ATTACHMENT (11)

TRANSNUCLEAR, INC. CALCULATION, "THERMAL ANALYSIS OF NUHOMS® 32P+ DSC FOR VACUUM DRYING CONDITION," DOCUMENT NO. NUH32P+.0401

Calvert Cliffs Nuclear Power Plant, Inc.
June 15, 2009

AREVA TRANSNUCLEAR INC.	**Form 3.2-1** **Calculation Cover Sheet** TIP 3.2 (Revision 3)	Calculation No.:	NUH32P+.0401
		Revision No.:	1
		Page: 1 of 19	

DCR NO (if applicable) : 10950-48	PROJECT NAME: NUHOMS® 32P+
PROJECT NO: 10953	CLIENT: Calvert Cliffs Nuclear Power Plant

CALCULATION TITLE:

Thermal Analysis of NUHOMS® 32P+ DSC for Vacuum Drying Conditions

SUMMARY DESCRIPTION:

1) Calculation Summary

This calculation evaluates the NUHOMS® 32P+ DSC component and fuel cladding temperatures during vacuum drying operations using ANSYS model with fine 14x14 mesh in homogenized fuel regions.

2) Storage Media Description

1 DVD

If original issue, is licensing review per TIP 3.5 required?

Yes ☐ **No** ☒ **(explain below)** **Licensing Review No.:** N/A

This calculation is issued in support of amendment application subject to NRC review.

Software Utilized: ANSYS	**Version:** 8.1
Calculation is complete: Originator Name and Signature: Slava Guzeyev	8/15/08 Date:
Calculation has been checked for consistency, completeness and correctness: Checker Name and Signature: Davy Qi	Date: 8/15/08
Calculation is approved for use: Project Engineer Name and Signature: Peter Shih P. Shih	8/15/08 Date:

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REVISION SUMMARY

REV.	DATE	DESCRIPTION	AFFECTED PAGES	AFFECTED DISKS
0	8/3/08	Initial Issue	All	All
1	8/25/08	Revision 1 of this calculation provides thermal analysis results of NUHOMS® 32P+ DSC for helium backfill conditions, which follow vacuum drying. It also provides additional justification and references for conclusion about thermal cycling criteria applicability.	1-4, 7, 8, 12-17	1

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1 Purpose

Calculation [3] provides thermal analysis of NUHOMS® 32P DSC for vacuum drying operation using coarse (5x5 and 6x6) mesh in homogenized fuel regions, steady-state conditions, and fuel cladding temperature limit of 1058°F [2].

Thermal analysis [1] shows that using fine 14x14 mesh in homogenized fuel region is appropriate to predict DSC component and fuel cladding temperatures for normal and accident blocked vent storage operations.

This calculation uses 14x14 mesh from [1] for thermal analysis of NUHOMS® 32P+ DSC for vacuum drying conditions.

It also addresses thermal requirements of ISG-11 rev. 3 [5]. According to [5], the maximum fuel cladding temperature cannot exceed $T_{ISG\ limit}$ = 400°C (752°F) and maximum fuel cladding temperature difference during thermal cycling cannot exceed $\Delta T_{ISG\ limit}$ = 65°C (117°F).

2 Assumptions and Conservatism

All assumptions and conservatism discussed in [3] are applicable to this calculation.

It is assumed that guidelines given in ISG-22 [6] will be satisfied since 32P+ DSC is designed to store intact fuel with no pinhole leaks and hairline cracks [4]. Therefore, use of air for blow-down is acceptable.

Helium or nitrogen can be used for blow-down the water from the DSC cavity.

Since helium thermal conductivity is much higher than air thermal conductivity, using helium for blow-down reduces maximum fuel cladding and DSC component temperatures compared to blow-down with air. Subsequent vacuum drying and helium backfilling occurs with a helium environment, which eliminates fuel cladding and DSC component temperature change since helium thermal conductivity does not change with pressure drop (See Section 4.1).

Nitrogen can also be used for blow-down with negligible effect on maximum fuel cladding and DSC component temperatures due to insignificant difference in air and nitrogen thermal conductivity (See Table 2-1 below).

