PRC-STP-00187
Revision 0

Sludge Treatment Project KOP Disposition - Thermal and Gas Analysis for the Cold Vacuum Drying Facility

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

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

CH2MHILL
Plateau Remediation Company

P.O. Box 1600
Richland, Washington 99352

PRC-STP-00187
Revision 0

EDC #: PRC-EDC-10-45214

Sludge Treatment Project KOP Disposition - Thermal and Gas Analysis for the Cold Vacuum Drying Facility

Project No: STP

Document Type: TR

Program/Project: STP

J. A. Swenson
AREVA

R. D. Crowe
Fluor Government Group

R. Apthorpe
M. G. Plys
Fauske & Associates LLC

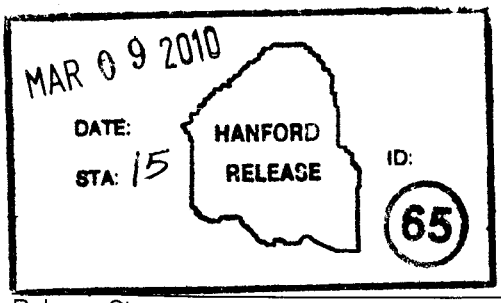
Date Published
March 2010

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

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

CH2MHILL
Plateau Remediation Company

P.O. Box 1600
Richland, Washington



Nancy A Fouad 3-9-10
Release Approval Date

Release Stamp

Approved for Public Release;
Further Dissemination Unlimited

TRADEMARK DISCLAIMER

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

This report has been reproduced from the best available copy.

Printed in the United States of America

Total Pages: 131

Table of Contents

List of Terms

CSB	Canister Storage Building
CVDF	Cold Vacuum Drying Facility
FAI	Fauske & Associates, LLC
KOP	Knock out pot
KW	105-K West
MCO	multi-canister overpack
MLS	MCO Loading System
PCM	Primary cleaning machine
SNF	Spent Nuclear Fuel
STP	Sludge Treatment Project
TWS	tempered water (annulus) system

EXECUTIVE SUMMARY

The purpose of this document is to present conceptual design phase thermal process calculations that support the process design and process safety basis for the cold vacuum drying of K Basin KOP material. This document is intended to demonstrate that the conceptual approach:

- Represents a workable process design that is suitable for development in preliminary design
- Will support formal safety documentation to be prepared during the definitive design phase to establish an acceptable safety basis.

The Sludge Treatment Project (STP) is responsible for the disposition of Knock Out Pot (KOP) sludge within the 105-K West (KW) Basin. KOP sludge consists of size segregated material (primarily canister particulate) from the fuel and scrap cleaning process used in the Spent Nuclear Fuel process at K Basin. The KOP sludge will be pre-treated to remove fines and some of the constituents containing chemically bound water, after which it is referred to as KOP material. The KOP material will then be loaded into a Multi-Canister Overpack (MCO), dried at the Cold Vacuum Drying Facility (CVDF) and stored in the Canister Storage Building (CSB).

This process is patterned after the successful drying of 2100 metric tons of spent fuel, and uses the same facilities and much of the same equipment that was used for drying fuel and scrap. Table ES-1 present similarities and differences between KOP material and fuel and between MCOs loaded with these materials. The potential content of bound water bearing constituents limits the mass of KOP material in an MCO load to a fraction of that in an MCO containing fuel and scrap; however, the small particle size of the KOP material causes the surface area to be significantly higher. This relatively large reactive surface area represents an input to the KOP thermal calculations that is significantly different from the calculations for fuel MCOs.

Table ES-1: Comparison of Key Parameters for KOP Material and Fuel MCOs

	Fuel	Scrap	KOP Material
Particle Size	**Fuel Assemblies**	**> ¼"**	**> 600**
Total Quantity	**~2100 tons**	**~36 tons**	**< 1 ton**
MCO Load	**Up to ~6 tons**	**Up to ~ 2 tons**	**Up to ~ 0.15 ton**
MCO Reactive Surface	**Up to 12 m^2 for fuel and scrap**		**Up to ~46.3 m^2**

The conceptual design provides for a copper insert block that limits the volume available to receive KOP material, enhances heat conduction, and functions as a heat source and sink during drying operations. This use of the copper insert represents a significant change to the thermal model compared to that used for the fuel calculations.

A number of cases were run representing a spectrum of normal and upset conditions for the drying process. Dozens of cases have been run on cold vacuum drying of fuel MCOs. Analysis of these previous calculations identified four cases that provide a solid basis for judgments on the behavior of MCO in drying operations. These four cases are

- Normal Process
- Degraded vacuum pumping
- Open MCO with loss of annulus water
- Cool down after vacuum drying

The four cases were run for two sets of input parameters for KOP MCOs: (1) a set of parameters drawn from safety basis values from the technical data book and (2) a sensitivity set using parameters selected to evaluate the impact of lower void volume and smaller particle size on MCO behavior. Results of the calculations for the drying phase cases are shown in Table ES-2. Cases using data book safety basis values showed dry out in 9.7 hours and heat rejection sufficient to hold temperature rise to less than 25° C. Sensitivity cases which included unrealistically small particle sizes and corresponding high reactive surface area showed higher temperature increases that were limited by water consumption.

Table ES-2: Summary Results of Thermal Calculations			
Cases Using Databook Safety Basis Values (40% Void Fraction & 1500μ Particle)	Time to Dry	Peak Temp	Comments
1. Normal Process	9.7 hrs	57° C	Stable
2. Degraded Vacuum Pumping	18 hrs	72° C	Stable
3. Open MCO - No Annulus H_2O	N/A	62° C	Stable
Sensitivity Cases (25% Void Fraction & 600μ Particle)	Time to Dry	Peak Temp	Comments
1. Normal Process	9.7 hrs	70° C	Stable
2. Degraded Vacuum Pumping	18 hrs	88° C	Limited by water availability
3. Open MCO - No Annulus H_2O	N/A	70° C	Stable

In this document and in the attachment (Apthorpe, R. and M.G. Plys, 2010) cases using Technical Databook safety basis values are referred to as nominal cases. In future calculations such cases will be called safety basis cases. Also in these documents cases using parameters that are less favorable to acceptable performance than databook safety values are referred to as safety cases. In future calculations such cases will be called sensitivity cases or sensitivity evaluations

Calculations to be performed in support of the detailed design and formal safety basis documentation will expand the calculations presented in this document to include: additional features of the drying cycle, more realistic treatment of uranium metal consumption during oxidation, larger water inventory, longer time scales, and graphing of results of hydrogen gas concentration.

1. INTRODUCTION

The Sludge Treatment Project (STP) is responsible for the disposition of Knock Out Pot (KOP) sludge within the 105-K West (KW) Basin. KOP sludge consists of size-segregated material (primarily canister particulate) from the fuel and scrap cleaning process used in the Spent Nuclear Fuel process at K Basin. The KOP sludge will undergo a physical separation process to remove fines and compounds bearing chemically bound water to ensure that Multi-Canister Overpack (MCO) water inventory limits are met; after processing the sludge is referred to as KOP material. The KOP material will then be placed in scrap baskets in an MCO. The MCO will be transported to the cold vacuum drying facility (CVDF). The MCO will be dried at CVDF and then placed in storage in a CSB storage tube.

CH2MHILL Plateau Remediation Company (CHPRC) contracted with Fauske & Associates, LLC (FAI) to evaluate the thermal stability of KOP material during vacuum drying and during transport when the KOP material is submerged in water. Thus, during the latter half of FY09 FAI has worked interactively with the Sludge Treatment Project to evaluate the thermal and gas generation issues associated with placing KOP material into a MCO for cold vacuum drying at CVDF. On the design side, a number of potential designs, features, dimensions, and material loadings have been explored, and on the modeling side, physical models have evolved and been assessed.

FAI completed the analysis and documented the results in a report, FAI/10-28, *Cold Vacuum Drying of Knock Out Pot Material in the Scrap Basket Insert Blocks (Apthorpe and Plys, 2010).* The FAI report presents results for the current design using the most mature model approach. The crucial feature of results to be found is thermal stability of the KOP material under restrictive operating conditions and bounding design assumptions. Model features and inputs are selected to minimize the need for technical specifications that would require verification, so that results presented here are therefore conservative. Additionally, this conservative model is compared against a model using safety-basis parameters to illustrate the degree of conservatism in the conservative approach.

In simulation of the normal CVD processing of MCOs with KOP material using conservative, bounding values for the material characteristics, reaction rates, and MCO conditions, the KOP material is predicted to have stable temperature behavior and the MCO is expected to dry out after about 9.5 hours. Stable behavior is also predicted for one key accident scenario, loss of annulus water. Acceptable behavior is predicted for another key accident scenario, degraded vacuum pumping with no helium purge. In this case, the KOP material temperature is below 100 °C when the large residual water heel is evaporated after a duration of 18 hours. A case for MCO cool down is also presented here for comparison to backfill conditions required for the canister storage building (CSB).

