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Safety Equipment List	☐	Cell Arrangement Drawing	☐	Process Flow Chart	☐		
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Environmental Report	☐	Inspection Plan	☐		☐		
Environmental Permit	☐	Inventory Adjustment Request	☐		☐		

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Thermal Analysis of Cold Vacuum Drying of Spent Nuclear Fuel

M. G. Piepho
Fluor Federal Services, Inc.

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Abstract: The thermal analysis examined transient thermal and chemical behavior of the Multi-Canister Overpack (MCO) container for a broad range of cases that represent the Cold Vacuum Drying (CVD) processes. The cases were defined to consider both normal and off-normal operations at the CVD Facility for an MCO with N Reactor spent fuel. This analysis provides the basis for the MCO thermal behavior at the CVD Facility in support of the safety basis documentation.

Key Words: MCO thermal analysis, CVD thermal analysis, N-Reactor fuel, spent nuclear fuel

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Thermal Analysis of Cold Vacuum Drying of Spent Nuclear Fuel

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
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Fluor Hanford

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**THERMAL ANALYSIS OF COLD VACUUM DRYING
OF SPENT NUCLEAR FUEL**

HNF-SD-SNF-CN-023
Revision 2

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THERMAL ANALYSIS OF COLD VACUUM DRYING OF SPENT NUCLEAR FUEL

EXECUTIVE SUMMARY

This report documents analysis of the thermal behavior of the multi-canister overpack (MCO) and the chemical behavior of the fuel inside the MCO at the Cold Vacuum Drying Facility for a broad range of conditions postulated to occur during cold vacuum drying. The HANSF computer code¹ and its previous input² were updated to perform this analysis. New models were developed for off-normal and accident conditions during the cold vacuum drying process to determine the effectiveness of the MCO's thermal design for safety basis parameter values under off-normal and accident conditions.

The following conclusions have been drawn from the thermal analysis.

1. The bounding MCO is thermally stable during vacuum drying except when the vacuum is degraded or there is excess residual water following draining of the MCO.
2. The bounding MCO is thermally stable during the 8-4-4 vacuum-helium purge cycle for all conditions including the loss of annulus water (drying is completed if the normal vacuum cycle is performed).

¹SNF-3650, 1999, *HANSF 1.3.2 User's Manual*, Rev. 2, Fluor Daniel Hanford, Incorporated, Richland, Washington.

²HNF-SD-SNF-CN-023, 1998, *Thermal Analysis of Cold Vacuum Drying of Spent Nuclear Fuel*, Rev. 1, Fluor Daniel Hanford, Incorporated, Richland, Washington.

3. The bounding MCO under positive pressure is thermally stable with only helium purge unless the annulus water is lost.
4. Open bounding MCOs are thermally stable under most conditions except loss of annulus water.
5. Under bounding conditions, closed MCOs take 36 hours to reach a pressure of 150 lb/in² gauge and 96 hours to reach 345 lb/in² gauge.
6. Open MCOs with nominal parameter values are stable under all conditions.
7. Refilling the annulus within 11 hours of a loss of annulus water prevents a thermal runaway in the bounding MCO.

In summary, the results of this analysis show that the safety basis MCO has stable temperatures for all cold vacuum drying processes after draining if the annulus is filled with water.

CONTENTS

1.0 INTRODUCTION	1-1
2.0 COLD VACUUM DRYING PROCESSES AND MODELS	2-1
2.1 COLD VACUUM DRYING PROCESSES	2-1
2.2 CONCEPTUAL AND NUMERICAL MODELS	2-1
2.3 DIFFERENCES BETWEEN THIS REPORT AND EARLIER REVISION	2-2
2.4 HANSF MODEL AND CODE LIMITATIONS	2-4
3.0 KEY INPUT PARAMETERS	3-1
4.0 COLD VACUUM DRYING CASES ANALYZED	4-1
4.1 RESULTS OF VACUUM DRYING CASES	4-1
4.2 RESULTS OF CASES FOR OPEN VENTED MULTI-CANISTER OVERPACKS WITH DIFFERENT TEMPERED WATER CONDITIONS	4-6
4.3 RESULTS OF CASES FOR CLOSED OVERPRESSURIZED MULTI-CANISTER OVERPACKS	4-10
4.4 RESULTS FOR MULTI-CANISTER OVERPACK COOLING CASES	4-12
5.0 CONCLUSIONS	5-1
6.0 REFERENCES	6-1
APPENDIXES	
A HANSF PLOTS OF ALL CASES	A-1
B INPUT FILE AND INPUT DIFFERENCES	B-1
C KEY INPUT PARAMETERS	C-1
D PEER REVIEW CHECKLIST	D-1

LIST OF TABLES

3-1 Key Input Parameters for Safety Basis (Bounding) Multi-Canister Overpack	3-2
4-1 Selected Cases and Their Rationale for Selection and Description	4-2
4-2 Heat Capacity of Major Components of the Cask--Multi-Canister Overpack	4-13
5-1 Results Summary of Simulated Cases	5-3

LIST OF TERMS

CVDF	Cold Vacuum Drying Facility
DBA	design basis accident
FSAR	final safety analysis report
MCO	multi-canister overpack
TWS	tempered water (annulus) system

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THERMAL ANALYSIS OF COLD VACUUM DRYING OF SPENT NUCLEAR FUEL

1.0 INTRODUCTION

This report documents the analysis of thermal behavior of the multi-canister overpack (MCO) and the chemical behavior of the fuel, and supports the safety analyses documented in SNF-2770, *Cold Vacuum Drying Facility Design Basis Accident Analysis Documentation*, and HNF-3553, *Spent Nuclear Fuel Project Final Safety Analysis Report*, Annex B, "Cold Vacuum Drying Facility Final Safety Analysis Report." The analysis was performed using the HANSF computer code, version 1.3.2, which is documented in SNF-3650, *HANSF 1.3.2: User's Manual*.

The cold vacuum drying processes and the HANSF computer code (SNF-3650) are described in Chapter 2.0. The key input parameters are presented in Chapter 3.0. The cases are presented in Chapter 4.0, and the conclusions are discussed in Chapter 5.0. Appendix A provides detailed plots from HANSF version 1.3.2 for the 20 cases analyzed. Appendix B provides a representative input file and a list of the differences between the representative input file and the other input files is provided. The key input parameter values used in this analysis along with brief explanations are contained in Appendix C. The software quality assurance and verification and validation for the HANSF code are described in SNF-5226, *Comparison Cases Simulated with HANSF 1.3.2 to Supplement Thermal Analyses Documented in HNF-SD-SNF-CN-023*.

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2.0 COLD VACUUM DRYING PROCESSES AND MODELS

2.1 COLD VACUUM DRYING PROCESSES

The basic cold vacuum drying process involves receipt of a fuel-loaded, water-flooded MCO confined within a shipping cask. The MCO is drained of most of the free water it contains and then dried under vacuum, with and without helium purge cycles and with some helium-purge-only cycles (HNF-3553, Annex B). During the multistep drying process, the temperature of the MCO and the fuel is controlled by the tempered water (annulus) system (TWS), which circulates tempered water in the annulus between the MCO and the shipping cask, and by the helium purge system, which pushes helium into the bottom of the MCO (via the long process tube) and out through the high-efficiency particulate air filter at the top of the MCO.

2.2 CONCEPTUAL AND NUMERICAL MODELS

The thermal conceptual model of the MCO at the Cold Vacuum Drying Facility (CVDF) consists of the processes and physical phenomena that need to be modeled numerically. The numerical model, which is a computer code, incorporates the conceptual model and calculates the numerical results. The conceptual model for the cold vacuum drying process needs to incorporate heat and mass transfer mechanisms that include (1) thermal conduction in solids, liquids, and gas mixtures, (2) radiative heat transfer from solid to solid, (3) convection of gases, (4) water evaporation and condensation, (5) dynamic gas-solid chemical reactions in confined spaces, and (6) thermal decomposition of hydrates.

The primary heat sources for the MCO at the CVDF are the decay heat of the spent fuel and the chemical heat from the following:

- The uranium–water reaction

- The uranium hydride–water reaction

- The thermal decomposition of uranium hydrates

The fuel–water chemical reactions, not the fuel–oxygen reactions, are the primary reactions during cold vacuum drying. All of the fuel reaction rates depend on the fuel surface temperature, water vapor pressure, and the exposed reaction surface area. The evaporation, condensation, and

hydrate decomposition rates depend not only on the fuel surface temperature and reaction area of the fuel, but also on the composition and temperature of the gas around the fuel and the area of the other surfaces.

Radiolysis, which is a very slow reaction, is considered unimportant on the relatively short time scales of interest (less than 1 week) at the CVDF and therefore is not included in any of the cases. Free water in the particulate-filled cracks in the fuel is not included in the model; free water in particulate-filled cracks will evaporate more slowly than free water on a surface. The hydrogen gettering by fuel reaction — $U + 1.5H_2 \rightarrow UH_3 + \text{heat}$ — also is not included in the conceptual model because, as discussed in *Uranium Computability Studies Part 6: The Products and Mechanisms of the Uranium-Water and Uranium Hydride-Water Reaction* (Baker et al. 1996), oxygen will react with the fuel first and inhibit the fuel-hydrogen reaction.

Air ingress into the MCO, an accident condition, and the fuel-oxygen reaction are included in the HANSF code. If air contacts the fuel in the MCO because of some accident event, the MCO will gain heat from the primary fuel-oxygen reaction — $U + O_2 \rightarrow UO_2 + \text{heat}$ — and from the main hydride-oxygen reaction — $2UH_3 + 3.5O_2 \rightarrow 2UO_2 + 3H_2O + \text{heat}$.

HANSF version 1.3.2 (SNF-3650) numerically solves the mathematical equations used to model the physical processes in the conceptual model described above. The code has gone through verification and validation (SNF-3650; SNF-5226). The thermal decomposition of aluminum hydroxide is not explicitly included in the HANSF code (SNF-3650). Hence, to simulate the effects of aluminum hydroxide decomposition, water vapor is added as a source to cases in which the fuel temperatures get hot enough to cause decomposition. Several other secondary reactions are not included in the model because they are not expected to be important to the results of interest (temperature, pressure, and uranium oxide and hydrogen generation). The details of these reactions, such as the numerical values of heat liberated or generated, can be found in SNF-3650.

2.3 DIFFERENCES BETWEEN THIS REPORT AND EARLIER REVISION

The primary differences between this analysis and the analysis documented in Revision 1 of this document are listed in this section. The current analysis uses version 1.3.2 of the HANSF code (SNF-3650), whereas the earlier revision used version 1.2 of the HANSF code, documented in FAI/98-40, *Hanford Spent Nuclear Fuel Safety Analysis Model HANSF 1.2: User's Manual*. The main improvements to the HANSF code include the following:

- Axial dependence of properties and heat transfer in fuel and scrap baskets
- Temperature-dependent cladding emissivity
- Center post and long process tube, with the long process tube transferring heat to the shield plug and to the bottom of the process tube (i.e., along all the baskets and the shield plug)

- Scrap basket innermost copper fin modeled with a higher temperature than the outermost copper fin
- Ability to decrease or increase gas and scrap basket thermal conductivity and scrap basket radiation heat transfer rate
- Oxidation rate option for rates provided in HNF-SD-SNF-TI-015, *Spent Nuclear Fuel Project Technical Databook*
- Uranium hydride–water reaction rate multiplier option, which maintains a constant reaction rate independent of hydride mass consumption, and a rate multiplier value of 12 from HNF-SD-SNF-TI-015.

The complete list of changes made to the HANSF code for version 1.3.2 is documented in EDT-627109, *Software Change Specification for HANSF 1.3.2; HANSF 1.3.2 Verification of Coding and Associated Documentation; Test Plan for Verification and Validation of HANSF 1.3.2 — Revised; Test Documentation of HANSF 1.3.2*. The new features, with verification and validation results, are described in SNF-3650. Selected thermal results from the HANSF code, version 1.3.2, were benchmarked against the thermal results from the GOTH-SNF code, version 5.0, documented in JMI-980306-3, *Technical Manual for GOTH_SNF Version 5.0*. The benchmarking of the two codes, documented in SNF-5226, showed that the HANSF code, version 1.3.2, produces more conservative results than the GOTH-SNF code, version 5.0, in regards to thermal runaways. Software quality assurance for HANSF version 1.3.2 is also described in SNF-5226.

In addition to the changes in the code, some of the parameter values have changed. Revision 1 of this document used parameter values based on Revision 4 of the Technical Databook (HNF-SD-SNF-TI-015); this revision uses parameter values based on the Revision 6 of the Technical Databook (HNF-SD-SNF-TI-015). The following key parameter values have changed.

- The scrap basket reaction surface area decreased from 6 m² to 4.5 m².
- The fuel basket reaction surface area decreased from 1.75 m² to 0.79 m².
- The safety basis MCO contains two scrap baskets, instead of just one, with one scrap basket at the top and the other at the bottom of the MCO.
- The safety basis uranium hydride reaction rate enhancement factor for all of the spent nuclear fuel in an MCO is fixed at 12 for all times (HNF-SD-SNF-TI-015). The safety basis fuel reaction rate enhancement factors (10 for uranium reactions, 12 for uranium hydride reactions) have been shown to include the effects of potential fuel crumbling. Fuel crumbling is discussed in SNF-5647, *Fuel Crumbling during Fuel Retrieval and Drying Issue Closure Package*; SNF-5488, *Fuel Fracture*

(Crumbling) Safety Impact (OCRWM); and SNF-5698, Comparison of Calculational Results from Different Spent Nuclear Fuel Crumbling Approaches.

- The thermal conductivity of the scrap fuel in the scrap basket is decreased by a factor of two for vacuum and vacuum with helium purge cases. This reduction of the thermal conductivity for these types of cases is intended to simulate the effects of gas stratification in the scrap basket on thermal conductivity (SNF-5226). This change increases the conservatism for vacuum drying cases, with or without helium.

2.4 HANSF MODEL AND CODE LIMITATIONS

Since all models are simpler than the real physical and chemical processes they model, there must be limitations on all models. Some of limitations of HANSF version 1.3.2 are described in this section.

In the HANSF code, the heat capacity and thermal conductivity of some of the stainless steel structures inside the MCO (e.g., basket bottom plates and support posts) are excluded from the model, which promotes more rapid temperature increases and is conservative. The heat capacity (or specific heat) of the inner MCO stainless steel structures is relatively small compared with the heat capacity of the fuel, shield plug, MCO wall and bottom, and the cask wall. The basket bottom plates could be added to the model for increased accuracy, but the results are more conservative when they are not included because the bottom plates act like a cooling fin and heat sink.

In the HANSF model, the solid material properties are independent of temperature during the simulation. Most of the material property values were chosen at a reference temperature of 100 °C. The thermal conductivity of uranium and stainless steel increases with temperature, therefore it is conservative to use the lower temperature values. All fluid properties are temperature-dependent in the HANSF model.

The effects of fuel damage (e.g., melting) are not considered in the model. Most of the off-normal conditions do not result in temperatures high enough to cause fuel damage. The accident cases, which result in very high temperatures, are prevented by safety equipment (HNF-3553, Annex B). As mentioned above, the thermal conductivities of uranium and stainless steel are held to their lower values at 100 °C even though their conductivity increases with increasing temperature, which makes the HANSF version 1.3.2 calculations at high temperatures more conservative.

Gaseous diffusion is not explicitly included in the HANSF model; the gases are uniform over each basket volume in the MCO model and are assumed to instantaneously mix all incoming and outgoing sources or flows in each volume. In effect, each basket volume has instantaneous diffusion, but there is no diffusion between baskets. For vacuum and helium purge cases, this makes no difference because gases flow through all of the baskets in these cases. For cases with no forced flow between baskets, this assumption is not conservative for the top scrap basket

temperature but is conservative for the bottom scrap basket temperature. The water vapor transfer rate into the top scrap basket from below by diffusion is zero in HANSF version 1.3.2, which means the top scrap basket receives less water for chemical reactions if there is no gas flow. However, the bottom scrap basket will have more water for chemical reactions. For no-forced-flow cases such as the CVDF high temperature design basis accident (DBA) (HNF-3553, Annex B), the bottom scrap basket is the one with the highest temperatures.

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3.0 KEY INPUT PARAMETERS

The cases analyzed in this document are based upon key input parameters and specific process and equipment designs. The CVDF DBA cases (HNF-3553, Annex B) exclude any operator intervention in order to estimate the behavior of an unmitigated accident based on just the physics and chemistry of the MCO under accident conditions.

The most important input parameters affecting the thermal analysis of the MCO during CVDF processing are the following:

- Uranium–water and hydride–water reaction areas and rate enhancement factors
- Thermal conductivity of the scrap fuel
- Heat transfer rate through the annulus
- Decay heat rate of fuel.

Except for one case with nominal parameter values, all of the cases use safety basis (or bounding) values for an MCO with two scrap baskets for chemical reaction rates and areas and for the decay heat rate. Therefore, the results presented here should be bounding for all MCOs. The effects of uranium hydride were included in all but one of the cases. All of the cases use a constant hydride–water reaction rate multiplier of 12 from HNF-SD-SNF-TI-015.

Except for one sensitivity case with Mark IA fuel, the thermal analysis considered only Mark IV fuel because the Mark IV fuel bounds the Mark IA fuel from a thermal perspective. The Mark IV fuel element mass per MCO is 25% larger than the Mark IA fuel element mass per MCO. According to HNF-SD-SNF-CSER-010, *Criticality Safety Evaluation Report for Storage and Removal of Spent Nuclear Fuel from K Basin*, the Mark IV scrap basket has a maximum load of 980 kg, whereas the Mark IA has a maximum load of 575 kg. There are also fewer Mark IA fuel elements (and mass) per basket, therefore there is less decay heat per basket, a smaller reaction area per basket, and a shorter conduction distance from the inner to the outer regions, all of which make the Mark IA fuel more favorable in regards to thermal behavior in the MCO.

The key input parameters used in the analysis for the bounding (safety basis) MCO, with two scrap baskets and three Mark IV fuel baskets, are shown in Table 3-1 and in Appendix C.

Table 3-1. Key Input Parameters for Safety Basis (Bounding)
Multi-Canister Overpack. (2 sheets)

Parameter	Value	Reference
HEAT GENERATION PARAMETERS: power, reaction area, reaction rate		
Safety basis decay power (776 W for five fuel baskets, 120 W per scrap basket)	741 W (4 fuel baskets, 1 scrap basket) 706 W (3 fuel baskets, 2 scrap baskets)	HNF-SD-SNF-TI-015 ^a Appendix C, Note 1
Safety basis scrap basket fuel reaction surface area	4.5 m ² Fine scrap: 2 m ² Coarse scrap: 2.5 m ²	HNF-SD-SNF-TI-015 ^a Appendix C, Note 2
Safety basis fuel basket reaction area	0.79 m ²	HNF-SD-SNF-TI-015 ^a
Safety basis reaction rate multiplier for uranium–water reaction	10	HNF-SD-SNF-TI-015 ^a
Safety basis rate multiplier for uranium hydride–water reaction	Fuel basket: 12 Scrap basket: 12	HNF-SD-SNF-TI-015 ^a
RADIATION HEAT TRANSFER PARAMETERS: emissivity, view factors		
Scrap fuel emissivity	0.7	HNF-SD-SNF-TI-015 ^a
Cladding emissivity	Function of temperature: 0.4 to 0.7	HNF-SD-SNF-TI-015 ^a
Inner shield plug emissivity	0.3	HNF-SD-SNF-TI-015 ^a Appendix C, Note 3
MCO wall emissivity	0.3	HNF-SD-SNF-TI-015 ^a
Cask, MCO bottom, and outer shield plug emissivity	0.25	SNF-3650 ^b Appendix C, Note 4
View factors between fuel rods and MCO wall	9-by-9 matrix	SNF-3650 ^b Appendix C, Note 5
CONDUCTION HEAT TRANSFER PARAMETERS: mass, conductivity, specific heat		
Effective fuel–cladding mass density	18,573.3 kg/m ³	Appendix C, Note 6
Uranium (scrap) mass density at 100 °C	19,000 kg/m ³	Holden 1958 ^c Appendix C, Note 7
Stainless steel mass density at 100 °C	8,000 kg/m ³	ORNL 1987 ^d Appendix C, Note 8
Maximum fuel mass load (Mark IV fuel)	Scrap basket: 980 kg Fuel basket: 1,268 kg	HNF-SD-SNF-TI-015 ^a
Effective fuel–cladding thermal conductivity	24.2 W/m/K	Appendix C, Note 9
Stainless steel thermal conductivity	16.0 W/m/K	ORNL 1987 ^d
Effective fuel–cladding and uranium specific heat	122.67 J/kg/K	Kaufman 1962 ^e Appendix C, Note 10
Stainless steel specific heat	500.0 J/kg/K	ORNL 1987 ^d

Table 3-1. Key Input Parameters for Safety Basis (Bounding)
Multi-Canister Overpack. (2 sheets)

Parameter	Value	Reference
Free residual water after draining (1.5 kg per top scrap basket, 6.0 kg per fuel basket, 6.0 kg per bottom scrap basket, and 1.0 kg per MCO bottom)	26.5 kg per MCO	JMI-980305-10 ^f
Water in uranium hydrates, $\text{UO}_3 \cdot 2\text{H}_2\text{O}$	1.19 kg	HNF-SD-SNF-TI-015 ^a
Normal process bay temperature	26.7 °C (80 °F)	HNF-3553, Annex B ^g
Bounding annulus water temperature	50 °C	HNF-3553, Annex B ^g
CONVECTIVE HEAT AND MASS TRANSFER PARAMETERS: gas volume, flow area, flow rate		
Minimum top scrap basket and shield plug gas volume	0.118 m ³ ($<0.136 \text{ m}^3$)	HNF-2169 ^h Appendix C, Note 11
Fuel basket gas volume	0.10 m ³	HNF-2169 ^h Appendix C, Note 12
Minimum bottom scrap basket gas volume	0.10 m ³ ($<0.119 \text{ m}^3$)	HNF-2169 ^h Appendix C, Note 13
Fine scrap porosity	0.40	Appendix C, Note 14
Course scrap porosity	0.723	Appendix C, Note 15
Flow area in fuel basket bottom	0.025 m ²	Appendix C, Note 16
Flow area in scrap basket bottom	0.0078 m ²	Appendix C, Note 17
Vacuum pumping rate	0.01416 m ³ /s (30 ft ³ /min)	HNF-3553, Annex B ^g
Base helium mass purge rate	0.526 E-04 kg/s (0.7 standard ft ³ /min)	HNF-3553, Annex B ^g

^aHNF-SD-SNF-TI-015, 1998, *Spent Nuclear Fuel Project Technical Databook*, Rev. 6, Fluor Daniel Hanford, Incorporated, Richland, Washington.

^bSNF-3650, 1999, *HANSF 1.3.2: User's Manual*, Rev. 2, Fluor Daniel Hanford, Incorporated, Richland, Washington.

^cHolden, A. N., 1958, *Physical Metallurgy of Uranium*, Addison-Wesley Publishing Company, Reading, Massachusetts.

^dORNL, 1987, *Nuclear Systems Material Handbook*, Volume 1, "Design Data," TID 26666, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

^eKaufman, A. R., 1962, *Nuclear Reactor Fuel Elements*, Interscience Publication, New York, New York.

^fJMI-980305-10, 1999, *GOTH SNF Simulations of Selected CVDF Vacuum Pumping and Design Basis Accident Cases*, John Marvin, Incorporated, Richland, Washington.

^gHNF-3553, 1999, *Spent Nuclear Fuel Project Final Safety Analysis Report*, Annex B, "Cold Vacuum Drying Facility Final Safety Analysis Report," Rev. 0, Fluor Daniel Hanford, Incorporated, Richland, Washington.

^hHNF-2169, 1998, *MCO Loading and Cask Loadout Technical Manual*, Rev. 0, Fluor Daniel Hanford, Incorporated, Richland, Washington.

MCO = multi-canister overpack.

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4.0 COLD VACUUM DRYING CASES ANALYZED

This chapter provides the description and results of 20 cases analyzed for the MCO in various processing states at the CVDF. The cases were selected based on their importance to safety at the CVDF and are classified into four groups:

1. Vacuum processing
2. Open vented MCOs with different TWS states
3. Closed MCOs with overpressurization
4. Cooling after vacuum drying.

The 20 cases are listed in Table 4-1 along with their names, identifiers, descriptions, and the rationale for selection. The 20 cases cover the important issues at the CVDF and simulate the thermal and pressure behavior in the MCO under off-normal and accident conditions. In each case, unless noted otherwise, the total residual free water remaining after draining is 26.5 kg — 1.5 kg in the top scrap basket, 6 kg in each of the other four baskets, and 1 kg in the heel of the MCO at the bottom. Detailed results for all 20 cases are shown graphically in Appendix A.

4.1 RESULTS OF VACUUM DRYING CASES

Five vacuum drying cases have been analyzed — four cases with a degraded vacuum rate and normal annulus water, and one case with normal vacuum and an air ingress with loss of annulus water. These are the only cases in the report that have degraded thermal conductivity in the scrap fuel basket because of gas stratification (see Section 2.4).

Case 1. VXDG — Degraded Vacuum Pumping with No Helium Purge. Thermal behavior in case VXDG depends on (1) the evaporation rate of water from fuel and MCO structures (e.g., wall), (2) the thermal effects of evaporation (initial cooling of fuel followed by temperature increases from decay heat and uranium–water and uranium hydride–water chemical reactions), (3) the removal rate of the water vapor from MCO, and (4) heat transfer from the inner fuel to the outer fuel to the MCO boundaries (wall, shield plug, and MCO bottom). During normal operation, the vacuum rate is at least 30 ft³/min. The degraded vacuum condition (13 ft³/min) is used to show a large thermal stress on the scrap fuel in the MCO. The degraded vacuum case has a thermal excursion. The maximum fine scrap temperature (the key variable for this case) is shown Appendix A, Figure A-1 (sheet 2). The HANSF code calculated a thermal runaway in this case starting after 15.5 hours of degraded vacuum pumping with a peak temperature of 740 °C occurring at 17.8 hours.

Table 4-1. Selected Cases and Their Rationale for Selection and Description. (3 sheets)

Case number	Case name and identifier ^a	Rationale for selection	Brief summary of case results	Summary of key input
Vacuum processing cases				
1	VXDG Degraded vacuum	To determine effects of vacuum rate degradation	Vacuum degradation cannot be tolerated without helium flow	Vacuum rate = 13 ft ³ /min Annulus water at 50 °C No helium
2	VPXDGP7 Degraded vacuum with helium purge	To determine effects of helium purge on degraded vacuum	Vacuum degradation with helium purge and residual water from normal drain is acceptable	Vacuum rate = 13 ft ³ /min Annulus water at 50 °C Helium flow = 0.7 standard ft ³ /min
3	VPXDGP7W Degraded vacuum with helium purge and reflood	To determine effects of very high residual water on degraded vacuum with helium purge	Vacuum degradation with helium purge and very high residual water from reflood cannot be tolerated	Vacuum rate = 13 ft ³ /min Annulus water at 50 °C Helium flow = 0.7 standard ft ³ /min Residual water = 120 kg
4	VPDG8-4-4W Degraded vacuum with 8-4-4 cycle and reflood ^b	To determine effects of 8-4-4 cycle on case (case 3) with high residual water, degraded vacuum, and helium purge	8-4-4 cycle is necessary if vacuum is degraded and very high residual water is present	Vacuum rate = 13 ft ³ /min Annulus water at 50 °C Helium flow = 0.7 standard ft ³ /min Residual water = 120 kg
5	VARILOC Normal vacuum with air ingress	To determine whether an air ingress event can lead to a thermal runaway	Air ingress with loss of annulus water does not result in a thermal runaway	Vacuum rate = 30 ft ³ /min Annulus water lost No helium flow
Open vented MCO cases with various tempered water conditions				
6	OVLOCXAL High-temperature DBA	To determine the effects of a loss of annulus water event	Loss of annulus water cannot be tolerated	MCO at atmospheric pressure Loss of annulus water No helium flow
7	OVLOCRHE High-temperature DBA with helium flow	To determine the effects of helium flow on a thermal runaway	Helium flow partially mitigates and delays thermal excursion but does not prevent it	MCO at atmospheric pressure Loss of annulus water Helium flow
8	OVLOCREC Thermal runaway recovery	To determine the effectiveness of restoring the lost annulus water on a thermal runaway	Restoration of annulus water within 11 hours prevents or terminates thermal runaway	Annulus water restored at 11 hours No helium flow
9	OVLOF Stationary annulus water	To determine effects of stationary annulus water on an open or vented MCO	Open or vented MCO with stationary annulus water is safe and stable	Stationary annulus water starting at 50 °C No helium flow

Table 4-1. Selected Cases and Their Rationale for Selection and Description. (3 sheets)

Case number	Case name and identifier ^a	Rationale for selection	Brief summary of case results	Summary of key input
10	OV50C Normal flowing annulus water	To determine the effects of 50 °C flowing annulus water on an open or vented MCO	Open or vented MCO with flowing annulus water at 50 °C is safe and stable	Normal annulus water No helium flow
11	OVLOF99C Hot stationary annulus water	To determine the effects of a thermal transient in tempered water (annulus) system on vented MCO	Open or vented MCO with very hot stationary annulus water is safe and stable	Stationary annulus water starting at 99 °C No helium flow
12	OVLOCNOH Loss of annulus water and no uranium hydride	To determine effects of absence of uranium hydride on the thermal runaway DBA	Thermal runaway DBA (case 6) is bounding for recovery time and MAR, but this case results in higher temperatures at later times	MCO at atmospheric pressure Loss of annulus water No helium flow No uranium hydride
13	OVLOCNOM Loss of annulus water and nominal MCO	To determine effects of nominal values of key parameters for the thermal runaway DBA	Nominal values of reaction area, rate multiplier, and decay heat rate result in low and stable temperatures	MCO at atmospheric pressure Loss of annulus water No helium flow
14	OVLOC1AX Loss of annulus water and Mark IA fuel	To determine the effects of Mark IA fuel for the thermal runaway DBA	Mark IV fuel bounds Mark IA fuel for thermal runaway DBA	MCO at atmospheric pressure Loss of annulus water No helium flow Mark IA fuel
Closed MCOs and overpressurization cases				
15	DS32C2HZ Overpressurization DBA	To determine time to pressurize to 345 lb/in ² gauge and 150 lb/in ² gauge	Overpressurization DBA, 96 hours to 345 lb/in ² gauge, 36 hours to 150 lb/in ² gauge	Closed MCO Stationary annulus water initially at 50 °C
16	B32C2HZ Blowdown release at 345 lb/in ² gauge	To quantify blowdown release at 345 lb/in ² gauge	Overpressurization DBA release	Breached MCO at 345 lb/in ² gauge Stationary annulus water
17	B32C2HZ2 Blowdown release at 150 lb/in ² gauge	To quantify blowdown release through rupture disk at 150 lb/in ² gauge	Mitigation of overpressurization DBA release	Rupture disk opens at 150 lb/in ² gauge Stationary annulus water
18	CV32C2HX Blowdown release through vent path	To quantify blowdown release through 30 lb/in ² gauge vent path	Mitigation of overpressurization DBA release	Vent path opens at 35 lb/in ² gauge Stationary annulus water

Table 4-1. Selected Cases and Their Rationale for Selection and Description. (3 sheets)

Case number	Case name and identifier ^a	Rationale for selection	Brief summary of case results	Summary of key input
Cooling cases after vacuum drying				
19	COOL1HXXH Cooling of bounding MCO	To determine maximum gas temperature of cooled MCO	Maximum gas temperature in MCO after cooling operation is less than 50 °C	Bounding decay power of 776 W Cooling water at 17 °C
20	COOL1HXXM Cooling of nominal MCO	To determine expected value of gas temperature for cooled MCO	Nominal gas temperature in MCO after cooling operation around 35 °C	Nominal decay power of 403 W Cooling water at 10 °C

^a Each case name reveals the type of simulation:

V stands for vacuum

P stands for helium purge

OV stands for open vent

DS stands for drain stop

B stands for blowdown

CV stands for check valve

X stands for axial dependence

P7 stands for purge rate at 0.7 standard ft³/min

LOC stands for loss of coolant (i.e., loss of annulus water)

LOF stands for loss of flow (i.e., stationary annulus water)

DG stands for degraded.

Other letters are specific to each case.

^b This case is made up of five separate runs:

1. VPXDGW0 (8 hours), degraded vacuum and helium purge
2. HEP7W1 (4 hours), helium purge only
3. VPXDGW2 (4 hours), degraded vacuum and helium purge
4. HEP7W3 (4 hours), helium purge only
5. VPXDGW4 (4 hours), degraded vacuum and helium purge.

8-4-4 = 8-hour initial vacuum cycle, 4-hour subsequent vacuum cycles, 4-hour return to pressure between vacuum cycles.

DBA = design basis accident.

MAR = material at risk.

MCO = multi-canister overpack.

For a vacuum degraded to a rate of 2 or 3 ft³/min, the thermal behavior of the MCO is better than the case analyzed here because with a very low vacuum rate, the hydrogen concentration and the thermal conductivity in the scrap basket increases. Thus a normal or very low vacuum pumping rate is thermally acceptable, but if the vacuum rate is degraded to around 13 ft³/min, a thermal excursion is possible.

Thermal conductivity was numerically degraded in the HANSF model for vacuum cases in order to model the conductivity degradation caused by gas stratification. Heavier gases like water vapor and lighter gases like hydrogen and helium are not uniformly distributed throughout the MCO, especially with more hydrogen being generated by hotter fuel in the radial center of the MCO. Therefore the thermal conductivity is reduced in those regions where the water vapor dominates. Since the HANSF code does not calculate this phenomenon, the thermal conductivity of the entire scrap basket was degraded (by a factor of two) in the HANSF model to conservatively model conductivity degradation caused by gas stratification.

Case 2. VPXDGP7 — Degraded Vacuum Pumping with Helium Purge. This case models degraded vacuum pumping (13 ft³/min) with helium purge (0.7 standard ft³/min). The results show the MCO to be thermally stable with a peak fuel temperature of 90 °C. The helium purge during degraded vacuum pumping adds about 0.06 atm of pressure to MCO. During normal vacuum pumping (approximately 30 ft³/min), the helium purge will add less pressure (SNF-5226). The dryout time for this case is calculated to be about 18.5 hours (see Appendix A, Figure A-2).

Case 3. VPXDGP7W — Degraded Vacuum Pumping with Helium Purge and 120 kilograms of Undrained Water. This case includes the effects of a large pool of undrained water with degraded vacuum processing (13 ft³/min), helium purge (0.7 standard ft³/min), and annulus water flowing at 50 °C. The 120 kg of undrained water modeled in this case are not possible to achieve unless there is a reflood of water back into the MCO after draining. However, the 120 kg of water are representative of an undrained MCO or of a reflooded MCO. The maximum scrap fuel temperature occurs in the fine scrap in the top basket with a thermal excursion starting after about 17 hours. Peak fuel temperatures of about 850 °C are reached in about 18.5 hours.

This case demonstrates that a thermal excursion in the top scrap basket is possible if a large quantity of water remains in the MCO before vacuuming at a degraded rate even if the helium purge is present and the annulus water is flowing at 50 °C. Even though 120 kg of water was used for this case, a thermal excursion can result with as little as 35 kg of water in the MCO with 15 kg of water pooled on the bottom of MCO.

Case 4. VPDG8-4-4W — Degraded Vacuum Pumping with Helium Purge, 120 kilograms of Undrained Water, and Normal Vacuum-Purge Cycle. This case is the same as case 3 (VPXDGP7W) except that an 8-hour initial vacuum cycle, 4-hour subsequent vacuum cycles, and 4-hour return to pressure between vacuum cycles (8-4-4) is employed instead of a continuous vacuum. This case demonstrates that the 8-4-4 vacuum-helium purge cycle results in stable temperatures even with degraded vacuum and incomplete drain. Unlike the

case 3 (VPXDGP7W), where there is a thermal excursion, fuel temperatures in this case remain stable if the vacuum pumping is turned off after 8 hours while helium keeps flowing, started again after the 4-hour helium purge, continued for another 4 hours, and then continues to alternate 4-hour cycles until the fuel is dry.

This case simulates the 8-4-4 cycle for just 24 hours, resulting in 16 hours of vacuum pumping with helium purge, and 8 hours of helium-only purge. During this 24-hour time period, 30 kg of the initial 120 kg of undrained or reflooded water in the MCO is removed from the MCO. At this rate, about 4 days of vacuum processing with the 8-4-4 cycle are needed to remove all of the water. During this time, fuel temperatures remain stable even if the vacuum pumping is degraded. If the vacuum pumping rate is normal, the water vapor pressures will be lower causing lower reaction rates and temperatures. For normal residual water after draining, the 8-4-4 vacuum-helium purge cycle provides an additional safety margin when compared with continuous vacuum processing.

Case 5. VAIRILOC — Normal Vacuum Pumping with Air Ingress and Loss of Annulus Water. In this case, the vacuum pumping rate is normal (30 ft³/min), but there is a loss of annulus water, no helium flow, and air ingress through a pin-hole leak. This case is an unmitigated scenario that bounds the source term for a thermal runaway because of the unlimited amount of oxidant available. However, the calculations show that fuel temperatures are stable for at least 4 days (the length of the run) even with air entering through a pin hole with an area of 0.1 cm². The hole is small enough that the pressure in the MCO is not significantly different from normal vacuum pressure at the start of drying when the vapor pressure is highest. Air is pulled through the pin hole at a rate of almost 2.3 g/s, which is equivalent to a pressure of less than 120 torr in the MCO. The maximum fuel temperature occurs in the fuel basket and not in the scrap basket because the scrap fuel basket with copper fins has better heat removal capability.

4.2 RESULTS OF CASES FOR OPEN VENTED MULTI-CANISTER OVERPACKS WITH DIFFERENT TEMPERED WATER CONDITIONS

Nine open or vented MCO cases have been analyzed with different annulus water conditions — annulus water flowing at 50 °C, stationary annulus water at 50 °C and 99 °C, and loss of annulus water. All of these cases involve an open or vented MCO at atmospheric pressure. To eliminate the benefits of oxygen poisoning, no oxygen is included in the MCO atmosphere. With the resistance in the piping and shield plug, a significant countercurrent flow of air into the vented MCO is not expected.

6. OVLOCXAL — Open Multi-Canister Overpack with Loss of Annulus Water. This case models the unmitigated high-temperature DBA used in the CVDF Final Safety Analysis Report (FSAR) (HNF-3553, Annex B). The scenario assumes the annulus water is lost and air replaces the water in the annulus. Air has a thermal conductivity about 25 times smaller than that of water. The gap between the MCO and cask severely degrades the main mechanism for removing heat from the MCO. The MCO is simulated with the fuel at 50 °C and drained but still containing 26.5 kg of residual water. Based on engineering judgement, the amount of free water

required to cause a thermal runaway is at least 5 kg. About 1.19 kg of uranium hydrate water is present for the bounding MCO, with about 0.67 kg of it is released during thermal decomposition of the hydrate. About 3.3 kg of aluminum hydroxide water is present for the bounding case (HNF-SD-SNF-TI-015), but only about 0.74 kg of water is freed during the partial thermal decomposition of the aluminum hydroxide. Most of this is freed in the hot bottom scrap basket. Using a value of 0.74 kg for the freed water is conservative since HNF-3035, *MCO Gas Composition of Low Reactive Surface Areas*, has shown fuel with aluminum hydroxide to have less than 528 W of decay power for five fuel baskets, and this case uses 706 W for two scrap and three fuel baskets (see Table 3-1), which is equivalent to 776 W for five fuel baskets.

Calculations for these conditions show a thermal excursion for the MCO fuel. The maximum scrap basket temperature occurs in the fine scrap in the bottom scrap basket. The drain feature in the HANSF code was turned on to make a more conservative case by maximizing the amount of water available in the bottom scrap basket for fuel-water reactions. With the drain feature on, the HANSF code models the water on the fuel evaporating, cooling the wet fuel, and the water vapor condensing on the MCO wall and running down to the bottom scrap basket. The HANSF code has a uniform gas distribution in each basket and no diffusion between baskets (see Section 2.4).

The results show a maximum fuel temperature of about 1,010 °C after approximately 11.5 hours. The HANSF code indicates that about 700 kg of fuel (all in the bottom scrap basket) will reach a temperature in excess of 700 °C, with the maximum center post temperature less than 1,000 °C. The maximum MCO wall temperature is about 500 °C. The HANSF code models a uniform vapor concentration in each basket, which allows water vapor to reach the hottest fuel. However, the temperature increase calculated by the HANSF code is limited by the overall evaporation rate of water from the cooler MCO wall and the countercurrent flow of vapor from the baskets above the bottom scrap basket. Countercurrent flow of water vapor downward occurs because the water vapor has a higher mass density than hydrogen. Countercurrent flow is always present but can be very small if hydrogen flow upward is large enough, as is the case before 12 hours. Also, the bottom basket starts to cool after 12 hours, which draws more water vapor down. The temperature effects of this countercurrent flow of vapor from higher baskets are shown in Appendix A, Figure A-6. The first temperature peak occurs as all of the existing water vapor in the bottom scrap basket is consumed and the newly generated vapor is not produced fast enough to maintain the high fuel temperature. As a result, the fuel starts to cool while the MCO wall temperature is increasing from the continuing heatup of the upper baskets. With the MCO wall and bottom temperatures increasing, the water on the bottom of MCO evaporates faster, causing the fuel temperature to increase again. Some additional vapor is flowing down from the higher baskets. In Appendix A, Figure A-6, sheet 2, this effect is shown in the second peak temperature, which declines as the higher baskets dry out after 13.5 hours.

7. OVLOCRHE — Open Multi-Canister Overpack with Loss of Annulus Water but with Helium Flow. This case simulates the effects of helium flow as a cooling mechanism should the annulus water be lost and not replaced. In this case, helium is flowing at 0.7 standard ft³/min and the pressure in the MCO is 10 lb/in² gauge. This scenario is very similar to a safe shutdown scenario except that the annulus water is missing and replaced with air, which has a lower thermal

conductivity than water. This case is very similar to the high-temperature DBA in case 6 (OVLOCXAL), except that helium is flowing and the MCO is pressurized above atmospheric pressure.

The calculations show that helium flow is not sufficient to prevent a thermal runaway if the annulus water is lost. Helium flow does, however, delay the onset of the thermal runaway and keeps the fuel temperatures lower than the temperatures in the high-temperature DBA (case 6, OVLOCXAL). The maximum fuel temperature is about 850 °C at 18 hours after the loss of annulus water, which is a lower temperature at a later time than the maximum fuel temperature reached in the high-temperature DBA. The helium flow delays and mitigates the thermal runaway caused by loss of annulus water, but does not prevent it.

8. OVLOCREC — Open Multi-Canister Overpack with Loss of Annulus Water and Recovery of Annulus Water. This case examines the effect of refilling the annulus with water following the loss of annulus water event. Since helium flow does not cool the fuel enough to completely recover from a loss of annulus water (case 7, OVLOCRHE), refilling the annulus with water is the recommended recovery mode. This case starts with the high-temperature DBA (case 6, OVLOCXAL) and replaces the air in the annulus with water at 26.7 °C (80 °F) at 11 hours after the loss of annulus water. In case 6 (OVLOCXAL), the thermal runaway is shown to be just starting at 11 hours (see Appendix A, Figure A-6).

This case shows that replacing the lost annulus water is very effective in cooling the MCO as it begins a thermal runaway. As shown in Appendix A, Figure A-8, the new annulus water cools the hot MCO wall very quickly, which causes the high water vapor concentrations to condense rapidly on the cooling wall. This decrease in water vapor pressure lowers the fuel-water reaction rate immediately, which eventually causes fuel temperatures to decrease. The maximum fuel temperature occurs at about 11.5 hours, one-half hour after refilling the annulus with water. However, the maximum fuel temperature is only 170 °C, which is not hot enough to cause a thermal runaway. Therefore, refilling the annulus with water at 11 hours after the initial loss of annulus water prevents the thermal runaway.

9. OVLOF — Open Multi-Canister Overpack with Stationary Annulus Water. This case is a conservative model of the MCO isolation and purge condition. This case is conservative in that the helium flow is not included, and helium flow would result in cooler fuel temperatures. The process bay, which provides the heat sink when annulus water is not flowing, is at a temperature of 26.7 °C (80 °F). The annulus water is initially at 50 °C and cools over time as heat is transferred to the process bay.

The fuel temperatures remain below 75 °C for at least the 4-day simulation. This case demonstrates that the MCO isolation and purge state is safe and sufficient for controlling fuel temperatures.

10. OV50C — Open Multi-Canister Overpack with Flowing Annulus Water. This case is the same as case 9 (OVLOF) except that the annulus water is flowing instead of stationary. As previously mentioned, the temperature of the annulus water in the stationary annulus water

case (case 9, OVLOF) decreases over time and is below 50 °C after initiation. The flowing annulus water at a constant temperature of 50 °C is, therefore, hotter than the water in the stationary annulus water case and will add more heat to the MCO.

The fuel temperatures in this case remain stable with maximum temperatures below 81 °C, which is about 6 °C higher than the maximum fuel temperature in the stationary annulus case (case 9, OVLOF). This case demonstrates that the MCO isolation and purge condition is safe and sufficient for controlling fuel temperatures.

11. OVLOF99C — Open Multi-Canister Overpack with Very Hot Stationary Annulus Water. This case is the same as case 9 (OVLOF) except that the annulus water is initially very hot at 99 °C. This case represents overheating of the TWS that results in water hotter than 50 °C being placed into the annulus while the TWS is being shut down. The initial annulus water temperature is chosen to be just below the boiling point (99 °C), which is not ever expected even with a TWS failure. The process bay, which is the heat sink for the MCO in this case, is at a temperature of 26.7 °C (80 °F).

The fuel temperatures remain stable for this case and are below 66 °C. This case demonstrates that the MCO isolation and purge state is safe and sufficient for controlling fuel temperatures even if the TWS fails and heats the annulus water up to 99 °C.

12. OVLOCNOH — Loss of Annulus Water with No Uranium Hydride. This case is identical to the high-temperature DBA case (case 6, OVLOCXAL) except that no uranium hydride is present in the fuel. This means that the reaction rate enhancement factor is only 10 for the uranium–water reaction and zero for the hydride–water reaction.

With no uranium hydride present in the fuel, the thermal runaway is delayed by about 13 hours, with the peak temperature occurring around 24.5 hours after the loss of annulus water instead of 11.5 hours as in case 6 (OVLOCXAL). Even though the peak temperature occurs much later than it does in the high-temperature DBA, the temperatures are higher. With more time to heat up, the MCO wall gets much hotter, and the water evaporates faster from this hotter wall and provides more oxidant to the fuel, resulting in higher temperatures. Even though this case results in higher fuel temperatures than case 6 (OVLOCXAL), it takes longer to reach high temperatures, permitting a longer time to refill the annulus. The amount of particulate generated is smaller.

13. OVLOCNOM — Loss of Annulus Water with Nominal Reaction Area and Rates. This case is identical to the high-temperature DBA case (case 6, OVLOCXAL) except that nominal (design basis) values for the fuel surface reaction area, the fuel reaction rate enhancement factors, and the decay heat rate are used. The design basis values are provided in HNF-SD-SNF-TI-015:

- Fuel surface reaction area — 1.7 m² per scrap basket and 0.425 m² per fuel basket for a total of 3.53 m² for an MCO with three fuel baskets and two scrap baskets

- Reaction rate enhancement factor — factors of 3 for the uranium–water reaction and 12 for the uranium hydride–water reaction
- Decay heat rate — 403 W for five fuel baskets, and 366 W for two scrap baskets and three fuel baskets.

Using these nominal values for the key heat generation parameters, there is no thermal runaway. The fuel temperatures for this nominal case are low and stable. The heat generation rate is low enough that air in the annulus provides enough heat transfer capability to promote low and stable temperatures. The particulate generated during the 4 day simulation is only 12.7 kg UO_2 .

14. OVLOC1AX — Loss of Annulus Water with Mark IA Fuel in Multi-Canister Overpack. This case simulates the high-temperature DBA with an MCO containing Mark IA fuel instead of Mark IV fuel. An MCO with Mark IA fuel has lower decay heat and lower reaction surface areas than an MCO with Mark IV fuel. As discussed in Section 3.0, the MCOs containing Mark IA fuel should always be cooler than the MCOs containing Mark IV fuel. This case examines an MCO containing Mark IA fuel under the same accident conditions as those used for the high-temperature DBA (case 6, OVLOCXAL). Even the same amount of aluminum hydroxide water (0.74 kg) was added to the fuel in this case, which is conservative because the Mark IA MCO contains less fuel and will therefore have less hydroxide.

The thermal runaway in an MCO containing Mark IA fuel starts at a later time (after approximately 22 hours), peaks at a later time (approximately 29 hours), and has a peak scrap fuel temperature of 745 °C, which is lower than the peak fuel temperature of about 1,010 °C for the Mark IV fuel (case 6, OVLOCXAL). The maximum center post temperature is about 670 °C, and maximum MCO wall temperature is less than 540 °C.

4.3 RESULTS OF CASES FOR CLOSED OVERPRESSURIZED MULTI-CANISTER OVERPACKS

Four overpressurization cases have been analyzed with three of them focused on releases at various pressure levels and different release points.

15. DS32C2HZ — Closed Multi-Canister Overpack with Drain Stopped, Stationary Annulus Water, and Warm Process Bay. This case models the overpressurization DBA used in the CVDF FSAR (HNF-3553, Annex B). The MCO is isolated (i.e., closed), and the flowing annulus water stops. Initially, the MCO is drained but still contains 26.5 kg of residual water and the fuel is at 50 °C. The process bay temperature is set at 32.2 °C (90 °F). The process bay is the heat sink for MCOs with stationary annulus water; hence, a warmer process bay will result in an MCO with higher fuel temperatures, which will cause a more rapid rate of hydrogen generation, particulate generation, and pressurization.

This case is thermally stable. For this case, the "drain" option in the HANSF code¹ was turned off so that water would not be modeled as draining down the side of the MCO wall and be removed from the upper baskets, which would have kept the water from reacting with the large reaction surface area in the top scrap basket. By turning the MCO wall drain option off in the HANSF code, water vapor that condenses on the wall adjacent to each basket stays in place and evaporates to feed the fuel in the adjacent basket. Note that this is just the opposite of what was done for case 6 (OVLOCXAL). Turning on the MCO wall drain option in case 6 (OVLOCXAL) caused the hottest basket (bottom scrap basket) to be hotter because water originating in the upper baskets was added to the bottom basket after running down the wall. Turning off the MCO wall drain option in this overpressurization case causes higher pressures by providing more water for the top scrap basket.

The pressure increase in this case slows down after 50 hours because the top scrap basket dries out (top basket has only 1.5 kg of water initially), stopping the fuel-water chemical reaction in the top scrap basket, and hence, stopping hydrogen production.

16. B32C2HZ — Blowdown Release of Overpressurized Multi-Canister Overpack.

This case calculates the release from the overpressurization DBA in case 15 (DS32C2HZ). The release occurs at 345 lb/in² gauge about 96 hours after the MCO is closed. A large orifice size (5×10^{-4} m² [equivalent to a 1-in.-diameter hole]) is assumed in order to cause a very rapid release of gas. The blowdown release lasts about 10 seconds. To be conservative, the process bay temperature is set at 32.2 °C (90 °F). The process bay is the heat sink for MCOs with stationary annulus water; hence, a warmer process bay will result in an MCO with higher fuel temperatures, which will cause a more rapid rate of hydrogen and particulate (UO₂) generation.

The fuel temperatures in this case are stable, and about 9 kg of particulate are generated over the 24 hours following the blowdown. Very little air enters the orifice, so the hydrogen generation rate is not significantly reduced, but without oxygen no flammability condition exists (oxygen content is less than 3% at all times). Most of the air that enters the MCO is primarily consumed in the top scrap basket. As a result, the lower four baskets keep generating hydrogen and particulate, which also hinders the air counter-flowing down into the lower baskets.

17. B32C2HZ2 — Blowdown Release at Design Pressure for Mechanically Sealed Multi-Canister Overpack.

This case also calculates the release from an overpressurized MCO. The release occurs at 150 lb/in² gauge through the rupture disk about 36 hours after the MCO is closed. The orifice of the rupture disk has a 1-in. diameter (an area of about 5×10^{-4} m²). The blowdown release takes about 8 seconds to finish. The process bay temperature is kept at 32.2 °C (90 °F) as in cases 15 (DS32C2HZ) and 16 (B32C2HZ).

¹ Note that in the HANSF code, this drain option has nothing to do with the draining of the MCO but rather with the liquid that condenses on the MCO wall and runs down to the bottom of the MCO.

The fuel temperatures are stable and very little particulate is generated for 24 hours after the blowdown release. This is primarily because the air enters the rupture disk after the blowdown release, and air has a lower reaction rate with the fuel than water vapor. Hence, the chemical heat is not as high and the particulate generation is slower. With air entering the MCO and hydrogen already present in the MCO, flammable conditions are reached within a few hours (oxygen content is greater than 8% at 3 hours after the blowdown).

This case results in flammable conditions whereas case 16 (B32C2HZ) does not. The key difference between case 17 and case 16 is that the blowdown at 345 lb/in² gauge happens after 96 hours, and the blowdown at 150 lb/in² gauge happens after 36 hours. As a result, the warmer bottom scrap basket in case 16 generates more hydrogen from fuel-water reactions. This extra hydrogen flows up and causes less oxygen to counter-flow into the MCO. The countercurrent flow of air into the MCO is very sensitive to the amount of hydrogen being generated and flowing out of the MCO.

18. CV32C2HX — Blowdown Releases through Vent Path Check Valve. This case calculates the release from an overpressurized MCO through the 30 lb/in² gauge vent path. This vent path has a check valve that opens and closes based upon the pressure. In this case, the check valve opens when the pressure reaches 35 lb/in² gauge and closes when the pressure reaches 20 lb/in² gauge. The first release happens about 8.5 hours after the MCO is closed, with additional releases occurring over the following 24 hours. These pressure reliefs can be easily seen in Appendix A, Figure A-18 (4 sheets). If the check valve's open and close points were modeled with different values than 35 lb/in² gauge and 20 lb/in² gauge, there would be more (or fewer) releases, but each release would be smaller (or larger) than the currently calculated one, so the total release would be approximately the same.

4.4 RESULTS FOR MULTI-CANISTER OVERPACK COOLING CASES

Two cases have been analyzed that simulate the cooling period that follows the completion of the proof-of-dryness test.

19. COOL1HXX — Cooling of Bounding Multi-Canister Overpack after Vacuum Drying. This case simulates the cooling period after the proof-of-dryness test is completed. After the rebound test, no more than 200 g of water are left in the MCO. The MCO is pressurized with helium to a pressure of 4 lb/in² gauge. This case determines the maximum gas temperature after 5 hours of cooling. To maximize the gas temperature, an MCO with four fuel baskets and one scrap basket was simulated, and the scrap basket was given the same decay power as a fuel basket, causing the MCO to have a bounding decay power of 776 W. Since the MCO is dry, except for the 200 g of free water in cracks and crevices and the chemically bound water in uranium hydrates, very little chemical heat is generated, leaving fuel decay heat the major source of heat. The helium is also assumed to contain 0.5% water, thus allowing some fuel-water reactions to take place. The heat capacity of the fuel basket plates and support posts is included in the center of the MCO causing this simulation to promote a slower cooling rate. The bounding heat capacities of all of the major components of a dry MCO with one scrap basket are shown in Table 4-2.

Table 4-2. Heat Capacity of Major Components of the Cask-Multi-Canister Overpack.

Structure	Heat capacity (Joules per °C)
Cask wall and cask floor	7.78 E+06
Fuel and cladding	9.03 E+05
Shield plug and MCO floor	3.95 E+05
MCO wall	3.30 E+05
Center post, long access tube, support posts, basket plates	2.92 E+05
copper scrap basket fins	2.56 E+04
Total for MCO and cask	9.73 E+06

MCO = multi-canister overpack.

As shown in Table 4-2, the cask dominates the heat capacity of the MCO and cask combination, which is cooled in the simulation. The temperature of the cooling water is 17 °C at the entrance into the cask-MCO annulus, and the flow rate is 15 gal/min. Unlike all of the other cases, the annulus in this case is modeled as five reservoirs of water containing a total of 125 kg of water. Multiple reservoirs of the annulus water were modeled so that the axial temperature effects of the annulus could be included. The top fuel basket has warmer annulus water than the lower fuel baskets, because the annulus water heats up as it travels upward.

The initial temperatures of the MCO and fuel are determined from a vacuum drying simulation of the 20-hour proof-of-dryness test that consists of a vacuum with no helium purge. After 5 hours of cooling, the maximum gas temperature is less than 50 °C, with the gas in the scrap basket being cooler. This case shows the maximum gas temperature in an MCO after cooling will be less than 50 °C. This case also demonstrates that the gas and fuel in a scrap basket is cooler, indicating the enhanced cooling effects of the copper fins. The ambient bay temperature is not important for the cooling cases because the cool flowing water dominates heat removal from the MCO.

20. COOL1HXM — Cooling of Nominal Multi-Canister Overpack after Vacuum Drying. This case is same as case 19 (COOL1HXXH) except that the decay power is lowered to 403 W instead of 776 W, and the cooling water is set to 10 °C instead of 17 °C. The purpose of this case is to show that the gas temperature in the MCO will be much cooler than in the bounding cooling case (case 19, COOL1HXXH). The maximum gas temperature for this case is about 35 °C after 5 hours of cooling. The two most important parameters in governing the final gas temperature are the temperature of the cooling water and the decay power of the fuel.

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5.0 CONCLUSIONS

The following conclusions have been drawn from the thermal analysis.

1. The bounding MCO is thermally stable during vacuum drying except when the vacuum is degraded or there is excess residual water following draining of the MCO.

Vacuum drying with or without helium purge is thermally stable for most conditions with bounding residual water (26.5 kg) and normal annulus water temperature ($\leq 50^{\circ}\text{C}$). However, vacuum drying with no helium purge or degraded vacuum drying with helium purge and more than 35 kg of residual water is not thermally stable with the normal annulus water condition (flowing at $\leq 50^{\circ}\text{C}$).

2. The bounding MCO is thermally stable during the 8-4-4 vacuum-helium purge cycle for all conditions including loss of annulus water (drying is completed if the normal vacuum cycle is performed).

The 8-4-4 vacuum-helium purge cycle results in stable temperatures with degraded vacuum, very high residual water (>35 kg), and loss of annulus water. For air ingress scenarios, the fuel temperatures are stable under vacuum processing without helium purge even if the annulus water is lost.

3. The bounding MCO under positive pressure is thermally stable with only helium purge unless the annulus water is lost.

The helium purge only process (i.e., no vacuum cycle) has stable temperatures for the normal (50°C and flowing) annulus water and the stationary annulus water flow cases, but it is not stable if the annulus water is lost. Helium flow is not a substitute for water in the annulus in preventing thermal runaway reactions, but helium will delay the thermal runaway reaction and reduce the fuel temperatures caused by the loss of annulus water.

4. Open bounding MCOs are thermally stable under most conditions except loss of annulus water.

An open MCO with no vacuum and no helium purge has stable fuel temperatures for more than 4 days (the length of time used in the analysis) for the normal (50°C and flowing) annulus water and the stationary annulus water cases but is unstable (fuel temperature $> 1,000^{\circ}\text{C}$) if annulus water is lost for more than 11 hours and enough residual water (>5 kg) is available.

5. Under bounding conditions, closed MCOs take 36 hours to reach a pressure of 150 lb/in² gauge and 96 hours to reach 345 lb/in² gauge.

A closed (isolated) MCO will pressurize and eventually reach the rupture disk burst pressure of 150 lb/in² gauge for all annulus water conditions, but reaching the rupture disk pressure takes 36 hours in the stationary annulus water case. Reaching 345 lb/in² gauge takes about 96 hours.

6. Open MCOs with nominal parameter values are stable under all conditions.

An open MCO with nominal parameter values for fuel–water reaction rate, enhancement factors, reaction surface area, and decay heat rate has stable fuel temperatures under all conditions including the loss of annulus water condition.

7. Refilling the annulus within 11 hours of a loss of annulus water prevents a thermal runaway in the bounding MCO.

For the safety basis MCO with the loss of annulus water condition, the MCO vapor pressure can be reduced very quickly (<60 seconds) by introducing 26.7 °C (80 °F) water into the annulus. The water injected into the annulus cools the stainless steel MCO wall and MCO bottom very quickly, and the water vapor inside the MCO starts to condense on the cooler MCO wall and bottom immediately. The condensation of water vapor lowers the gas and vapor pressure, which lowers the fuel–water reaction rates and reduces generated chemical heat. The maximum scrap fuel temperature at 11 hours after the loss of annulus water is less than 150 °C. The temperature continues rising to a peak that is less than 170 °C at about 11.5 hours and then begins decreasing. The MCO wall temperature is about 80 °C at 11 hours after the loss of the annulus water; hence, there is no danger of the water flashing or boiling when it is introduced into annulus during recovery at or before 11 hours.

The results of this analysis are summarized in Table 5-1. They show that the bounding MCO has stable temperatures for all cold vacuum drying processes after draining if the annulus is filled with water. The temperature of the stationary annulus water may be up to 99 °C initially, and the temperature of the flowing annulus water may be up to 50 °C.

Table 5-1. Results Summary of Simulated Cases. (3 sheets)

Case number	Case name, description	Annulus water and helium conditions	Particulate, (kg UO ₂) generated in 24 hours	Maximum H ₂ generation rate (mg/s) and time of maximum	Results summary
Vacuum processing cases					
1	VXDG Degraded vacuum	Water at 50 °C and flowing, no helium flow	40.5	58 at 17.8 hours	Dry in 21.5 hours Thermal excursion at 15 hours Scrap fuel temperature = 740 °C at 17.8 hours
2	VPXDGP7 Degraded vacuum with helium flow	Water at 50 °C and flowing, helium flow at 0.7 standard ft ³ /min	7.1	2.6 at 14.5 hours	Dry in 19 hours Scrap fuel temperature = 90 °C at 16.5 hours
3	VPXDGP7W Degraded vacuum with helium purge and reflood	Water at 50 °C and flowing, helium flow at 0.7 standard ft ³ /min	55	87 at 18.7 hours	Scrap fuel temperature = 850 °C at 18.5 hours
4	VPDG8-4-4W Degraded vacuum with 8-4-4 cycle and reflood	Water at 50 °C and flowing, helium flow at 0.7 standard ft ³ /min	12	3.8 at 24 hours	30 kg of water removed Scrap fuel temperature < 98 °C Temperatures stable forever
5	VAIRLOC Normal vacuum with air ingress	Loss of annulus water, no helium flow	1.5	3.0 at zero seconds	Fuel temperature < 123 °C Scrap fuel temperature < 111 °C
Open vented MCO cases with different tempered water conditions					
6	OVLOCXAL High-temperature DBA	Loss of annulus water, no helium flow	163	560 at 11.6 hours	Fuel temperature < 245 °C Scrap fuel temperature < 1,015 °C
7	OVLOCRHE High-temperature DBA with helium flow	Loss of annulus water, helium flow at 0.7 standard ft ³ /min	176	350 at 19 hours	Fuel temperature < 180 °C Scrap fuel temperature = 820 °C at 19 hours
8	OVLOCREC Thermal runaway recovery	Loss of annulus water, no helium flow	22	20 at 11 hours	Scrap fuel temperature = 170 °C at 12 hours
9	OVLOF Stationary annulus water	Stationary annulus water initially at 50 °C, no helium flow	30.5 in 96 hours	3.2 at 8.9 hours	Fuel temperature < 75 °C Scrap fuel temperature < 60 °C over 96 hours

Table 5-1. Results Summary of Simulated Cases. (3 sheets)

Case number	Case name, description	Annulus water and helium conditions	Particulate, (kg UO ₂) generated in 24 hours	Maximum H ₂ generation rate (mg/s) and time of maximum	Results summary
10	OV50C Normal flowing annulus water	Annulus water flowing at 50 °C, no helium flow	38 in 96 hours	3.4 at 49 hours	Fuel temperature < 81 °C Scrap fuel temperature < 69 °C over 96 hours
11	OVLOF99C Hot stationary annulus water	Stationary annulus water initially at 99 °C, no helium flow	14	4.1 at 7.5 hours	Fuel temperature < 62 °C Scrap fuel temperature < 66 °C over 24 hours
12	OVLOCNOH Loss of annulus water and no uranium hydride	Loss of annulus water, no helium flow	160 in 28 hours	400 at 24.5 hours	Fuel temperature < 210 °C Scrap fuel temperature > 1,100 °C at 24.5 hours
13	OVLOCNOM Loss of annulus water and nominal MCO	Loss of annulus water, no helium flow	12.7 in 96 hours	1.0 at 20 hours	Fuel temperature < 72 °C Scrap fuel temperature < 67 °C at 72 hours
14	OVLOC1AX Loss of annulus water with Mark 1A fuel	Loss of annulus water, no helium flow	172 in 32 hours	250 at 28.7 hours	Fuel temperature = 210 °C Scrap fuel temperature = 745 °C at 28.7 hours
Closed MCO cases with overpressurization					
15	DS32C2HZ Overpressurization DBA	Stationary annulus water initially at 50 °C, no helium flow	44 in 96 hours	3.3 at 46 hours	Fuel temperature < 71 °C Scrap fuel temperature < 62 °C
16	B32C2HZ Blowdown release at 345 lb/in ² gauge	Stationary annulus water, no helium flow	9	2.6 at 96 hours	Fuel temperature < 84 °C Scrap fuel temperature < 84 °C
17	B32C2HZ2 Blowdown release at 150 lb/in ² gauge	Stationary annulus water, no helium flow	0.4	3.2 at 96 hours	Fuel temperature < 88 °C Scrap fuel temperature < 69 °C
18	CV32C2HX Blowdown release through vent path	Stationary annulus water, no helium flow	19 in 36 hours	3.4 at 36 hours	Fuel temperature < 65 °C Scrap fuel temperature < 64 °C

Table 5-1. Results Summary of Simulated Cases. (3 sheets)

Case number	Case name, description	Annulus water and helium conditions	Particulate, (kg UO ₂) generated in 24 hours	Maximum H ₂ generation rate (mg/s) and time of maximum	Results summary
MCO cooling cases					
19	COOL1HXXH Cooling of bounding MCO	Annulus water flowing at 17 °C, helium at 4 lb/in ² gauge	0.9 in 6 hours	1.5 at 9 min	Fuel temperature < 75 °C Scrap fuel temperature < 65 °C Maximum gas temperature = 49 °C
20	COOL1HXXM Cooling of nominal MCO	Annulus water flowing at 10 °C, helium at 4 lb/in ² gauge	0.15 in 6 hours	0.45 at 1 min	Fuel temperature < 59 °C Scrap fuel temperature < 57 °C Maximum gas temperature = 35 °C

DBA = design basis accident.

MCO = multi-canister overpack.

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APPENDIX A
HANSF PLOTS OF ALL CASES

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Figure A-1. Case VXDG. (4 sheets)

VXDG: VAC=13 cfm, He=0.0 scfm, Netw U=10 UH3=12 H2O=26.5 Kg, ILAW=3

Figure A-1. Case VXDG. (4 sheets)

VXDG: VAC=13 cfm, He=0.0 scfm, Netw U=10 UH3=12 H2O=26.5 Kg, ILAW=3

Figure A-1. Case VXDG. (4 sheets)

Figure A-1. Case VXDG. (4 sheets)

Figure A-2. Case VPXDGP7. (4 sheets)

VPXDGP7: VAC=13 cf.m, He=0.7 scf.m, U=10 UH3=12 H2O=26.5 Kg

Figure A-2. Case VPXDGP7. (4 sheets)

VPXDGP7: VAC=13 cfm, He=0.7 scfm, U=10 UH3=12 H2O=26.5 Kg

Figure A-2. Case VPXDGP7. (4 sheets)

VPXDGP7: VAC=13 cfm, He=0.7 scfm, U=10 UH3=12 H2O=26.5 Kg

Figure A-2. Case VPXDGP7. (4 sheets)

Figure A-3. Case VPXDGP7W. (4 sheets)

VPXDGP7W: VAC=13 cfm, He=0.7 scfm, U=10 UH3=12 H2O=120 Kg

Figure A-3. Case VPXDGP7W. (4 sheets)

VPXDGP7W: VAC=13 cf.m, He=0.7 scfm, U=10 UH3=12 H2O=120 Kg

Figure A-3. Case VPXDGP7W. (4 sheets)

Figure A-3. Case VPXDGP7W. (4 sheets)

Figure A-4.1. Case VPDG8-4-4W: Run VPXDGW0 for 0 to 8 Hours. (2 sheets)

VPXDGW0: VAC=13 cf.m, He=0.7 scfm, U=10 UH3=12 H2O=120 Kg, 0-8 hr

Figure A-4.1. Case VPDG8-4-4W: Run VPXDGW0 for 0 to 8 Hours. (2 sheets)

Figure A-4.2. Case VPDG8-4-4W: Run HEP7W1 for 8 to 12 Hours. (2 sheets)

Figure A-4.2. Case VPDG8-4-4W: Run HEP7W1 for 8 to 12 Hours. (2 sheets)

Figure A-4.3. Case VPDG8-4-4W: Run VPXDGW2 for 12 to 16 Hours. (2 sheets)

Figure A-4.3. Case VPDG8-4-4W: Run VPXDGW2 for 12 to 16 Hours. (2 sheets)

Figure A-4.4. Case VPDG8-4-4W: Run HEP7W3 for 16 to 20 Hours. (2 sheets)

HEP7W3: VAC=0 cfm, He=0.7 scfm, U=10 UH3=12 H2O=120 Kg, 16-20 hr

Figure A-4.4. Case VPDG8-4-4W: Run HEP7W3 for 16 to 20 Hours. (2 sheets)

Figure A-4.5. Case VPDG8-4-4W: Run VPXDGW4 for 20 to 24 Hours. (2 sheets)

Figure A-4.5. Case VPDG8-4-4W: Run VPXDGW4 for 20 to 24 Hours. (2 sheets)

Figure A-5. Case VAIRILOC. (4 sheets)

VAIRILOC: VAC=30 cfm, He=0, Air In, LOC U=10 UH3=12 H2O=26.5

Figure A-5. Case VAIRILOC. (4 sheets)

Figure A-5. Case VAIRILOC. (4 sheets)

Figure A-5. Case VAIRILOC. (4 sheets)

Figure A-6. Case OVLOCXAL. (4 sheets)

OVLOCXAL: Open MCO, LOC AL>0 U=10 UH3=12 H2O=26.5 Kg dnn>0 ILAW=3

Figure A-6. Case OVLOCXAL. (4 sheets)

OVLOCXAL: Open MCD, LOC AL>0 U=10 JH3=12 H2O=26.5 Kg dnn>0 ILAW=3

Figure A-6. Case OVLOCXAL. (4 sheets)

OVLOCXAL: Oper. MCD, LOC AL>C U=10 UH3=12 H2O=26.5 Kg drn>0 ILAW=3

Figure A-6. Case OVLOCXAL. (4 sheets)

Figure A-7. Case OVLOCRHE. (4 sheets)

OVLOCRHE: Open MCO,LOC, He=0.7 scfm, U=10 UH3=12 H2O=26.5 Kg

Figure A-7. Case OVLOC RHE. (4 sheets)

OVLOC RHE: Open MCD LOC, He=0.7 scfm, U=10 UH3=12 H2O=26.5 Kg

Figure A-7. Case OVLOC RHE. (4 sheets)

OVLOC RHE: Open MCO, LOC, He=0.7 scfm, U=10 UH3=12 H2O=26.5 Kg

Figure A-7. Case OVLOC RHE. (4 sheets)

OVLOC RHE: Open MCC.LOC, He=0.7 scfm, U=10 UH3=12 H2O=26.5 Kg

Figure A-8. Case OVLOCREC. (4 sheets)

OVLOCREC: Open MCO w Loss of Ann. Restored: 11 hr U=10 UH3=12 H2O=26.5 Kg

Figure A-8. Case OVLOCREC. (4 sheets)

OVLOCREC: Open MCD w Loss of Ann. Restored: 11 hr U=10 UH3=12 H2O=26.5 Kg

Figure A-8. Case OVLOCREC. (4 sheets)

OVLOCREC: Open MCO w Loss of Ann. Restored: 11 hr U=10 UH3=12 H2O=26.5 Kg

Figure A-8. Case OVLOCREC. (4 sheets)

Figure A-9. Case OVLOF. (4 sheets)

OVLOF: Open MCD, Loss of Annulus Water Flow U=10, UH3=12

Figure A-9. Case OVLOF. (4 sheets)

OVLOF: Open MCO, Loss of Annulus Water Flow U=10, UH3=12

Figure A-9. Case OVLOF. (4 sheets)

OVLOF: Open MCO. Loss of Annulus Water Flow U=10, UH3=12

Figure A-9. Case OVLOF. (4 sheets)

OVLOF: Open MCO, Loss of Annulus Water Flow U=10. UH3=12

Figure A-10. Case OV50C. (4 sheets)

OV50C: Open MCO, Annulus water flowing at 50 C U=10, UH3=12

Figure A-10. Case OV50C. (4 sheets)

OV50C: Open MCO, Annulus water flowing at 50 C U=10, UH3=12

Figure A-10. Case OV50C. (4 sheets)

Figure A-10. Case OV50C. (4 sheets)

Figure A-11. Case OVLOF99C. (4 sheets)

OVLOF99C: Open MCO, Loss of Ann. Wat. Flow water at 99 C, U=10, UH3=12

Figure A-11. Case OVLOF99C. (4 sheets)

Figure A-11. Case OVLOF99C. (4 sheets)

Figure A-11. Case OVLOF99C. (4 sheets)

Figure A-12. Case OVLOCNOH. (4 sheets)

OVLOCNOH: Open MCD, Loss of Ann. Wat., U=10 UH3=0 H2O=26.5 Kg

Figure A-12. Case OVLOCNOH. (4 sheets)

OVLOCNOH: Open MCO, Loss of Ann. Wat., U=10 UH3=0 H2O=26.5 Kg

Figure A-12. Case OVLOCNOH. (4 sheets)

Figure A-12. Case OVLOCNOH. (4 sheets)

Figure A-13. Case OVLOCNOM. (4 sheets)

OVLOCNOM: Open MCO,LOC, Nominal Rates+Area U=3 UH3=12 H2O=26.5 Kg

Figure A-13. Case OVLOCNOM. (4 sheets)

OVLOCNOM: Open MCD, LOC, Nominal Rates+Area U=3 UH3=12 H2O=26.5 Kg

Figure A-13. Case OVLOCNOM. (4 sheets)

OVLOCNOM: Open MCD, LOC. Nominal Rate, Area U=3 UH3=12 H2O=26.5 Kg

Figure A-13. Case OVLOCNOM. (4 sheets)

OVLOCNOM: Open MCD,LOC, Nominal Rates+Area U=3 UH3=12 H2O=26.5 Kg

Figure A-14. Case OVLOC1AX. (4 sheets)

OVLOC1AX: Open MCO w Mark 1A fuel LOC, U=10 UH3=12 H2O=26.5 Kg

Figure A-14. Case OVLOC1AX. (4 sheets)

OVLOC1AX: Open MCD w Mark IA fuel LOC, U=10 UH3=12 H2O=26.5 Kg

Figure A-14. Case OVLOC1AX. (4 sheets)

OVLOC1AX: Open MCD w Mark IA fuel LOC, U=10 UH3=12 H2O=26.5 Kg

Figure A-14. Case OVLOC1AX. (4 sheets)

OVLOC1AX: Open MCD w Mark IA fuel LOC, U=10 UH3=12 H2O=26.5 Kg

Figure A-15. Case DS32C2HZ. (4 sheets)

DS32C2HZ: Closed MCC, no wall drn 30F Boy U=10 UH3=12 H2O=26.5 Kg ILAW=3

Figure A-15. Case DS32C2HZ. (4 sheets)

Figure A-15. Case DS32C2HZ. (4 sheets)

DS32C2HZ: Closed MCO, no wall drn 90F Bay U=10 UH3=12 H2O=26.5 Kg ILAW=3

Figure A-15. Case DS32C2HZ. (4 sheets)

DS32C2HZ: Closed MCO, no wall den 90F Bay U=10 UH3=12 H2O=26.5 Kg ILAW=3

Figure A-16. Case B32C2HZ. (4 sheets)

B32C2HZ: Blow Down(345 psig), 90F Bay U=10 UH3=12 H2O=26.5 Kg

Figure A-16. Case B32C2HZ. (4 sheets)

B32C2HZ: Blow Down(345 psig), 90F Boy U=10 UH3=12 H2O=26.5 Kg

Figure A-16. Case B32C2HZ. (4 sheets)

B32C2HZ: Blow Down(345 psig), 90F Bay U=10 UH3=12 H2O=26.5 Kg

Figure A-16. Case B32C2HZ. (4 sheets)

B32C2HZ: Blow Down(345 psig), 90F Bay U=10 UH3=12 H2O=26.5 Kg

Figure A-17. Case B32C2HZ2. (4 sheets)

B32C2HZ2: Blow Down(150 psig), 90F Bay U=10 UH3=12 F20=26.5 Kg drn=0

Figure A-17. Case B32C2HZ2. (4 sheets)

B32C2HZ2: Blow Down(150 psig). 90F Bay. U=10 UH3=12 H2O=26.5 Kg dnn=0

Figure A-17. Case B32C2HZ2. (4 sheets)

B32C2-HZ2: Blow Down(150 psig), 90F Bay U=10 UH3=12 H2O=26.5 Kg dnn=0

Figure A-17. Case B32C2HZ2. (4 sheets)

Figure A-18. Case CV32C2HX. (4 sheets)

Figure A-18. Case CV32C2HX. (4 sheets)

Figure A-18. Case CV32C2HX. (4 sheets)

CV32C2HX: 35-20psig Check Valve 90F Boy LOF U=10 UH3=12 H2O=26.5 Kg ILAW=3

Figure A-18. Case CV32C2HX. (4 sheets)

Figure A-19. Case COOL1HXX. (3 sheets)

COOL1HXX: 17C-axial cooling, 15gpm flow, 4 psig Het. 5% H₂O, 114 F Boy. 776 W

Figure A-19. Case COOL1HXXH. (3 sheets)

Figure A-19. Case COOL1HXXH. (3 sheets)

COOL1HXXH: 17C-oxial cooling, 15gpm flow, 4 psig He+5%H₂O, 114 F Bay, 776 W

Figure A-20. Case COOL1HXM. (3 sheets)

COOL1HXM: 10C-axial cooling, 15 gpm flow, 4 psig, HE+5%H₂O, 80 F Box, 403 W

Figure A-20. Case COOL1HXM. (3 sheets)

COOL1HXM: 10C-axial cooling, 15 gpm flow, 4 psig, HE+5%H₂O, 80 F Bay, 403 W

Figure A-20. Case COOL1HXM. (3 sheets)

COOL1HXM: 100° axial cooling, 15 gpm flow, 4 psig, HE+5% H₂O, 80 F Bay, 403 W

APPENDIX B
INPUT FILE AND INPUT DIFFERENCES

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APPENDIX B

INPUT FILE AND INPUT DIFFERENCES

This section provides a listing of the HANSF version 1.3.2 input file for case 1, VXDG. The input files for cases 2 through 6 are compared with the VXDG file with only the differences indicated (ignoring format, comment, and nonessential input differences). The differences indicated in case 6, OVLOXAL, are compared with the input files from cases 7 through 18. Lastly, the entire input file for case 19, COOL1HXH, is listed, and the input file from case 20 is compared with the COOL1HXH input file.

CASE 1, VXDG, INPUT FILE

```

*****
*
* CASE VXDG:
*
* TWO SCRAP BASKETS (SFFFS)
*
* REACTION AREA = 4.5 M^2 PER SCRAP BASKET
*                0.790 M^2 PER FUEL BASKET
*
* UNLESS OTHERWISE NOTED, MKS UNITS
*
* GENERAL INPUTS:
*
* - FIVE TIERS OF FUEL PLUS SCRAP EXPLICITLY MODELED
* - VACUUM FLOW RATE IS 13 CFM
* - HE INJECTION IS 0.7 SCFM
* - 1.5 Kg H2O IN TOP SCRAP BASKET,
* - 6.0 Kg PER FUEL BASKET,
* - 1.0 Kg WATER HEEL
* - SCRAP BASKET DIVIDED INTO FINE AND COARSE SECTIONS, WITH
*   RADIAL CONDUCTION TO THE COPPER DIVIDER "FIN"
* - AMBIENT TEMPERATURE (CASK EXTERIOR) IS 80 F (26.7 C)
* - CASK/MCO GAP IS 0.61 INCH (0.0155 M)
* - BOTH SIDES OF THE CASK AND OUTER SURFACE OF MCO WALL TEMPERATURES
*   ARE FIXED USING NEW 'IMPOSED HEAT SINK SURFACE TEMPERATURE' FOR
*   WATER FILLED ANNULUS
* - THE CASK HAS INNER DIAMETER OF 25.19" AND OUTER DIAMETER OF 39.81"
*   I.E. 7.31" (0.1857 M) THICK
* - 'WATER' GAS IN THE MCO/CASK GAP
* - RADIATION HEAT TRANSFER FROM FUEL/SCRAP TO LID/FLOOR.
*****
*
*-----
CONTROL      ! Major keyword group
*-----
*
*
* TITLE      ! Keyword; next line is title, title can be any length
* CASE VXDG: vac= 13 cfm, INDEFINITE VACUUM CYCLE,
*             degraded vacuum
*             UH3=12, U=10, H2O=26.5 kg, SFFFS,          TWO SCRAP BASKETS (SFFFS)

```

HNF-SD-SNF-CN-023 REV 2

```

END TITLE ! Anything after END is a comment
*
*
TIMING      ! Keyword
  TSTART      0.0      ! START TIME, >0 FOR RESTART RUN
C RESTART_FILE NOHEAXRR.REW ! RESTART FILE NAME FOR RESTART RUN
                        ! IF NOT SPECIFIED, READ FROM
                        ! 'input deck name'.RER
  TLAST      86400.    ! END TIME (Seconds)
* for next six parameters (DTMIN, DTMAX, DTPRIN, PLTMAX, PLTMIN, DTRST),
* the user can specify either a fixed value or time dependent value. For
* example:
* DTMIN      0.01      will cause the code to use minimum time step of 0.01
*                      second all the time
*
* DTMIN
* 0.          0.01
* 100.        1.0
* 500.        2.0      will cause the code to use minimum time step of 0.01
*                      for the first 100 seconds, 1.0 second for next 400
*                      seconds, and then 2.0 second for the the rest of the run
*
* DTMIN      0.0001    ! MIN TIMESTEP (Seconds)
* DTMAX      ! MAX TIMESTEP (Seconds)
* 0.          0.1
* 5.          0.5
* 30.         1.0
* 53400.      0.5
* DTPRIN      3600.    ! PRINT INTERVAL (Seconds)
* PLTMIN      100.     ! MIN PLOT INTERVAL (Seconds)
* PLTMAX      1000.    ! MAX INTERVAL WITHOUT PLOT (Seconds)
* DTRST       3600.    ! RESTART INTERVAL (Seconds)
* FTPCH       0.005    ! FRACTIONAL CHANGE IN T AND P
* FAECH       0.005    ! FRACTIONAL CHANGE IN AEROSOL MASS
* FPPLCH      0.03     ! FRACTIONAL CHANGE FOR PLOTTING
* STARVTD     0.15
END TIMING ! TIMING is a comment.
*
*
PRINT      ! Keyword for printing section
*
* Printing syntax:
* HS  n hlist - Heat Sink Temperatures, C
*
* HS 10 1 2 3 4 5 6 7 8 9 10
* HS 10 11 12 13 14 15 16 17 18 19 20
* HS 10 21 22 23 24 25 26 27 28 29 30
* HS 10 31 32 33 34 35 36 37 38 39 40
* HS 10 41 42 43 44
END PRINT ! PRINT is a comment
*
*
PLOT      ! Keyword for plotting section
* Plotting syntax:
*
* PRESSURE n rlist - Pressure, Pa
* GAS-T n rlist - Gas Temperature, K
* HS-TI n hlist - Heat Sink Temperature - Inner Surface, K
* HS-TO n hlist - Heat Sink Temperature - Outer Surface, K
* HS-TA n hlist - Heat Sink Temperature - Average, K
* AEROSOL n rlist - Aerosol Mass (Total), kg
* GAS-W n jlist - Mass Flowrate, kg/s
* GAS-WX n jlist - CounterCurrent Mass Flowrate, kg/s
* GAS-X GASNAME n rlist - Gas Mole Fraction

```

HNF-SD-SNF-CN-023 REV 2

```

* GAS-RH  GASNAME n rlist - Gas Relative Humidity
* GAS-MASS GASNAME n rlist - Gas Mass (Species), kg
* AER-MASS GASNAME n rlist - Aerosol Mass (Species), kg
* MASS     GASNAME n rlist - Total Mass (Species), kg
* LIQ-MASS - GASNAME n rlist - Deposited Mass (Species), kg
*
* Pressure, Gas Temperature, and total aerosol mass require a region
* list
*
* Heat Sink Temperatures need a heat sink number list
*
* Flowrates need a junction number list
*
* Gas concentration, relative humidity, individual species gas mass,
* individual species aerosol mass, total (gas+aerosol) individual
* species mass, and individual species deposited liquid mass require
* a region and gas name
*
* Note: plot routine can only accept 99 items; can't plot all things.
* So plot all scrap T's but only 5 fuel (plus MCO)
*
PRESSURE      1      1      ! Pressure in MCO
GAS-T         5      1      2      3      4      5      ! Temperature in MCO
HS-TA         6      387 389 46 394 390 399      ! Insert, Scrap 1, fin, MCO
HS-TA         6      439 441 56 446 442 451      ! Insert, Scrap 2, fin, MCO
HS-TI         3      68 69 70      ! Cask, MCO bott & lid
HS-TO         3      68 69 70      ! Cask, MCO bott & lid
HS-TA         7      1 168 4 7 10 14 15      ! Fuel 1
HS-TA         6      16 270 22 25 29 30      ! Fuel 2
HS-TA         6      31 372 37 40 44 45      ! Fuel 3
GAS-X  NITROGEN 5      1      2      3      4      5      ! N2 %
GAS-X  OXYGEN   5      1      2      3      4      5      ! O2 %
GAS-X  STEAM    5      1      2      3      4      5      ! H2O %
GAS-X  HYDROGEN 5      1      2      3      4      5      ! H2 %
GAS-X  HELIUM   5      1      2      3      4      5      ! He %
GAS-W         5      1      2      3      4      5      ! Junc. flow
GAS-WX        5      1      2      3      4      5      ! Junc. cc flow
GAS-MASS  HYDROGEN 1      7      ! H2 release
GAS-MASS  STEAM   1      7      ! H2O release
END PLOT      ! PLOT is a comment
*
*
ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
IJUNC 1      ! Junction flow model
ICCFLW 1     ! Counter-current flow model
IHSINK 1     ! Heat sinks
ICNDS 0     ! Condensation
IASSED 0     ! Aerosol Sedimentation
IALEAK 0     ! Aerosol Leakage
IFOG 0     ! Fog formation
ISRC 0     ! User-defined sources
IMCO 1     ! MCO models
ISENS 0     ! Sensitivity runs
* multipliers for region gas conductivities
* syntax:
* FKGAS fkgas1 fkgas2 fkgas3 ...
END ACTIVE MODELS ! ACTIVE MODELS is a comment
*
*
C-----
C SOURCE GROUP: GROUPS REPEATED FOR INPUT # OF REGIONS
C END OF GROUP DESIGNATED BY 'REGION' OR 'END' KEYWORDS
C ENTER: TIME, TEMP, FLOWRATES, POWER

```

HNF-SD-SNF-CN-023 REV 2

```

C      SYNTAX EXAMPLE:
* 1.6 FT^3/MIN * 1 MIN/60 SEC * 0.02832 M^3/1 FT^3 = 0.000755 M^3/SEC
* 2.5 FT^3/MIN * 1 MIN/60 SEC * 0.02832 M^3/1 FT^3 = 0.00118 M^3/SEC
* He density @ stp is 0.16 kg/m^3, hence 1.88e-4 about 1.2e-4 kg/s
* He density @ stp is 0.16 kg/m^3, hence 1.88e-4 about 1.9e-4 kg/s
CSOURCES 1      ! -- KEYWORD AND # SOURCE GROUPS
C REGION 2 GASES 1      !-- REGION #, # GASES
C HELIUM      !-- GAS NAMES MUST BE ON NEXT LINE
C 0 26.85 1.2E-4 0.E0
C 1.E6 26.85 1.2E-4 0.E0
C END REGION      !-- ENDS A REGION SOURCEi
C END SOURCE      !-- ENDS ALL SOURCE INPUT
*
*
END CONTROL      ! End of CONTROL keyword group
*
*
-----
VOLUMES 7      ! total number of control volumes
*
* total MCO gas volume is about 0.52 m^3,
* Units:
* VOLUME m^3, SED_AREA m^2, ELEVATION m, TEMP_GAS C, PRESSURE Pa
*
*
Regions 1 to 5 each contain a basket, top to bottom
*
*      scrap1      scrap2      fuel1      fuel2      fuel3
REGIONS      1      2      3      4      5
VOLUME      0.118      0.100      0.100      0.1      0.1
SED_AREA      0.172      0.172      0.172      0.172      0.172
ELEVATION      2.85      0.0      2.15      1.45      0.75
TEMP_GAS      50.0      50.0      50.0      50.0      50.0
PRESSURE      1.013E5      1.013E5      1.013E5      1.013E5      1.013E5
END REGIONS
*
*
gap      environment
REGIONS      6      7
VOLUME      0.12      1.E9
SED AREA      0.0      0.0
ELEVATION      0.0      0.0
TEMP_GAS      50.0      50.0
PRESSURE      1.013E5      1.013E5
END REGIONS      ! REGIONS is a comment
*
* Gas composition of each region; specify mole fraction of each gas
* No more than five columns at a time
*
GASES      1      2      3      4      5
HELIUM      0.89      0.89      0.89      0.89      0.89
STEAM      0.11      0.11      0.11      0.11      0.11
OXYGEN      0.0      0.0      0.0      0.0      0.0
NITROGEN      0.0      0.0      0.0      0.0      0.0
WATER      0.0      0.0      0.0      0.0      0.0
END GASES
*
* If there are more than five regions, continue here.
*
GASES      6      7
HELIUM      0.0      0.0
STEAM      0.0      0.0
OXYGEN      0.0      0.00
NITROGEN      0.0      1.00

```

```

WATER      1.0      0.0
END GASES      ! GASES is a comment
*
* Aerosol concentration of each region (kg/m^3)
* No more than five columns at a time
*
* AEROSOLS      1      2      3      4      5
• STEAM      0.0001      0.0      0.0      0.0      0.0
* END AEROSOLS ! AEROSOLS is a comment
*
* No more than five columns at a time, so continue with 6 & 7
•
• AEROSOLS      6      7
* STEAM      0.0      0.0
• END AEROSOLS ! AEROSOLS is a comment
*
* OPTIONAL TEMPERATURE AND PRESSURE CONTROL
• CONTROL MCO HEATUP GASES AND MCO INLET GAS TEMPERATURE
* IMPOSE TEMPERATURE LOOK-UP TABLE
* SYNTAX:
*   OFFSET TIMETG
*   EXTRAPOLATION TIMETG
*   TIMETG IREG TIME1, TIME2...TIMELAST
*   TGFIX IREG TEMP1, TEMP2... TEMPLAST      TEMPS ARE IN K!!!
*   LINEAR INTERPOLATION BETWEEN VALUES
*
*   SIMILAR SYNTAX FOR PRESSURE:
*   OFFSET TIMEPG
*   EXTRAPOLATION TIMEPG
*   TIMEPG IREG TIME1, TIME2...
*   PREFIX IREG PRES1, PRES2...PRESSURES ARE IN PA!!!
*
*   OFFSET_TIMETG=  OFFSET TIME; ENTER LOOKUP TABLE WITH
*                   TIME+OFFSET_TIMETG
*   EXTRAPOLATION_TIMETG= LAST TO USE LAST VALUE IN THE TABLE,
*                        = EXTRAP TO EXTRAPOLATE FROM LAST TWO POINTS,
*                        = PERIOD TO WRAP AROUND.
*   OFFSET_TIMETG      50.
*   EXTRAPOLATION_TIMETG      LAST
*   TIMETG 1      0.0      100.      200.
*   TGFIX 1      20.0      100.      200.
*
*   CONTROL MCO BOUNDARY P,
*   OFFSET_TIMEPG      30.
*   EXTRAPOLATION_TIMEPG      EXTRAP
*   TIMEPG 1      0.0      100.      200.
*   PREFIX 1      1.E5      1.2E5      1.4E5
*
END VOLUMES ! VOLUMES is a comment
*
*
• Major keyword-----
HEAT_SINKS      80      ! Total number of heat sinks
*-----
* No more than 5 columns at a time,
• Repeat the following structure,
* SINKS
* .
* .
* .
* END
*
• Syntax:

```

HNF-SD-SNF-CN-023 REV 2

* IGEOM 1 for plane, 0 or 2 for cylinder
 * IMATHS material type
 * RHO Density (kg/m^3), if different from material type
 * KHS Thermal Conductivity (W/m/K), if different from material type
 * CPHS Specific Heat (J/kg/K), if different from material type
 * QV Volumetric Heat Generation (W/m^3), if different from material type
 * EHSI Emissivity of inner surface, if different from material type
 * User has an option to input a temperature dependent emissivity by
 * inputting a negative integer for the emissivity and supplying the
 * corresponding temperature versus emissivity look-up table. See
 * TTABLE & ETABLE keywords.
 * EHSO Emissivity of outer surface, if different from material type
 * XRI Inner Radius (m)
 * XRO Outer Radius (m); for plane wall, thickness = XRO-XRI
 * AHS One-sided heat sink area (m^2)
 * XZHS Axial length for conduction (m)
 * TIINIT Initial inside surface temperature (C)
 * TOINIT Initial outside surface temperature (C)
 * IMSLAB Number of slabs; 3 is minimum
 * IREGI Region index for inner surface or 0 (insulated)
 * or -1 for constant temperature
 * TIHS Region surface temperature when IREGI = -1 (C)
 * IREGO Region index for outer surface or 0 (insulated)
 * or -1 for constant temperature
 * TOHS Region surface temperature when IREGO = -1 (C)
 * XLHS Characteristic length for natural convection (m)
 *

* Fuel Basket #1 heat sinks 1 through 15
 *

SINKS	1	2	3	4	5
• IGEOM	0	0	0	0	0
IMATHS	1	1	1	1	1
XRI	0.00610	0.02160	0.00610	0.02160	0.00610
XRO	0.01625	0.03075	0.01625	0.03075	0.01625
AHS	0.278	0.655	0.278	0.655	0.278
XZHS	0.661	0.663	0.661	0.663	0.661
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	3	3	3	3	3
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	3	3	3	3	3
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.661	0.663	0.661	0.663	0.661

END

SINKS	6	7	8	9	10
• IGEOM	0	0	0	0	0
IMATHS	1	1	1	1	1
XRI	0.02160	0.00610	0.02160	0.00610	0.02160
XRO	0.03075	0.01625	0.03075	0.01625	0.03075
AHS	0.655	0.557	1.310	0.278	0.655
XZHS	0.663	0.661	0.663	0.661	0.663
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	3	3	3	3	3
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	3	3	3	3	3
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.663	0.661	0.663	0.661	0.663

HNF-SD-SNF-CN-023 REV 2

END

*

	11	12	13	14	MCO WALL 15
SINKS					
IGEOM	0	0	0	0	0
IMATHS	1	1	1	1	2
XRI	0.00610	0.02160	0.00610	0.02160	0.3050
XRO	0.01625	0.03075	0.01625	0.03075	0.3177
AHS	0.278	0.655	0.557	1.310	1.3
XZHS	0.661	0.663	0.661	0.663	0.80
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	3	3	3	3	3
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	3	3	3	3	6
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.661	0.663	0.661	0.663	0.80

END

*

* Fuel Basket #2 heat sinks 16 through 30

*

	16	17	18	19	20
SINKS					
IGEOM	0	0	0	0	0
IMATHS	1	1	1	1	1
XRI	0.00610	0.02160	0.00610	0.02160	0.00610
XRO	0.01625	0.03075	0.01625	0.03075	0.01625
AHS	0.278	0.655	0.278	0.655	0.278
XZHS	0.661	0.663	0.661	0.663	0.661
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	4	4	4	4	4
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	4	4	4	4	4
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.661	0.663	0.661	0.663	0.661

END

*

	21	22	23	24	25
SINKS					
IGEOM	0	0	0	0	0
IMATHS	1	1	1	1	1
XRI	0.02160	0.00610	0.02160	0.00610	0.02160
XRO	0.03075	0.01625	0.03075	0.01625	0.03075
AHS	0.655	0.557	1.310	0.278	0.655
XZHS	0.663	0.661	0.663	0.661	0.663
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	4	4	4	4	4
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	4	4	4	4	4
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.663	0.661	0.663	0.661	0.663

END

*

	26	27	28	29	MCO WALL 30
SINKS					
IGEOM	0	0	0	0	0
IMATHS	1	1	1	1	2
XRI	0.00610	0.02160	0.00610	0.02160	0.3050

HNF-SD-SNF-CN-023 REV 2

XRO	0.01625	0.03075	0.01625	0.03075	0.3177
AHS	0.278	0.655	0.557	1.310	1.3
XZHS	0.661	0.663	0.661	0.663	0.70
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	4	4	4	4	4
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	4	4	4	4	6
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.661	0.663	0.661	0.663	0.70

END

•

* Fuel Basket #3 heat sinks 31 through 45

•

SINKS	31	32	33	34	35
* IGEOM	0	0	0	0	0
IMATHS	1	1	1	1	1
XRI	0.00610	0.02160	0.00610	0.02160	0.00610
XRO	0.01625	0.03075	0.01625	0.03075	0.01625
AHS	0.278	0.655	0.278	0.655	0.278
XZHS	0.661	0.663	0.661	0.663	0.661
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	5	5	5	5	5
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	5	5	5	5	5
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.661	0.663	0.661	0.663	0.661

END

*

SINKS	36	37	38	39	40
* IGEOM	0	0	0	0	0
IMATHS	1	1	1	1	1
XRI	0.02160	0.00610	0.02160	0.00610	0.02160
XRO	0.03075	0.01625	0.03075	0.01625	0.03075
AHS	0.655	0.557	1.310	0.278	0.655
XZHS	0.663	0.661	0.663	0.661	0.663
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	5	5	5	5	5
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	5	5	5	5	5
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.663	0.661	0.663	0.661	0.663

END

*

SINKS	41	42	43	44	MCO WALL 45
* IGEOM	0	0	0	0	0
IMATHS	1	1	1	1	2
XRI	0.00610	0.02160	0.00610	0.02160	0.3050
XRO	0.01625	0.03075	0.01625	0.03075	0.3177
AHS	0.278	0.655	0.557	1.310	1.3
XZHS	0.661	0.663	0.661	0.663	0.70
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	5	5	5	5	5

HNF-SD-SNF-CN-023 REV 2

TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	5	5	5	5	6
TOHS	0.0	0.0	0.0	0.0	0
XLHS	0.661	0.663	0.661	0.663	0.70

END

*

* scrap basket # 1 heat sinks 46 through 55 (MCO later)

•

	R1-1	R2-2	R2-3	R3-4	R4-5
SINKS	46	55	48	49	50
IGEOM	0	0	0	0	0
IMATHS	4	4	4	4	4
XRI	0.03493	0.055	0.075	0.09654	0.130
XRO	0.055	0.075	0.09336	0.130	0.160
AHS	0.191	0.276	0.358	0.481	0.616
XZHS	0.676	0.676	0.676	0.676	0.676
TIINIT	50.00	50.00	50.00	50.00	50.0
TOINIT	50.00	50.00	50.00	50.00	50.0
IMSLAB	7	7	7	5	5
IREGI	1	1	1	1	1
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	1	1	1	1	1
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.676	0.676	0.676	0.676	0.676

END

*

	R5-6	R6-7	R7-8	R8-9	FIN
SINKS	51	52	53	54	47
IGEOM	0	0	0	0	0
IMATHS	4	4	4	4	3
XRI	0.160	0.190	0.220	0.250	0.2842
XRO	0.190	0.220	0.250	0.2842	0.28738
AHS	0.743	0.871	0.998	1.134	1.2
XZHS	0.676	0.676	0.676	0.676	0.676
TIINIT	50.00	50.00	50.00	50.00	50.0
TOINIT	50.00	50.00	50.00	50.00	50.0
IMSLAB	5	5	5	5	3
IREGI	1	1	1	1	1
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	1	1	1	1	1
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.676	0.676	0.676	0.676	0.676

END

*

* scrap basket # 2 heat sinks 56 through 65 (MCO later)

•

	R1-1	R2-2	R2-3	R3-4	R4-5
SINKS	56	65	58	59	60
IGEOM	0	0	0	0	0
IMATHS	4	4	4	4	4
XRI	0.03493	0.055	0.075	0.09654	0.130
XRO	0.055	0.075	0.09336	0.130	0.160
AHS	0.191	0.276	0.358	0.481	0.616
XZHS	0.676	0.676	0.676	0.676	0.676
TIINIT	50.00	50.00	50.00	50.00	50.0
TOINIT	50.00	50.00	50.00	50.00	50.0
IMSLAB	7	7	7	5	5
IREGI	2	2	2	2	2
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	2	2	2	2	2
TOHS	0.0	0.0	0.0	0.0	0.0

HNF-SD-SNF-CN-023 REV 2

XLHS	0.676	0.676	0.676	0.676	0.676
END					
* R5-6		R6-7	R7-8	R8-9	FIN
SINKS 61		62	63	64	57
* IGEOM	0	0	0	0	0
IMATHS	4	4	4	4	3
XRI	0.160	0.190	0.220	0.250	0.2842
XRO	0.190	0.220	0.250	0.2842	0.28738
AHS	0.743	0.871	0.998	1.134	1.2
XZHS	0.676	0.676	0.676	0.676	0.676
TIINIT	50.00	50.00	50.00	50.00	50.0
TOINIT	50.00	50.00	50.00	50.00	50.0
IMSLAB	5	5	5	5	3
IREGI	2	2	2	2	2
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	2	2	2	2	2
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.676	0.676	0.676	0.676	0.676

END

	MCO SCRAP1	MCO SCRAP2
* SINKS 66		67

* IGEOM	0	0
IMATHS	2	2
XRI	0.3050	0.3050
XRO	0.3177	0.3177
AHS	1.3	1.3
XZHS	0.75	0.75
TIINIT	50.00	50.00
TOINIT	50.00	50.00
IMSLAB	3	3
IREGI	1	2
TIHS	0.0	0.0
IREGO	6	6
TOHS	0.0	0.0
XLHS	0.75	0.75

END

*

* MCO lid emissivity increased to account for convection to scrap

	CASK WALL	MCO BOT	MCO LID	INS FUEL#1
* SINKS 68		69	70	71

* IGEOM	0	1	1	0
IMATHS	2	2	2	2
XRI	0.3199	0.0	0.0	0.022225
XRO	0.5056	0.051	0.29	0.034925
AHS	10.24	0.29	0.29	0.1281
XZHS	3.95	0.51	0.3	0.71309
TIINIT	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00
IMSLAB	10	5	20	3
IREGI	6	2	1	0
TIHS	0.0	0.0	0.0	0.0
IREGO	7	6	7	0
TOHS	0.0	0.0	0.0	0.0
XLHS	3.95	0.3	0.3	0.71309
EHSI	0.25	0.19	0.3	0.3
EHSO	0.25	0.25	0.25	0.3

END

	DT FUEL#1	INS FUEL#2	DT FUEL#2	INS FUEL#3	DT FUEL#3
* SINKS 72		73	74	75	76

*

HNF-SD-SNF-CN-023 REV 2

IGEOM	0	0	0	0	0
IMATHS	2	2	2	2	2
XRI	0.0076075	0.022225	0.0076075	0.022225	0.0076075
XRO	0.0167005	0.034925	0.0167005	0.034925	0.0167005
AHS	0.05063	0.1281	0.05063	0.1281	0.05063
XZHS	0.71309	0.71309	0.71309	0.71309	0.71309
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	0	0	0	0	0
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	0	0	0	0	0
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.71309	0.71309	0.71309	0.71309	0.71309

END

	INS SCRAP#1	DT SCRAP#1	INS SCRAP#2	DT SCRAP#2
SINKS	77	78	79	80

•

IGEOM	0	0	0	0
IMATHS	2	2	2	2
XRI	0.022225	0.0076075	0.022225	0.0076075
XRO	0.034925	0.0167005	0.034925	0.0167005
AHS	0.1281	0.05063	0.1281	0.05063
XZHS	0.71309	0.71309	0.71309	0.71309
TIINIT	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3
IREGI	0	0	0	0
TIHS	0.0	0.0	0.0	0.0
IREGO	0	0	0	0
TOHS	0.0	0.0	0.0	0.0
XLHS	0.71309	0.71309	0.71309	0.71309

END

*

MATERIAL LIBRARY

*

* MATERIAL LIBRARY - SPECIFY MATERIAL PROPERTIES FOR MATERIAL 'imaths'

* UPTO 20 (INMAT) MATERIALS CAN BE SPECIFIED

• SYNTAX:

name	imaths	rho	khs	cp	qv	ehsi	ehso
URANIUM	1	18573.3	24.2	122.67	1955.2	-1	-1
STAINLESS-STEEL	2	8000.	16.0	500.	0.	0.30	0.3
COPPER	3	8954.	398.0	384.	0.	0.3	0.3
SCRAP-URANIUM	4	19000.	26.9	122.67	2326.53	0.70	0.7

END

•

* SANDWICH HEAT SINKS - STRING TOGETHER NUMER OF CONSECUTIVE HEAT SINKS
 * TO MIMIC A SANDWICH WALL. UPTO 100 SANDWICH WALLS CAN BE SPECIFIED, WITH
 * UPTO 10 LAYERS IN EACH WALL. THE SANDWICH HEAT SINK SERIES SHOULD BE
 * ARRANGED SUCH THAT THE OUTER FACE OF THE FIRST HEAT SINK AND THE INNER FACE
 * OF THE LAST HEAT SINK IN THE SERIES FACE THE GAS REGIONS (OR INSULATED).

* SYNTAX:

* SANDWICH hsl hgap1 hs2 hgap2 hs3 hgap3 ... hsn

* WHERE 'hgap' is the gap conductance (W/m²/C) between the layers

* BETWEEN THE INSERT AND THE DIP TUBE, THERE IS A AIR GAP OF THICKNESS

* 0.00076 M. THEREFORE, THE GAP CONDUCTANCE IS 0.03/0.00076=40 W/m²/C

SANDWICH 71 5.4 72

SANDWICH 73 5.4 74

SANDWICH 75 5.4 76

SANDWICH 77 5.4 78

SANDWICH 79 5.4 80

*

* Represent the thermal resistance in the spokes in the scrap basket

```

* 12 spokes, 1/8"(0.003175m) thick, 0.676 m high, and 0.191 m long
• Therefore, the gap conductance is:
*  $398/0.191 * (12 * 0.003175 / (2 * 3.14 * 0.2842)) = 44.48 \text{ W/m}^2/\text{C}$ 
SANDWICH 47 44.48 48
SANDWICH 390 44.48 391
SANDWICH 403 44.48 404
SANDWICH 416 44.48 417
SANDWICH 57 44.48 58
SANDWICH 429 44.48 430
SANDWICH 442 44.48 443
SANDWICH 455 44.48 456
*
* TEMPERATURE DEPENDENT EMISSIVITY:
• USER CAN INPUT A TEMPERATURE DEPENDENT EMISSIVITY BY INPUTTING A
* NEGATIVE INTEGER FOR THE EMISSIVITY AND PROVIDING THE CORRESPONDING
* TEMPERATURE VERSUS EMISSIVITY LOOK-UP TABLE.
* SYNTAX:
* TTABLE n temperature-entry(C)
* ETABLE n emissivity-entry n is the table designator
*
TTABLE 1 1. 50. 700. 1100. 1500.
ETABLE 1 0.7 0.7 0.4 0.4 0.5
*
* USER CAN DEFINE CONDUCTION NETWORKS
* SYNTAX:
* COND_NETWORK ihs1 ihs2 ihs3 .... ihsn upto 100 heat sinks
• COND_NETWORK ihs1 ihs2 ihs3 .... ihsn upto 100 heat sinks
*
* upto 5 networks
*
* MUST BE ORDERED TOP TO BOTTOM TO BE CONSISTENT WITH AXIAL NODALIZATION
* MODEL CONTIGUOUS DIP TUBE CONNECTED TO THE SHIELD PLUG(HS #74)
COND_NETWORK 70 78 72 74 76 80
* MODEL CONTIGUOUS INSERT CONNECTED TO THE SHIELD PLUG(HS #74)
COND_NETWORK 77 71 73 75 79
* MODEL CONTIGUOUS MCO WALL CONNECTED TO THE SHIELD PLUG(HS #74)
COND_NETWORK 70 66 15 30 45 67
•
* USER CAN CONTROL HEAT SINK BOUNDARY TEMPERATURE
* SYNTAX:
* OFFSET_TIMEHS
* EXTRAPOLATION_TIMEHS
* TIMTHS IHS ISD TIME1, TIME2...
* THSFIX IHS ISD TEMP1, TEMP2..
* IHS = HEAT SINK NO.; ISD = SIDE NO. (1 OR 2) FOR IHS
* CONTROL HEAT SINK BOUNDARY T
OFFSET_TIMEHS 0.
EXTRAPOLATION_TIMEHS EXTRAP
TIMTHS 15 2 0.0 1.E6
THSFIX 15 2 50.0 50.0
TIMTHS 30 2 0.0 1.E6
THSFIX 30 2 50.0 50.0
TIMTHS 45 2 0.0 1.E6
THSFIX 45 2 50.0 50.0
TIMTHS 66 2 0.0 1.E6
THSFIX 66 2 50.0 50.0
TIMTHS 67 2 0.0 1.E6
THSFIX 67 2 50.0 50.0
TIMTHS 68 1 0.0 1.E6
THSFIX 68 1 50.0 50.0
TIMTHS 69 2 0.0 1.E6
THSFIX 69 2 50.0 50.0

```

```

*
*
END HEAT_SINKS ! HEAT_SINKS is a comment
*-----
JUNCTIONS      5 ! # of Junctions
*-----
* Volume 2 placed on bottom with scrap basket 2
*
* 1) MCO scrap 2 to fuel 3 2->5
* 2) MCO fuel 3 to fuel 2 5->4
* 3) MCO fuel 2 to fuel 1 4->3
* 4) MCO fuel 1 to scrap 1 3->1
* 5) MCO top to Outlet volume, 1->7 (deactivated)
*
* Syntax:
* IJTYP Junction Type: 1 = Normal, 2 = HEPA, 3 = Cover, 4 = Failure,
*                    5 = Check valve
* DP1 for failure junction, it is the pressure differential required
* to fail from the upstream compartment to the downstream compt.
* for check valve junction, it is the differential pressure
* required to open the junction from upstream to downstream only.
* DP2 for failure junction, it is the pressure differential required
* to fail from the downstream compartment to the upstream compt.
* for check valve junction, it is the differential pressure
* required to open the junction from downstream to upstream only.
* IFAN Fan type: 1 = constant volumetric flow fan
*        2 = constant delt_P fan
* WVFAN volumetric flow rate of the fan. for constant delt_P fan,
* the volumetric flow rate is converted to the corresponding
* delt_P at time=0
* IR1 Upstream Region
* IR2 Downstream Region
* AJN Area (m^2)
* ABYP Bypass area for HEPA junction (m^2)
* PHEPA HEPA Filter Failure Pressure (Pa)
* ACOV Cover Area (m^2)
* MCOV Cover Weight (kg)
* Z1JN Elevation wrt floor of IR1 opening (m)
* Z2JN " " " " IR2 " "
* CJN Loss coefficient multiplies 0.5*rho*v^2
* IHORIZ Orientation: 1 = horizontal, 0 = vertical
* XWJN Characteristic width, m
* XHJN Characteristic height, m
* XLJN Characteristic length, m
* DFJN Decontamination Factor
* N90 No. of 90 bends
*

```

PATHS	1	2	3	4	5
IJTYP	1	1	1	1	1
IR1	2	5	4	3	1
IR2	5	4	3	1	7
IHORIZ	1	1	1	1	1
XWJN	0.61	0.61	0.61	0.61	2.54E-2
XHJN	0.61	0.61	0.61	0.61	2.54E-2
XLJN	0.03	0.03	0.03	0.03	0.03
AJN	0.025	0.025	0.025	0.0078	0.0
Z1JN	0.72	0.67	0.67	0.67	0.80
Z2JN	0.0	0.0	0.0	0.0	3.68
CJN	1.0	1.0	1.0	1.0	4.0
DFJN	1.0	1.0	1.0	1.0	1.0
N90	0	0	0	0	3

```

      END PATHS      ! PATHS is a comment.
*
END JUNCTIONS      ! JUNCTIONS is a comment.
*-----
MCO      ! MCO Major Keyword
*-----
GENERAL      ! Keyword for general inputs
  IOXDTN  2      ! =0, disable oxidation of fuel/scrap
                ! =1, do oxidation of fuel/scrap
                ! =2, oxidation of covered surface uses water prop for rate
  IHYD     0      ! =1, do hydriding/dehydriding calculation
                ! =0, disable hydriding/dehydriding calculation
  IDIVRT   3      ! =1, divert heat transfer to gas
                ! =0, do not divert heat transfer to gas
  IEVAP    1      ! =1, do evaporation/condensation of water
                ! =0, do not do evaporation/condensation
  ILAW     3      ! oxidation rate law, 0 - McGillivray/Ritchie
                !                      1 - Pearce
  IDEENT   0      ! =1, de-entrainment of aerosol due to scrap basket
                ! =0, disable de-entrainment calculation
  IENTR    0      ! =1, do entrainment of sludge particle calculation
                ! =0, disable entrainment calculation
  IHYDRA   1      ! =1, do decomposition of fuel oxide hydrate
                ! =0, disable hydrate decomposition calculation
  INITRI   0      ! =1, do nitriding calculation
                ! =0, disable nitriding calculation
  IRADIO   0      ! =1, do radiolysis calculation
                ! =0, disable radiolysis calculation
  IHYDKP   1      ! =0, normal depletion of hydride (rate decreases with mass)
                ! =1, disable depletion of hydride (but the phantom
                !      calculation of hydride mass depletion will be shown)
                ! =2, use constant rate but the rate goes to zero when
                !      all the mass is depleted
  FO2HYH2  0.      ! the fraction of the oxygen, reacting with uranium
                ! hydride, which produces hydrogen instead of water vapor
  XDHYD    4.28E-5 4.28E-5 4.28E-5 4.28E-5 4.28E-5 ! average diameter of
hydride
                ! overridden by basket specific parameters, XDHYFL & XDHYSC
  IHSCSK   68      ! define the cask heat sink
  IRGAP     6      ! define the gap node (between MCO wall and the cask)
                ! radiative/convective h.t. between the MCO wall and
                ! the cask is computed and some of the heat is diverted
                ! to gas for stability
  XGPCSK   0.0155 ! gap distance between the MCO wall and the cask
  FHTLID   1.0      ! =0, turn off the radiative heat transfer between the
                ! fuel/scrap and the lid/floor
                ! =1, fully account for the radiative heat transfer
  RHOSL    5000.    ! sludge particle density (kg/m^3)
  SASL     1000.    ! sludge specific area (m^2/m^3)
  XDSSL    1.E-6    ! sludge particle diameter (m)
*
* Hydrate Model: two-step decomposition,
*   input curves for ln P and ln K
*   first step for x > XHYD2, second step for x < XHYD2
*
* Bounding case: 42 kg particulate, 0.8 kg h2o = 1.9%
* of sludge being hydrated with 2 moles of
* water per mole of uranium oxide
*
  FHYSL    0.535    ! fraction of sludge that is hydrated
  XHYSL     2.0      ! stoichiometry number of hydrate: no. of moles of
                ! water per mole of uranium oxide (UO3.H2O)
  XHYD2    1.0      ! H2O/U ratio (stoich. number) to switch

```

HNF-SD-SNF-CN-023 REV 2

```

! from first to second correlation
XHYD3    0.5    ! H2O/U ratio (stoich. number) to switch
! from second to third correlation
*
AHYEQ1   15.912 ! 'A' IN LN P = A + B/T FOR X > XHYD2
BHYEQ1  -6131.E0 ! 'B' IN LN P = A + B/T FOR X > XHYD2
AHYEQ2   18.382 ! 'A' IN LN P = A + B/T FOR X < XHYD2
BHYEQ2  -7766.E0 ! 'B' IN LN P = A + B/T FOR X < XHYD2
AHYEQ3   18.408 ! 'A' IN LN P = A + B/T FOR X < XHYD3
BHYEQ3  -8488.E0 ! 'B' IN LN P = A + B/T FOR X < XHYD3
*
ADEHY1   2.793E0 ! 'A' IN LN K = A + B/T FOR X > XHYD2
BDEHY1  -5111.E0 ! 'B' IN LN K = A + B/T FOR X > XHYD2
ADEHY2   6.348E0 ! 'A' IN LN K = A + B/T FOR X < XHYD2
BDEHY2  -7241.E0 ! 'B' IN LN K = A + B/T FOR X < XHYD2
ADEHY3   4.632E0 ! 'A' IN LN K = A + B/T FOR X < XHYD3
BDEHY3  -7548.E0 ! 'B' IN LN K = A + B/T FOR X < XHYD3
*
DHHY1    2.86E6 ! Decomposition enthalpy J/kg H2O: 1st step
DHHY2    3.70E6 ! Decomposition enthalpy J/kg H2O: 2nd step
DHHY3    3.70E6 ! Decomposition enthalpy J/kg H2O: 3rd step
FPROHY    1.0    ! hydride production rate law multiplier
FCONHY    1.0    ! hydride consumption rate law multiplier
FNITRI    1.0    ! nitriding rate law multiplier
*
* PUMP, FEED, AND CONDENSER MODELS
* Syntax:
* PUMP IRIPUM IROPUM ICONPM ITFEED WVPUMP WVFEED TGFEED TCONPM
*
* Definitions:
* IRIPUM - Pump inlet region
* IROPUM - Pump outlet region
* ICONPM - Node to which the condensed steam is dumped for book-keeping
* ITFEED - If non-zero, overrides TGFEED with the designated region
*          temperature. Used to specify time-varying feed temperature
* WVPUMP - Pump volumetric flowrate (m^3/s)
* WVFEED - Feed volumetric flowrate (m^3/s)
* TGFEED - Feed temperature (C)
* TCONPM - Condenser cooling coil temperature (C)
*
* 35 FT^3/MIN * 1 MIN/60 SEC * 0.02832 M^3/1 FT^3 = 0.01652 M^3/SEC
* 30 FT^3/MIN * 1 MIN/60 SEC * 0.02832 M^3/1 FT^3 = 0.01416 M^3/SEC
* PUMP IRIPUM IROPUM ICONPM ITFEED WVPUMP WVFEED TGFEED TCONPM
*   PUMP 1      7      0      0      0.614E-2 0.0      0.0      0.0
*
* Radiolysis parameters
*
* FRAD      1.0      ! multiplier for radiolysis
* FALPHA    0.197    ! alpha fractional heat load
* FBETA     0.486    ! beta fractional heat load
* FGAMMA    0.317    ! gamma fractional heat load
* QPHOTO    2.4E-6    ! heat deposition rate in MCO free water per gram
*              ! per MTU of fuel loading
*
* Water film drain on MCO wall
* DRAIN 66 15 30 45 67
* END GENERAL      ! GENERAL is a comment
*
* PLOT      ! Keyword for MCO-specific plotting section
*           ! A plot file with the name 'input deck name'.PL1 is generated
*
* Plotting syntax:
*
* PUMPH2      - Hydrogen flow rate into the vacuum pump, kg/s
* GAS-WH2 n jlist - Hydrogen flow rate through junctions, kg/s

```


HNF-SD-SNF-CN-023 REV 2

```

* CORRODH2      - Hydrogen genration rate by fuel/scrap corrosion
* HS-H2O n hlist - Water mass on heat sink surfaces, kg
* HS-HYH2O n hlist - Water mass in sludge on heat sink surfaces, kg
* WH2F1 n flist  - Hydrogen generation rate by corrosion/dehydriding/
*                  radiolysis in fuel baskets, kg/s
* WH2SC n slist  - " in scrap baskets, kg/s
* WH2TT          - total hydrogen generation by corrosion/dehydriding/
*                  radiolysis in MCO, kg/s
* MH2TT          - cumulative hydrogen generated in MCO, kg
*
* QDECFL n flist - decay heat in fuel baskets, W
* QDECSC n slist - decay heat in scrap baskets, W
* QDECTT         - total decay heat in MCO, W
* UDECTT         - cumulative decay heat in MCO, J
*
* QOXOFL, QOXOSC, QOXOTT, UOXOTT      fuel corrosion by O2 heat
* QOXWFL, QOXWSC, QOXWTT, UOXWTT      fuel corrosion by H2O heat
* QNTRFL, QNTRSC, QNTRTT, UNTRTT      nitriding heat
* QHYDFL, QHYDSC, QHYDTT, UHYDTT      hydriding/dehydriding heat
* QINFL,  QINSC,  QINTT,  UINTT       total energy in
*
* QMCOFL, QMCOSC, QMCOTT, UMCOTT      heat loss to MCO wall
* QLIDFL, QLIDSC, QLIDTT, ULIDTT      heat loss to lid/floor/insert
* QGASFL, QGASSC, QGASTT, UGASTT      heat loss to gas
* QEVFPL, QEVFSC, QEVPTT, UEVPTT      heat loss due to evaporation
* QCNDFL, QCNDSC, QCNDTT, UCNDTT      heat loss by axial conduction
* QOUTFL, QOUTSC, QOUTTT, UOUTTT      total energy out
*
* UMCO          - total energy in fuel
* UINTGT        - initial energy in fuel + integrated(source-sink)
* FUEERR        - relative energy imbalance
* TOTUO2        - total UO2 in MCO
*
* Note: plot routine can only accept 99 items; can't plot all things.
* So plot all scrap T's but only 5 fuel (plus MCO)
* jlist - junction list
* hlist - heat sink list
* flist - fuel basket list
* slist - scrap basket list

```

```

CORRODH2
WH2TT
MH2TT
QDECFL 1 1
QDECSC 2 1 2
QDECTT
UDECTT
QOXOFL 1 1
QOXOSC 2 1 2
QOXOTT
UOXOTT
QOXWFL 1 1
QOXWSC 2 1 2
QOXWTT
UOXWTT
QINTT
UINTT
QMCOFL 1 1
QMCOSC 2 1 2
QMCOTT
UMCOTT
QLIDFL 1 1
QLIDSC 2 1 2

```

```

QLIDTT
ULIDTT
QGASFL 1 1
QGASSC 2 1 2
QGASTT
UGASTT
QEV PFL 1 1
QEV PSC 2 1 2
QEV PTT
UEV PTT
QCND FL 1 1
QCND SC 2 1 2
QCND TT
UCND TT
QOUT TT
UOUT TT
UINT GT
UMCO
FUERR
TOTUO2
END PLOT

```

•

SOLAR_RAD

*
* pointers to heat sinks representing the cask wall and the top
* solar radiation impinges on these
•

IHCASK 68
IHTOP 70
•

* look-up table for solar radiation throughout a day (sec .vs. W/m^2)
*
OFFSET_TIMDAY 21600. ! offset by six hours
EXTRAPOLATION_TIMDAY PERIOD ! repeat the diurnal cycle
TIMDAY 0.0 3600.0 7200.0 10800.0 14400.0 18000.0 21600.0
25200.0 28800.0 32400.0 36000.0 39600.0 43200.0 46800.0
50400.0 54000.0 57600.0 61200.0 64800.0 68400.0 72000.0
75600.0 79200.0 82800.0 86400.0
RAD SUN 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0
END SOLAR_RAD

•

FUEL_BSKT 3 ! Total number of fuel baskets
*
* 1st Fuel Basket
*
* heat sink pairs for fuel basket #1
*
IHSFL 1 2 3 4 5 6 7 8 9 10 11 12 13 14
IFLINS 71 ! define the adjacent center insert heat sink,
! 0 for no insert
IFLMCO 15 ! define the adjacent MCO wall heat sink
IFLLID 0 ! define the lid or floor heat sink to which the fuel
! radiate to
AFLFL 0.131 ! flow area in the basket,
*
* fraction of geometric area exposed for oxidation
* $3.5 \text{ m}^2 / (4 \times 16.8 \text{ m}^2) = 0.0521$
FAOXFL 0.00 0.06702 0.00 0.06702 0.00 0.06702 0.00
0.06702 0.00 0.06702 0.00 0.06702 0.00 0.06702
FOX 10 0 ! multiplier for FAOXFL

HNF-SD-SNF-CN-023 REV 2

```

XDHYFL 5.05E-5      ! average diameter of hydride particle (m)
*
* Nominal hydride: 4% of exposed surface with multiplier of 300
*   XFLOX0*FXHD0 = Fx * Fa * XDHYD / 6, where Fx is multiplier
*                   and Fa is area fraction
*                   = 0.04 * 300 * 2.E-5 / 6
*                   = 4.0E-5
*
* XFLOX0: initial oxide (oxide+hydride) thickness
*   (to be applied to exposed area)
* FXHYD0: fraction of initial oxide which is hydride
*
XFLOX0 10.21E-5 10.21E-5 10.21E-5 10.21E-5 10.21E-5 10.21E-5 10.21E-5 10.21E-5
10.21E-5 10.21E-5 10.21E-5 10.21E-5 10.21E-5 10.21E-5 10.21E-5 10.21E-5
FXHYD0 1.0      1.0      1.0      1.0      1.0      1.0      1.0      1.0
1.0      1.0      1.0      1.0      1.0      1.0      1.0      1.0
*
* initial amount (kg) of water per geometric surface area (m^2) of fuel
* 0.1 kg / 16.8 m^2 = 0.0060
CFWFLO 0.0060 0.0060 0.0060 0.0060 0.0060 0.0060 0.0060 0.0060
C      0.0060 0.0060 0.0060 0.0060 0.0060 0.0060 0.0060 0.0060
FWFLO  0.3571 0.3571 0.3571 0.3571 0.3571 0.3571 0.3571 0.3571
0.3571 0.3571 0.3571 0.3571 0.3571 0.3571 0.3571 0.3571
FWFLIO 0.0      ! on the outer surface of the insert
FWFLMO 0.0      ! on the inner surface of the MCO wall
FAWFL  0.1      ! wetted fraction of fuel surface
FAWFLM 1.0      ! wetted fraction of MCO wall
MSLFL  1.16     ! mass of sludge particles (kg) in the fuel basket
              ! 4.64total fuel @ 4 baskets, so 1.16 per basket
*
* view factor matrix between the insert,
* outer surface of outer fuel elements,
* and the MCO wall. Therefore, the dimension of the square matrix is
* 1+number of fuel rods+1. If there is no insert, number of fuel rods+1.
*
FVIEW  0.000 0.926 0.074 0.000 0.000 0.000 0.000 0.000 0.000
0.175 0.316 0.306 0.181 0.028 0.000 0.000 0.000 0.000
0.014 0.306 0.028 0.306 0.306 0.028 0.014 0.000 0.000
0.000 0.181 0.306 0.000 0.334 0.153 0.000 0.028 0.000
0.000 0.014 0.153 0.167 0.167 0.153 0.153 0.167 0.028
0.000 0.000 0.028 0.153 0.306 0.000 0.028 0.306 0.181
0.000 0.000 0.014 0.000 0.306 0.028 0.000 0.306 0.348
0.000 0.000 0.000 0.014 0.167 0.153 0.153 0.049 0.466
0.000 0.000 0.000 0.000 0.035 0.115 0.220 0.590 0.040
*
* gap distance for micro-convection calculation
*
XGAP   0.000 0.018 0.000 0.000 0.000 0.000 0.000 0.000 0.000
0.018 0.000 0.021 0.021 0.073 0.000 0.000 0.000 0.000
0.000 0.021 0.000 0.021 0.021 0.073 0.073 0.000 0.000
0.000 0.021 0.021 0.000 0.021 0.021 0.000 0.073 0.000
0.000 0.073 0.021 0.021 0.000 0.021 0.021 0.021 0.083
0.000 0.000 0.073 0.021 0.021 0.000 0.073 0.021 0.058
0.000 0.000 0.073 0.000 0.021 0.073 0.000 0.021 0.026
0.000 0.000 0.000 0.073 0.021 0.021 0.021 0.000 0.016
0.000 0.000 0.000 0.000 0.083 0.058 0.026 0.016 0.000
*
* axial conduction tracked in the fuel elements
*
* top to bottom axial partitions of the basket
AXIAL  0.0521 0.0425 0.0648 0.0995 0.152 0.234 0.3551
* multiplier to FAOXFL(fraction of geometric area exposed for
* oxidation) for each axial basket. clad damage confined to the tip.

```

```

* 1./0.0521=19.19
C FOXAX 19.19 0.0 0.0 0.0 0.0 0.0 0.0
FOXAX 1.00 1.0 1.0 1.0 1.0 1.0 1.0
* multiplier to FWFL0, FWFLI0, and FWFM0 (initial amount of water per
* geometric surface area of fuel, insert, and MCO wall) for each axial
* basket. water on the tip of fuel. 1./0.0521=19.19
C FWAX 19.19 0.0 0.0 0.0 0.0 0.0 0.0
FWAX 1.00 1.0 1.0 1.0 1.0 1.0 1.0
* multiplier to XFLOX0 (initial oxide/hydride thickness) for each axial basket
FUH3AX 1.0 1.0 1.0 1.0 1.0 1.0 1.0
* partition of MSLFL(mass of sludge particles) for each axial basket. uniform.
FSLAX 0.0521 0.0425 0.0648 0.0995 0.152 0.234 0.3551
END IHSFL for 1st fuel basket
*
* 2nd Fuel Basket
*
* "SAME AS FUEL BASKET n" - duplicates the fuel basket data
SAME AS FUEL BASKET 1
* any overriding parameters can be followed
* define the heat sinks comprising the first fuel basket (must be
* in pairs, for inner and outer elements)
IHSFL 16 17 18 19 20 21 22 23 24 25 26 27 28 29
*
IFLINS 73 ! define the adjacent center insert heat sink,
* 0 for no insert
IFLMCO 30 ! define the adjacent MCO wall heat sink
*
* initial amount (kg) of water per geometric surface area (m^2) of fuel
* 6 kg / (16.8 m^2) = 0.3571
FWFL0 0.3571 0.3571 0.3571 0.3571 0.3571 0.3571 0.3571
0.3571 0.3571 0.3571 0.3571 0.3571 0.3571 0.3571
END IHSFL for 2nd fuel basket
*
* 3rd Fuel Basket
*
SAME AS FUEL BASKET 2
IHSFL 31 32 33 34 35 36 37 38 39 40 41 42 43 44
IFLINS 75 ! define the adjacent center insert heat sink
IFLMCO 45 ! define the adjacent MCO wall heat sink
END IHSFL for 3rd fuel basket
END FUEL_BSKT
*
SCRAP_BSKT 2 ! Total number of scrap baskets
*
* First scrap basket
*
IHSSC 46 55 48 49 50 51 52 53 54 ! radial outward
*
ISCINS 77 ! define the adjacent center insert heat sink,
! 0 for no insert
ISCFIN 47 ! define copper fin heat sink
ISCMCO 66 ! define the adjacent MCO wall heat sink
ISCLID 70 ! define the lid or floor heat sink to which the scrap
! radiate to
* multiplier for effective conductivity in scrap basket in the order read in
* (only conduction part)
FKSC 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5
* multiplier for effective conductivity in scrap basket in the order read in
* (only radiation part)
FRSC 0.71 0.71 0.71 0.29 0.29 0.29 0.29 0.29 0.29
* porosity of the scrap for each heat sink in the order read in
FPOROS 0.40 0.40 0.40
0.723 0.723 0.723 0.723 0.723 0.723

```

HNF-SD-SNF-CN-023 REV 2

```

* characteristic size for each scrap heat sink in the order read in (m)
  XDSCR  0.00635 0.00635 0.00635
          0.0254 0.0254 0.0254 0.0254 0.0254 0.0254
  XRSCBK 0.2842 ! radius of scrap basket (m)
  XHSCBK 0.676  ! height of scrap basket (m)
*
* exposed surface area available for oxidation
* per unit volume of scrap (1/m) for
* each scrap basket heat sink in the order read in
* Fine: Area= 2.0 m^2 Volume= 1.59e-2 m^3 A/V=125.63
* Coarse: Area= 2.5 m^2 Volume= 1.517e-1 m^3 A/V=16.48
  AVOXSC 125.63 125.63 125.63
          16.48 16.48 16.48 16.48 16.48 16.48
  FOXSC  10 0 ! multiplier for AVOXSC
  XDHYS  4.28E-5 ! average diameter of hydride particle (m)
*
* Nominal hydride: 4% of exposed surface with multiplier of 300
* XSCOX0*FSCHD = Fx * Fa * XDHYD / 6, where Fx is multiplier
* and Fa is area fraction
* = 0.04 * 300 * 2.E-5 / 6
* = 4.0E-5
* XSCOX0 initial oxide thickness on the exposed surface (m)
* FSCHYD fraction of oxide which is hydride
* see fuel basket
  XSCOX0 8.56E-5 8.56E-5 8.56E-5 8.56E-5 8.56E-5 8.56E-5
          8.56E-5 8.56E-5 8.56E-5
  FSCHYD 1.0 1.0 1.0 1.0 1.0 1.0
          1.0 1.0 1.0
*
* 1.5 kg of water total for scrap basket; 1.5/0.1676 = 8.950 kg/m^3
  MVWSC0 8.950 ! initial amount (kg) of water per unit bulk volume
          ! (m^3) of scrap
  FWSCI0 0.0 ! on the outer surface of the insert
          ! (per unit area, m^2)
  FWSCM0 0.0 ! on the inner surface of the MCO wall
          ! (per unit area, m^2)
  FAWSC 0.1 ! wetted fraction of surface area
  FAWSCM 1.0 ! wetted fraction of MCO wall
  XSCINS 0.001 ! gap distance between the insert and scrap basket
          ! 1/4" gap for scrap basket and mco wall
  XSCMCO 0.00635 ! gap distance between scrap basket and MCO wall
  MSLSC 8.25 ! mass of sludge particles (kg) in the scrap basket
*
* axial conduction tracked in the scrap basket
*
* top to bottom axial partition
  AXIAL 0.1 0.4 0.4 0.1
* multiplier for FPOROS (porosity of scrap) for each axial basket
  FFPOR 1.0 1.0 1.0 1.0
* multiplier for FOXSC (multiplier for oxidation area) for each axial basket
  FFOXSC 1.0 1.0 1.0 1.0
* multiplier for MVWSC0 (initial amount of water per unit volume) for each
* axial basket. 1 kg on the bottom node, remaining 0.5 kg uniformly
* distributed to top three nodes.
C FMWSC 0.3704 0.3704 0.3704 6.667
  FMWSC 0.333 0.333 0.333 7.00
* multiplier for XDSCR (characteristic scrap size) for each axial basket
  FXDSC 1.0 1.0 1.0 1.0
* multiplier for FKSC (multiplier for effective conductivity in scrap)
  FFKSC 1.0 1.0 1.0 1.0
  END IHSSC for 1st scrap basket
*
* Second scrap basket

```

```

*
  SAME AS SCRAP BASKET 1
*
  IHSSC   56  65  58  59  60  61  62  63  64      ! radial outward
*
  ISCINS  79      ! define the adjacent center insert heat sink,
                ! 0 for no insert
  ISCFIN  57      ! define copper fin heat sink
  ISCMCO  67      ! define the adjacent MCO wall heat sink
  ISCLID -69      ! define the lid or floor heat sink to which the scrap
                ! radiate to
  MWWSC0  35.80   ! initial amount (kg) of water per unit bulk volume
                ! (m^3) of scrap
  FWSCIO  0.0     ! on the outer surface of the insert
                ! (per unit area, m^2)
  FWSCMO  0.79    ! on the inner surface of the MCO wall
                ! (per unit area, m^2)
  FAWSC   0.1     ! wetted fraction of surface area
  FAWSCM  1.0     ! wetted fraction of MCO wall
* top to bottom axial partition
  AXIAL  0.25    0.25    0.25    0.25
* multiplier for FPOROS (porosity of scrap) for each axial basket
  FFPOR  1.0     1.0     1.0     1.0
* multiplier for FOXSC (multiplier for oxidation area) for each axial basket
  FOXSC  1.0     1.0     1.0     1.0
* multiplier for MWWSC0 (initial amount of water per unit volume) for each
* axial basket. 1 kg on the bottom node, remaining 0.5 kg uniformly
* distributed to top three nodes.
C  FMWSC 0.3704 0.3704 0.3704 6.667
  FMWSC 1.00 1.00 1.00 1.00
* multiplier for XDSCR (characteristic scrap size) for each axial basket
  FXDSC  1.0     1.0     1.0     1.0
* multiplier for FKSC (multiplier for effective conductivity in scrap)
  FFKSC  1.0     1.0     1.0     1.0
  END IHSSC for 2st scrap basket
  END SCRAP_BSKT
*
END MCO

```

CASE 2, VPXDGP7

```

< VXDG.DAT
> VPXDGP7.DAT
<   CASE VXDG: vac= 13 cfm, INDEFINITE VACUUM CYCLE,
<     degraded vacuum
>   CASE VPXDGP7: vac= 30 cfm, He=0.7 scfm
<   ISRC   0      ! User-defined sources
>   ISRC   1      ! User-defined sources
>   SOURCES 1      ! -- KEYWORD AND # SOURCE GROUPS
>   REGION  2  GASES 1      !-- REGION #, # GASES
>   HELIUM      !-- GAS NAMES MUST BE ON NEXT LINE
>   0      50.00    0.528E-4  0.E0
>   1.E6  50.00    0.528E-4  0.E0
>   END REGION      !-- ENDS A REGION SOURCEi
>   END SOURCE      !-- ENDS ALL SOURCE INPUT

```

CASE 3, VPXDGP7W

```

< VXDG.DAT
> VPXDGP7W.DAT

```

```

< * CASE VXDG:
> • CASE VPXDGP7W:
< ISRC 0 ! User-defined sources
> ISRC 1 ! User-defined sources
> FKGAS 1.0 3.0
> SOURCES 1 ! -- KEYWORD AND # SOURCE GROUPS
> REGION 2 GASES 1 !-- REGION #, # GASES
> HELIUM !-- GAS NAMES MUST BE ON NEXT LINE
> 0 50.00 0.528E-4 0.E0
> 1.E6 50.00 0.528E-4 0.E0
> END REGION !-- ENDS A REGION SOURCEi
> END SOURCE !-- ENDS ALL SOURCE INPUT
< MVWSCO 35.80 ! initial amount (kg) of water per unit bulk volume
> MVWSCO 300.00 ! initial amount (kg) of water per unit bulk volume
< FWSCMO 0.79 ! on the inner surface of the MCO wall
> FWSCMO 39.50 ! on the inner surface of the MCO wall

```

CASE 4, VPDG8-4-4W

RUN 4A, VPXDGW0

```

< VXDG.DAT
> VPXDGW0.DAT
< * CASE VXDG:
> * CASE VPXDGW0:
< ISRC 0 ! User-defined sources
> ISRC 1 ! User-defined sources
> MODEL
> FKGAS 1.0 3.0
> END MODEL
> SOURCES 1 ! -- KEYWORD AND # SOURCE GROUPS
> REGION 2 GASES 1 !-- REGION #, # GASES
> HELIUM !-- GAS NAMES MUST BE ON NEXT LINE
> 0 50.00 0.528E-4 0.E0
> 1.E6 50.00 0.528E-4 0.E0
> END REGION !-- ENDS A REGION SOURCEi
> END SOURCE !-- ENDS ALL SOURCE INPUT
< MVWSCO 35.80 ! initial amount (kg) of water per unit bulk volume
> MVWSCO 300.00 ! initial amount (kg) of water per unit bulk volume
< FWSCMO 0.79 ! on the inner surface of the MCO wall
> FWSCMO 39.50 ! on the inner surface of the MCO wall

```

RUN 4B, HEP7W1

```

< VXDG.DAT
> HEP7W1.DAT
< * CASE VXDG:
> * CASE HEP7W1:
< TSTART 0.0 ! START TIME, >0 FOR RESTART RUN
> TSTART 28805.0 ! START TIME, >0 FOR RESTART RUN
> RESTART_FILE VPXDGP7W.REW ! RESTART FILE NAME FOR RESTART RUN
< TLAST 86400. ! END TIME (Seconds)
> TLAST 43200. ! END TIME (Seconds)
< ISRC 0 ! User-defined sources
> ISRC 1 ! User-defined sources
> MODEL
> FKGAS 1.0 3.0
> END MODEL
> REGION 2 GASES 1 !-- REGION #, # GASES
> HELIUM !-- GAS NAMES MUST BE ON NEXT LINE
> 0 50.00 0.528E-4 0.E0

```

```

> 1.E6 50.00 0.528E-4 0.E0
> END REGION !-- ENDS A REGION SOURCEi
> END SOURCE !-- ENDS ALL SOURCE INPUT
< AJN 0.025 0.025 0.025 0.0078 0.0
> AJN 0.025 0.025 0.025 0.0078 5.06E-4
< PUMP 1 7 0 0 0.614E-2 0.0 0.0 0.0
< MVWSCO 35.80 ! initial amount (kg) of water per unit bulk volume
> MVWSCO 300.00 ! initial amount (kg) of water per unit bulk volume
< FWSCMO 0.79 ! on the inner surface of the MCO wall
> FWSCMO 39.50 ! on the inner surface of the MCO wall

```

RUN 4C, VPXDGW2

```

< VXDG.DAT
> VPXDGW2.DAT
< * CASE VXDG:
> * CASE VPXDGW2:
< TSTART 0.0 ! START TIME, >0 FOR RESTART RUN
> TSTART 43205.0 ! START TIME, >0 FOR RESTART RUN
> RESTART_FILE HEP7W1.REW ! RESTART FILE NAME FOR RESTART RUN
< TLAST 86400. ! END TIME (Seconds)
> TLAST 57600. ! END TIME (Seconds)
< ISRC 0 ! User-defined sources
> ISRC 1 ! User-defined sources
> MODEL
> FKGAS 1.0 3.0
> END MODEL
> SOURCES 1 ! -- KEYWORD AND # SOURCE GROUPS
> REGION 2 GASES 1 !-- REGION #, # GASES
> HELIUM !-- GAS NAMES MUST BE ON NEXT LINE
> 0 50.00 0.528E-4 0.E0
> 1.E6 50.00 0.528E-4 0.E0
> END REGION !-- ENDS A REGION SOURCEi
> END SOURCE !-- ENDS ALL SOURCE INPUT
< MVWSCO 35.80 ! initial amount (kg) of water per unit bulk volume
> MVWSCO 300.00 ! initial amount (kg) of water per unit bulk volume
< FWSCMO 0.79 ! on the inner surface of the MCO wall
> FWSCMO 39.50 ! on the inner surface of the MCO wall

```

RUN 4D, HEP7W3

```

< VXDG.DAT
> HEP7W3.DAT
< * CASE VXDG:
> * CASE HEP7W3:
< TSTART 0.0 ! START TIME, >0 FOR RESTART RUN
> TSTART 57605.0 ! START TIME, >0 FOR RESTART RUN
> RESTART_FILE VPXDGW2.REW ! RESTART FILE NAME FOR RESTART RUN
< TLAST 86400. ! END TIME (Seconds)
> TLAST 72000. ! END TIME (Seconds)
< ISRC 0 ! User-defined sources
> ISRC 1 ! User-defined sources
> MODEL
> FKGAS 1.0 3.0
> END MODEL
> REGION 2 GASES 1 !-- REGION #, # GASES
> HELIUM !-- GAS NAMES MUST BE ON NEXT LINE
> 0 50.00 0.528E-4 0.E0
> 1.E6 50.00 0.528E-4 0.E0
> END REGION !-- ENDS A REGION SOURCEi
> END SOURCE !-- ENDS ALL SOURCE INPUT

```


HNF-SD-SNF-CN-023 REV 2

```

<      AJN      0.025    0.025    0.025    0.0078    0.0
>      AJN      0.025    0.025    0.025    0.0078    5.06E-4
<    PUMP  1      7      0      0    0.614E-2    0.0    0.0    0.0
<    MVWSCO 35.80    ! initial amount (kg) of water per unit bulk volume
>    MVWSCO 300.00    ! initial amount (kg) of water per unit bulk volume
<    FWSCMO 0.79     ! on the inner surface of the MCO wall
>    FWSCMO 39.50    ! on the inner surface of the MCO wall

```

RUN 4E, VPXDGW4

```

< VXDG.DAT
> VPXDGW4.DAT
< • CASE VXDG:
> • CASE VPXDGW2:
<   TSTART      0.0      ! START TIME, >0 FOR RESTART RUN
>   TSTART      72005.0    ! START TIME, >0 FOR RESTART RUN
>   RESTART_FILE HEP7W3.REW ! RESTART FILE NAME FOR RESTART RUN
<   TLAST       86400.     ! END TIME (Seconds)
>   TLAST       86400.     ! END TIME (Seconds)
<   ISRC        0      ! User-defined sources
>   ISRC        1      ! User-defined sources
> MODEL
>   FKGAS  1.0    3.0
> END MODEL
> SOURCES 1
>   REGION 2  GASES 1      ! -- KEYWORD AND # SOURCE GROUPS
>   HELIUM      !-- REGION #, # GASES
>   0      50.00    0.528E-4  0.E0      !-- GAS NAMES MUST BE ON NEXT LINE
>   1.E6 50.00    0.528E-4  0.E0
> END REGION      !-- ENDS A REGION SOURCEi
> END SOURCE      !-- ENDS ALL SOURCE INPUT
<   MVWSCO 35.80    ! initial amount (kg) of water per unit bulk volume
>   MVWSCO 300.00    ! initial amount (kg) of water per unit bulk volume
<   FWSCMO 0.79     ! on the inner surface of the MCO wall
>   FWSCMO 39.50    ! on the inner surface of the MCO wall

```

CASE 5, VAIRILOC

```

< VXDG.DAT
> VAIRILOC.DAT
<   CASE VXDG: vac= 13 cfm, INDEFINITE VACUUM CYCLE,
<     degraded vacuum
<     UH3=12, U=10, H2O=26.5 kg, SFFFS,      TWO SCRAP BASKETS (SFFFS)
>   CASE VAIRILOC: vac= 30 cfm, He=0 scfm INDEFINITE VACUUM CYCLE,
>     UH3=12, U=10, H2O= .5 kg, SFFFS,      TWO SCRAP BASKETS (SFFFS)
<   OXYGEN      0.0      0.00
<   NITROGEN    0.0      1.00
<   WATER       1.0      0.0
>   OXYGEN      0.21     0.21
>   NITROGEN    0.79     0.79
>   WATER       0.0      0.0
<   EXTRAPOLATION TIMEHS      EXTRAP
<   TIMTHS 15 2 0.0      1.E6
<   THSFIX 15 2 50.0      50.0
<   TIMTHS 30 2 0.0      1.E6
<   THSFIX 30 2 50.0      50.0
<   TIMTHS 45 2 0.0      1.E6
<   THSFIX 45 2 50.0      50.0
<   TIMTHS 66 2 0.0      1.E6
<   THSFIX 66 2 50.0      50.0
<   TIMTHS 67 2 0.0      1.E6
<   THSFIX 67 2 50.0      50.0

```

```

< TIMTHS 68 1 0.0      1.E6
< THSFIX 68 1 50.0     50.0
< TIMTHS 69 2 0.0      1.E6
< THSFIX 69 2 50.0     50.0
< JUNCTIONS 5 ! # of Junctions
> JUNCTIONS 6 ! # of Junctions
>   PATHS 6
>     IJTY 1
>     IR1 7
>     IR2 2
>     IHORIZ 1
>     XWJN 0.61
>     XHJN 0.61
>     XLJN 0.03
>     AJN 0.00001
>     ZLJN 0.00
>     Z2JN 0.00
>     CJN 1.0
>     DFJN 1.0
>     N90 0
>   END PATHS ! PATHS is a comment.
< PUMP 1 7 0 0 0.614E-2 0.0 0.0 0.0
> PUMP 1 7 0 0 1.416E-2 0.0 0.0 0.0

```

CASE 6, OVLOCXAL

```

< VXDG.DAT
> OVLOCXAL.DAT
< CASE VXDG: vac= 13 cfm, INDEFINITE VACUUM CYCLE,
  degraded vacuum
<   UH3=12, U=10, H2O=26.5 kg, SFFFS, TWO SCRAP BASKETS (SFFFS)
> CASE OVLOCXAL: OPEN MCO w 1 hole, U=10, UH3=12, H2O=26.5
>   AL(OH)3 water in 3 regions,
< ISRC 0 ! User-defined sources
> ISRC 1 ! User-defined sources
> SOURCES 3 ! -- KEYWORD AND # SOURCE GROUPS
> REGION 2 GASES 1 !-- REGION #, # GASES
> STEAM !-- GAS NAMES MUST BE ON NEXT LINE
> 0. 150.00 0.0 0.E0
> 41400. 150.00 0.0 0.E0
> 41410. 150.00 5.4E-5 0.E0
> 51400. 150.00 5.4E-5 0.E0
> 51410. 150.00 0.0 0.E0
> 1.E6 150.00 0.0 0.E0
> END REGION !-- ENDS A REGION SOURCE
> REGION 1 GASES 1 !-- REGION #, # GASES
> STEAM !-- GAS NAMES MUST BE ON NEXT LINE
> 0. 150.00 0.0 0.E0
> 63000. 150.00 0.0 0.E0
> 63010. 150.00 8.1E-6 0.E0
> 73000. 150.00 8.1E-6 0.E0
> 73010. 150.00 0.0 0.E0
> 1.E6 150.00 0.0 0.E0
> END REGION !-- ENDS A REGION SOURCE
> REGION 5 GASES 1 !-- REGION #, # GASES
> STEAM !-- GAS NAMES MUST BE ON NEXT LINE
> 0. 150.00 0.0 0.E0
> 63000. 150.00 0.0 0.E0
> 63010. 150.00 0.9E-5 0.E0
> 93000. 150.00 0.9E-5 0.E0
> 93010. 150.00 0.0 0.E0
> 1.E6 150.00 0.0 0.E0

```

HNF-SD-SNF-CN-023 REV 2

```

> END REGION                                !-- ENDS A REGION SOURCE
> END SOURCE                                !-- ENDS ALL SOURCE INPUT
< OXYGEN 0.0 0.00
< NITROGEN 0.0 1.00
< WATER 1.0 0.0
> OXYGEN 0.21 0.00
> NITROGEN 0.79 1.00
> WATER 0.0 0.0
< EXTRAPOLATION TIMEHS EXTRAP
< TIMTHS 15 2 0.0 1.E6
< THSFIX 15 2 50.0 50.0
< TIMTHS 30 2 0.0 1.E6
< THSFIX 30 2 50.0 50.0
< TIMTHS 45 2 0.0 1.E6
< THSFIX 45 2 50.0 50.0
< TIMTHS 66 2 0.0 1.E6
< THSFIX 66 2 50.0 50.0
< TIMTHS 67 2 0.0 1.E6
< THSFIX 67 2 50.0 50.0
< TIMTHS 68 1 0.0 1.E6
< THSFIX 68 1 50.0 50.0
< TIMTHS 69 2 0.0 1.E6
< THSFIX 69 2 50.0 50.0
< XWJN 0.61 0.61 0.61 0.61 2.54E-2
< XHJN 0.61 0.61 0.61 0.61 2.54E-2
> XWJN 0.61 0.61 0.61 0.61 0.64E-2
> XHJN 0.61 0.61 0.61 0.61 0.64E-2
< AJN 0.025 0.025 0.025 0.0078 0.0
> AJN 0.025 0.025 0.025 0.0078 3.17E-5
< PUMP 1 7 0 0 0.614E-2 0.0 0.0 0.0
< FAWFLM 1.0 ! wetted fraction of MCO wall
> FAWFLM 0.1 ! wetted fraction of MCO wall
< FKSC 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5
> FKSC 1.0 1.0 1.0 0.7 0.7 0.7 0.7 0.7
< XSCINS 0.001 ! gap distance between the insert and scrap basket
> FAWSCM 0.1 ! wetted fraction of MCO wall
> XSCINS 0.0001 ! gap distance between the insert and scrap basket
< FAWSCM 1.0 ! wetted fraction of MCO wall
> FAWSCM 0.1 ! wetted fraction of MCO wall
> XSCINS 0.0001 ! gap distance between the insert and scrap basket

```

CASE 7, OVLOC RHE (compared to OVLOCXAL)

```

< OVLOCXAL.DAT
> OVLOC RHE.DAT
< CASE OVLOCXAL: OPEN MCO w 1 hole, U=10,UH3=12, H2O=26.5
< AL(OH)3 water in 3 regions, fksc=0.7, frsc=0.71&.29
> CASE OVLOC RHE: SCHe on w 10 psig relief, U=10,UH3=12, H2O=26.5
< SOURCES 3 ! -- KEYWORD AND # SOURCE GROUPS
> SOURCES 1 ! -- KEYWORD AND # SOURCE GROUPS
< STEAM !-- GAS NAMES MUST BE ON NEXT LINE
< 0. 150.00 0.0 0.E0
< 41400. 150.00 0.0 0.E0
< 41410. 150.00 5.4E-5 0.E0
< 51400. 150.00 5.4E-5 0.E0
< 51410. 150.00 0.0 0.E0
< 1.E6 150.00 0.0 0.E0
> HELIUM !-- GAS NAMES MUST BE ON NEXT LINE
> 0 50.00 0.528E-4 0.E0
> 1.E6 50.00 0.528E-4 0.E0
< REGION 1 GASES 1 !-- REGION #, # GASES
< STEAM !-- GAS NAMES MUST BE ON NEXT LINE

```

HNF-SD-SNF-CN-023 REV 2

```

< 0. 150.00 0.0 0.E0
< 63000. 150.00 0.0 0.E0
< 63010. 150.00 8.1E-6 0.E0
< 73000. 150.00 8.1E-6 0.E0
< 73010. 150.00 0.0 0.E0
< 1.E6 150.00 0.0 0.E0
< END REGION !-- ENDS A REGION SOURCE
< REGION 5 GASES 1 !-- REGION #, # GASES
< STEAM !-- GAS NAMES MUST BE ON NEXT LINE
< 0. 150.00 0.0 0.E0
< 63000. 150.00 0.0 0.E0
< 63010. 150.00 0.9E-5 0.E0
< 93000. 150.00 0.9E-5 0.E0
< 93010. 150.00 0.0 0.E0
< 1.E6 150.00 0.0 0.E0
< END REGION !-- ENDS A REGION SOURCE
< PRESSURE 1.013E5 1.013E5 1.013E5 1.013E5 1.013E5
> PRESSURE 1.703E5 1.703E5 1.703E5 1.703E5 1.703E5
< PRESSURE 1.013E5 1.013E5
> PRESSURE 1.013E5 1.703E5
< XWJN 0.61 0.61 0.61 0.61 0.64E-2
< XHJN 0.61 0.61 0.61 0.61 0.64E-2
> XWJN 0.61 0.61 0.61 0.61 1.24E-2
> XHJN 0.61 0.61 0.61 0.61 1.24E-2
< AJN 0.025 0.025 0.025 0.0078 3.17E-5
> AJN 0.025 0.025 0.025 0.0078 1.27E-4

```

CASE 8, OVLOCREC

```

< OVLOCXAL.DAT
> OVLOCREC.DAT
< CASE OVLOCXAL: OPEN MCO w 1 hole, U=10,UH3=12, H2O=26.5
> CASE OVLOCREC: OPEN MCO w 1 hole, U=10,UH3=12, H2O=26.5
< TSTART 0. ! START TIME, >0 FOR RESTART RUN
> TSTART 39605. ! START TIME, >0 FOR RESTART RUN
> RESTART FILE OVLOCXAL.REW ! RESTART FILE NAME FOR RESTART RUN
< ISRC 1 ! User-defined sources
> ISRC 0 ! User-defined sources
< SOURCES 3 ! -- KEYWORD AND # SOURCE GROUPS
< REGION 2 GASES 1 !-- REGION #, # GASES
< STEAM !-- GAS NAMES MUST BE ON NEXT LINE
< 0. 150.00 0.0 0.E0
< 41400. 150.00 0.0 0.E0
< 41410. 150.00 5.4E-5 0.E0
< 51400. 150.00 5.4E-5 0.E0
< 51410. 150.00 0.0 0.E0
< 1.E6 150.00 0.0 0.E0
< END REGION !-- ENDS A REGION SOURCE
< REGION 1 GASES 1 !-- REGION #, # GASES
< STEAM !-- GAS NAMES MUST BE ON NEXT LINE
< 0. 150.00 0.0 0.E0
< 63000. 150.00 0.0 0.E0
< 63010. 150.00 8.1E-6 0.E0
< 73000. 150.00 8.1E-6 0.E0
< 73010. 150.00 0.0 0.E0
< 1.E6 150.00 0.0 0.E0
< END REGION !-- ENDS A REGION SOURCE
< REGION 5 GASES 1 !-- REGION #, # GASES
< STEAM !-- GAS NAMES MUST BE ON NEXT LINE
< 0. 150.00 0.0 0.E0
< 63000. 150.00 0.0 0.E0
< 63010. 150.00 0.9E-5 0.E0

```

HNF-SD-SNF-CN-023 REV 2

```

< 93000. 150.00 0.9E-5 0.E0
< 93010. 150.00 0.0 0.E0
< 1.E6 150.00 0.0. 0.E0
< END REGION !-- ENDS A REGION SOURCE
< END SOURCE !-- ENDS ALL SOURCE INPUT
< VOLUMES 7 ! total number of control volumes
> VOLUMES 8 ! total number of control volumes
< * gap environment
< REGIONS 6 7
< VOLUME 0.12 1.E9
< SED_AREA 0.0 0.0
< ELEVATION 0.0 0.0
< TEMP_GAS 50.0 26.7
< PRESSURE 1.013E5 1.013E5
> * gap environment cool annulus
> REGIONS 6 7 8
> VOLUME 0.12 1.E9 0.12
> SED_AREA 0.0 0.0 0.0
> ELEVATION 0.0 0.0 0.0
> TEMP_GAS 50.0 26.7 26.7
> PRESSURE 1.013E5 1.013E5 1.013E5
< GASES 6 7
< HELIUM 0.0 0.0
< STEAM 0.0 0.0
< OXYGEN 0.21 0.00
< NITROGEN 0.79 1.00
< WATER 0.0 0.0
> GASES 6 7 8
> HELIUM 0.0 0.0 0.0
> STEAM 0.0 0.0 0.0
> OXYGEN 0.21 0.00 0.0
> NITROGEN 0.79 1.00 0.0
> WATER 0.0 0.0 1.0
< IREGO 3 3 3 3 6
> IREGO 3 3 3 3 8
< IREGO 4 4 4 4 6
> IREGO 4 4 4 4 8
< IREGO 5 5 5 5 6
> IREGO 5 5 5 5 8
< IREGO 6 6
> IREGO 8 8
< IREGI 6 2 1 0
> IREGI 8 2 1 0
< IREGO 7 6 7 0
> IREGO 7 8 7 0
< IHSCSK 68 ! define the cask heat sink
< IRGAP 6 ! define the gap node (between MCO wall and the cask)
< IHSCSK 0 ! define the cask heat sink
> IRGAP 0 ! define the gap node (between MCO wall and the cask)

```

CASE 9, OVLOF

```

< OVLOCXAL.DAT
> OVLOF.DAT
< CASE OVLOCXAL: OPEN MCO w 1 hole, U=10,UH3=12, H2O=26.5
< AL(OH)3 water in 3 regions,
> CASE OVLOF: OPEN MCO w 1 hole, U=10,UH3=12, H2O=26.5
< ISRC 1 ! User-defined sources
> ISRC 0 ! User-defined sources
< SOURCES 3 ! -- KEYWORD AND # SOURCE GROUPS
< REGION 2 GASES 1 !-- REGION #, # GASES
< STEAM !-- GAS NAMES MUST BE ON NEXT LINE

```

HNF-SD-SNF-CN-023 REV 2

```

< 0.      150.00 0.0  0.E0
< 41400.  150.00 0.0  0.E0
< 41410.  150.00 5.4E-5 0.E0
< 51400.  150.00 5.4E-5 0.E0
< 51410.  150.00 0.0  0.E0
< 1.E6    150.00 0.0  0.E0
< END REGION                                !-- ENDS A REGION SOURCE
< REGION 1 GASES 1                          !-- REGION #, # GASES
< STEAM                                       !-- GAS NAMES MUST BE ON NEXT LINE
< 0.      150.00 0.0  0.E0
< 63000.  150.00 0.0  0.E0
< 63010.  150.00 8.1E-6 0.E0
< 73000.  150.00 8.1E-6 0.E0
< 73010.  150.00 0.0  0.E0
< 1.E6    150.00 0.0  0.E0
< END REGION                                !-- ENDS A REGION SOURCE
< REGION 5 GASES 1                          !-- REGION #, # GASES
< STEAM                                       !-- GAS NAMES MUST BE ON NEXT LINE
< 0.      150.00 0.0  0.E0
< 63000.  150.00 0.0  0.E0
< 63010.  150.00 0.9E-5 0.E0
< 93000.  150.00 0.9E-5 0.E0
< 93010.  150.00 0.0  0.E0
< 1.E6    150.00 0.0  0.E0
< END REGION                                !-- ENDS A REGION SOURCE
< END SOURCE                                !-- ENDS ALL SOURCE INPUT
< OXYGEN      0.21      0.00
< NITROGEN    0.79      1.00
< WATER       0.0       0.0
> OXYGEN      0.00      0.00
> NITROGEN    0.00      1.00
> WATER       1.0       0.0

```

CASE 10, OV50C

```

< OVLOCXAL.DAT
> OV50C.DAT
< CASE OVLOCXAL: OPEN MCO w 1 hole, U=10,UH3=12, H2O=26.5
< AL(OH)3 water in 3 regions
> CASE OV50C: OPEN MCO w 1 hole, U=10,UH3=12, H2O=26.5
< ISRC 1 ! User-defined sources
< ISRC 0 ! User-defined sources
< SOURCES 3 ! -- KEYWORD AND # SOURCE GROUPS
< REGION 2 GASES 1 !-- REGION #, # GASES
< STEAM !-- GAS NAMES MUST BE ON NEXT LINE
< 0.      150.00 0.0  0.E0
< 41400.  150.00 0.0  0.E0
< 41410.  150.00 5.4E-5 0.E0
< 51400.  150.00 5.4E-5 0.E0
< 51410.  150.00 0.0  0.E0
< 1.E6    150.00 0.0  0.E0
< END REGION                                !-- ENDS A REGION SOURCE
< REGION 1 GASES 1                          !-- REGION #, # GASES
< STEAM                                       !-- GAS NAMES MUST BE ON NEXT LINE
< 0.      150.00 0.0  0.E0
< 63000.  150.00 0.0  0.E0
< 63010.  150.00 8.1E-6 0.E0
< 73000.  150.00 8.1E-6 0.E0
< 73010.  150.00 0.0  0.E0
< 1.E6    150.00 0.0  0.E0
< END REGION                                !-- ENDS A REGION SOURCE
< REGION 5 GASES 1                          !-- REGION #, # GASES

```

HNF-SD-SNF-CN-023 REV 2

```

< STEAM                                !-- GAS NAMES MUST BE ON NEXT LINE
< 0.      150.00 0.0 0.E0
< 63000.   150.00 0.0 0.E0
< 63010.   150.00 0.9E-5 0.E0
< 93000.   150.00 0.9E-5 0.E0
< 93010.   150.00 0.0 0.E0
< 1.E6     150.00 0.0 0.E0
< END REGION                          !-- ENDS A REGION SOURCE
< END SOURCE                          !-- ENDS ALL SOURCE INPUT
< OXYGEN    0.21      0.00
< NITROGEN  0.79      1.00
< WATER     0.0       0.0
> OXYGEN    0.00      0.00
> NITROGEN  0.00      1.00
> WATER     1.0       0.0
> OFFSET TIMEHS 0.
> EXTRAPOLATION TIMEHS EXTRAP
> TIMTHS 15 2 0.0 1.E6
> THSFIX 15 2 50.0 50.0
> TIMTHS 30 2 0.0 1.E6
> THSFIX 30 2 50.0 50.0
> TIMTHS 45 2 0.0 1.E6
> THSFIX 45 2 50.0 50.0
> TIMTHS 66 2 0.0 1.E6
> THSFIX 66 2 50.0 50.0
> TIMTHS 67 2 0.0 1.E6
> THSFIX 67 2 50.0 50.0
> TIMTHS 68 1 0.0 1.E6
> THSFIX 68 1 50.0 50.0
> TIMTHS 69 2 0.0 1.E6
> THSFIX 69 2 50.0 50.0

```

CASE 11, OVLOF99C

```

< OVLOCXAL.DAT
> OVLOF99C.DAT
< CASE OVLOCXAL: OPEN MCO w 1 hole, U=10,UH3=12, H2O=26.5
< AL(OH)3 water in 3 regions,
> CASE OVLOF99C: OPEN MCO w 1 hole, U=10,UH3=12, H2O=26.5
< ISRC 1 ! User-defined sources
> ISRC 0 ! User-defined sources
< SOURCES 3 ! -- KEYWORD AND # SOURCE GROUPS
< REGION 2 GASES 1 !-- REGION #, # GASES
< STEAM !-- GAS NAMES MUST BE ON NEXT LINE
< 0.      150.00 0.0 0.E0
< 41400.   150.00 0.0 0.E0
< 41410.   150.00 5.4E-5 0.E0
< 51400.   150.00 5.4E-5 0.E0
< 51410.   150.00 0.0 0.E0
< 1.E6     150.00 0.0 0.E0
< END REGION                          !-- ENDS A REGION SOURCE
< REGION 1 GASES 1 !-- REGION #, # GASES
< STEAM !-- GAS NAMES MUST BE ON NEXT LINE
< 0.      150.00 0.0 0.E0
< 63000.   150.00 0.0 0.E0
< 63010.   150.00 8.1E-6 0.E0
< 73000.   150.00 8.1E-6 0.E0
< 73010.   150.00 0.0 0.E0
< 1.E6     150.00 0.0 0.E0
< END REGION                          !-- ENDS A REGION SOURCE
< REGION 5 GASES 1 !-- REGION #, # GASES
< STEAM !-- GAS NAMES MUST BE ON NEXT LINE

```

HNF-SD-SNF-CN-023 REV 2

```

< 0. 150.00 0.0 0.E0
< 63000. 150.00 0.0 0.E0
< 63010. 150.00 0.9E-5 0.E0
< 93000. 150.00 0.9E-5 0.E0
< 93010. 150.00 0.0 0.E0
< 1.E6 150.00 0.0 0.E0
< END REGION !-- ENDS A REGION SOURCE
< END SOURCE !-- ENDS ALL SOURCE INPUT
< TEMP_GAS 50.0 26.7
> TEMP_GAS 99.0 26.7
< OXYGEN 0.21 0.00
< NITROGEN 0.79 1.00
< WATER 0.0 0.0
> OXYGEN 0.00 0.00
> NITROGEN 0.00 1.00
> WATER 1.0 0.0
< TIINIT 50.00 50.00 50.00 50.00 50.00
< TOINIT 50.00 50.00 50.00 50.00 50.00
> TIINIT 50.00 50.00 50.00 50.00 95.00
> TOINIT 50.00 50.00 50.00 50.00 95.00
< TIINIT 50.00 50.00 50.00 50.00 50.00
< TOINIT 50.00 50.00 50.00 50.00 50.00
> TIINIT 50.00 50.00 50.00 50.00 95.00
> TOINIT 50.00 50.00 50.00 50.00 95.00
< TIINIT 50.00 50.00 50.00 50.00 50.00
< TOINIT 50.00 50.00 50.00 50.00 50.00
> TIINIT 50.00 50.00 50.00 50.00 95.00
> TOINIT 50.00 50.00 50.00 50.00 95.00
< TIINIT 50.00 50.00
< TOINIT 50.00 50.00
> TIINIT 95.00 95.00
> TOINIT 95.00 95.00
< TIINIT 50.00 50.00 50.00 50.00
< TOINIT 50.00 50.00 50.00 50.00
> TIINIT 50.00 95.00 50.00 50.00
> TOINIT 50.00 95.00 50.00 50.00
< IHSCSK 68 ! define the cask heat sink
< IRGAP 6 ! define the gap node (between MCO wall and the cask)
> IHSCSK 0 ! define the cask heat sink
> IRGAP 0 ! define the gap node (between MCO wall and the cask)

```

CASE 12, OVLOCNOH

```

< OVLOCXAL.DAT
> OVLOCNOH.DAT
< CASE OVLOCXAL: OPEN MCO w 1 hole, U=10,UH3=12, H2O=26.5
< AL(OH)3 water in 3 regions,
> CASE OVLOCNOH: OPEN MCO w 1 hole, U=10,UH3=0, H2O=26.5
< ISRC 1 ! User-defined sources
> ISRC 0 ! User-defined sources
< SOURCES 3 ! -- KEYWORD AND # SOURCE GROUPS
< REGION 2 GASES 1 !-- REGION #, # GASES
< STEAM !-- GAS NAMES MUST BE ON NEXT LINE
< 0. 150.00 0.0 0.E0
< 41400. 150.00 0.0 0.E0
< 41410. 150.00 5.4E-5 0.E0
< 51400. 150.00 5.4E-5 0.E0
< 51410. 150.00 0.0 0.E0
< 1.E6 150.00 0.0 0.E0
< END REGION !-- ENDS A REGION SOURCE
< REGION 1 GASES 1 !-- REGION #, # GASES
< STEAM !-- GAS NAMES MUST BE ON NEXT LINE

```


HNF-SD-SNF-CN-023 REV 2

```

< 0.      150.00 0.0  0.E0
< 63000.  150.00 0.0  0.E0
< 63010.  150.00 8.1E-6 0.E0
< 73000.  150.00 8.1E-6 0.E0
< 73010.  150.00 0.0  0.E0
< 1.E6    150.00 0.0  0.E0
< END REGION                                !-- ENDS A REGION SOURCE
< REGION 5  GASES 1                        !-- REGION #, # GASES
< STEAM                                         !-- GAS NAMES MUST BE ON NEXT LINE
< 0.      150.00 0.0  0.E0
< 63000.  150.00 0.0  0.E0
< 63010.  150.00 0.9E-5 0.E0
< 93000.  150.00 0.9E-5 0.E0
< 93010.  150.00 0.0  0.E0
< 1.E6    150.00 0.0  0.E0
< END REGION                                !-- ENDS A REGION SOURCE
< END SOURCE                                !-- ENDS ALL SOURCE INPUT
< IHYDKP 1      ! =0, normal depletion of hydride (rate decreases with mass)
> IHYDKP 0      ! =0, normal depletion of hydride (rate decreases with mass)
< FXHYD0 1.0    1.0    1.0    1.0    1.0    1.0    1.0
< 1.0      1.0    1.0    1.0    1.0    1.0    1.0
> FXHYD0 0.0    0.0    0.0    0.0    0.0    0.0    0.0
> 0.0      0.0    0.0    0.0    0.0    0.0    0.0
< FSCHYD 1.0    1.0    1.0    1.0    1.0    1.0
< 1.0      1.0    1.0
> FSCHYD 0.0    0.0    0.0    0.0    0.0    0.0
> 0.0      0.0    0.0

```

CASE 13, OVLOCNOM

```

< OVLOCXAL.DAT
> OVLOCNOM.DAT
< * CASE OVLOCXAL:
> * CASE OVLOCNOM:
< ISRC 1      ! User-defined sources
> ISRC 0      ! User-defined sources
< SOURCES 3      ! -- KEYWORD AND # SOURCE GROUPS
< REGION 2  GASES 1      !-- REGION #, # GASES
< STEAM                                         !-- GAS NAMES MUST BE ON NEXT LINE
< 0.      150.00 0.0  0.E0
< 41400.  150.00 0.0  0.E0
< 41410.  150.00 5.4E-5 0.E0
< 51400.  150.00 5.4E-5 0.E0
< 51410.  150.00 0.0  0.E0
< 1.E6    150.00 0.0  0.E0
< END REGION                                !-- ENDS A REGION SOURCE
< REGION 1  GASES 1      !-- REGION #, # GASES
< STEAM                                         !-- GAS NAMES MUST BE ON NEXT LINE
< 0.      150.00 0.0  0.E0
< 63000.  150.00 0.0  0.E0
< 63010.  150.00 8.1E-6 0.E0
< 73000.  150.00 8.1E-6 0.E0
< 73010.  150.00 0.0  0.E0
< 1.E6    150.00 0.0  0.E0
< END REGION                                !-- ENDS A REGION SOURCE
< REGION 5  GASES 1      !-- REGION #, # GASES
< STEAM                                         !-- GAS NAMES MUST BE ON NEXT LINE
< 0.      150.00 0.0  0.E0
< 63000.  150.00 0.0  0.E0
< 63010.  150.00 0.9E-5 0.E0
< 93000.  150.00 0.9E-5 0.E0
< 93010.  150.00 0.0  0.E0

```

HNF-SD-SNF-CN-023 REV 2

```

< 1.E6      150.00 0.0   0.E0
< END REGION                                !-- ENDS A REGION SOURCE
< END SOURCE                                !-- ENDS ALL SOURCE INPUT
< URANIUM      1      18573.3 24.2   122.67 1955.2   -1      -1
> URANIUM      1      18573.3 24.2   122.67 1015.4   -1      -1
< SCRAP-URANIUM 4      19000. 26.9   122.67 2326.53  0.70   0.7
> SCRAP-URANIUM 4      19000. 26.9   122.67 1208.24  0.70   0.7
< FAOXFL 0.00 0.06702 0.00 0.06702 0.00 0.06702 0.00
<           0.06702 0.00 0.06702 0.00 0.06702 0.00 0.06702
< FOX 10 0 ! multiplier for FAOXFL
> FAOXFL 0.00 0.00362 0.00 0.00362 0.00 0.00362 0.00
>           0.00362 0.00 0.00362 0.00 0.00362 0.00 0.00362
> FOX 3 0 ! multiplier for FAOXFL
< AVOXSC 125.63 125.63 125.63
<           16.48 16.48 16.48 16.48 16.48 16.48
< FOXSC 10 0 ! multiplier for AVOXSC
> AVOXSC 47.46 47.46 47.46
>           6.25 6.25 6.25 6.25 6.25 6.25
> FOXSC 3 0 ! multiplier for AVOXSC

```

CASE 14, OVLOC1AX

```

< OVLOCXAL.DAT
> OVLOC1AX.DAT
< CASE OVLOCXAL: OPEN MCO w 1 hole, U=10,UH3=12, H2O=26.5
> CASE OVLOC1AX: OPEN MCO w 1 hole, U=10,UH3=12, H2O=26.5
< 41400. 150.00 0.0 0.E0
< 41410. 150.00 5.4E-5 0.E0
< 51400. 150.00 5.4E-5 0.E0
< 51410. 150.00 0.0 0.E0
> 93400. 150.00 0.0 0.E0
> 93410. 150.00 5.4E-5 0.E0
> 103400. 150.00 5.4E-5 0.E0
> 103410. 150.00 0.0 0.E0
---
< 63000. 150.00 0.0 0.E0
< 63010. 150.00 8.1E-6 0.E0
< 73000. 150.00 8.1E-6 0.E0
< 73010. 150.00 0.0 0.E0
> 79000. 150.00 0.0 0.E0
> 79010. 150.00 8.1E-6 0.E0
> 89000. 150.00 8.1E-6 0.E0
> 89010. 150.00 0.0 0.E0
---
< 63000. 150.00 0.0 0.E0
< 63010. 150.00 0.9E-5 0.E0
< 93000. 150.00 0.9E-5 0.E0
< 93010. 150.00 0.0 0.E0
> 93000. 150.00 0.0 0.E0
> 93010. 150.00 0.9E-5 0.E0
> 123000. 150.00 0.9E-5 0.E0
> 123010. 150.00 0.0 0.E0
< XRI 0.03493 0.055 0.075 0.09654 0.130
< XRO 0.055 0.075 0.09336 0.130 0.160
> XRI 0.0841 0.095 0.105 0.1183 0.155
> XRO 0.095 0.105 0.1183 0.155 0.180
---
< XRI 0.160 0.190 0.220 0.250 0.2842
< XRO 0.190 0.220 0.250 0.2842 0.28738
> XRI 0.180 0.205 0.230 0.255 0.2824
> XRO 0.205 0.230 0.255 0.2824 0.28557
---

```

HNF-SD-SNF-CN-023 REV 2

```

< XRI      0.03493      0.055      0.075      0.09654      0.130
< XRO      0.055      0.075      0.09336      0.130      0.160
> XRI      0.0841      0.095      0.105      0.1183      0.155
> XRO      0.095      0.105      0.1183      0.155      0.180
---
< XRI      0.160      0.190      0.220      0.250      0.2842
< XRO      0.190      0.220      0.250      0.2842      0.28738
> XRI      0.180      0.205      0.230      0.255      0.2824
> XRO      0.205      0.230      0.255      0.2824      0.28557
---
< XRI      0.3050      0.3050
< XRO      0.3177      0.3177
> XRI      0.29191      0.29191
> XRO      0.30461      0.30461
---
< XRO      0.5056      0.051      0.29      0.034925
< AHS      10.24      0.29      0.29      0.1281
> XRO      0.5056      0.051      0.29      0.08414
> AHS      10.24      0.29      0.29      0.23828
---
< XRO      0.0167005      0.034925      0.0167005      0.034925      0.0167005
< AHS      0.05063      0.1281      0.05063      0.1281      0.05063
> XRO      0.0167005      0.08414      0.0167005      0.08414      0.0167005
> AHS      0.05063      0.23828      0.05063      0.23828      0.05063
---
< XRO      0.034925      0.0167005      0.034925      0.0167005
< AHS      0.1281      0.05063      0.1281      0.05063
> XRO      0.08414      0.0167005      0.08414      0.0167005
> AHS      0.23828      0.05063      0.23828      0.05063
---
< URANIUM      1      18573.3  24.2  122.67  1955.2  -1      -1
> URANIUM      1      14001.5  24.2  122.67  1474.0  -1      -1
< FAWFLM 0.1      ! wetted fraction of MCO wall
> FAWFLM 1.0      ! wetted fraction of MCO wall
< MVWSC0 8.950      ! initial amount (kg) of water per unit bulk volume
> MVWSC0 9.72      ! initial amount (kg) of water per unit bulk volume
< FAWSCM 0.1      ! wetted fraction of MCO wall
> FAWSCM 1.0      ! wetted fraction of MCO wall
<      0.723 0.723 0.723 0.723 0.723 0.723
>      0.76 0.76 0.76 0.76 0.76 0.76
< FAWSCM 0.1      ! wetted fraction of MCO wall
> FAWSCM 1.0      ! wetted fraction of MCO wall

```

CASE 15, DS32C2HZ

```

< OVLOCXAL.DAT
> DS32C2HZ.DAT
< CASE OVLOCXAL: OPEN MCO w 1 hole, U=10,UH3=12, H2O=26.5
< AL(OH)3 water in 3 regions, fksc=0.7, frsc=0.71&.29
> CASE DS32C2HZ: Isolated MCO, U=10,UH3=12, H2O=26.5
< ISRC 1      ! User-defined sources
> ISRC 0      ! User-defined sources
< SOURCES 3      ! -- KEYWORD AND # SOURCE GROUPS
< REGION 2 GASES 1      !-- REGION #, # GASES
< STEAM      !-- GAS NAMES MUST BE ON NEXT LINE
< 0.      150.00 0.0 0.E0
< 41400.      150.00 0.0 0.E0
< 41410.      150.00 5.4E-5 0.E0
< 51400.      150.00 5.4E-5 0.E0
< 51410.      150.00 0.0 0.E0
< 1.E6      150.00 0.0 0.E0
< END REGION      !-- ENDS A REGION SOURCE

```

HNF-SD-SNF-CN-023 REV 2

```

< REGION 1 GASES 1      !-- REGION #, # GASES
< STEAM                !-- GAS NAMES MUST BE ON NEXT LINE
<   0.      150.00 0.0   0.E0
<   63000.  150.00 0.0   0.E0
<   63010.  150.00 8.1E-6 0.E0
<   73000.  150.00 8.1E-6 0.E0
<   73010.  150.00 0.0   0.E0
<   1.E6    150.00 0.0   0.E0
< END REGION          !-- ENDS A REGION SOURCE
< REGION 5 GASES 1    !-- REGION #, # GASES
< STEAM                !-- GAS NAMES MUST BE ON NEXT LINE
<   0.      150.00 0.0   0.E0
<   63000.  150.00 0.0   0.E0
<   63010.  150.00 0.9E-5 0.E0
<   93000.  150.00 0.9E-5 0.E0
<   93010.  150.00 0.0   0.E0
<   1.E6    150.00 0.0   0.E0
< END REGION          !-- ENDS A REGION SOURCE
< END SOURCE          !-- ENDS ALL SOURCE INPUT
< TEMP_GAS      50.0      26.7
> TEMP_GAS      50.0      32.2
< OXYGEN        0.21      0.00
< NITROGEN      0.79      1.00
< WATER         0.0       0.0
> OXYGEN        0.00      0.21
> NITROGEN      0.00      0.79
> WATER         1.0       0.0
<   XWJN        0.61      0.61      0.61      0.61      0.64E-2
<   XHJN        0.61      0.61      0.61      0.61      0.64E-2
>   XWJN        0.61      0.61      0.61      0.61      2.54E-2
>   XHJN        0.61      0.61      0.61      0.61      2.54E-2
<   AJN         0.025     0.025     0.025     0.0078     3.17E-5
>   AJN         0.025     0.025     0.025     0.0078     0.0
< DRAIN 66 15 30 45 67
> C DRAIN 66 15 30 45 67

```

CASE 16, B32C2HZ

```

< DS32C2HZ.DAT
> B32C2HZ.DAT
< CASE DS32C2HZ: Isolated MCO, U=10,UH3=12, H2O=26.5
> CASE B32C2HZ: Isolated MCO, U=10,UH3=12, H2O=26.5
< TSTART      0.      ! START TIME, >0 FOR RESTART RUN
> TSTART      345601.101 ! START TIME, >0 FOR RESTART RUN
<   AJN        0.025     0.025     0.025     0.0078     0.0
>   AJN        0.025     0.025     0.025     0.0078     5.07E-4

```

CASE 17, B32C2HZ2

```

< DS32C2HZ.DAT
> B32C2HZ2.DAT
< CASE DS32C2HZ: Isolated MCO, U=10,UH3=12, H2O=26.5
> CASE B32C2HZ2: blowdown (150 psig), U=10,UH3=12, H2O=26.5
< TSTART      0.      ! START TIME, >0 FOR RESTART RUN
> TSTART      129601.501 ! START TIME, >0 FOR RESTART RUN
> RESTART_FILE DS32C2HZ.REW ! RESTART FILE NAME FOR RESTART RUN
<   AJN        0.025     0.025     0.025     0.0078     0.0
>   AJN        0.025     0.025     0.025     0.0078     5.07E-4

```

CASE 18, CV32C2HX

HNF-SD-SNF-CN-023 REV 2

```

< OVLOXCAL.DAT
> CV32C2HX.DAT
< CASE OVLOXCAL: OPEN MCO w 1 hole, U=10,UH3=12, H2O=26.5
< AL(OH)3 water in 3 regions, fksc=0.7, frsc=0.71&.29
> CASE CV32C2HX: Isolated MCO, U=10,UH3=12, H2O=26.5Kg
> 90F Bay, check valve @ 35 psig fksc=0.7, frsc=0.71&.29
> Loss of ANN. Flow, TWO SCRAP BASKETS (SFFFS)
< ISRC 1 ! User-defined sources
> ISRC 0 ! User-defined sources
< SOURCES 3 ! -- KEYWORD AND # SOURCE GROUPS
< REGION 2 GASES 1 !-- REGION #, # GASES
< STEAM !-- GAS NAMES MUST BE ON NEXT LINE
< 0. 150.00 0.0 0.E0
< 41400. 150.00 0.0 0.E0
< 41410. 150.00 5.4E-5 0.E0
< 51400. 150.00 5.4E-5 0.E0
< 51410. 150.00 0.0 0.E0
< 1.E6 150.00 0.0 0.E0
< END REGION !-- ENDS A REGION SOURCE
< REGION 1 GASES 1 !-- REGION #, # GASES
< STEAM !-- GAS NAMES MUST BE ON NEXT LINE
< 0. 150.00 0.0 0.E0
< 63000. 150.00 0.0 0.E0
< 63010. 150.00 8.1E-6 0.E0
< 73000. 150.00 8.1E-6 0.E0
< 73010. 150.00 0.0 0.E0
< 1.E6 150.00 0.0 0.E0
< END REGION !-- ENDS A REGION SOURCE
< REGION 5 GASES 1 !-- REGION #, # GASES
< STEAM !-- GAS NAMES MUST BE ON NEXT LINE
< 0. 150.00 0.0 0.E0
< 63000. 150.00 0.0 0.E0
< 63010. 150.00 0.9E-5 0.E0
< 93000. 150.00 0.9E-5 0.E0
< 93010. 150.00 0.0 0.E0
< 1.E6 150.00 0.0 0.E0
< END REGION !-- ENDS A REGION SOURCE
< END SOURCE !-- ENDS ALL SOURCE INPUT
< TEMP_GAS 50.0 26.7
> TEMP_GAS 50.0 32.2
< OXYGEN 0.21 0.00
< NITROGEN 0.79 1.00
< WATER 0.0 0.0
> OXYGEN 0.00 0.00
> NITROGEN 0.00 1.00
> WATER 1.0 0.0
< IJTYP 1 1 1 1 1
> IJTYP 1 1 1 1 5
> DP1 0 0 0 0 2.412E5
> DP2 0 0 0 0 1.378E5
< XWJN 0.61 0.61 0.61 0.61 0.64E-2
< XHJN 0.61 0.61 0.61 0.61 0.64E-2
> XWJN 0.61 0.61 0.61 0.61 5.04E-3
> XHJN 0.61 0.61 0.61 0.61 5.04E-3
< AJN 0.025 0.025 0.025 0.0078 3.17E-5
> AJN 0.025 0.025 0.025 0.0078 2.03E-5
< * Water film drain on MCO wall
< DRAIN 66 15 30 45 67
> C DRAIN 66 15 30 45 67

```

CASE 19, COOL1HXXH, entire input file

HNF-SD-SNF-CN-023 REV 2

```

*****
*
* CASE COOL1HXH: VACUUM CYCLE (30 cfm),UH3=12,U=10,H2O=26.5 Kg
*   ONE SCRAP BASKET AT THE TOP(FFFFS)
*
* REACTION AREA = 4.5 M^2 PER SCRAP BASKET
*               0.790 M^2 PER FUEL BASKET
*
* UNLESS OTHERWISE NOTED, MKS UNITS
*
* GENERAL INPUTS:
*
* - FIVE TIERS OF FUEL PLUS SCRAP EXPLICITLY MODELED
* - 6.0 Kg PER FUEL BASKET
* - 1.0 Kg WATER HEEL
* - SCRAP BASKET DIVIDED INTO FINE AND COARSE SECTIONS, WITH
*   RADIAL CONDUCTION TO THE COPPER DIVIDER "FIN"
*   ON THE TOP SCRAP FUEL BASKET
* - AMBIENT TEMPERATURE (CASK EXTERIOR) IS 80 F (26.7 C)
* - CASK/MCO GAP IS 0.61 INCH (0.0155 M)
* - BOTH SIDES OF THE CASK AND OUTER SURFACE OF MCO WALL TEMPERATURES
*   ARE FIXED USING NEW 'IMPOSED HEAT SINK SURFACE TEMPERATURE' FOR
*   WATER FILLED ANNULUS
* - THE CASK HAS INNER DIAMETER OF 25.19" AND OUTER DIAMETER OF 39.81"
*   I.E. 7.31" (0.1857 M) THICK
* - 'WATER' GAS IN THE MCO/CASK GAP
* - RADIATION HEAT TRANSFER FROM FUEL/SCRAP TO LID/FLOOR.
*****
*
*-----
CONTROL      ! Major keyword group
*-----
*
*
* TITLE      ! Keyword; next line is title, title can be any length
* CASE COOL1HXH: VACUUM CYCLE (30 cfm),UH3=12,U=10,H2O=26.5 Kg
* Annulus Temp Inlet=17 C, ONE SCRAP BASKET AT THE TOP(FFFFS)
* END TITLE ! Anything after END is a comment
*
*
* TIMING      ! Keyword
* TSTART 144004.01      ! START TIME, >0 FOR RESTART RUN
* RESTART_FILE VX1HX2.REW ! RESTART FILE NAME FOR RESTART RUN
*                        ! IF NOT SPECIFIED, READ FROM
*                        ! 'input deck name'.RER
* TLAST 172800.      ! END TIME (Seconds)
* for next six parameters (DTMIN, DTMAX, DTPRIN, PLTMAX, PLTMIN, DTRST),
* the user can specify either a fixed value or time dependent value. For
* example:
* DTMIN 0.01      will cause the code to use minimum time step of 0.01
*                second all the time
*
* DTMIN
* 0.      0.01
* 100.    1.0
* 500.    2.0      will cause the code to use minium time step of 0.01
*                for the first 100 seconds, 1.0 second for next 400
*                seconds, and then 2.0 second for the the rest of the run
* DTMIN 0.0001      ! MIN TIMESTEP (Seconds)
* DTMAX      ! MAX TIMESTEP (Seconds)
* 0.      0.01
* 144030. 0.1
* 144100. 2.5

```

```

DTPRIN
0.0 120. ! PRINT INTERVAL (Seconds)
145750.0 1800. ! PRINT INTERVAL (Seconds)
PLTMIN 100. ! MIN PLOT INTERVAL (Seconds)
PLTMAX 1000. ! MAX INTERVAL WITHOUT PLOT (Seconds)
DTRST 14400. ! RESTART INTERVAL (Seconds)
FTPCH 0.005 ! FRACTIONAL CHANGE IN T AND P
FAECH 0.005 ! FRACTIONAL CHANGE IN AEROSOL MASS
FPPLCH 0.03 ! FRACTIONAL CHANGE FOR PLOTTING
END TIMING ! TIMING is a comment.
*
* PRINT ! Keyword for printing section
*
* Printing syntax:
* HS n hlist - Heat Sink Temperatures, C
*
* HS 10 1 2 3 4 5 6 7 8 9 10
* HS 10 11 12 13 14 15 16 17 18 19 20
* HS 10 21 22 23 24 25 26 27 28 29 30
* HS 10 31 32 33 34 35 36 37 38 39 40
* HS 10 41 42 43 44
* HS 10 15 30 45 60 71 72 73 74 85 86
* HS 2 87 88
END PRINT ! PRINT is a comment
*
* PLOT ! Keyword for plotting section
* Plotting syntax:
*
* PRESSURE n rlist - Pressure, Pa
* GAS-T n rlist - Gas Temperature, K
* HS-TI n hlist - Heat Sink Temperature - Inner Surface, K
* HS-TO n hlist - Heat Sink Temperature - Outer Surface, K
* HS-TA n hlist - Heat Sink Temperature - Average, K
* AEROSOL n rlist - Aerosol Mass (Total), kg
* GAS-W n jlist - Mass Flowrate, kg/s
* GAS-WX n jlist - CounterCurrent Mass Flowrate, kg/s
* GAS-X GASNAME n rlist - Gas Mole Fraction
* GAS-RH GASNAME n rlist - Gas Relative Humidity
* GAS-MASS GASNAME n rlist - Gas Mass (Species), kg
* AER-MASS GASNAME n rlist - Aerosol Mass (Species), kg
* MASS GASNAME n rlist - Total Mass (Species), kg
* LIQ-MASS - GASNAME n rlist - Deposited Mass (Species), kg
*
* Pressure, Gas Temperature, and total aerosol mass require a region
* list
*
* Heat Sink Temperatures need a heat sink number list
*
* Flowrates need a junction number list
*
* Gas concentration, relative humidity, individual species gas mass,
* individual species aerosol mass, total (gas+aerosol) individual
* species mass, and individual species deposited liquid mass require
* a region and gas name
*
* Note: plot routine can only accept 99 items; can't plot all things.
* So plot all scrap T's but only 5 fuel (plus MCO)
*
PRESSURE 1 1 ! Pressure in MCO
GAS-T 5 1 2 3 4 5 ! Temperature in MCO
HS-TI 5 61 62 63 64 65 ! Scrap 1 + MCO

```

HNF-SD-SNF-CN-023 REV 2

```

HS-TI      6   66  67  68  69  70  71
HS-TI      3   72  73  74
HS-TO      3   72  73  74
HS-TA      6    1   4   7  10  14  15
HS-TA      6   16  19  22  25  29  30
HS-TA      6   31  34  37  40  44  45
HS-TA      6   46  49  52  55  59  60
GAS-X NITROGEN  5    1   2   3   4   5
GAS-X OXYGEN   5    1   2   3   4   5
GAS-X STEAM    5    1   2   3   4   5
GAS-X HYDROGEN 5    1   2   3   4   5
GAS-X HELIUM   5    1   2   3   4   5
GAS-W        5    1   2   3   4   5
GAS-WX       5    1   2   3   4   5
GAS-MASS HYDROGEN 1    7
GAS-MASS STEAM  1    7
END PLOT ! PLOT is a comment
*
*
ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
IJUNC 1 ! Junction flow model
ICCFLW 1 ! Counter-current flow model
IHSINK 1 ! Heat sinks
ICNDS 0 ! Condensation
IASSED 0 ! Aerosol Sedimentation
IALEAK 0 ! Aerosol Leakage
IFOG 0 ! Fog formation
ISRC 1 ! User-defined sources
IMCO 1 ! MCO models
ISENS 0 ! Sensitivity runs
END ACTIVE MODELS ! ACTIVE MODELS is a comment
MODEL
* multipliers for region gas conductivities
* syntax:
* FKGAS fkgas1 fkgas2 fkgas3 ...
FKGAS 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.055 1.0 0.055 0.055 0.055 0.055
END MODEL
*
*
C-----
C SOURCE GROUP: GROUPS REPEATED FOR INPUT # OF REGIONS
C END OF GROUP DESIGNATED BY 'REGION' OR 'END' KEYWORDS
C ENTER: TIME, TEMP, FLOWRATES, POWER
C SYNTAX EXAMPLE:
* 1.6 FT^3/MIN * 1 MIN/60 SEC * 0.02832 M^3/1 FT^3 = 0.000755 M^3/SEC
* 2.5 FT^3/MIN * 1 MIN/60 SEC * 0.02832 M^3/1 FT^3 = 0.00118 M^3/SEC
* He density @ stp is 0.16 kg/m^3, hence 1.88e-4 about 1.2e-4 kg/s
* He density @ stp is 0.16 kg/m^3, hence 1.88e-4 about 1.9e-4 kg/s
SOURCES 5 ! -- KEYWORD AND # SOURCE GROUPS
REGION 1 GASES 1 !-- REGION #, # GASES
STEAM !-- GAS NAMES MUST BE ON NEXT LINE
0 60.0 8.64E-6 0.0
1.E2 60.0 8.64E-6 0.0
1.E6 60.0 8.00E-8 0.0
END REGION !-- ENDS A REGION SOURCE
REGION 2 GASES 1 !-- REGION #, # GASES
STEAM !-- GAS NAMES MUST BE ON NEXT LINE
0 60.0 8.64E-6 0.0
1.E2 60.0 8.64E-6 0.0
1.E6 60.0 8.00E-8 0.0
END REGION !-- ENDS A REGION SOURCE
REGION 3 GASES 1 !-- REGION #, # GASES
STEAM !-- GAS NAMES MUST BE ON NEXT LINE

```


HNF-SD-SNF-CN-023 REV 2

```

0      60.0  8.64E-6   0.0
1.E2   60.0  8.64E-6   0.0
1.E6   60.0  8.00E-8   0.0
END REGION                                !-- ENDS A REGION SOURCE
REGION 4  GASES 1                                !-- REGION #, # GASES
STEAM                                     !-- GAS NAMES MUST BE ON NEXT LINE
0      60.0  8.28E-5   0.0
1.E2   60.0  1.28E-5   0.0
1.E6   60.0  1.60E-7   0.0
END REGION                                !-- ENDS A REGION SOURCE
REGION 8  GASES 1                                !-- REGION #, # GASES
WATER                                     !-- GAS NAMES MUST BE ON NEXT LINE
0      17.0  0.95      0.0
1.E6   17.0  0.95      0.0
END REGION                                !-- ENDS A REGION SOURCE
END SOURCE                                !-- ENDS ALL SOURCE INPUT
*
*
END CONTROL      ! End of CONTROL keyword group
*
*
-----
VOLUMES      13      ! total number of control volumes
*
* total MCO gas volume is 0.55 m^3, 0.55/3=0.183 per each node
* No more than 5 columns (regions) at a time
* Units:
* VOLUME m^3, SED_AREA m^2, ELEVATION m, TEMP_GAS C, PRESSURE Pa
*
*
*           Regions 1 to 5 each contain a basket, top to bottom
*           scrap1      fuel1      fuel2      fuel3      Fuel4
REGIONS      1              2              3              4              5
VOLUME      0.118      0.100      0.100      0.1      0.1
SED_AREA     0.172      0.172      0.172      0.172      0.172
ELEVATION    2.85      2.15      1.45      0.75      0.0
TEMP_GAS     50.0      50.0      50.0      50.0      50.0
PRESSURE     1.013E5    1.013E5    1.013E5    1.013E5    1.013E5
END REGIONS
*
*           gap      environment new cool gap      New Environment
REGIONS      6              7              8              9
VOLUME      0.12      1.E9      0.00365      1.E9
SED_AREA     0.0      0.0      0.0      0.0
ELEVATION    0.0      0.0      0.0      0.0
TEMP_GAS     50.0      45.55      50.0      45.55
PRESSURE     1.013E5    1.013E5    1.013E5    1.289E5      ! 4 psig
END REGIONS      ! REGIONS is a comment
*
*           4th FB-ann  3rd FB-ann  2nd FB-ann  TOP Cask-MCO
REGIONS      10             11             12             13
VOLUME      0.0168      0.0168      0.0168      0.0365
SED_AREA     0.0      0.0      0.0      0.0
ELEVATION    0.0      0.0      0.0      0.0
TEMP_GAS     50.0      50.0      50.0      50.0
PRESSURE     1.013E5    1.013E5    1.013E5    1.013E5      ! 4 psig
END REGIONS      ! REGIONS is a comment
*
* Gas composition of each region; specify mole fraction of each gas
* No more than five columns at a time
*
GASES      1              2              3              4              5
HELIUM     1.00      1.00      1.00      1.00      1.00

```

STEAM	0.00	0.00	0.00	0.00	0.00
OXYGEN	0.0	0.0	0.0	0.0	0.0
NITROGEN	0.0	0.0	0.0	0.0	0.0
WATER	0.0	0.0	0.0	0.0	0.0

END GASES

*

* If there are more than five regions, continue here.

*

GASES	6	7	8	9
HELIUM	0.0	0.0	0.0	0.995
STEAM	0.0	0.0	0.0	0.005
OXYGEN	0.0	0.21	0.0	0.0
NITROGEN	0.0	0.79	0.0	0.0
WATER	1.0	0.0	1.0	0.0

END GASES ! GASES is a comment

GASES	10	11	12	13
HELIUM	0.0	0.0	0.0	0.0
STEAM	0.0	0.0	0.0	0.0
OXYGEN	0.0	0.00	0.0	0.0
NITROGEN	0.0	0.00	0.0	0.0
WATER	1.0	1.0	1.0	1.0

END GASES ! GASES is a comment

*

* Aerosol concentration of each region (kg/m³)

* No more than five columns at a time

*

AEROSOLS	1	2	3	4	5
STEAM	0.0001	0.0	0.0	0.0	0.0

* END AEROSOLS ! AEROSOLS is a comment

*

* No more than five columns at a time, so continue with 6 & 7

*

AEROSOLS	6	7
STEAM	0.0	0.0

* END AEROSOLS ! AEROSOLS is a comment

*

END VOLUMES ! VOLUMES is a comment

*

*

* Major keyword-----

HEAT_SINKS 88 ! Total number of heat sinks

*-----

* No more than 5 columns at a time,

* Repeat the following structure,

* SINKS

*

*

*

* END

*

* Syntax:

* IGEOM 1 for plane, 0 or 2 for cylinder

* IMATHS material type

* RHO Density (kg/m³), if different from material type

* KHS Thermal Conductivity (W/m/K), if different from material type

* CPHS Specific Heat (J/kg/K), if different from material type

* QV Volumetric Heat Generation (W/m³), if different from material type

* EHSI Emissivity of inner surface, if different from material type

* User has an option to input a temperature dependent emissivity by

* inputting a negative integer for the emissivity and supplying the

* corresponding temperature versus emissivity look-up table. See

* TTABLE & ETABLE keywords.

HNF-SD-SNF-CN-023 REV 2

* EHSO Emissivity of outer surface, if different from material type
 * XRI Inner Radius (m)
 * XRO Outer Radius (m); for plane wall, thickness = XRO-XRI
 * AHS One-sided heat sink area (m²)
 * XZHS Axial length for conduction (m)
 * TIINIT Initial inside surface temperature (C)
 * TOINIT Initial outside surface temperature (C)
 * IMSLAB Number of slabs; 3 is minimum
 * IREGI Region index for inner surface or 0 (insulated)
 * or -1 for constant temperature
 * TIHS Region surface temperature when IREGI = -1 (C)
 * IREGO Region index for outer surface or 0 (insulated)
 * or -1 for constant temperature
 * TOHS Region surface temperature when IREGO = -1 (C)
 * XLHS Characteristic length for natural convection (m)
 *

• Fuel Basket #2 heat sinks 1 through 15

SINKS	1	2	3	4	5
IGEOM	0	0	0	0	0
IMATHS	1	1	1	1	1
XRI	0.00610	0.02160	0.00610	0.02160	0.00610
XRO	0.01625	0.03075	0.01625	0.03075	0.01625
AHS	0.278	0.655	0.278	0.655	0.278
XZHS	0.661	0.663	0.661	0.663	0.661
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	3	3	3	3	3
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	3	3	3	3	3
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.661	0.663	0.661	0.663	0.661

END

SINKS	6	7	8	9	10
IGEOM	0	0	0	0	0
IMATHS	1	1	1	1	1
XRI	0.02160	0.00610	0.02160	0.00610	0.02160
XRO	0.03075	0.01625	0.03075	0.01625	0.03075
AHS	0.655	0.557	1.310	0.278	0.655
XZHS	0.663	0.661	0.663	0.661	0.663
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	3	3	3	3	3
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	3	3	3	3	3
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.663	0.661	0.663	0.661	0.663

END

SINKS	11	12	13	14	MCO WALL 15
IGEOM	0	0	0	0	0
IMATHS	1	1	1	1	2
XRI	0.00610	0.02160	0.00610	0.02160	0.3050
XRO	0.01625	0.03075	0.01625	0.03075	0.3177
AHS	0.278	0.655	0.557	1.310	1.3
XZHS	0.661	0.663	0.661	0.663	0.70
TIINIT	50.00	50.00	50.00	50.00	50.00

HNF-SD-SNF-CN-023 REV 2

TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	3	3	3	3	3
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	3	3	3	3	12
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.661	0.663	0.661	0.663	0.70

END

*

* Fuel Basket #3 heat sinks 16 through 30

*

SINKS	16	17	18	19	20
IGEOM	0	0	0	0	0
IMATHS	1	1	1	1	1
XRI	0.00610	0.02160	0.00610	0.02160	0.00610
XRO	0.01625	0.03075	0.01625	0.03075	0.01625
AHS	0.278	0.655	0.278	0.655	0.278
XZHS	0.661	0.663	0.661	0.663	0.661
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	4	4	4	4	4
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	4	4	4	4	4
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.661	0.663	0.661	0.663	0.661

END

*

SINKS	21	22	23	24	25
IGEOM	0	0	0	0	0
IMATHS	1	1	1	1	1
XRI	0.02160	0.00610	0.02160	0.00610	0.02160
XRO	0.03075	0.01625	0.03075	0.01625	0.03075
AHS	0.655	0.557	1.310	0.278	0.655
XZHS	0.663	0.661	0.663	0.661	0.663
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	4	4	4	4	4
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	4	4	4	4	4
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.663	0.661	0.663	0.661	0.663

END

*

SINKS	26	27	28	29	MCO WALL 30
IGEOM	0	0	0	0	0
IMATHS	1	1	1	1	2
XRI	0.00610	0.02160	0.00610	0.02160	0.3050
XRO	0.01625	0.03075	0.01625	0.03075	0.3177
AHS	0.278	0.655	0.557	1.310	1.3
XZHS	0.661	0.663	0.661	0.663	0.70
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	4	4	4	4	4
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	4	4	4	4	11
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.661	0.663	0.661	0.663	0.70

HNF-SD-SNF-CN-023 REV 2

END

*

* Fuel Basket #4 heat sinks 31 through 45

*

SINKS	31	32	33	34	35
IGEOM	0	0	0	0	0
IMATHS	1	1	1	1	1
XRI	0.00610	0.02160	0.00610	0.02160	0.00610
XRO	0.01625	0.03075	0.01625	0.03075	0.01625
AHS	0.278	0.655	0.278	0.655	0.278
XZHS	0.661	0.663	0.661	0.663	0.661
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	5	5	5	5	5
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	5	5	5	5	5
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.661	0.663	0.661	0.663	0.661

END

*

SINKS	36	37	38	39	40
IGEOM	0	0	0	0	0
IMATHS	1	1	1	1	1
XRI	0.02160	0.00610	0.02160	0.00610	0.02160
XRO	0.03075	0.01625	0.03075	0.01625	0.03075
AHS	0.655	0.557	1.310	0.278	0.655
XZHS	0.663	0.661	0.663	0.661	0.663
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	5	5	5	5	5
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	5	5	5	5	5
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.663	0.661	0.663	0.661	0.663

END

*

SINKS	41	42	43	44	MCO WALL 45
IGEOM	0	0	0	0	0
IMATHS	1	1	1	1	2
XRI	0.00610	0.02160	0.00610	0.02160	0.3050
XRO	0.01625	0.03075	0.01625	0.03075	0.3177
AHS	0.278	0.655	0.557	1.310	1.3
XZHS	0.661	0.663	0.661	0.663	0.70
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	5	5	5	5	5
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	5	5	5	5	10
TOHS	0.0	0.0	0.0	0.0	0
XLHS	0.661	0.663	0.661	0.663	0.70

END

*

• Fuel Basket #1 heat sinks 46 through 60

•

SINKS	46	47	48	49	50
IGEOM	0	0	0	0	0

HNF-SD-SNF-CN-023 REV 2

	1	1	1	1	1
IMATHS	1	1	1	1	1
XRI	0.00610	0.02160	0.00610	0.02160	0.00610
XRO	0.01625	0.03075	0.01625	0.03075	0.01625
AHS	0.278	0.655	0.278	0.655	0.278
XZHS	0.661	0.663	0.661	0.663	0.661
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	2	2	2	2	2
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	2	2	2	2	2
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.661	0.663	0.661	0.663	0.661

END

*

SINKS	51	52	53	54	55
-------	----	----	----	----	----

*

IGEOM	0	0	0	0	0
IMATHS	1	1	1	1	1
XRI	0.02160	0.00610	0.02160	0.00610	0.02160
XRO	0.03075	0.01625	0.03075	0.01625	0.03075
AHS	0.655	0.557	1.310	0.278	0.655
XZHS	0.663	0.661	0.663	0.661	0.663
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	2	2	2	2	2
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	2	2	2	2	2
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.663	0.661	0.663	0.661	0.663

END

*

SINKS	56	57	58	59	MCO WALL 60
-------	----	----	----	----	----------------

*

IGEOM	0	0	0	0	0
IMATHS	1	1	1	1	2
XRI	0.00610	0.02160	0.00610	0.02160	0.3050
XRO	0.01625	0.03075	0.01625	0.03075	0.3177
AHS	0.278	0.655	0.557	1.310	1.3
XZHS	0.661	0.663	0.661	0.663	0.75
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	2	2	2	2	2
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	2	2	2	2	12
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.661	0.663	0.661	0.663	0.75

END

*

* scrap basket # 1 heat sinks 61 through 70 (MCO later)

* switch heat sink 62 & 70 so that fin can be sandwiched to 63

*

SINKS	61	70	63	64	65
-------	----	----	----	----	----

*

IGEOM	0	0	0	0	0
IMATHS	4	4	4	4	4
XRI	0.03493	0.055	0.075	0.09654	0.130
XRO	0.055	0.075	0.09336	0.130	0.160
AHS	0.191	0.276	0.358	0.481	0.616
XZHS	0.676	0.676	0.676	0.676	0.676
TIINIT	50.00	50.00	50.00	50.00	50.0

HNF-SD-SNF-CN-023 REV 2

TOINIT	50.00	50.00	50.00	50.00	50.0
IMSLAB	3	3	3	3	3
IREGI	1	1	1	1	1
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	1	1	1	1	1
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.676	0.676	0.676	0.676	0.676

END

*

SINKS	66	67	68	69	FIN 62
-------	----	----	----	----	-----------

*

IGEOM	0	0	0	0	0
IMATHS	4	4	4	4	3
XRI	0.160	0.190	0.220	0.250	0.2842
XRO	0.190	0.220	0.250	0.2842	0.28738
AHS	0.743	0.871	0.998	1.134	1.2
XZHS	0.676	0.676	0.676	0.676	0.676
TIINIT	50.00	50.00	50.00	50.00	50.0
TOINIT	50.00	50.00	50.00	50.00	50.0
IMSLAB	3	3	3	3	3
IREGI	1	1	1	1	1
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	1	1	1	1	1
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.676	0.676	0.676	0.676	0.676

END

• MCO lid emissivity increased to account for convection to scrap

	MCO SCRAP1	TopCASK WALL	MCO BOT	MCO LID	INS FUEL#2
SINKS	71	72	73	74	75

*

IGEOM	0	0	1	1	0
IMATHS	2	2	2	2	5
XRI	0.3050	0.3199	0.0	0.0	0.022225
XRO	0.3177	0.5056	0.051	0.29	0.034925
AHS	1.3	4.36	0.29	0.29	0.1281
XZHS	0.75	1.75	0.051	0.3	0.71309
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	10	3	20	3
IREGI	1	13	5	1	0
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	13	7	8	7	3
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.75	1.75	0.29	0.3	0.71309
EHSI	0.3	0.3	0.19	0.3	0.3

END

*

	DT FUEL#2	INS FUEL#3	DT FUEL#3	INS FUEL#4	DT FUEL#4
SINKS	76	77	78	79	80

*

IGEOM	0	0	0	0	0
IMATHS	2	5	2	5	2
XRI	0.0076075	0.022225	0.0076075	0.022225	0.0076075
XRO	0.0167005	0.034925	0.0167005	0.034925	0.0167005
AHS	0.05063	0.1281	0.05063	0.1281	0.05063
XZHS	0.71309	0.71309	0.71309	0.71309	0.71309
TIINIT	50.00	50.00	50.00	50.00	50.00
TOINIT	50.00	50.00	50.00	50.00	50.00
IMSLAB	3	3	3	3	3
IREGI	0	0	0	0	0
TIHS	0.0	0.0	0.0	0.0	0.0
IREGO	0	4	0	5	0
TOHS	0.0	0.0	0.0	0.0	0.0
XLHS	0.71309	0.71309	0.71309	0.71309	0.71309

HNF-SD-SNF-CN-023 REV 2

```

END
*
INS FUEL#1    DT FUEL#1    INS SCRAP#1    DT SCRAP#1
SINKS         81          82          83          84
*
IGEOM         0          0          0          0
IMATHS        5          2          5          2
XRI           0.022225    0.0076075    0.022225    0.0076075
XRO           0.034925    0.0167005    0.034925    0.0167005
AHS           0.1281      0.05063      0.1281      0.05063
XZHS          0.71309     0.71309     0.71309     0.71309
TIINIT        50.00      50.00      50.00      50.00
TOINIT        50.00      50.00      50.00      50.00
IMSLAB        3          3          3          3
IREGI         0          0          0          0
TIHS          0.0        0.0        0.0        0.0
IREGO         2          0          1          0
TOHS          0.0        0.0        0.0        0.0
XLHS          0.71309     0.71309     0.71309     0.71309

```

```

END
C           2nd FB-Csk    3rd FB-Csk    4th FB-Csk    Cask Bottom
SINKS       85          86          87          88
*
IGEOM         0          0          0          1
IMATHS        2          2          2          2
XRI           0.3199     0.3199     0.3199     0.0
XRO           0.5056     0.5056     0.5056     0.15
AHS           1.944      1.944      1.944      0.29
XZHS          0.75       0.75       0.75       0.15
TIINIT        50.00      50.00      50.00      50.00
TOINIT        50.00      50.00      50.00      50.00
IMSLAB        10         10         10         10
IREGI         12         11         10         8
TIHS          0.0        0.0        0.0        0.0
IREGO         7          7          7          7
TOHS          0.0        0.0        0.0        0.0
XLHS          0.75       0.75       0.75       0.15

```

END

MATERIAL

* UPTO 20 (INMAT) MATERIALS CAN BE SPECIFIED

* SYNTAX:

* MATERIAL	imaths	rho	khs	cp	qv	ehs1	ehso
URANIUM	1	18573.3	24.2	122.67	1955.2	-1	-1
STAIN-STEEL	2	8000.	16.0	500.	0.	0.30	0.30
COPPER	3	8954.	398.0	749.	0.	0.3	0.3
SCRAP-URAN	4	19000.0	26.9	183.0	3009.00	0.7	0.7
ST-STEEL-INS	5	8000.	16.0	4340.	0.	0.30	0.30

END MATERIAL

* SANDWICH HEAT SINKS - STRING TOGETHER NUMER OF CONSECUTIVE HEAT SINKS
 * TO MIMIC A SANDWICH WALL. UPTO 100 SANDWICH WALLS CAN BE SPECIFIED, WITH
 * UPTO 10 LAYERS IN EACH WALL. THE SANDWICH HEAT SINK SERIES SHOULD BE
 * ARRANGED SUCH THAT THE OUTER FACE OF THE FIRST HEAT SINK AND THE INNER FACE
 * OF THE LAST HEAT SINK IN THE SERIES FACE THE GAS REGIONS (OR INSULATED).

* SYNTAX:

* SANDWICH hsl hgapl hs2 hgap2 hs3 hgap3 ... hsn
 * WHERE 'hgap' is the gap conductance (W/m^2/C) between the layers
 * BETWEEN THE INSERT AND THE DIP TUBE, THERE IS A AIR GAP OF THICKNESS
 * 0.00076 M. THEREFORE, THE GAP CONDUCTANCE IS 0.03/0.00076=40 W/m^2/C
 SANDWICH 75 5.40 76
 SANDWICH 77 5.40 78
 SANDWICH 79 5.40 80
 SANDWICH 81 5.40 82
 SANDWICH 83 5.40 84


```

*
* Represent the thermal resistance in the spokes in the scrap basket
* 12 spokes, 1/8"(0.003175m) thick, 0.676 m high, and 0.191 m long
* Therefore, the gap conductance is:
*  $398/0.191 \times (12 \times 0.003175 / (2 \times 3.14 \times 0.2842)) = 44.48 \text{ W/m}^2/\text{C}$ 
SANDWICH 62 44.48 63
SANDWICH 500 44.48 501
SANDWICH 513 44.48 514
SANDWICH 526 44.48 527
*
* TEMPERATURE DEPENDENT EMISSIVITY:
* USER CAN INPUT A TEMPERATURE DEPENDENT EMISSIVITY BY INPUTTING A
* NEGATIVE INTEGER FOR THE EMISSIVITY AND PROVIDING THE CORRESPONDING
* TEMPERATURE VERSUS EMISSIVITY LOOK-UP TABLE.
* SYNTAX:
* TTABLE n temperature-entry(C)
* ETABLE n emissivity-entry n is the table designator
TTABLE 1 1. 50. 700. 1100. 1500.
ETABLE 1 0.7 0.7 0.4 0.4 0.5
*
*
* USER CAN DEFINE CONDUCTION NETWORKS
* SYNTAX:
* COND_NETWORK ihs1 ihs2 ihs3 .... ihsn upto 100 heat sinks
* COND_NETWORK ihs1 ihs2 ihs3 .... ihsn upto 100 heat sinks
*
* .
* upto 5 networks
*
* MUST BE ORDERED TOP TO BOTTOM TO BE CONSISTENT WITH AXIAL NODALIZATION
* MODEL CONTIGUOUS DIP TUBE CONNECTED TO THE SHIELD PLUG(HS #74)
COND_NETWORK 74 84 82 76 78 80
* MODEL CONTIGUOUS INSERT CONNECTED TO THE SHIELD PLUG(HS #74)
COND_NETWORK 83 81 75 77 79
* MODEL CONTIGUOUS MCO WALL CONNECTED TO THE SHIELD PLUG(HS #74)
COND_NETWORK 74 71 60 15 30 45 73
* MODEL CONTIGUOUS CASK WALL CONNECTED TO THE Bottom of Cask #88
COND_NETWORK 72 85 86 87 88
*
* USER CAN CONTROL HEAT SINK BOUNDARY TEMPERATURE
* SYNTAX:
* OFFSET TIMEHS
* EXTRAPOLATION TIMEHS
* TIMTHS IHS ISD TIME1, TIME2...
* THSFIX IHS ISD TEMP1, TEMP2..
* IHS = HEAT SINK NO.; ISD = SIDE NO. (1 OR 2) FOR IHS
* CONTROL HEAT SINK BOUNDARY T
C OFFSET TIMEHS 0.
C EXTRAPOLATION TIMEHS EXTRAP
C TIMTHS 15 2 0.0 1.E6
C THSFIX 15 2 50.0 50.0
C TIMTHS 30 2 0.0 1.E6
C THSFIX 30 2 50.0 50.0
C TIMTHS 45 2 0.0 1.E6
C THSFIX 45 2 50.0 50.0
C TIMTHS 60 2 0.0 1.E6
C THSFIX 60 2 50.0 50.0
C TIMTHS 71 2 0.0 1.E6
C THSFIX 71 2 50.0 50.0
C TIMTHS 72 1 0.0 1.E6
C THSFIX 72 1 50.0 50.0
C TIMTHS 73 2 0.0 1.E6
C THSFIX 73 2 50.0 50.0

```

```

*
*
END HEAT_SINKS ! HEAT_SINKS is a comment
*-----
JUNCTIONS 10 ! # of Junctions
*-----
* 1) MCO fuel 4 to fuel 3 5->4
* 2) MCO fuel 3 to fuel 2 4->3
* 3) MCO fuel 2 to fuel 1 3->2
* 4) MCO fuel 1 to scrap 1 2->1
* 5) MCO top to Outlet volume, 1->7 (deactivated)
*
* Syntax:
* IJTYP Junction Type: 1 = Normal, 2 = HEPA, 3 = Cover, 4 = Failure,
*                    5 = Check valve
* DP1 for failure junction, it is the pressure differential required
*     to fail from the upstream compartment to the downstream compt.
*     for check valve junction, it is the differential pressure
*     required to open the junction from upstream to downstream only.
* DP2 for failure junction, it is the pressure differential required
*     to fail from the downstream compartment to the upstream compt.
*     for check valve junction, it is the differential pressure
*     required to open the junction from downstream to upstream only.
* IFAN Fan type: 1 = constant volumetric flow fan
*       2 = constant delt_P fan
* WVEAN volumetric flow rate of the fan. for constant delt_P fan,
*       the volumetric flow rate is converted to the corresponding
*       delt_P at time=0
* IR1 Upstream Region
* IR2 Downstream Region
* AJN Area (m^2)
* ABYP Bypass area for HEPA junction (m^2)
* PHEPA HEPA Filter Failure Pressure (Pa)
* ACOV Cover Area (m^2)
* MCOV Cover Weight (kg)
* Z1JN Elevation wrt floor of IR1 opening (m)
* Z2JN " " " IR2 " "
* CJN Loss coefficient multiplies 0.5*rho*v^2
* IHORIZ Orientation: 1 = horizontal, 0 = vertical
* XWJN Characteristic width, m
* XHJN Characteristic height, m
* XLJN Characteristic length, m
* DFJN Decontamination Factor
* N90 No. of 90 bends
*
*
PATHS 1 2 3 4 5
*
IJTYP 1 1 1 1 1
IR1 2 5 4 3 1
IR2 5 4 3 1 9
IHORIZ 1 1 1 1 1
XWJN 0.61 0.61 0.61 0.61 2.54E-2
XHJN 0.61 0.61 0.61 0.61 2.54E-2
XLJN 0.03 0.03 0.03 0.03 0.03
AJN 0.025 0.025 0.025 0.0078 3.17E-5
Z1JN 0.72 0.67 0.67 0.67 0.80
Z2JN 0.0 0.0 0.0 0.0 3.68
CJN 1.0 1.0 1.0 1.0 4.0
DFJN 1.0 1.0 1.0 1.0 1.0
N90 0 0 0 0 3
END PATHS ! PATHS is a comment.
PATHS 6 7 8 9 10
IJTYP 1 1 1 1 1

```

HNF-SD-SNF-CN-023 REV 2

IR1	13	8	10	11	12
IR2	7	10	11	12	13
IHORIZ	1	1	1	1	1
XWJN	1.00	1.02	1.02	1.02	1.02
XHJN	0.02	0.02	0.02	0.02	0.02
XLJN	0.02	0.02	0.02	0.02	0.02
AJN	1.00	1.	1.	1.	1.
Z1JN	0.0	.0	0.	0.	0.
Z2JN	0.0	0.0	0.0	0.0	0.0
CJN	1.0	1.0	1.0	1.0	1.0
DFJN	1.0	1.0	1.0	1.0	1.0
N90	0	1	0	0	0

END PATHS

•
END JUNCTIONS ! JUNCTIONS is a comment.

*-----
MCO ! MCO Major Keyword

*-----
GENERAL ! Keyword for general inputs
IOXDTN 2 ! =0, disable oxidation of fuel/scrap
! =1, do oxidation of fuel/scrap
! =2, oxidation of covered surface uses water prop for rate
IHYD 0 ! =1, do hydriding/dehydriding calculation
! =0, disable hydriding/dehydriding calculation
IDIVRT 1 ! =1, divert heat transfer to gas
! =0, do not divert heat transfer to gas
IEVAP 1 ! =1, do evaporation/condensation of water
! =0, do not do evaporation/condensation
ILAW 3 ! oxidation rate law, 0 - McGillivray/Ritchie
! 1 - Pearce
IDEENT 0 ! =1, de-entrainment of aerosol due to scrap basket
! =0, disable de-entrainment calculation
IENTR 0 ! =1, do entrainment of sludge particle calculation
! =0, disable entrainment calculation
IHYDRA 1 ! =1, do decomposition of fuel oxide hydrate
! =0, disable hydrate decomposition calculation
INITRI 0 ! =1, do nitriding calculation
! =0, disable nitriding calculation
IRADIO 0 ! =1, do radiolysis calculation
! =0, disable radiolysis calculation
IHYDKP 1 ! =0, normal depletion of hydride (rate decreases with mass)
! =1, disable depletion of hydride (but the phantom
! calculation of hydride mass depletion will be shown)
! =2, use constant rate but the rate goes to zero when
! all the mass is depleted
FO2HYH2 0. ! the fraction of the oxygen, reacting with uranium
! hydride, which produces hydrogen instead of water vapor
XDHYD 4.28E-5 ! average diameter of hydride particle (m). this is
! overridden by basket specific parameters, XDHYFL & XDHYSC
IHSCSK 0 ! define the cask heat sink
IRGAP 0 ! define the gap node (between MCO wall and the cask)
! radiative/convective h.t. between the MCO wall and
! the cask is computed and some of the heat is diverted
! to gas for stability
XGPCSK 0.0155 ! gap distance between the MCO wall and the cask
FHTLID 1.0 ! =0, turn off the radiative heat transfer between the
! fuel/scrap and the lid/floor
! =1, fully account for the radiative heat transfer
RHOSL 5000. ! sludge particle density (kg/m³)
SASL 1000. ! sludge specific area (m²/m³)
XDSL 1.E-6 ! sludge particle diameter (m)

*
• Hydrate Model: two-step decomposition,

HNF-SD-SNF-CN-023 REV 2

```

*      input curves for ln P and ln K
*      first step for x > XHYD2, second step for x < XHYD2
*
*      Bounding case: 42 kg particulate, 0.8 kg h2o = 1.9%
*      of sludge being hydrated with 2 moles of
*      water per mole of uranium oxide
*
      FHYSL   0.535 ! fraction of sludge that is hydrated
      XHYSL   2.0    ! stoichiometry number of hydrate: no. of moles of
                   ! water per mole of uranium oxide (UO3.H2O)
      XHYD2   1.0    ! H2O/U ratio (stoich. number) to switch
                   ! from first to second correlation
      XHYD3   0.5    ! H2O/U ratio (stoich. number) to switch
                   ! from second to third correlation
*
      AHYEQ1  15.912 ! 'A' IN LN P = A + B/T FOR X > XHYD2
      BHYEQ1 -6131.E0 ! 'B' IN LN P = A + B/T FOR X > XHYD2
      AHYEQ2  18.382 ! 'A' IN LN P = A + B/T FOR X < XHYD2
      BHYEQ2 -7766.E0 ! 'B' IN LN P = A + B/T FOR X < XHYD2
      AHYEQ3  18.408 ! 'A' IN LN P = A + B/T FOR X < XHYD3
      BHYEQ3 -8488.E0 ! 'B' IN LN P = A + B/T FOR X < XHYD3
*
      ADEHY1  2.793E0 ! 'A' IN LN K = A + B/T FOR X > XHYD2
      BDEHY1 -5111.E0 ! 'B' IN LN K = A + B/T FOR X > XHYD2
      ADEHY2  6.348E0 ! 'A' IN LN K = A + B/T FOR X < XHYD2
      BDEHY2 -7241.E0 ! 'B' IN LN K = A + B/T FOR X < XHYD2
      ADEHY3  4.632E0 ! 'A' IN LN K = A + B/T FOR X < XHYD3
      BDEHY3 -7548.E0 ! 'B' IN LN K = A + B/T FOR X < XHYD3
*
      DHHY1   2.86E6 ! Decomposition enthalpy J/kg H2O: 1st step
      DHHY2   3.70E6 ! Decomposition enthalpy J/kg H2O: 2nd step
      DHHY3   3.70E6 ! Decomposition enthalpy J/kg H2O: 3rd step
      FPROHY   1.0    ! hydride production rate law multiplier
      FCONHY   1.0    ! hydride consumption rate law multiplier
      FNITRI   1.0    ! nitriding rate law multiplier
*
*      PUMP, FEED, AND CONDENSER MODELS
*      Syntax:
*      PUMP IRIPUM IROPUM ICONPM ITFEED WVPUMP WVFEED TGFEED TCONPM
*
*      Definitions:
*      IRIPUM - Pump inlet region
*      IROPUM - Pump outlet region
*      ICONPM - Node to which the condensed steam is dumped for book-keeping
*      ITFEED - If non-zero, overrides TGFEED with the designated region
*               temperature. Used to specify time-varying feed temperature
*      WVPUMP - Pump volumetric flowrate (m^3/s)
*      WVFEED - Feed volumetric flowrate (m^3/s)
*      TGFEED - Feed temperature (C)
*      TCONPM - Condenser cooling coil temperature (C)
*
*      35 FT^3/MIN * 1 MIN/60 SEC * 0.02832 M^3/1 FT^3 = 0.01652 M^3/SEC
*      PUMP IRIPUM IROPUM ICONPM ITFEED WVPUMP WVFEED TGFEED TCONPM
C   PUMP  1      7      0      0      1.416E-2  0.0      0.0      0.0
*
*      Radiolysis parameters
*
      FRAD     1.0    ! multiplier for radiolysis
      FALPHA   0.197  ! alpha fractional heat load
      FBETA    0.486  ! beta fractional heat load
      FGAMMA   0.317  ! gamma fractional heat load
      QPHOTO   2.4E-6 ! heat deposition rate in MCO free water per gram
                   ! per MTU of fuel loading

```

```

END GENERAL          ! GENERAL is a comment
*
PLOT                ! Keyword for MCO-specific plotting section
                   ! A plot file with the name 'input deck name'.PL1 is generated
* Plotting syntax:
*
* PUMPH2            - Hydrogen flow rate into the vacuum pump, kg/s
* • GAS-WH2 n jlist - Hydrogen flow rate through junctions, kg/s
* CORRODH2         - Hydrogen generation rate by fuel/scrap corrosion
* • HS-H2O n hlist  - Water mass on heat sink surfaces, kg
* HS-HYH2O n hlist - Water mass in sludge on heat sink surfaces, kg
* WH2F1 n flist    - Hydrogen generation rate by corrosion/dehydriding/
*                  radiolysis in fuel baskets, kg/s
* WH2SC n slist    - " in scrap baskets, kg/s
* • WH2TT          - total hydrogen generation by corrosion/dehydriding/
*                  radiolysis in MCO, kg/s
* MH2TT           - cumulative hydrogen generated in MCO, kg
*
* QDECF1 n flist   - decay heat in fuel baskets, W
* QDECSC n slist   - decay heat in scrap baskets, W
* QDECTT          - total decay heat in MCO, W
* UDECTT          - cumulative decay heat in MCO, J
*
* QOXOFL, QOXOSC, QOXOTT, UOXOTT      fuel corrosion by O2 heat
* QOXWFL, QOXWSC, QOXWTT, UOXWTT     fuel corrosion by H2O heat
* QNTRFL, QNTRSC, QNTRTT, UNTRTT     nitriding heat
* QHYDFL, QHYDSC, QHYDTT, UHYDTT     hydriding/dehydriding heat
* QINFL, QINSC, QINTT, UINTT         total energy in
*
* QMCOFL, QMCOSC, QMCOTT, UMCOTT     heat loss to MCO wall
* QLIDFL, QLIDSC, QLIDTT, ULIDTT     heat loss to lid/floor/insert
* QGASEFL, QGASSC, QGASTT, UGASTT     heat loss to gas
* QEVPEFL, QEVPESC, QEVPTT, UEVPTT   heat loss due to evaporation
* QCNDFL, QCNDSC, QCNDTT, UCNDTT     heat loss by axial conduction
* QOUTFL, QOUTSC, QOUTTT, UOUTTT     total energy out
*
* UMCO            - total energy in fuel
* • UINTGT        - initial energy in fuel + integrated(source-sink)
* FUERR           - relative energy imbalance
* TOTUO2          - total UO2 in MCO
*
* Note: plot routine can only accept 99 items; can't plot all things.
* So plot all scrap T's but only 5 fuel (plus MCO)
* jlist - junction list
* hlist - heat sink list
* • flist - fuel basket list
* slist - scrap basket list
*
PUMPH2
CORRODH2
WH2TT
MH2TT
QDECTT
UDECTT
QOXOTT
UOXOTT
QOXWTT
UOXWTT
QINTT
UINTT
QMCOTT
UMCOTT
QLIDTT

```

```

ULIDTT
QGASTT
UGASTT
QEVPTT
UEVPTT
QCNDTT
UCNDTT
QOUTTT
UOUTTT
TOTUO2
END PLOT
*
SOLAR_RAD
*
* pointers to heat sinks representing the cask wall and the top
* solar radiation impinges on these
*
IHCASK 72
IHTOP 74
*
* look-up table for solar radiation throughout a day (sec .vs. W/m^2)
*
OFFSET_TIMDAY 21600. ! offset by six hours
EXTRAPOLATION_TIMDAY PERIOD ! repeat the diurnal cycle
TIMDAY 0.0 3600.0 7200.0 10800.0 14400.0 18000.0 21600.0
25200.0 28800.0 32400.0 36000.0 39600.0 43200.0 46800.0
50400.0 54000.0 57600.0 61200.0 64800.0 68400.0 72000.0
75600.0 79200.0 82800.0 86400.0
RADSUN 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0
END SOLAR_RAD
*
FUEL_BSKT 4 ! Total number of fuel baskets
*
• 1st Fuel Basket
*
* heat sink pairs for fuel basket #1
*
IHSFL 46 47 48 49 50 51 52 53 54 55 56 57 58 59
IFLINS 81 ! define the adjacent center insert heat sink,
! 0 for no insert
IFLMCO 60 ! define the adjacent MCO wall heat sink
IFLLID 0 ! define the lid or floor heat sink to which the fuel
! radiate to
AFLFL 0.131 ! flow area in the basket,
*
* fraction of geometric area exposed for oxidation
*  $3.5 \text{ m}^2 / (4 * 16.8 \text{ m}^2) = 0.0521$ 
FAOXFL 0.00 0.06702 0.00 0.06702 0.00 0.06702 0.00
0.06702 0.00 0.06702 0.00 0.06702 0.00 0.06702
FOX 10 0 ! multiplier for FAOXFL
*
* Nominal hydride: 4% of exposed surface with multiplier of 300
XDHYFL 5.05E-5
*
* Bounding Base Hydride-mult of 300 * 0.04 * D/6
* = 8.65E-5 m if D=4.28E-5 m
* = 10.21E-5 m if D=5.05E-5 m --> .97 kg/3 FBs
*
XFLOX0 10.21E-5 10.21E-5 10.21E-5 10.21E-5 10.21E-5 10.21E-5 10.21E-5
10.21E-5 10.21E-5 10.21E-5 10.21E-5 10.21E-5 10.21E-5 10.21E-5

```

HNF-SD-SNF-CN-023 REV 2

```

FXHYDO  1.0      1.0      1.0      1.0      1.0      1.0      1.0
        1.0      1.0      1.0      1.0      1.0      1.0      1.0
*
* initial amount (kg) of water per geometric surface area (m^2) of fuel
* 0.1 kg / 16.8 m^2 = 0.0060
FWFLO   0.3571  0.3571  0.3571  0.3571  0.3571  0.3571  0.3571
        0.3571  0.3571  0.3571  0.3571  0.3571  0.3571  0.3571
FWFLIO  0.0      ! on the outer surface of the insert
FWFLMO  0.0      ! on the inner surface of the MCO wall
FAWFL   0.1      ! wetted fraction of fuel surface
FAWFLM  1.0      ! wetted fraction of MCO wall
MSLFL   1.16     ! mass of sludge particles (kg) in the fuel basket
                ! 4.64 total fuel @ 4 baskets, so 1.16 per basket
*
* view factor matrix between the insert,
* outer surface of outer fuel elements,
* and the MCO wall. Therefore, the dimension of the square matrix is
* 1+number of fuel rods+1. If there is no insert, number of fuel rods+1.
*
FVIEW   0.000  0.926  0.074  0.000  0.000  0.000  0.000  0.000  0.000
        0.175  0.316  0.306  0.181  0.028  0.000  0.000  0.000  0.000
        0.014  0.306  0.028  0.306  0.306  0.028  0.014  0.000  0.000
        0.000  0.181  0.306  0.000  0.334  0.153  0.000  0.028  0.000
        0.000  0.014  0.153  0.167  0.167  0.153  0.153  0.167  0.028
        0.000  0.000  0.028  0.153  0.306  0.000  0.028  0.306  0.181
        0.000  0.000  0.014  0.000  0.306  0.028  0.000  0.306  0.348
        0.000  0.000  0.000  0.014  0.167  0.153  0.153  0.049  0.466
        0.000  0.000  0.000  0.000  0.035  0.115  0.220  0.590  0.040
*
* gap distance for micro-convection calculation
*
XGAP    0.000  0.018  0.000  0.000  0.000  0.000  0.000  0.000  0.000
        0.018  0.000  0.021  0.021  0.073  0.000  0.000  0.000  0.000
        0.000  0.021  0.000  0.021  0.021  0.073  0.073  0.000  0.000
        0.000  0.021  0.021  0.000  0.021  0.021  0.000  0.073  0.000
        0.000  0.073  0.021  0.021  0.000  0.021  0.021  0.021  0.083
        0.000  0.000  0.073  0.021  0.021  0.000  0.073  0.021  0.058
        0.000  0.000  0.073  0.000  0.021  0.073  0.000  0.021  0.026
        0.000  0.000  0.000  0.073  0.021  0.021  0.021  0.000  0.016
        0.000  0.000  0.000  0.000  0.083  0.058  0.026  0.016  0.000
*
* axial conduction tracked in the fuel elements
*
* top to bottom axial partitions of the basket
AXIAL   0.0521  0.0425  0.0648  0.0995  0.152  0.234  0.3551
* multiplier to FAOXFL(fraction of geometric area exposed for
* oxidation) for each axial basket. clad damage confined to the tip.
* 1./0.0521=19.19
FOXAX   19.19  0.0      0.0      0.0      0.0      0.0      0.0
* multiplier to FWFLO, FWFLIO, and FWFMO (initial amount of water per
* geometric surface area of fuel, insert, and MCO wall) for each axial
* basket. water on the tip of fuel. 1./0.0521=19.19
FWAX    19.19  0.0      0.0      0.0      0.0      0.0      0.0
* multiplier to XFLOX0 (initial oxide/hydride thickness) for each axial basket
FUH3AX  1.0      0.0      0.0      0.0      0.0      0.0      0.0
* partition of MSLFL(mass of sludge particles) for each axial basket. uniform.
FSLAX   0.0521  0.0425  0.0648  0.0995  0.152  0.234  0.3551
END IHSFL for 1st fuel basket
*
* 2nd Fuel Basket
*
* "SAME AS FUEL BASKET n" - duplicates the fuel basket data
SAME AS FUEL BASKET 1

```

```

* any overriding parameters can be followed
* define the heat sinks comprising the first fuel basket (must be
* in pairs, for inner and outer elements)
IHSFL  1  2  3  4  5  6  7  8  9  10  11  12  13  14
*
IFLINS  75      ! define the adjacent center insert heat sink,
*              0 for no insert
IFLMCO  15      ! define the adjacent MCO wall heat sink
*
* initial amount (kg) of water per geometric surface area (m^2) of fuel
* 6 kg / (16.8 m^2) = 0.3571
FWFLO  0.3571  0.3571  0.3571  0.3571  0.3571  0.3571  0.3571  0.3571
        0.3571  0.3571  0.3571  0.3571  0.3571  0.3571  0.3571  0.3571
END IHSFL for 2nd fuel basket
*
* 3rd Fuel Basket
*
SAME AS FUEL BASKET 2
IHSFL  16 17 18 19 20 21 22 23 24 25 26 27 28 29
IFLINS  77      ! define the adjacent center insert heat sink
IFLMCO  30      ! define the adjacent MCO wall heat sink
END IHSFL for 3rd fuel basket
*
* 4th Fuel Basket
*
SAME AS FUEL BASKET 2
IHSFL  31 32 33 34 35 36 37 38 39 40 41 42 43 44
IFLINS  79      ! define the adjacent center insert heat sink,
IFLMCO  45      ! define the adjacent MCO wall heat sink
IFLLID  -73     ! define the lid or floor heat sink to which the fuel
                ! radiate to
FWFLMO  0.790   ! on the inner surface of the MCO wall
FAWFL   0.1     ! wetted fraction of fuel surface
FAWFML  0.25    ! wetted fraction of MCO wall
END IHSFL for 4th fuel basket
END FUEL_BSKT
*
SCRAP_BSKT  1    ! Total number of scrap baskets
*
* First scrap basket
*
IHSSC   61  70  63 64  65  66  67  68  69  ! radial outward
*
ISCINS  83      ! define the adjacent center insert heat sink,
                ! 0 for no insert
ISCFIN  62      ! define copper fin heat sink
ISCMCO  71      ! define the adjacent MCO wall heat sink
ISCLID  74      ! define the lid or floor heat sink to which the scrap
                ! radiate to
* multiplier for effective conductivity in scrap basket (only conduction part)
* syntax:
FKSC   0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5
FRSC   0.71  0.71  0.71  0.29  0.29  0.29  0.29  0.29  0.29  0.29
*
* porosity of the scrap for each heat sink in the order read in
FPOROS  0.40  0.40  0.40
        0.723 0.723 0.723 0.723 0.723 0.723
* characteristic size for each scrap heat sink in the order read in (m)
XDSCR   0.00635 0.00635 0.00635
        0.0254 0.0254 0.0254 0.0254 0.0254 0.0254
XRSCBK  0.2842 ! radius of scrap basket (m)
XHSCBK  0.676  ! height of scrap basket (m)

```


HNF-SD-SNF-CN-023 REV 2

```

* exposed surface area available for oxidation
* per unit volume of scrap (1/m) for
* each scrap basket heat sink in the order read in
* Fine: Area= 2.5 m^2 Volume= 1.59e-2 m^3 A/V=157.2
* Coarse: Area= 2.0 m^2 Volume= 1.517e-1 m^3 A/V=13.18
  AVOXSC 125.63 125.63 125.63
          16.48 16.48 16.48 16.48 16.48 16.48
  FOXSC 10 0 ! multiplier for AVOXSC
*
* Nominal hydride: 4% of exposed surface with multiplier of 300
* XSCOX0*FSCHD = Fx * Fa * XDHYD / 6, where Fx is multiplier
  XSCOX0 8.56E-5 8.56E-5 8.56E-5 8.56E-5 8.56E-5 8.56E-5 8.56E-5
          8.56E-5 8.56E-5
  FSCHYD 1.0 1.0 1.0 1.0 1.0 1.0
          1.0 1.0 1.0
*
* 1.5 kg of water total for scrap basket; 1.5/0.1676 = 8.950 kg/m^3
  MVWSC0 8.950 ! initial amount (kg) of water per unit bulk volume
              ! (m^3) of scrap
  FWSCIO 0.0 ! on the outer surface of the insert
              ! (per unit area, m^2)
  FWSCMO 0.0 ! on the inner surface of the MCO wall
              ! (per unit area, m^2)
  FAWSC 0.1 ! wetted fraction of surface area
  FAWSCM 1.0 ! wetted fraction of MCO wall
  XSCINS 0.001 ! gap distance between the insert and scrap basket
              ! 1/4" gap for scrap basket and mco wall
  XSCMCO 0.00635 ! gap distance between scrap basket and MCO wall
  MSLSC 8.25 ! mass of sludge particles (kg) in the scrap basket
*
* axial conduction tracked in the scrap basket, water on the bottom
* 4 nodes, one 2" node at the bottom
*
* top to bottom axial partition
  AXIAL 0.3083 0.3083 0.3083 0.0751
* multiplier for FPOROS(porosity of scrap) for each axial basket
  FFPOR 1.0 1.0 1.0 1.0
* multiplier for FOXSC(multiplier for oxidation area) for each axial basket
  FFOXSC 1.0 1.0 1.0 1.0
* multiplier for MVWSC0(initial amount of water per unit volume) for each
* axial basket. 1 kg on the bottom node, 0.167 kg on each of top three nodes.
  FMVWSC 0.3605 0.3605 0.3605 8.877
* multiplier for XDSCR(characteristic scrap size) for each axial basket
  FXDSC 1.0 1.0 1.0 1.0
* multiplier for FKSC(multiplier for effective conductivity in scrap)
  FFKSC 1.0 1.0 1.0 1.0
  END IHSSC for 1st scrap basket
  END SCRAP_BSKT
*
END MCO

```

CASE 20, COOL1HXM

```

< COOL1HXX.DAT
> COOL1HXM.DAT
< CASE COOL1HXX: VACUUM CYCLE (30 cfm),UH3=12,U=10,H2O=26.5 Kg
> CASE COOL1HXM: VACUUM CYCLE (30 cfm),UH3=12,U=10,H2O=26.5 Kg
< RESTART FILE VX1HX2.REW ! RESTART FILE NAME FOR RESTART RUN
> RESTART FILE VX1HX2m.REW ! RESTART FILE NAME FOR RESTART RUN
< 0 17.0 0.95 0.0
< 1.E6 17.0 0.95 0.0
> 0 10.0 0.95 0.0

```

HNF-SD-SNF-CN-023 REV 2

>	1.E6	10.0	0.95	0.0					
<	URANIUM	1		18573.3	24.2	122.67	1955.2	-1	-1
>	URANIUM	1		18573.3	24.2	122.67	1015.4	-1	-1
<	SCRAP-URAN	4		19000.0	26.9	183.0	3009.00	0.7	0.7
>	SCRAP-URAN	4		19000.0	26.9	183.0	1562.66	0.7	0.7

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APPENDIX C
KEY INPUT PARAMETERS

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APPENDIX C

KEY INPUT PARAMETERS

Key input parameters used in the thermal analysis for the bounding and nominal multi-canister overpack (MCO) are shown in Table C-1. Notes are provided following the table.

Table C-1. Key Input Parameters for Bounding and Nominal Multi-Canister Overpack. (3 sheets)

Parameter	Value	Reference
HEAT GENERATION PARAMETERS: power, reaction area, reaction rate		
Bounding decay power (776 W per 5 fuel baskets, 120 W per scrap basket)	741 W (4 fuel baskets, 1 scrap basket) 706 W (3 fuel baskets, 2 scrap baskets)	HNF-SD-SNF-TI-015 Note 1
Safety basis reaction surface area per scrap basket	4.5 m ² Fine scrap: 2.0 m ² Coarse scrap: 2.5 m ²	HNF-SD-SNF-TI-015 Note 2
Safety basis reaction surface area per fuel basket	0.79 m ²	HNF-SD-SNF-TI-015
Safety basis reaction rate multiplier for uranium–water reaction	10	HNF-SD-SNF-TI-015
Safety basis reaction rate multiplier for hydride–water reaction	Fuel basket: 12 Scrap basket: 12	HNF-SD-SNF-TI-015
RADIATION HEAT TRANSFER PARAMETERS: emissivity, view factors		
Scrap fuel emissivity	0.7	HNF-SD-SNF-TI-015
Cladding emissivity range	Function of temperature 0.4 to 0.7	HNF-SD-SNF-TI-015
Inner shield plug emissivity	0.3	HNF-SD-SNF-TI-015 Note 3
MCO wall emissivity	0.3	HNF-SD-SNF-TI-015
Cask, MCO bottom, and outer shield plug emissivity	0.25	SNF-3650 Note 4
View factors and gap distances between fuel rods and MCO wall	9-by-9 matrix	SNF-3650 Note 5

Table C-1. Key Input Parameters for Bounding and Nominal Multi-Canister Overpack. (3 sheets)

Parameter	Value	Reference
CONDUCTION HEAT TRANSFER PARAMETERS: mass, conductivity, specific heat, temperature		
Effective fuel-cladding mass density	18,573.3 kg/m ³	Note 6
Uranium (scrap) mass density at 100 °C	19,000 kg/m ³	Holden 1958 Note 7
Stainless steel mass density at 100 °C	8,000 kg/m ³	ORNL 1987 Note 8
Maximum fuel mass load (Mark IV fuel)	Scrap basket: 980 kg Fuel basket: 1,268 kg	HNF-SD-SNF-TI-015
Effective fuel-cladding thermal conductivity	24.2 W/m/K	Note 9
Stainless steel thermal conductivity	16.0 W/m/K	ORNL 1987
Effective fuel-cladding and uranium specific heat	122.67 J/kg/K	Kaufman 1962 Note 10
Stainless steel specific heat	500.0 J/kg/K	ORNL 1987
Free residual water after draining (1.5 kg per top scrap basket, 6.0 kg per fuel basket, 6.0 kg per bottom scrap basket, and 1.0 kg on the bottom of the MCO)	26.5 kg per MCO	JMI-980305-10
Water in uranium hydrates, UO ₃ ·2H ₂ O	1.19 kg (2 scrap baskets, 3 fuel baskets)	HNF-SD-SNF-TI-015
Normal process bay temperature	26.7 °C (80 °F)	HNF-3553, Annex B
Bounding annulus water temperature	50 °C	HNF-3553, Annex B

Table C-1. Key Input Parameters for Bounding and Nominal Multi-Canister Overpack. (3 sheets)

Parameter	Value	Reference
CONVECTIVE HEAT AND MASS TRANSFER PARAMETERS: gas volume, flow area, flow rate		
Minimum scrap basket and shield plug gas volume	0.118 m ³ ($< 0.136 \text{ m}^3$)	HNF-2169 Note 11
Fuel basket gas volume	0.10 m ³	HNF-2169 Note 12
Minimum bottom scrap basket gas volume	0.10 m ³ ($< 0.119 \text{ m}^3$)	HNF-2169 Note 13
Fine scrap porosity	0.40	Note 14
Course scrap porosity	0.723	Note 15
Flow area in fuel basket bottom	0.025 m ²	Note 16
Flow area in scrap basket bottom	0.0078 m ²	Note 17
Base vacuum pumping rate	0.01416 m ³ /s (30 ft ³ /min)	HNF-3553, Annex B
Base helium mass purge rate	0.526 E-04 kg/s (0.7 standard ft ³ /min)	HNF-3553, Annex B

MCO = multi-canister overpack.

Note 1 Bounding decay heat rate — The bounding decay power (i.e., decay heat rate) is given as 776 W per MCO with five Mark IV fuel baskets (155.2 W per fuel basket or 620.8 W for four fuel baskets), so the specific heat rate is 0.1224 W/kgU for Mark IV fuel (HNF-SD-SNF-TI-015). The scrap basket for Mark IV fuel has a maximum fuel loading of 980 kg (HNF-SD-SNF-SARR-005), so the scrap basket has a maximum decay power of about 120 W ($980 \text{ kgU} \times 0.1224 \text{ W/kgU}$), with the conservative assumption that no cladding is placed in this scrap basket. Hence, the bounding decay power (i.e., decay heat rate) is 740.8 W per MCO ($620.8 \text{ W} + 120 \text{ W}$) with four Mark IV fuel baskets and one Mark IV scrap basket, and 705.6 W per MCO with three Mark IV fuel baskets and two Mark IV scrap baskets.

Note 2 Scrap fuel reaction surface area — The safety basis value of 4.5 m² for the scrap fuel reaction surface area is given in HNF-SD-SNF-TI-015, but the split between the fine (2 m²) and coarse scrap (2.5 m²) reaction area is given in HNF-SD-SNF-CN-017.

- Note 3 Inner shield plug emissivity — The bottom of the MCO shield plug was given an emissivity value of 0.3 (HNF-SD-SNF-TI-015), which is more conservative than the higher value of 1.0 used in JMI-980305-10 and HNF-2256.
- Note 4 Cask, MCO bottom, and outer shield plug emissivity — The emissivity of the cask, MCO bottom plate, and the outer shield plug was decreased to 0.25 (from 0.30) in order to conservatively reduce the heat removal rate from the MCO (HNF-2256).
- Note 5 View factors and gap distances between fuel rods and MCO wall — The view factors and gap distances between the fuel rods in the fuel basket and the MCO wall, which are used in the radiative heat transfer model and convection heat transfer model for an MCO fuel basket, are documented in SNF-3650. The view factors and gap distances (9-by-9 matrix) include the middle center post or insert, the MCO wall, and seven whole or partial fuel assemblies in a 30° sector (which is multiplied by 12 for full MCO).
- Note 6 Effective fuel-cladding mass density — Since the cladding volume is merged with the fuel volume in the HANSF code (SNF-3650) as one heat structure, an effective mass density is needed for the combined fuel and cladding. To simplify the derivation, the inner fuel element and cladding are assumed to have the same effective mass density as the outer fuel element and its cladding. The total volume for the fuel elements and cladding used in the HANSF code is 0.31752 m³ (SNF-3650). Since the maximum fuel mass for 216 Mark IV elements (four fuel baskets) is 5,072 kg (23.48 kg per element [HNF-SD-SNF-TI-015]), the volume of the fuel is about 0.26695 m³, which is calculated by dividing the volume by the fuel density, 19,000 kg/m³ at 100 °C (Holden 1958). Even though this derivation is using four fuel baskets, the result would be the same if one, two or three fuel baskets were used. The cladding volume is found by subtracting the fuel volume from the total volume:

$$V_{\text{cladding}} = V_{\text{total}} - V_{\text{fuel}} = 0.31752 \text{ m}^3 - 0.26695 \text{ m}^3 = 0.05057 \text{ m}^3 .$$

Multiplying the density of the Zircaloy-2 cladding, 6,541 kg/m³ (UNI-M-61), by the volume of cladding gives a cladding mass of 330.8 kg:

$$M_{\text{cladding}} = 6,541 \text{ kg/m}^3 \times 0.05057 \text{ m}^3 = 330.8 \text{ kg} .$$

For thermal calculations, it is essential that the effective mass (and density) and specific heat product be conserved and, therefore, equal to the sum of the fuel and cladding parts:

$$(M \times C_p)_{\text{eff}} = M_{\text{fuel}} \times C_{p\text{-fuel}} + M_{\text{cladding}} \times C_{p\text{-cladding}}$$

where $C_{p\text{-fuel}} = 122.67 \text{ J/kg/K}$ (Kaufman 1962) and $C_{p\text{-cladding}} = 306.1 \text{ J/kg/K}$ (Scott 1965) .

For convenience, the effective specific heat is set equal to the specific heat of uranium and the effective mass calculated, which can be done because it's the product that must be conserved. Hence, the equation above becomes the following after dividing by the uranium specific heat:

$$\begin{aligned} M_{\text{eff}} &= M_{\text{fuel}} + M_{\text{cladding}} \times C_{p\text{-cladding}}/C_{p\text{-fuel}} \\ &= 5,072 \text{ kg} + 330.8 \text{ kg} \times (306.1 \text{ J/kg/K} \div 122.67 \text{ J/kg/K}) \\ &= 5,897.4 \text{ kg} . \end{aligned}$$

Since the Zircaloy-2 cladding has a higher heat capacity than uranium, the effective mass (in regards to mass times heat capacity product) is larger than just the sum of the masses. Using the calculated effective combined mass of the fuel and cladding above, the effective density of the fuel-cladding composite is simply the effective mass divided by the total volume:

$$\begin{aligned} \rho_{\text{eff}} &= M_{\text{eff}}/V_{\text{total}} \\ &= 5,897.4 \text{ kg}/0.31752 \text{ m}^3 \\ &= 18,573.3 \text{ kg/m}^3 . \end{aligned}$$

The temperature dependence of densities, specific heats, and conductivities is ignored in the analysis because the HANSF code does not have the capability to handle temperature-dependent material properties except for the cladding emissivity (SNF-3650). In order to be consistent, the material parameter values were chosen at around 100 °C and rounded off.

- Note 7 Uranium mass density — The mass density of uranium is about 19,000 kg/m³ at 100 °C. Since the HANSF code (SNF-3650) does not include temperature-dependent material parameters, approximate values are used. The standard reference temperature of 100 °C was chosen because it is between normal operating temperatures and most temperatures during off-normal conditions.
- Note 8 Stainless steel mass density — The mass density of 304L stainless steel is about 8,000 kg/m³ at 100 °C (ORNL 1987). See the discussion above in Note 10 about temperature-dependent material properties.
- Note 9 Effective fuel-cladding thermal conductivity — Since the fuel elements and cladding are combined in the model, an effective thermal conductivity is needed to represent the combined materials. Although the cladding has a lower conductivity, the conductivity of both metals is high, so the calculation of an effective thermal conductivity is not important to the calculational results.

The effective thermal conductivity, K_{eff} , in the radial direction was estimated using the following equation, which is valid for conductors connected in series such as the fuel and cladding in the radial direction:

$$x_{total}/K_{eff} = x_{fuel}/K_{fuel} + x_{cladding}/K_{cladding}$$

where

K_{fuel} = thermal conductivity of spent fuel (26.9 W/m/K [Kaufman 1962])

$K_{cladding}$ = thermal conductivity of Zircaloy-2 cladding (13.4 W/m/K [Scott 1965])

x_{total} = total radial thickness of fuel element and cladding ($x_{fuel} + x_{cladding}$) .

Since the cladding mass is about 7% of the spent fuel mass (HNF-SD-SNF-TI-015) and the cladding density is about one-third of the fuel density, the cladding was estimated to have about 20% ($\sim 7\% \times 3$) of the combined fuel-cladding volume for both inner and outer fuel elements on the average. The thickness is proportional to the volume, therefore the cladding thickness is estimated to be $0.2 \times x_{fuel}$, making the total thickness $1.2 \times x_{fuel}$. Substituting these values into the equation above, the value of K_{eff} is derived to be 24.2 W/m/K, which is close to fuel conductivity value. The equation used for the effective thermal conductivity in the axial direction is the following:

$$\begin{aligned} K_{eff} &= (x_{fuel} \times K_{fuel} + x_{cladding} \times K_{cladding})/x_{total} \\ &= 24.65 \text{ W/m/K} . \end{aligned}$$

Since the HANSF code uses the same value of thermal conductivity for both the axial and radial directions, the smaller value of 24.2 W/m/K was conservatively chosen for this analysis.

- Note 10 Effective fuel-cladding (and uranium) specific heat — As discussed in Note 9, which derived the effective mass density, the effective specific heat for the combined fuel and cladding elements was chosen to be equal to the uranium specific heat, 122.67 J/kg/K at 100 °C (Kaufman 1962). This choice was in conjunction with the effective mass density calculation since it is the product of mass density and specific heat that must be conserved (i.e., the specific heat of the cladding is included in the effective mass density [see Note 9]).
- Note 11 Scrap basket and shield plug gas volume — The value used in the HANSF cases was 0.118 m³, which is smaller and more conservative than the value of 1.2 m³ derived from Table 4.2.2-1 of HNF-2159 for just the scrap basket and not the shield plug gas volume. The shield plug gas (void) volume is about 0.016 m³ (for manifold) in the MCO shield plug assembly (HNF-2833), which is always open to

the MCO scrap basket on top, for a total combined gas volume of 0.136 m^3 for top scrap basket and shield plug manifold. To be conservative, a smaller value of 0.118 m^3 is used in the HANSF cases. A smaller volume will result in a higher MCO pressure when the MCO is closed. The scrap basket gas (or void) volume excludes the volume of the stainless steel parts, support post inner volume, center post inner volume and scrap fuel.

- Note 12 Fuel basket gas volume — The fuel basket has an approximate minimum gas volume of 0.10 m^3 (Table 4.2.2-1, HNF-2159) when it contains E-length Mark IV fuel assemblies. The fuel basket gas volume excludes the volume of the stainless steel parts, support post inner volume, center post inner volume, and fuel assemblies.
- Note 13 Bottom scrap basket gas volume — The fuel basket has an approximate minimum gas volume of 0.119 m^3 (Table 4.2.2-1, HNF-2159) when it contains Mark IV scrap fuel. The scrap basket gas volume excludes the volume of the stainless steel parts, support post inner volumes, center post inner volume, and fuel assemblies. To be conservative, a smaller gas volume of 0.10 m^3 is used in the HANSF cases, which results in a higher MCO pressure when the MCO is closed.
- Note 14 Fine scrap porosity — The porosity of the fine scrap fuel (0.25 in. to 1 in. maximum dimension) in the scrap basket is the void or gas space fraction (void volume divided by total volume) in the total scrap volume when the scrap is completely dry. The porosity of porous media such as a coarse sand is about 0.35 to 0.45. The porosity of fine scrap was calculated to be in the same range with a midpoint of 0.40 (HNF-SD-SNF-CN-017). A fine scrap porosity of 0.40 was used for this analysis.
- Note 15 Course scrap porosity — The largest dimension of the course scrap will not be less than 1 in. or greater than 3 in. The total open volume of an empty scrap basket is 0.16762 m^3 (total inner volume minus the insert and copper fin volumes). The fine scrap volume is 0.01592 m^3 , and the course scrap volume is 0.1517 m^3 . The total solid scrap volume is calculated by dividing the total bounding scrap mass, 980 kg, by the fuel mass density, $19,000 \text{ kg/m}^3$, resulting in a total solid volume of 0.05158 m^3 . The solid (fuel) volume in the fine portion is 0.6 (1-porosity) times the total fine scrap volume, 0.01592 m^3 , resulting in 0.009552 m^3 . Hence, the coarse scrap solid volume is 0.05158 m^3 minus the fine scrap solid volume, 0.009552 m^3 , for a value of 0.042028 m^3 . Dividing the coarse scrap solid volume (0.042028 m^3) by the total coarse scrap volume (0.1517 m^3) gives the solid fraction of 0.27707 for the coarse portion. Hence, the porosity of the coarse scrap is just 1.0 minus 0.27707 for a coarse scrap porosity value of 0.72293, which is rounded to 0.723. This value is higher than the coarse scrap porosity value (0.685) reported in SNF-3650, mainly because no cladding is assumed in the bounding scrap basket used in this analysis. Cladding has a lower mass density than uranium fuel and would occupy more space, which would lower the porosity value.

- Note 16 Flow area in fuel basket bottom — The flow area at the bottom of the fuel basket is the same flow area as the scrap basket bottom because the plates are same. However, the fuel basket, without the copper fin, can have some gas flow around the plate through the 0.25-in. gap between bottom plate and MCO wall. Also, there is no fine wire mesh covering the bottom of fuel basket. Hence, the flow area for a fuel basket was rounded up to 0.25 m², which includes the 108 0.5-in.-diameter holes and the 0.25-in. gap between bottom plate and MCO wall.
- Note 17 Flow area in scrap basket bottom — The flow area at the bottom of the scrap basket is the only flow area available for gas entry into the scrap fuel. Since copper shims or wipers have been added between the outer scrap basket and MCO wall, the upward gas flow has a lot of resistance through the gap between outer fin and wall. Hence, most of the gas has nowhere to go except through the bottom of the scrap basket by design. The scrap basket bottom has 108 open 0.5-in.-diameter holes in it (HNF-SD-SNF-SARR-005). Hence, the total flow area is calculated as follows:

$$\begin{aligned}
 A_{SB} &= 108 \times 3.14159 \times (0.5 \times 0.0254/2)^2 \text{ m}^2 \\
 &= 108 \times 1.2668 \times 10^{-4} \text{ m}^2 \\
 &= 0.0137 \text{ m}^2 .
 \end{aligned}$$

This is reduced to 0.0078 m² because the wire screen on the bottom plate covers about 43% of the hole area leaving about 57% of the hole open for flow. This flow area is not an important parameter since very little flow resistance is present for the flows encountered during vacuum drying.

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APPENDIX D
PEER REVIEW CHECKLIST

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CHECKLIST FOR PEER REVIEW

Document Reviewed: HNF-SD-SNF-CN-023, *Thermal Analysis of Cold Vacuum Drying of Spent Nuclear Fuel*

Scope of Review: Full document

Author: M. G. Piepho

Yes No NA

☐	☐	☒ *	Previous reviews complete and cover analysis, up to scope of this review, with no gaps.
☒	☐	☐	Problem completely defined.
☒	☐	☐	Accident scenarios developed in a clear and logical manner.
☒	☐	☐	Necessary assumptions explicitly stated and supported.
☒	☐	☐	Computer codes and data files documented.
☒	☐	☐	Data used in calculations explicitly stated in document.
☒	☐	☐	Data checked for consistency with original source information as applicable.
☐	☐	☒	Mathematical derivations checked including dimensional consistency of results.
☒	☐	☐	Models appropriate and used within range of validity or use outside range of established validity justified.
☐	☐	☒	Hand calculations checked for errors. Spreadsheet results should be treated exactly the same as hand calculations.
☒	☐	☐	Software input correct and consistent with document reviewed.
☒	☐	☐	Software output consistent with input and with results reported in document reviewed.
☐	☐	☒	Limits/criteria/guidelines applied to analysis results are appropriate and referenced. Limits/criteria/guidelines checked against references.
☒	☐	☐	Safety margins consistent with good engineering practices.
☒	☐	☐	Conclusions consistent with analytical results and applicable limits.
☒	☐	☐	Results and conclusions address all points required in the problem statement.
☒	☐	☐	Format consistent with appropriate NRC Regulatory Guide or other standards
☐	☐	☒ *	Review calculations, comments, and/or notes are attached.

☒ ☐ ☐ **Document approved.**

RALPH CROWE
Reviewer (Printed Name and Signature)

3/21/00
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* Any calculations, comments, or notes generated as part of this review should be signed, dated and attached to this checklist. Such material should be labeled and recorded in such a manner as to be intelligible to a technically qualified third party.

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