Table 2-1 Air and Nitrogen Thermal Conductivity Comparison

T	$K_{air\ @\ 0.1\ bar}$ [3] (1)	$K_{nitrogen}$ [12] (2)	$K_{air\ @\ 0.1\ bar}/K_{nitrogen}$
°F	Btu/(hr-in-°F)	Btu/(hr-in-°F)	-
200	0.00150	0.00147	1.03
300	0.00169	0.00164	1.03
400	0.00187	0.00180	1.04
500	0.00204	0.00195	1.05
600	0.00221	0.00210	1.05
700	0.00236	0.00224	1.06
800	0.00251	0.00237	1.06

1 – Thermal conductivity values are interpolated based on values from [12].
2 – Thermal conductivity values are interpolated based on values from [3].

Vacuum drying procedure precludes any thermal cycling of fuel cladding. Backfilling the DSC with helium gas after first vacuum drying causes one-time temperature drop, which is not considered as a repeated thermal cycling in CoC 1030 application [14]. Re-evacuation of the DSC under helium atmosphere does not reduce the pressure sufficiently to decrease the thermal conductivity of helium. Therefore, evacuation and re-pressurizing the DSC under helium atmosphere proceed on a descending curve to the minimum steady-state temperatures, and does not include any thermal cycling. This clarification was accepted by NRC in Section 4.8 of SER [15] which states: "... DSC only undergoes a one time temperature drop during the backfilling of the DSC with helium gas. Because this is a one time event, the DSC does not undergo any thermal cycling".

It concludes that the limit of 65°C (117°F) considered for thermal cycling is not applicable for NUHOMS$^{®}$ 32P+ system.

3 Design Input

Thermal properties listed in [3, 10] were used in this calculation, including effective properties of fuel assembly in air at low pressure (Since air is used for water blow-down prior to vacuum drying) and fuel assembly in helium. No additional properties are used in this calculation.

The total decay heat load per 32P+ DSC is 21.12 kW [4].

The vacuum drying operation time starts from the beginning of the water blow-down from DSC.

4 Methodology

This analysis uses the NUHOMS® 32P+ DSC ANSYS refined finite element model developed in [1] (shown in Figure 4-1) for normal and accident storage conditions.

The boundary conditions for the vacuum drying discussed in [3] are applied to the refined model. Radiation super-element file was regenerated for refined model using ANSYS /AUX12 processor. No other changes are considered for this analysis.

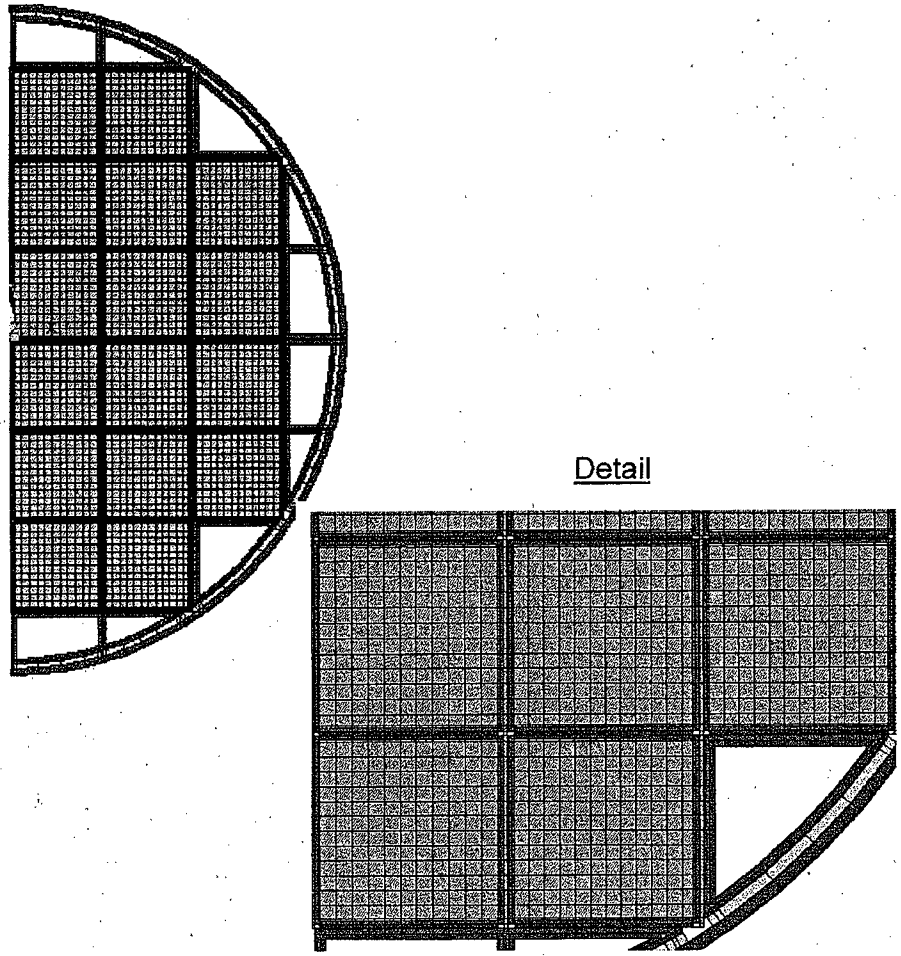


Figure 4-1 32P+ DSC Finite Element Model

4.1 Gas Thermal Conductivity at Low pressure

The thermal analysis of vacuum drying in air or helium case assumes that the thermal conductivity of these gases remains unchanged for lowest vacuum drying pressure of 3 Torr. There are two states that define the process of heat transfer by gas [8]:

viscous state, in which the totality of molecules is responsible for the heat transfer. The viscous state occurs as long as the pressure is higher than the range in which the molecular state occurs. Within the viscous state, the thermal conductivity of a gas is independent of pressure.

Molecular state, Heat conductivity in the molecular state is when the gas pressure is so low that the molecular mean free path is about equal or greater than the distance between the plates. The gas is no longer characterized by viscosity. The viscous state for conductivity is no longer valid and therefore the conductivity is found to be dependent on pressure. The process under these conditions is called free molecular conduction.

The pressure, at which the molecular mean free path is equal to the minimum distance between the surfaces within the NUHOMS® 32P+ DSC package is determined below. These data show that using the helium thermal conductivity at normal pressure is sufficient for this analysis.

Helium Thermal Conductivity at Low pressure

The thermal analysis of vacuum drying in helium case assumes that the helium thermal conductivity remains unchanged for lowest vacuum drying pressure of 3 Torr, and the helium conductivity at normal pressure can be used in this calculation to analyze the vacuum drying case. Following calculation show that using the helium thermal conductivity at normal pressure for lowest vacuum drying pressure of 3 Torr is sufficient for this analysis.

The smallest gap used in the thermal model is 0.01 inches. The smallest gap is set equal to the mean free path to determine the minimum pressure, at which the molecular state occurs. According to [9] a mean free path of the molecules is:

$$L = \frac{k \cdot T}{\pi \cdot \sqrt{2} \cdot P \cdot d^2}, \text{ m} \quad (4\text{-}1)$$

where $k = 1.380658 \cdot 10^{-23}$ J/K – Boltzmann constant,

P - pressure in Pa,

T - temperature in K,

d - molecule diameter in m.

At standard conditions (P = 100000 Pa = 750.062 Torr and T = 298.15 K = 77°F) [9]:

$$L = \frac{9.27 \cdot 10^{-27}}{d^2}, \text{ m} \qquad (4\text{-}2)$$

For helium at T = 25°C = 77°F, d_{He}=2.15·10^{-10} m [9] and therefore L_{He} = 2.0·10^{-7} m.

The minimum internal pressure when free path is equal to the smallest gap can be calculated as:

$$p = \frac{k \cdot T}{\pi \cdot \sqrt{2} \cdot \delta \cdot d^2}, \text{ Pa} \qquad (4\text{-}3)$$

where

δ - smallest gap in the model (0.01 in = 0.000254 m) [10].

The formula (4-3) for T = 752°F (673 K) (conservatively assuming maximum DSC component temperature equals to fuel cladding maximum allowable temperature) returns the pressure value of p = 178.2 Pa = 1.34 Torr, which mean that for pressures above 1.34 Torr, heat transfer of the helium within the basket during vacuum drying can be characterized by the viscous state. The practical lowest vacuum drying pressure of 3 Torr is above this pressure and the conductivity of the helium during vacuum drying is not pressure dependent.

5 References

1. Calculation, *Sensitivity Analysis of Homogenized Fuel Region*, Transnuclear, Inc., Calculation No. 1095-84 Rev.1.
2. Topical Report for the NUTECH Horizontal Storage System for Irradiated Nuclear Fuel, NUHOMS-24P, NUH-002, Rev. 1A.
3. Calculation, *Thermal Analysis of Vacuum Drying*, Transnuclear, Inc., Calculation No. 1095-57 Rev. 0.
4. Specification, *Design Criteria for the NUHOMS®-32P Storage System for Calvert Cliff Nuclear Plant*, Transnuclear Inc., Specification No. E-18851 Rev. 7.
5. U.S. Nuclear Regulatory Commission, Spent Fuel Project Office, Interim Staff Guidance (ISG-11), on Issue: *"Cladding Considerations for the Transportation and Storage of Spent Fuel,"* Revision 3, November 17, 2003.
6. U.S. Nuclear Regulatory Commission, Spent Fuel Project Office, Interim Staff Guidance-22: "*Potential Rod Splitting due to Exposure to an Oxidizing Atmosphere during Short-term Cask Loading Operations in LWR or Other Uranium Oxide based Fuel,"* Revision 0, May 8, 2006.
7. On-line User's Manual for ANSYS, version 8.1.
8. Roth, A., *Vacuum Technology*, 2nd Edition, 1982.
9. David R. Lide, *CRC Handbook of Chemistry and Physics*, 83rd edition, 2002-2003, CRC Press.
10. Calculation, *Finite Element Model, Thermal Analysis*, Transnuclear, Inc., Calculation No. 1095-5 Rev. 0.
11. Bolz, R. E., G. L. Tuve, *CRC Handbook of Tables for Applied Engineering Science*, 2nd Edition, 1973.
12. Roshenow, W. M., J. P. Hartnett, and Y. I. Cho, *Handbook of Heat Transfer*, 3rd Edition, 1998.
13. Calculation, *NUHOMS-32P, Transfer Thermal Analysis*, Transnuclear, Inc., Calculation No. 1095-6 Rev. 1.
14. NUHOMS® HD System Final Safety Analysis Report, Rev.1, Transnuclear Inc.

15. Transnuclear Inc., NUHOMS® HD Horizontal Modular Storage System for Irradiated Nuclear Fuel, Safety Evaluation Report, NRC Docket No. 72-1030.

6 Computations

The analysis is performed using ANSYS version 8.1 [7] running in Microsoft Windows XP Professional operating system. An ANSYS run summary and associated files used in the analysis are shown in Table 6-1 and Table 6-2.

Table 6-1 ANSYS run summary

Operating Conditions	Run Name	Date and Time	Platform
Vacuum drying	32P+vd	10/12/2006 15:56:16	P4 2.4 GHz
Helium Backfilling	32P+He_bkf	8/14/2008 9:56:06	P4 2.4 GHz

Table 6-2 Associated files and macros

Files and macros	Comments
32P+vd.inp, 32P+He_bkf	Input files
ACC48.db	Initial database file [1]
gap-rad.sub	Radiation super-element file

7 Results

The maximum fuel cladding temperatures during vacuum drying (transient and steady-state results) and helium backfilling (steady-state results) computed by refined model are shown in Table 7-1.

Table 7-1 Maximum Fuel Cladding Temperature during Vacuum Drying and Helium Backfilling Operations

Operating conditions	Time (hr)	$T_{fuel\ clad\ max}$ (°F)
Vacuum drying	0	215
	5	284
	10	343
	15	394
	20	439
	25	479
	30	514
	35	545
	40	572
	45	595
	50	615
	55	632
	60	647
	65	660
	70	672
	75	682
	80	691
	85	698
	90	705
	95	710
	100	715
	105	719
	110	722
	Steady-state	742
Helium backfilling	Steady-state	536

Figure 7-1 provides history of maximum fuel cladding temperatures during vacuum drying operation.

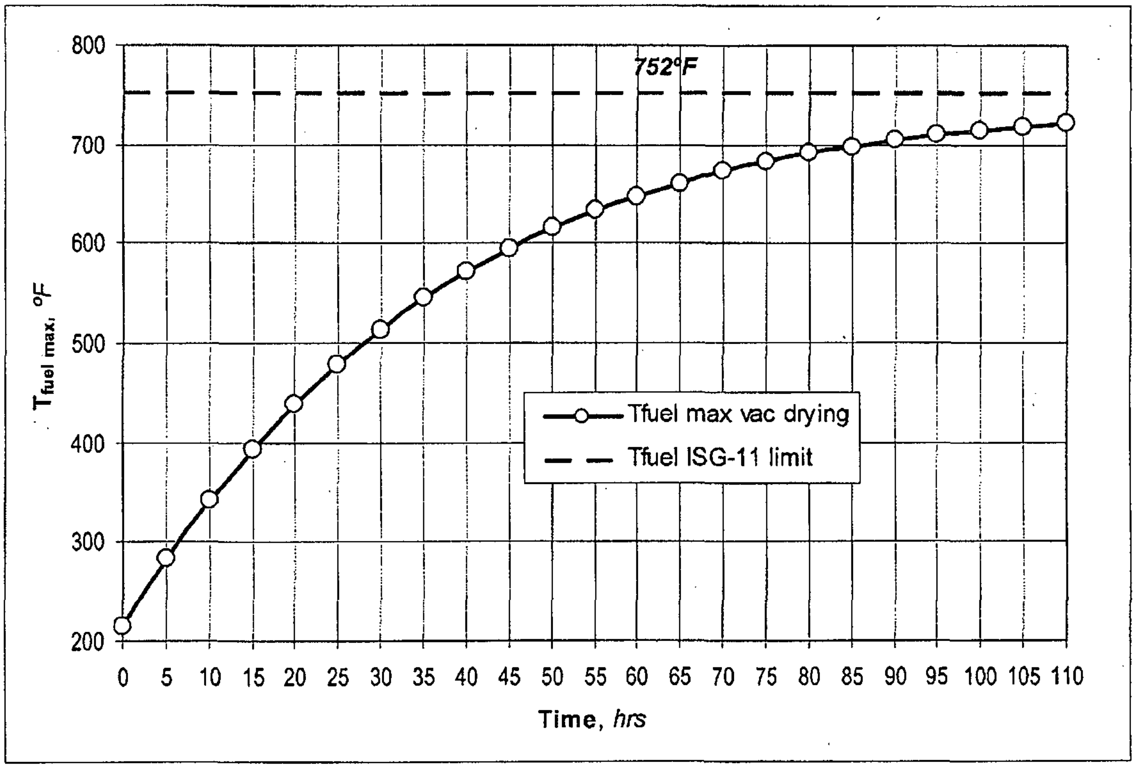
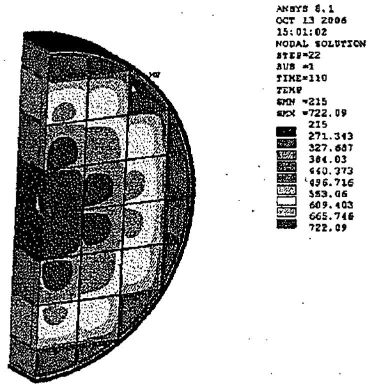


Figure 7-1 Maximum Fuel Cladding Temperature during Vacuum Drying

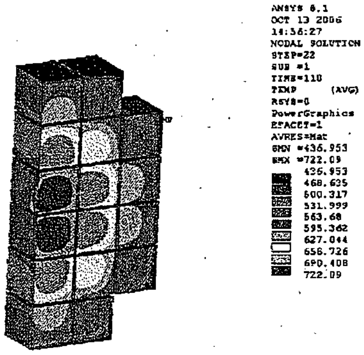
As seen from Table 7-1 and Figure 7-1, the vacuum drying time have to be limited to 110 hours to provide maximum fuel cladding temperature of 722°F and 30°F margin to the fuel cladding temperature limit of 752°F provided in [5].

Figure 7-2 illustrates the resultant 32P+ DSC component and fuel region temperature distribution at 110 hours of vacuum drying.

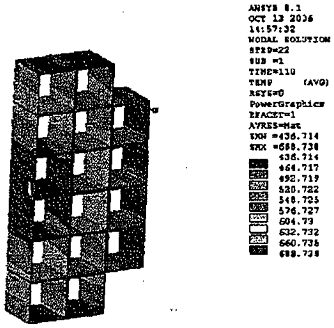
As seen from Table 7-1, the helium backfill causes maximum fuel cladding temperature drop to 536°F, but this temperature is lower than one predicted for normal transfer operating condition, which is 742°F [13] (Note: By coincidence this value is equal to steady-state vacuum drying value shown in Table 7-2). The maximum drop in maximum fuel cladding temperature after helium backfill is 742°F - 536°F=206°F. As clarified in Section 2, this one time event is not a thermal cycling as described in CoC 1030 SAR [14], this clarification is approved by SER [15] concluding that the limit of 65°C (117°F) required for thermal cycling in [5] is not applicable for 32P+ system.



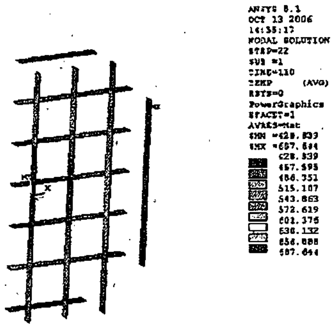
Entire model



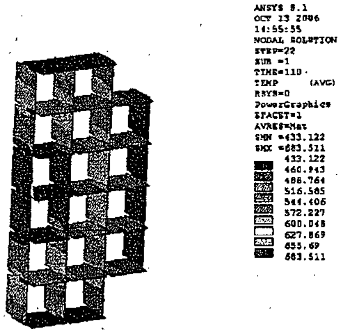
Fuel Regions



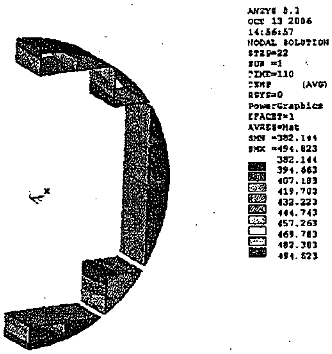
Fuel Compartments



Stainless Steel Bars



Aluminum Basket Plates



Rails

Figure 7-2 32P+ DSC Component Temperature Distribution at 110 Hours of Vacuum Drying

The maximum 32P+ DSC component and fuel cladding temperatures for vacuum drying conditions are summarized in Table 7-2.

Table 7-2 Maximum DSC Component and Fuel Cladding Temperatures for Vacuum Drying Conditions

	Transient Time=110 hours	*Steady –State Time=∞*
Component	(°F)	(°F)
Fuel Cladding	722	742
Fuel Compartments	689	708
Basket SS Bars	688	707
Basket Al Plates	684	702
Basket Rails	495	505
DSC shell	218	218

As seen from results listed in Table 7-2, the maximum fuel cladding temperature for vacuum drying satisfy the limit of 752°F provided in ISG-11 [5] at vacuum drying time limit of 110 hours and for steady-state conditions. Despite of this fact, 110 hours are selected as vacuum drying time limit to provide additional margin to maximum fuel cladding temperature during vacuum drying.