Using safety basis KOP material properties, the KOP material is predicted to have stable temperature behavior and MCO dry out is expected at 9 hours. Approximately 3.4 kg of uranium dioxide is predicted to be produced. Cases analyzed using conservative KOP material properties bound those using safety basis material properties.

Section 3.0 of this document provides background including a description of the planned KOP process. Section 4 follows with the key input parameters and assumptions provided for FAI analysis. The cases and results are summarized in Section 5.0. The attachment to this document provides the complete copy of the FAI report.

2. PURPOSE

The purpose of this document is to present conceptual design phase thermal process calculations that support the process design and process safety basis for the cold vacuum drying of K Basin KOP material. This document is intended to demonstrate that the conceptual approach:

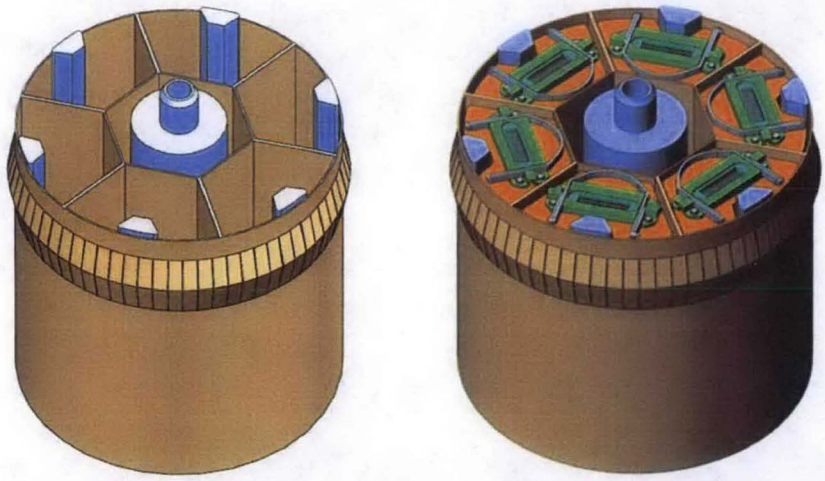
- Represents a workable process design that is suitable for development in preliminary design
- Will support formal safety documentation prepared during the definitive design phase to establish an acceptable safety basis.

These calculations describe the thermal behavior of the process system. This document melds the thermal calculations prepared by FAI (Apthorpe and Plys, 2010) into the CHPRC document system. The document describes the cold vacuum drying system performance during nominal and bounding conditions.

3. BACKGROUND

KOP material will be loaded into copper inserts and the inserts placed in MCO Mark 1A scrap baskets. The retrieval, sorting, and loading processes that were used for spent fuel and scrap will be adapted to the KOP material, but once the baskets are loaded, they will be handled in the same manner as for spent fuel. Figure 3-1 shows an empty Mark 1A scrap basket and the scrap basket with copper inserts in place.

Figure 3-1. Mark 1A Scrap Baskets; Empty (L) and with Copper Inserts Installed (R)



The loaded MCO scrap baskets will be placed in the MCO basket queue and moved from there to the MCO Loading System (MLS) shuttle. The MLS shuttle transports the MCO baskets to the MCO. The MLS gantry loads the baskets into a water filled MCO located in the MCO Cask and Immersion Pail assembly. The MCO is closed and transported to the Cold Vacuum Drying Facility.

The MCO will be dried at CVDF. MCOs are received at CVDF and hooked up to the process system. MCO temperature is raised to process temperature and the bulk water removed. The pressure is drawn down causing the water to evaporate and be drawn off. After completing vacuum cycle a thermal reset is performed in which helium is introduced to bring the pressure back to near atmospheric and allow the MCO to return to thermal equilibrium at process temperature. After process behavior indicates dryness, a pressure rebound dryness test is performed. After dryness is demonstrated the MCO is cooled, filled with helium, sealed, transferred to CSB and placed in a storage tube. MCO load parameters in combination with dryness test results will demonstrate that the dried MCOs containing KOP material will fit within the safety envelope established for the MCOs containing Spent Fuel currently stored at CSB. The MCOs containing KOP material are planned to be shipped to the HLW Repository with the other MCOs containing Spent Fuel.

Differences from Spent Nuclear Fuel MCO and KOP Material MCO Analysis

The primary difference between this analysis and the original safety analysis report for MCO processing at CVDF (HNF-SD-SNF-CN-023, *Thermal Analysis of Cold Vacuum Drying of Spent Nuclear Fuel*) is that the original report analyzed N-Reactor fuel and N-Reactor fuel scrap in the MCO while the current analyses analyze KOP material in the MCO. The main differences between an SNF MCO and a KOP material MCO include the following:

- The bounding Mark IV fuel MCO had three baskets of fuel and two baskets of scrap. The KOP material MCO will use six Mark IA baskets, three baskets with KOP sludge in copper inserts and the remaining three baskets empty.
- The Mark IV-type MCO loading ranged from intact fuel pieces to small scrap pieces greater than 0.25 in (6250 μm). The KOP material MCO will be loaded with sludge that consists of particles ranging in size from approximately 600 μm to 6250 μm.
- The bounding Mark IV fuel MCO had an exposed uranium surface area of 12 m^2. The KOP MCO based on safety basis parameter values has 49 m^2.
- The maximum mass of Mark IV fuel in a scrap basket was limited to 980 kg. The mass of KOP material that can be stored in a single MCO is constrained by the limit of the mass of hydrate and will be less than 200 kg or about 65 kg per basket containing KOP material.

4. INPUT PARAMETERS AND ASSUMPTIONS

4.1 Summary of Data Book Data for Knock Out Pot Sludge

The cases analyzed in this document are based upon key input parameters and specific process and equipment designs. The design basis accident scenarios 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 reaction areas and rate enhancement factors
- Heat transfer rate through the annulus from the MCO to the cask

- Decay heat rate of KOP material

Detailed data for sludge properties, including KOP sludge, is defined in HNF-SD-SNF-TI-015, Vol. 2, *Sludge Technical Data Book.* The technical basis for selection of data in HNF-SD-SNF-TI-015 is contained in SNF-7765, *Supporting Basis for Spent Nuclear Fuel Project Sludge Technical Databook.*

Knock-Out Pot (KOP)/Strainer Sludge is not a representative/controlling sludge - its composition is derived/calculated based on ratios to representative/controlling sludge sources (see Tables 3-2 and 5-1 of HNF-SD-SNF-TI-015, Vol.2). KOP sludge consists of size-segregated material from the fuel, canister, and scrap cleaning. The representative sludge for safety basis KOP is size-segregated fuel piece sludge. Fuel piece sludge encompasses KE and KW Basins sludge dislodged when the fuel was cleaned in preparation for dry storage. Based on the physical state of the fuel and the fractured state of the uranium within the breached fuel elements, further breakage of the fuel elements also dislodged corroded uranium metal pieces with zirconium cladding. During fuel washing in the Primary Cleaning Machine (PCM), sludge removed from the fuel elements was passed through a ¼ in screen, and then passed through a strainer basket with 1/8 in openings prior to going to the KOPs.

Containers of KOP material vary significantly in density and composition, but are known to contain uranium metal, hydrated forms of uranium, iron, and aluminum, as well as other foreign material. This sludge will be highly radioactive with relatively high concentrations of uranium metal.

Table 4-1 KOP Sludge Databook Values

Property (per volume of wet sludge)	Safety Basis Values	Reference
KOP sludge	Size-Segregated Fuel Piece Sludge	Databook, Vol. 2, Table 3-2
Wet sludge density	10.5 g/cm^3	Databook, Vol. 2, Table 4-1
Reaction rate Enhancement Factor	3	Databook, Vol. 1, Table 4-10a
Decay power per volume of uranium	117 W/MTU (1100 W/m^3 U)	Databook, Vol. 2, Table 4-11
Thermal conductivity of sludge	3.90 W/m/K	Databook, Vol. 2, Table 4-12
Total Uranium concentration	9.40 g/cm^3	Databook, Vol. 2, Table 4-3
Reaction Rate with Liquid Water (Oxygen Free)	Same as for fuel with water	Databook, Vol. 2, Table 4-4
Uranium Metal Concentration	9.40 g/cm^3	Databook, Vol. 2, Table 4-4a
Water volume fraction	40%	Databook, Vol. 2, Table-4-2
Reactive Sludge Particle Size for Uranium Metal – Segregated Diameter	1500 μm	Databook, Vol. 2, Tables 4-5b
Reactive Sludge Particle Size for Uranium Long Term Survival Diameter	2300 μm	Databook, Vol. 2, Tables 4-5c
Formula weight of U oxide compounds	288.6	SNF-7765, page C-4
Uranium oxide density	7.50 g/cm^3	SNF-7765, page C-7
Uranium metal density	19.0 g/cm^3	SNF-7765, page C-7
Water density	1.0 g/cm^3	SNF-7765, page C-7

HNF-SD-SNF-TI-015, *Spent Nuclear Fuel Project Technical Databook, Vol 1*
HNF-SD-SNF-TI-015, *Spent Nuclear Fuel Project Technical Databook, Vol 2, Sludge*
SNF-7765, *Supporting Basis for SNF Project Technical Databook*

It is assumed that a separations process will be used to remove most particles of less than 500 to 600 micron size. The purpose of the separations process is to eliminate very small particles that are known to prevent water draining and to greatly impede drying of the KOP material, and to eliminate material that was not part of the original KOP stream (which was all above 500 or 600 microns). KOP material is presently categorized as a K Basins sludge stream. Sludge properties are summarized in the HNF-SD-SNF-TI-015, *Spent Nuclear Fuel Project Technical Databook, Vol 2, Sludge* and supporting documents (SNF-7765, 2006, *Supporting Basis for Spent Nuclear Fuel Project Sludge Technical Databook*). Limited KOP material inspections confirmed that the density is less than that of fuel piece material. However, due to the assumed process to remove fines, fuel piece properties in Table 4-1 apply.

4,2 Summary of Design Parameters

The key input parameters used in the analysis for the bounding (safety basis) MCO are shown in Table 4-2.

Table 4-2 Key Input Parameters for Safety Basis (Bounding) Knock Out Pot Multi-Canister Overpack

Parameter	Value		Reference
	Cases 1, 2, 3, & 4	Cases 5, 6, 7, & 8	
KOP MCO Loading			
KOP basket insert loading height (estimate)	20 in		
KOP basket insert cross sectional area	4.25 in^2		
Volume of KOP material per basket insert	1.39 L		20 in × 4.25 in^2 = 85 in^3 = 1.39 L
Number of inserts per KOP basket	6		
Volume of KOP material per basket	8.36 L		6 × 1.39 L = 8.36 L
Number of baskets per KOP MCO	3		
Maximum Total Sludge Volume per MCO	25 L		3× 8.36 L = 25 L
Material Properties			
Wet sludge density (g/cm^3)		10500	
Total Uranium concentration (g/cm^3)	11,750	9400	
Uranium Metal Concentration (g/cm^3)	11,750	9400	
Water volume fraction	.25	.40	
Thermal conductivity of uranium metal (W/m/K)	26.9		
Thermal conductivity of KOP sludge with 40% water (W/m/K)	Thermal conductivity model described in Appendix B, Section 3.4.3, KBC-38156, *Conceptual Feasibility Report for KOP Accelerated Disposition.*		
Stainless steel density at 100 °C (kg/m^3)	8000		
Stainless steel thermal conductivity (W/m/K)	16.0		
Stainless steel specific heat (J/kg/K)	500		
Copper insert density at 100 °C (kg/cm^3)	8954		
Copper insert thermal conductivity (W/m/K)	398		
Copper insert specific heat (J/kg/K)	384		
Heat Generation Parameters			
Particle Diameter (short term) (μm)	600	1500	TI-015, Tables 4-5a and 4-5b
Particle Diameter (long term)(μm)		2300	TI-015, Table 4-5a
Radiation Heat Transfer Parameters			
Cladding emissivity	0.7	0.7	
Inner shield plug emissivity	0.3	0.3	
MCO wall emissivity	0.3	0.3	

Nominal Process Parameters			
Vacuum pumping rate	30	30/13	
Helium purge rate	1.5 scfm	1.5 scfm	
Free residual water after draining	0.2	0.2	
Normal process bay temperature	50	50	

5. SOFTWARE APPLICATION, DESCRIPTIONS, INSTALLATION AND STATEMENT OF VALIDITY

The FATE™ computer program is used for this work [SNF-23281, Lee and Plys, 2006] (the TM symbol will be dropped for simplicity). The FATE sludge model was developed by FAI for the Hanford Spent Nuclear Fuel Program and the K Basins Closure Project under the FAI Quality Assurance Program. FATE has been used for K Basins sludge applications including scoping calculations, normal and off-normal behavior, and accidents including pump station spills and spray leaks at Cold Vacuum Drying Facility (CVDF).

The FATE computer program was modified to address differences between MCOs containing spent fuel and MCOs containing KOP Material. This modified program is suitable for the conceptual phase KOP Material scoping calculations presented in this document; QA and V&V of this modified program will be conducted prior to the use of the model to perform next phase calculations that will be used for detailed design and formal safety analysis.

Briefly, FATE can model heat transfer, fluid flow, and chemical reactions in a vessel as well as the building or facility containing the vessel, and the environment. Decay power, oxidation power, and conversion of metal to oxide with the associated decrease of reactive surface area are included.

The thermal conceptual model of the MCO at the 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. A separate report, FAI/09-254 by M. Epstein, describes analyses of phenomena during CVD, models, and stand-alone assessments in detail.

The FATE model representation for CVDF processing of KOP material is shown in Figure 5-1. Since the copper block is nearly isothermal, by (thermal) symmetry the KOP material is modeled as a layer with ½ inch thickness insulated in what would be the middle of the 1 inch thick fuel section. Conduction heat transfer across the steam/helium gap from the copper block to the scrap basket shroud to the MCO wall is considered. The gap distance is conservatively taken to be 0.0143 m, a 0.00476 m gap between the MCO wall and the basket shroud plus two 3/16 in gaps between the basket shroud and copper block. The description of the conduction path through these gaps that appears on page 15 of the attachment is not consistent with the description presented here. The attachment describes a configuration of the model used in an earlier set of calculations and does not correctly reflect the calculations presented in these documents.

Per the design, three baskets containing KOP material are separated by empty baskets with an empty basket in the bottom of the MCO. After draining, residual water remains in KOP material pores, and a heel of water remains on the MCO bottom, which can partially submerge KOP material if it is loaded in the bottom basket. Since the bottom basket is empty in the current design, submerged KOP material is not a concern in this analysis.

Calculations are based on a simplified drying cycle and assume vacuum is applied at the start of the cycle and continues uninterrupted until free water is removed. The actual drying cycle may be more complex and may include such steps as thermal resets requiring a return to atmospheric pressure. The simplified cycle has generated results suitable for these conceptual phase calculations.

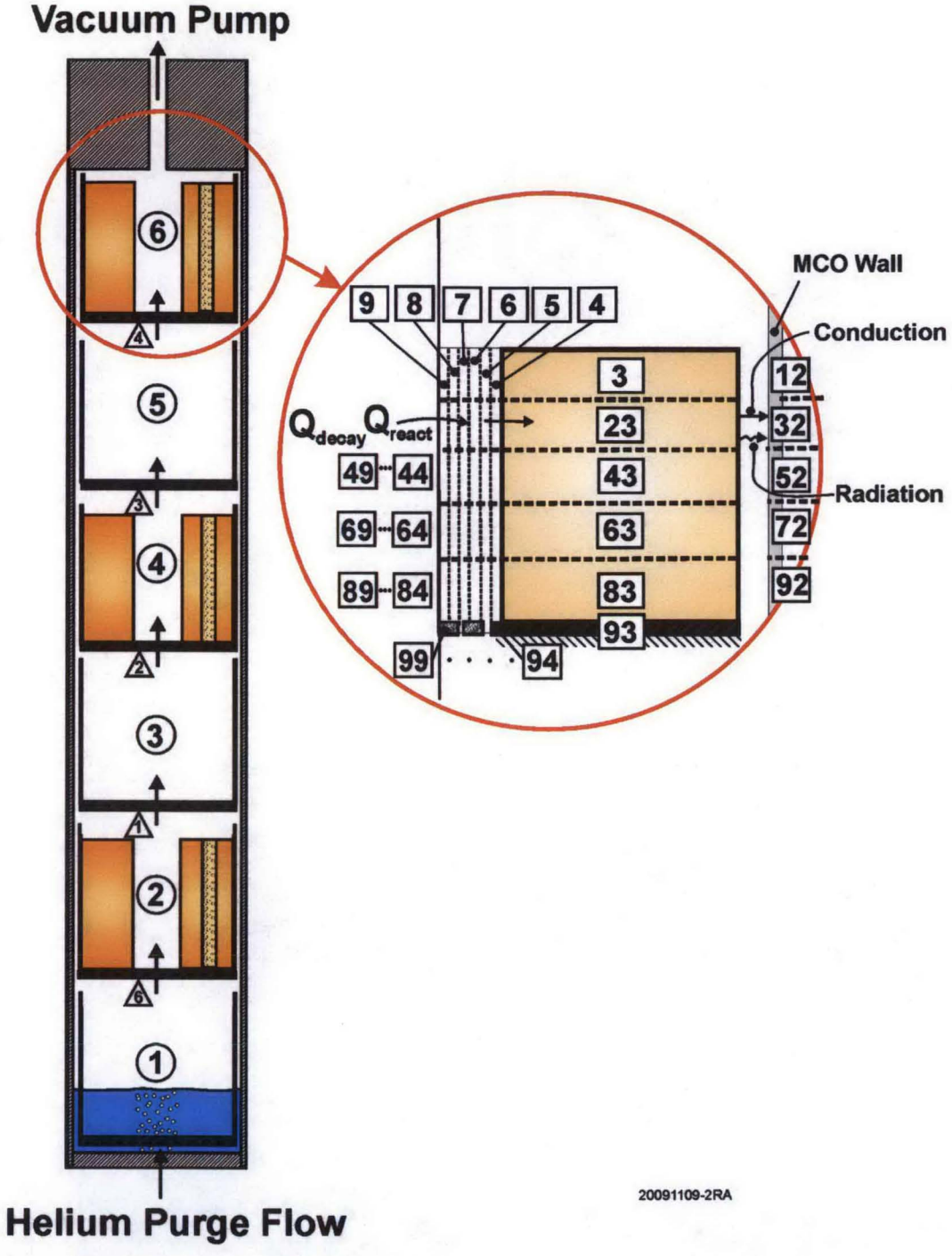
The following input values are used for both the conservative and nominal calculations:

- 50 °C initial temperature (all cases except MCO cool down),
- 1.5 scfm Helium purge rate (normal CVD only),
- 1" effective KOP material thickness, (modeled as 1/2" KOP thickness with one side insulated boundary),
- 3/8" gap between copper insert and scrap basket copper shroud,
- 20 liters free water heel at MCO bottom (all cases except MCO cool down), and
- 10 X reaction rate law multiplier (literature rate multiplied by 10)

In the conservative case (25% void fraction), we use:

- 600 μm particle diameter for reactive surface area,
- 11.77 kg/liter uranium loading in the block,
- 75% volume fraction of uranium (25% free volume),
- 12 vol% residual free water in KOP material.

Figure 5-1 FATE model representation for CVD of KOP material in an insert block



Several input values are used for the design calculations that are more conservative than the safety basis values supplied by the HNF-SD-SNF-TI-015, Vol. 2. The void fraction for the KOP material was reduced from 40% to 25% which increases the surface area and uranium metal and thus increases the KOP material oxidation rate. The 600 micron particle size is less than half the safety basis size of 1500 microns, so it provides 2.5 times the reactive surface area per unit

volume. Since visual observation of KOP material indicates that a significant fraction of the material is larger than 600μ, this represents a bounding case so that results are not sensitive to variations of a separations process. The volume fraction of residual water was previously estimated at 7.5 vol% in the nominal case (see Epstein, 2008), however in the conservative case it is assumed to be 12 vol% pending further investigation.

Water vapor available for reaction with KOP material is either residual water initially present in the pores in the KOP material, or it is water vapor that diffuses inward (i.e., upward or downward through the porous bed) from the local gas surrounding a copper insert. As water vapor diffuses into the relatively long and narrow porous bed, reacting with uranium, the water vapor mass fraction decreases. The reaction rate depends upon the square root of the water vapor partial pressure, which is proportional to the water vapor mass fraction. A model for this phenomenon is described in Section 6 of FAI/09-254, *Correlations and Models in Support of FATE Computer Program Thermal Analyses of KOP Material During CVD and Shipping*, (Epstein, 2009), and it provides a step-by-step prescription to evaluate the "reaction efficiency," which is the reduction of the reaction rate compared to what it would be if all the KOP material were exposed to water vapor at the pressure outside the copper block.

Note that if residual water remains on the KOP material, then steam is produced locally and the reaction is not limited by diffusion. If the saturation pressure of wetted KOP material, evaluated at the KOP material temperature, is above the MCO total pressure, this corresponds to boiling of the residual water. If the saturation pressure is below the MCO total pressure, then evaporation occurs just at the rate required to supply the reaction with uranium. This conservatively supplies reactant. If residual water has vanished and additional water to support the oxidation reaction can be supplied only from water vapor in the local gas surrounding the insert, then the diffusion limitation applies.

6. COLD VACUUM DRYING CASES, CALCULATIONS AND RESULTS

This chapter provides the description and results of cases analyzed for the KOP MCO in various processing states at the CVDF. The KOP process scenarios were selected based on their importance to understanding nominal performance and safety at the CVDF. The thermal models used in these calculations have been used previously to run a broad spectrum of cases for the processing of 2100 tons of N Reactor Fuel and scrap at CVDF. The set of cases run in this calculation have been shown by previous analyses to adequately represent the system performance (HNF-SD-SNF-CN-023). The cases are classified into four groups:

- **Base CVD case**
- **Degraded Vacuum Pumping with No Helium Purge**
- **Open MCO with loss of Annulus water**
- **Cooling after vacuum drying**

These four cases were re-analyzed here using safety basis KOP material properties (1500 μm diameter and 40% void fraction). The purpose of these analyses is to document the safety basis results. An additional purpose of the baseline CVD case is to document the amount of particulate generated.

6.1 Base Case Behavior – Normal CVDF processing

Normal thermal behavior during vacuum processing depends on (1) the evaporation rate of water from KOP material and MCO structures (e.g., wall), (2) the thermal effects of evaporation (initial cooling of KOP sludge 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 the MCO, and (4) heat transfer from the KOP material. During normal operation, the vacuum rate is at least 30 ft^3/min.

Detailed investigation has shown the copper blocks are nearly isothermal, which is essential to their feature in providing heat capacity to suppress temperature increases. Residual water on the KOP material is gone after about 30 minutes, so that for most of the drying period, water vapor is supplied by the bottom heel but a diffusion limitation occurs within KOP material. Results shown here are influenced in a conservative manner by the large residual water heel, and drying would be faster with a smaller heel. Also, this case is truly thermally stable, because heat losses are able eventually to equal heat sources (to observe this requires an alternate scenario with a considerably larger water heel, and duration of about 24 hours).

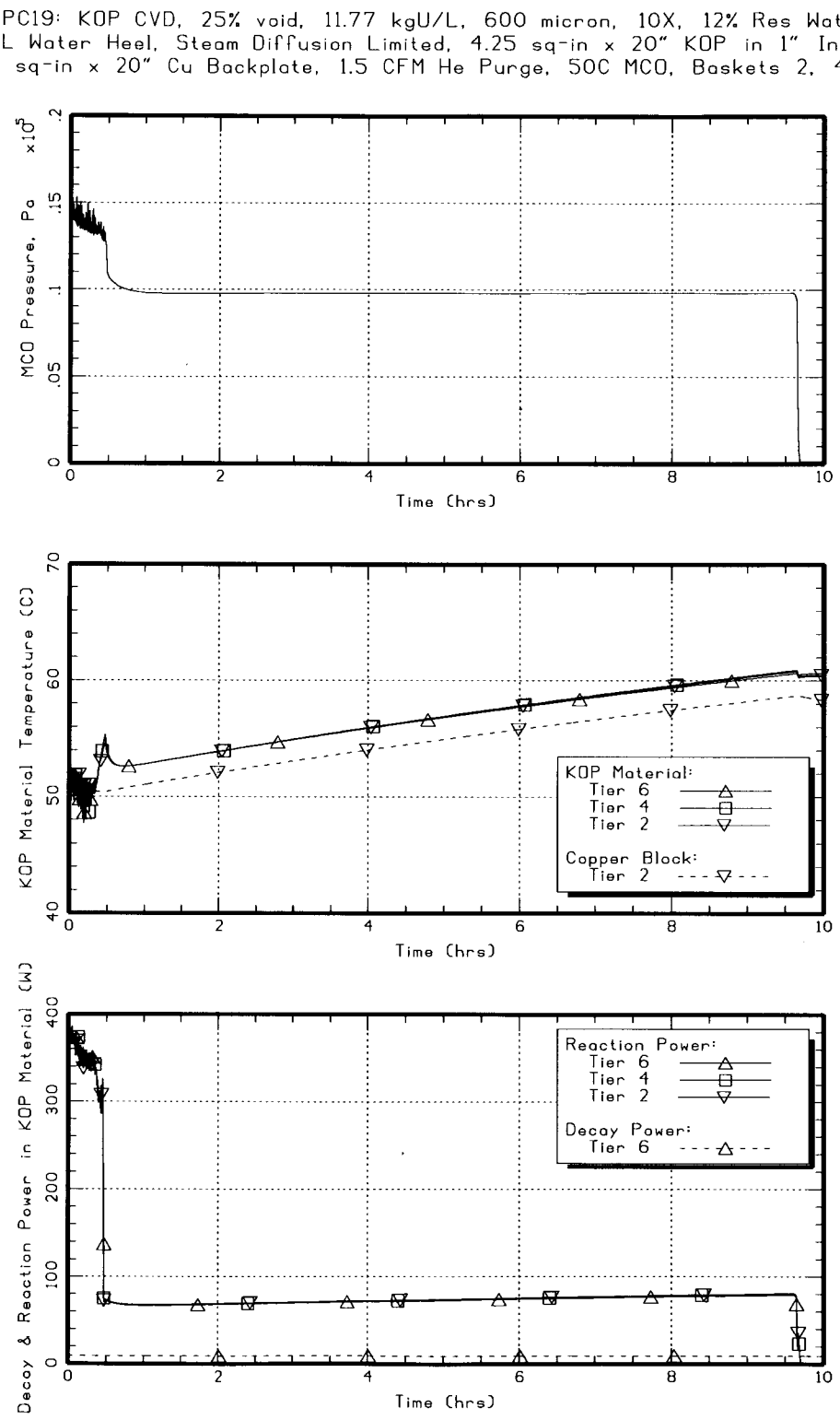
The results of simulating the normal processing at CVD with 25% void fraction KOP material are shown in Figure 6-1. These results demonstrate thermal stability during the MCO drying. The figure has three separate history plots as follows (figures for the other cases have equivalent plots):

Top: **MCO pressure (Pa)**. The pressure gradually decreases as residual water is evaporated from various scrap baskets, and it decreases suddenly when the bottom water heel dries out. The KOP material dries out in approximately 30 minutes and the bottom water heel has evaporated after about 9.7 hours.

Middlet: **KOP material temperature per tier, °C**. Temperatures stay within about 12 degrees of the initial temperature. "Noise" in the temperature and steam concentration early in the calculation is during the period when water is boiling inside the KOP material, and the end of the "noise" corresponds to dry-out of the KOP material.

Bottom: **Reaction power per tier and decay power (W)**. Reaction power far exceeds decay power, while local surface water is available. After the KOP material dries out, the reaction rate is limited by diffusion of steam into the KOP material.

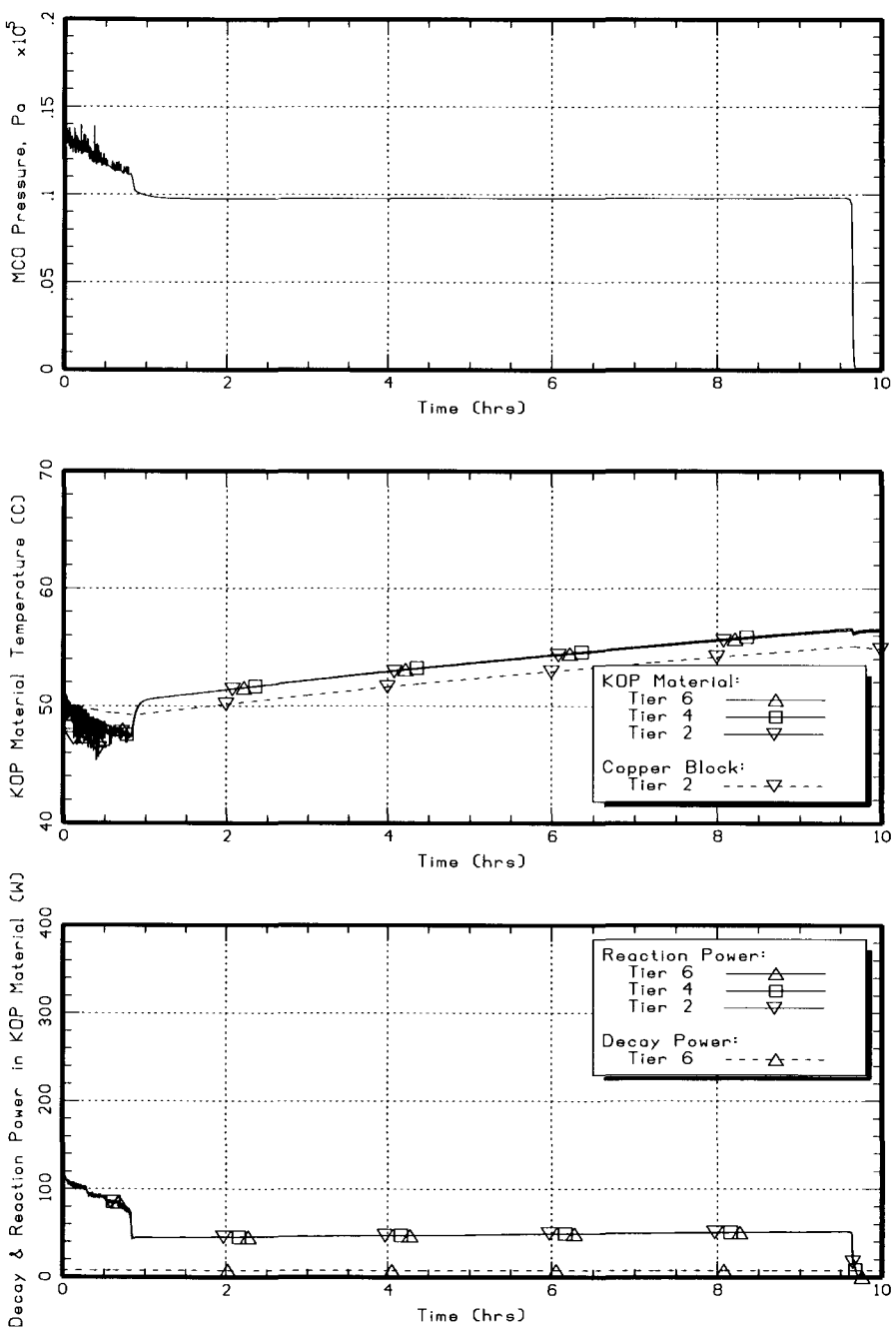
Figure 6-1 Case 1: CVD of 25% Void Fraction KOP Material (Design Parameters)



The results of simulating CVDF safety basis KOP material are shown in

Figure 6-2. The results also demonstrate thermal stability during the processing. Residual water in the scrap baskets boils away in slightly less than one hour, and the residual water heel evaporates in about 9.7 hours. Uranium dioxide is steadily produced with a maximum mass of 3.4 kg produced before the MCO is dry.

Figure 6-2 Case 5: CVD of Safety Basis KOP Material (Safety Basis Parameters)

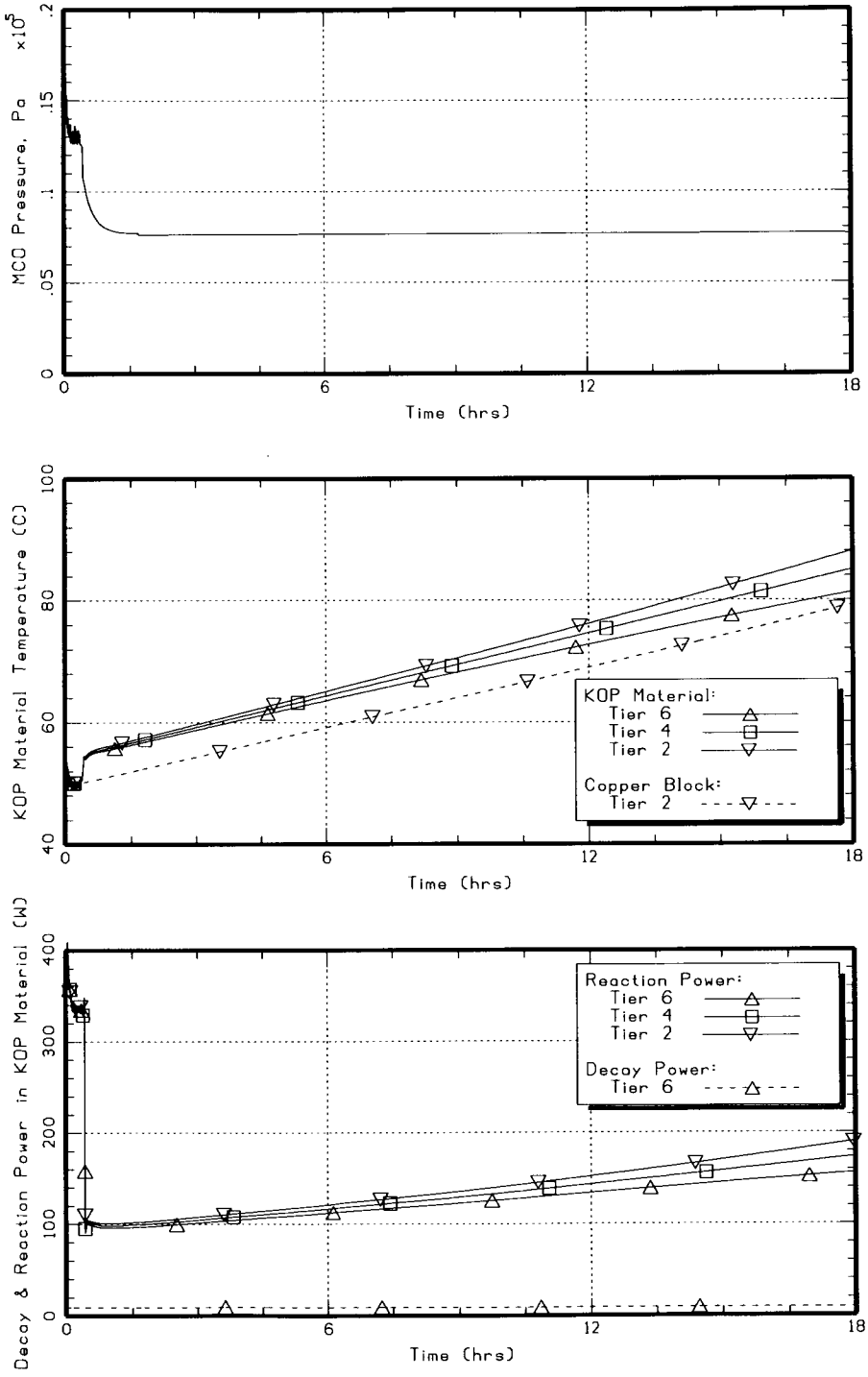


6.2 Degraded Vacuum Pumping with No Helium Purge

The degraded vacuum pumping accident case considers a low vacuum pumping rate, 13 scfm (compared to the normal rate of 30 scfm) and no helium injection flow. The degraded-vacuum case bounds all of the other vacuum cases in the original MCO accident calculations (HNF-SD-SNF-CN-023). Based upon this experience, if the degraded vacuum case for KOP material is benign, there is no reason to simulate the other vacuum cases.

Figure 6-3 Case 2: Degraded Vacuum Pumping With No Helium Purge (Design Parameters)

KOP_VACXDG_19: KOP CVD, 11.77 kgU/L, 600 micron, 10X, 12% Res Water, 20L Water Heel, (0.126m high), Steam Diffusion Limited, 38 SQ IN Cu No He Purge, Degraded Vacuum, 50C MCO, Baskets 2, 4, 6

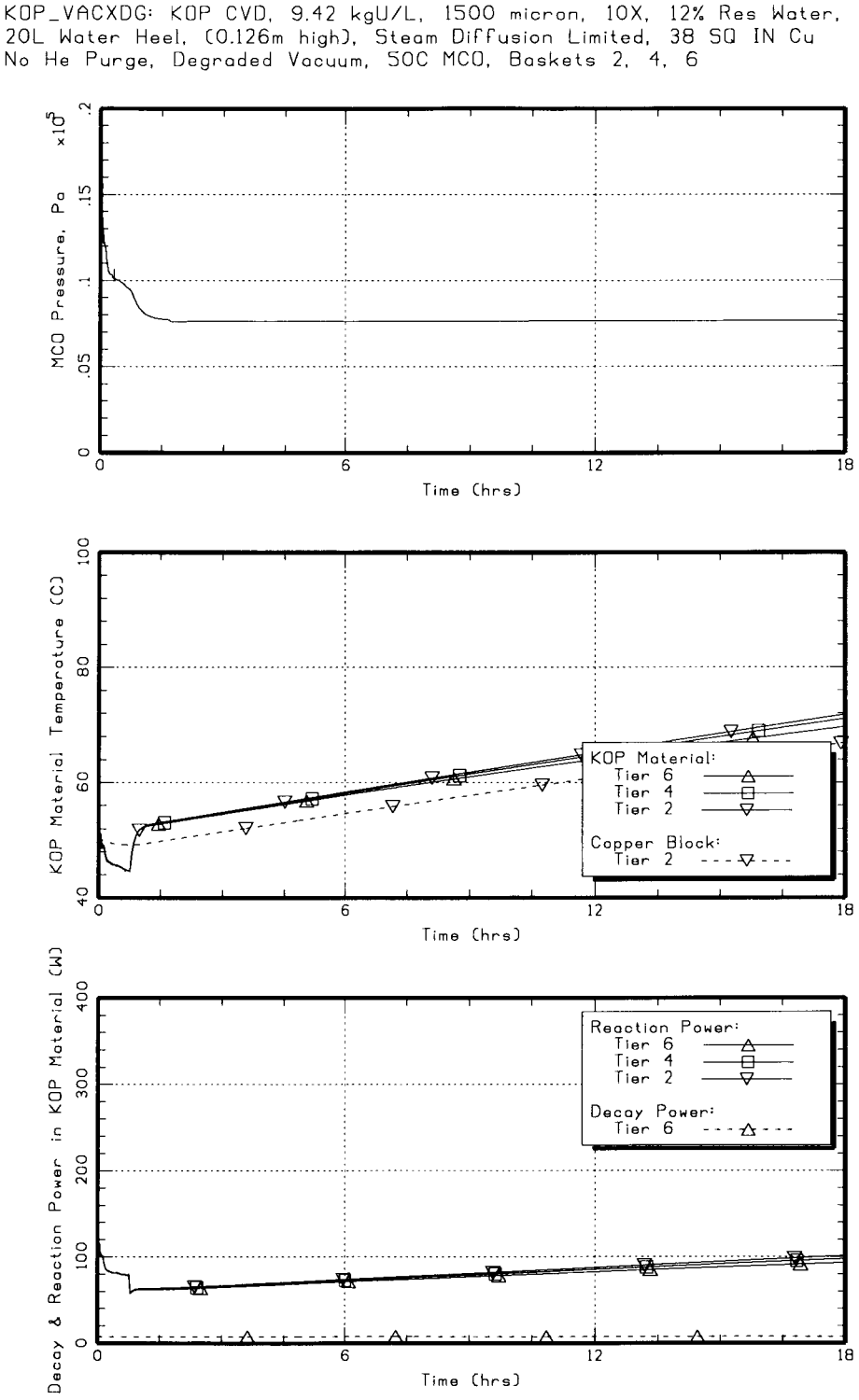


Transient results histories for this case are shown in Figure 6-3 in the same format as described above for normal CVD. KOP material is thermally stable for this case with conservative values of parameters. The pressure is lower compared to normal CVD with the helium purge, so water in the KOP material boils off faster. However, the water heel evaporates more slowly without the helium purge, and dries out after about 18 hours. The KOP material temperature steadily rises while the heel evaporates, attaining about 88 °C in the lower basket.

The degraded-vacuum rate case bounds all of the other vacuum cases in the original report (HNF-SD-SNF-CN-023). So if the degraded vacuum case for KOP material is benign, then there is no reason to simulate the other vacuum cases to show the beneficial effects of helium during vacuuming or the 8-4-4 vacuum cycle. Also, the air-ingress case was benign with Mark IV fuel, so it would also be benign with KOP material with its small mass of uranium metal and large copper insert mass per basket and the smaller decay power.

Results for the safety basis degraded vacuum case are shown in Figure 6-4 KOP material is thermally stable, and the peak temperatures is 72 °C, about 6 °C lower than for the design parameter case. The time for water heel evaporation is 18 hours.

Figure 6-4 Case 6: Degraded Vacuum Pumping With No Helium Purge (Safety Basis Parameters)



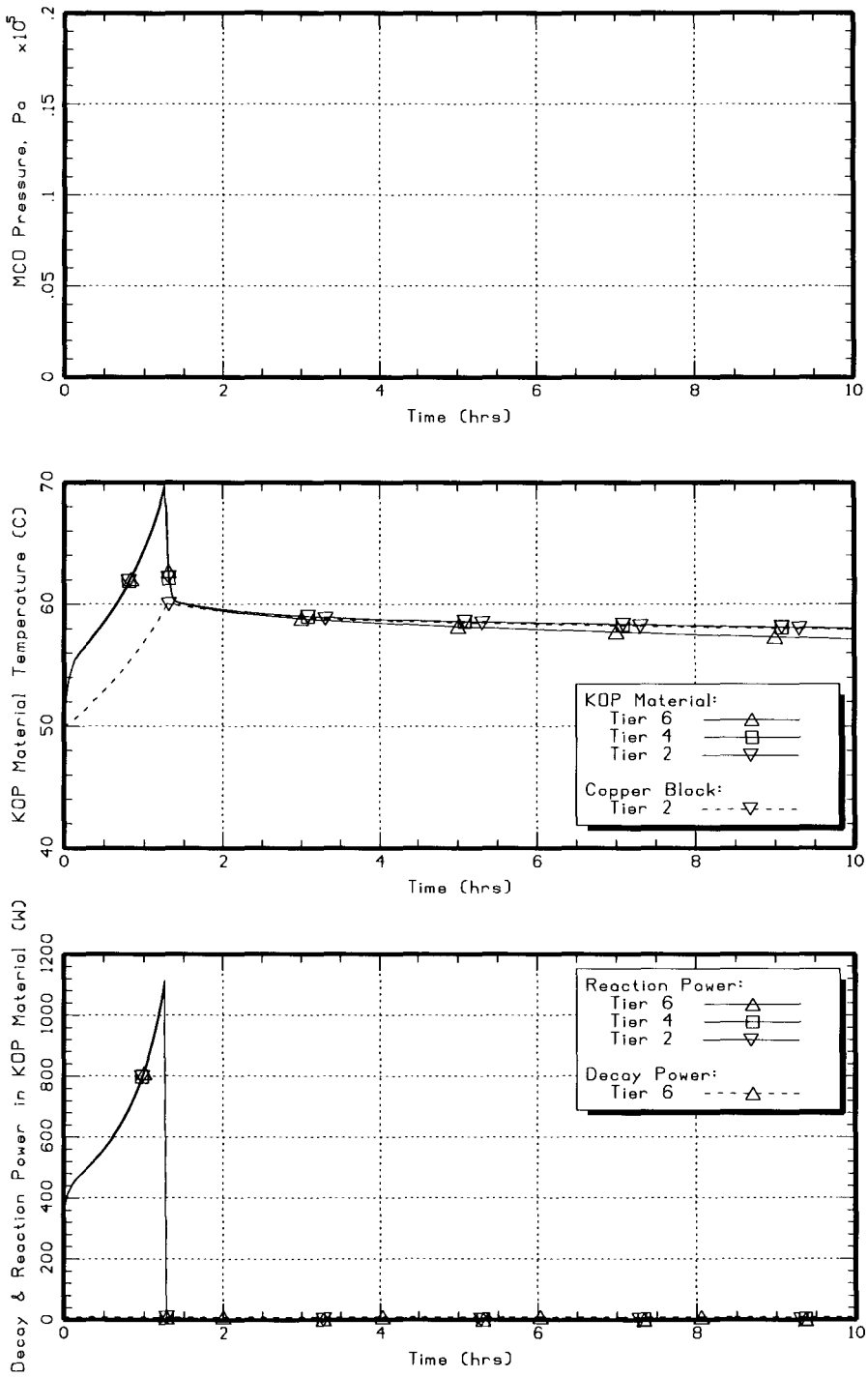
6.3 Open MCO with loss of Annulus water.

This case assumes the annulus water is lost during draining of the MCO at CVDF 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 KOP material at 50 °C and partially drained but still containing 20 kg of residual water. To eliminate the benefits of oxygen poisoning, no oxygen is included in the MCO atmosphere. With the flow resistance in the piping and shield plug, little countercurrent flow of air into the vented MCO is expected.

Only one open vented MCO case needs to be analyzed, which has a loss of annulus water. This is the bounding thermal case for the SNF fuel and results in a thermal runaway after about 11 hours. The other open MCO cases in HNF-SD-SNF-CN-023 should not be needed for KOP material because the cases for Mark IV fuel/MCO should bound the cases for KOP material in regards to thermal behavior. Since the thermal runaway accident with KOP material is so much more benign (or not possible) than the thermal runaway with Mark IV fuel, all of the cases that were thermally stable with Mark IV fuel would also be thermally stable with KOP material and need not be rerun.

Figure 6-5 Case 3: Open MCO with Loss of Annulus Water (Design Parameters)

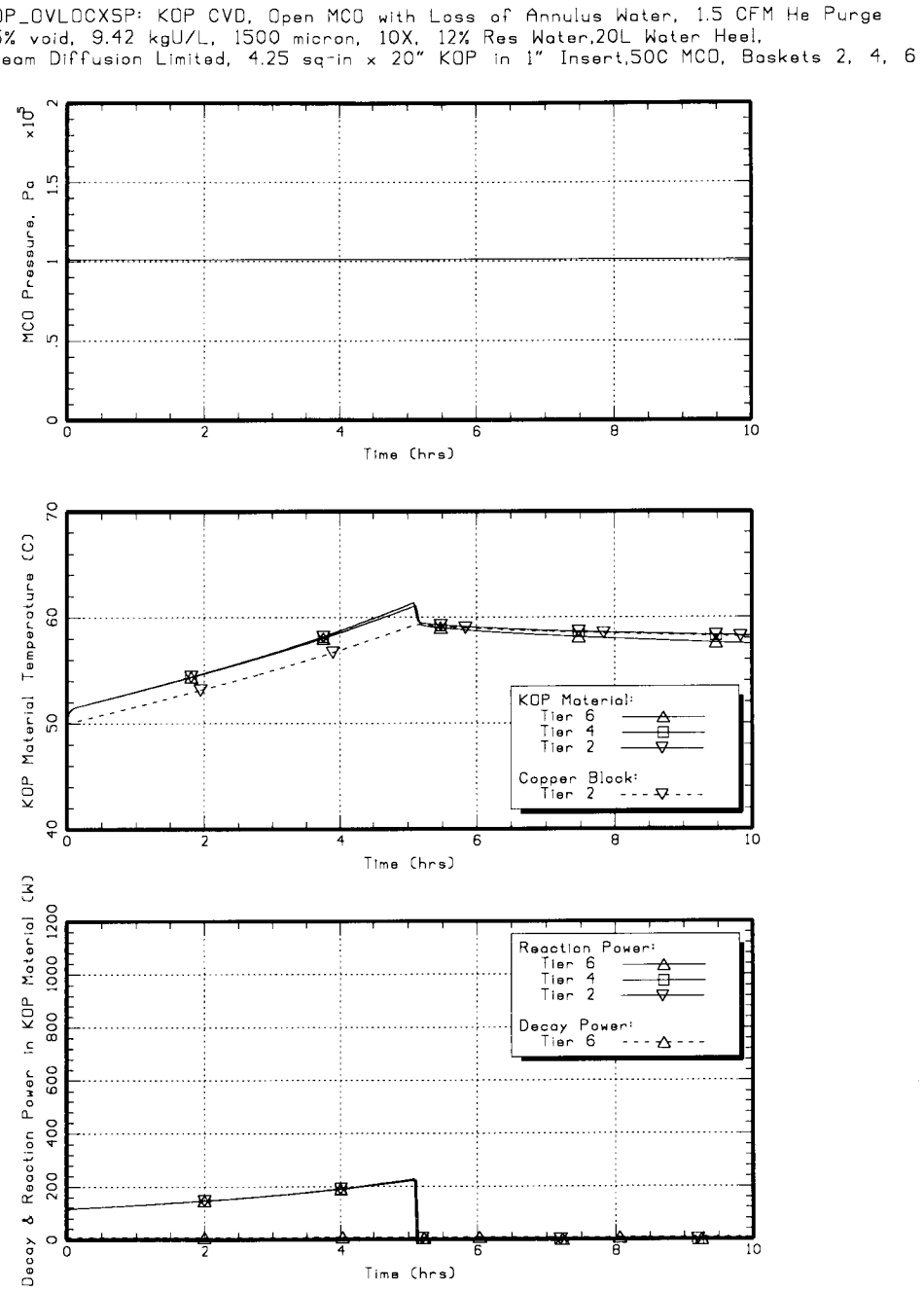
KOP_OVLOCXSP_19: KOP CVD, Open MCO with Loss of Annulus Water, 1.5 CFM He Purge
25% void, 11.77 kgU/L, 600 micron, 10X, 12% Res Water,20L Water Heel,
Steam Diffusion Limited, 4.25 sq-in x 20" KOP in 1" Insert,50C MCO, Baskets 2, 4, 6



Results for the safety basis loss of annulus water are shown in Figure 6-6. The time period for evaporation of water on KOP material, and its complete local reaction with uranium metal, is

about 5 hours. This process leads to increased reaction power and temperature rise in the KOP material compared to normal CVD. The KOP material temperature stabilizes near 60°C shortly after the residual water in the material is consumed. The residual water heel remains intact.

Figure 6-6 Case 7: Open MCO With Loss of Annulus Water (Safety Basis Parameters)

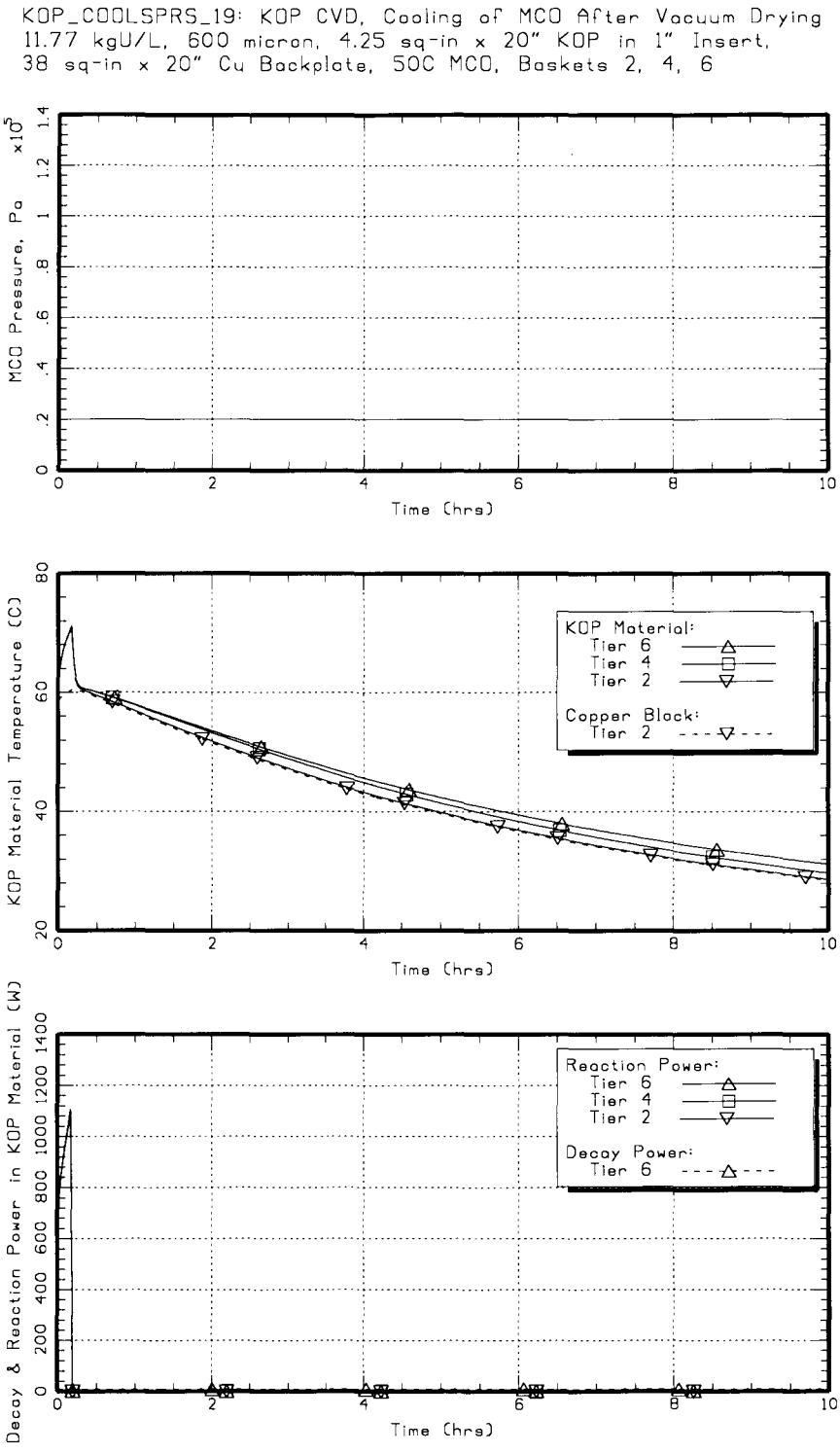


6.4 Results Multi-canister Overpack Cooling Evaluation

This case addresses the minimum fuel temperature after a thermal reset and before a pressure rebound test by simulating the cooling period after vacuum drying is completed and final pressure rebound test has been passed. After the rebound test, no more than 200 g of free water

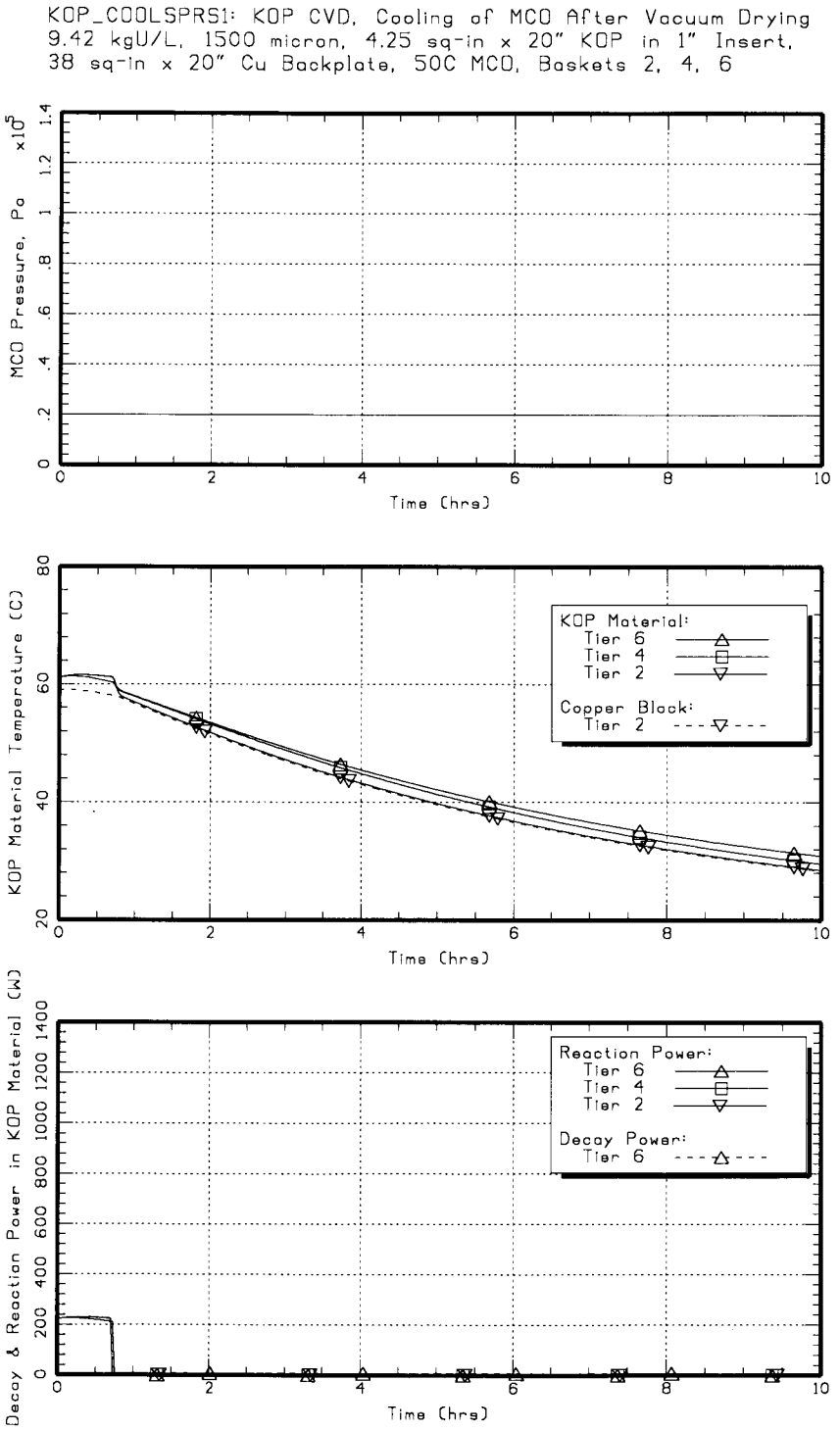
with high flow resistance are left in the MCO. During cooling, the MCO is pressurized with helium to a pressure of 4 lb/in^2 gauge. This case determines the maximum gas temperature during cooling with cooling water, 17 °C, injected into the annulus at a rate of 15 gallons per minute.

Figure 6-7 Case 4: Cooling of MCO and KOP Sludge After Vacuum Drying (Design Parameters)



Results for the safety basis cool down case are shown in Figure 6-8 These results are nearly identical to those presented for the design parameters. After residual water is consumed in about 45 minutes, KOP material slowly cools to about 30°C at the end of 10 hours.

Figure 6-8 Case 8: Cooling of MCO and KOP Sludge After Vacuum Drying (Safety Basis Parameters)



7. REFERENCES

Apthorpe, R. and M.G. Plys, M.G., *2010, Cold Vacuum Drying of Knock Out Pot Material in Scrap Basket Insert Blocks,* FAI/10-28, Fauske & Associates, LLC, submitted to CH2M Hill Plateau Remediation Company, Richland, Washington.

Epstein, M., 2008, "Residual Saturation Measurements," FAI Internal Memorandum to M.G. Plys, Fauske & