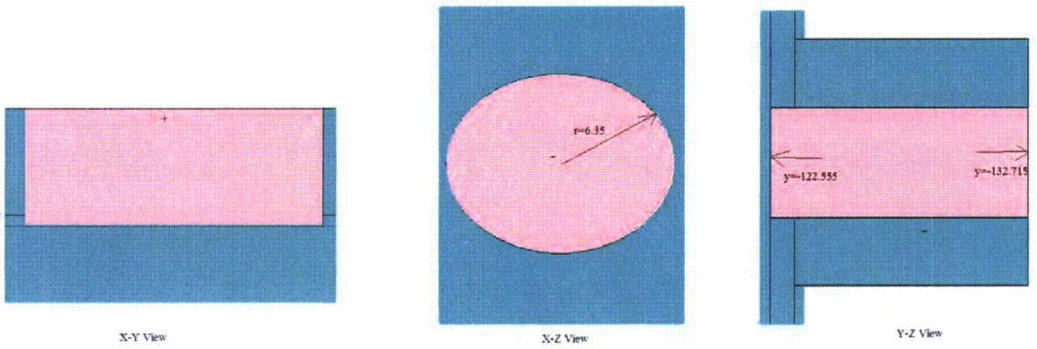

Figure 9-3 Views of Side Resin- Upper Trunnion (not to scale)

The area from X-Z view = $\pi \times 6.35^2 = 126.68\ cm^2$

The volume of the Side Resin-Upper Trunnion = $2 \times 126.68 \times (132.715 - 122.555) = 2574.1\ cm^3$

9.4 Side Resin-Top Trunnion

The Side Resin-Top Trunnion has similar shape as the Side Resin-Middle except different height and the part close to the trunnion (Figure 10-4).

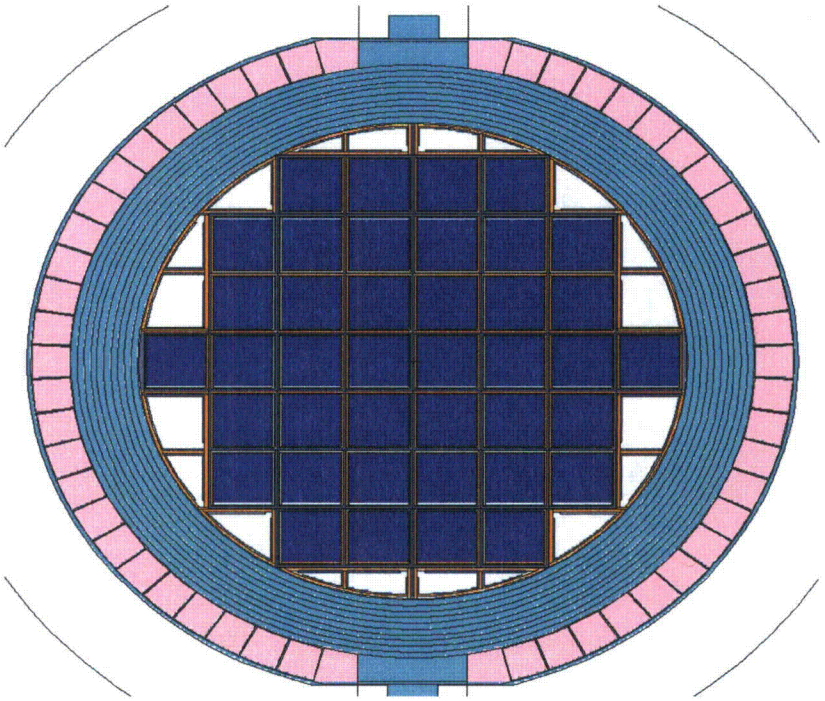

Figure 9-4 X-Y View of the Side Resin-Top Trunnion (not to scale)

The half of the Side Resin-Top Trunnion close to the trunnion is a ring cut at the edge and drilled through by a hole at the side and is shown in Figure 9-5.

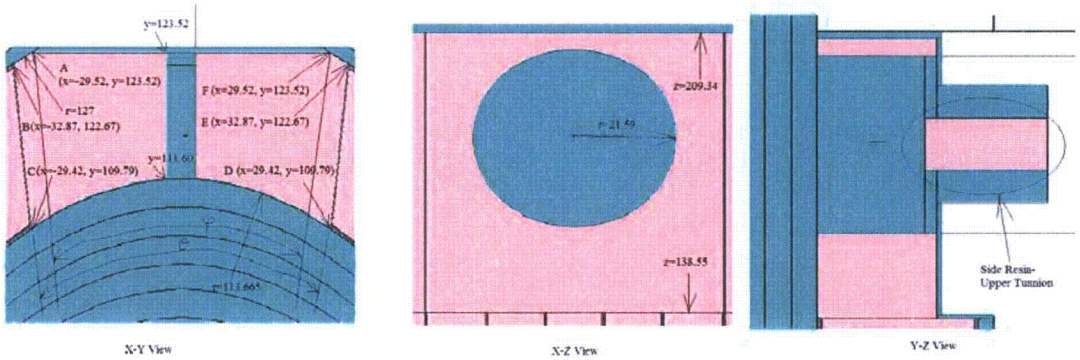

Figure 9-5 Views of Side Resin- Top Trunnion (not to scale)

The angle $\theta = 2 \times \sin^{-1}\left(\frac{32.87}{127}\right) = 30.00°$

The angle $\varphi = 2 \times \sin^{-1}\left(\frac{29.52}{127}\right) = 26.88°$

The area from X-Y view including the hole in the middle = $\pi \times (127^2 - 113.665^2) \times \frac{30}{360} - \left(\pi \times 127^2 \times \frac{26.88}{360} - 29.52 \times 127 \times \cos(0.5 \times 26.88)\right) = 702.89\ cm^2$

The volume of half of the Side Resin-Top Trunnion close to the trunnion =

$$(702.89 \times (209.34 - 138.55) - \pi \times 21.59^2 \times (123.52 - 111.60)) = 32302.3\ cm^3$$

The volume of 1/50 of the Side Resin-Top Trunnion (other parts) = $160.03 \times (209.34 - 138.55) = 11328.8\ cm^3$

The total volume is $2 \times 32302.3 + 50 \times 11328.8 = 631046\ cm^3$

9.5 Side Resin-Bottom Trunnion

The Side Resin-Bottom Trunnion has similar shape as the Side Resin-Middle except different height and the part below the trunnion (Figure 10-6).

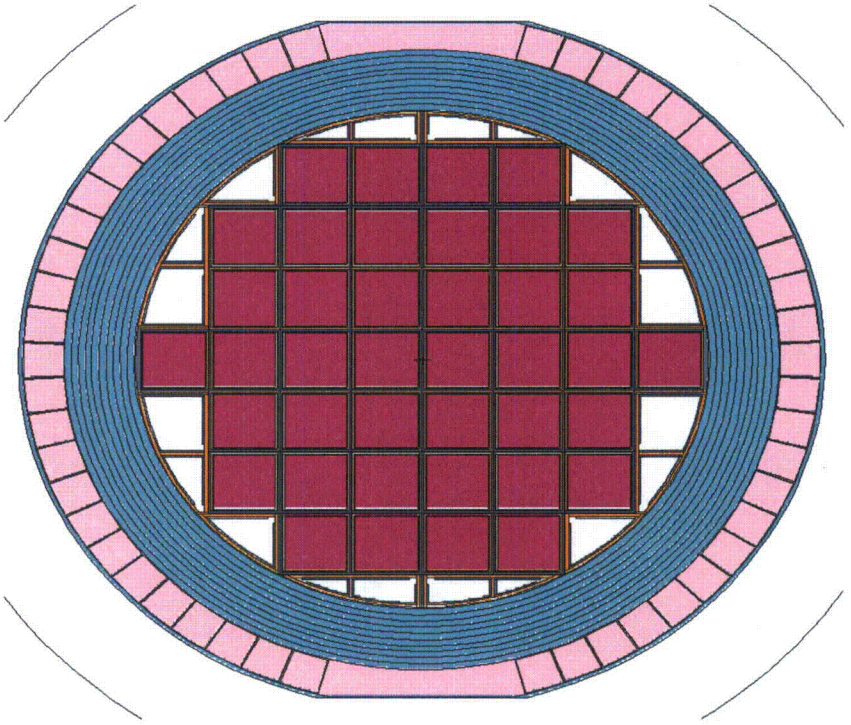

Figure 9-6 X-Y View of the Side Resin-Bottom Trunnion (not to scale)

The half of the Side Resin-Bottom Trunnion below the trunnion is a ring cut at the edge and is shown in Figure 9-7. It is very similar as the half of the Side Resin-Top Trunnion except no hole in the side and different thickness.

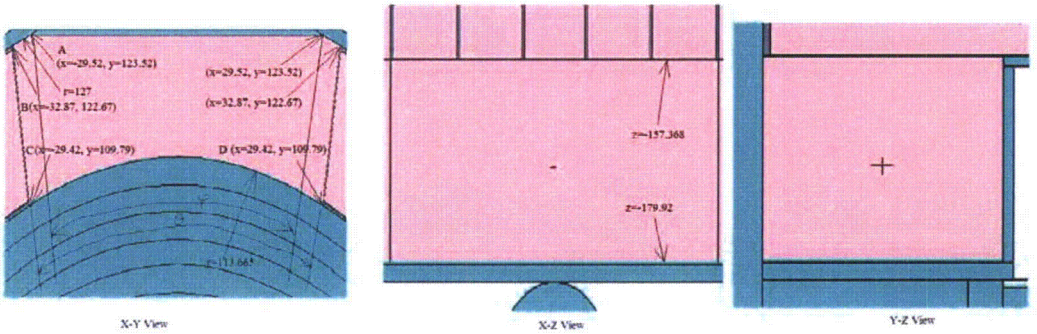

Figure 9-7 Views of Side Resin- Bottom Trunnion (not to scale)

The angle $\theta = 2 \times \sin^{-1}\left(\frac{32.87}{127}\right) = 30.00°$

The angle $\varphi = 2 \times \sin^{-1}\left(\frac{29.52}{127}\right) = 26.88°$

The area from X-Y view = $\pi \times (127^2 - 113.665^2) \times \frac{30}{360} - \left(\pi \times 127^2 \times \frac{26.88}{360} - 29.52 \times 127 \times \cos(0.5 \times 26.88)\right) = 702.89\ cm^2$

The volume of half of the Side Resin-Bottom Trunnion below the trunnion = $702.89 \times (179.92 - 157.368) = 15851.6\ cm^3$

The volume of the Side Resin-Top Trunnion (other parts) = $160.03 \times (179.92 - 157.368) = 3609.1\ cm^3$

The total volume is $2 \times 15851.6 + 50 \times 3609.1 = 212158\ cm^3$

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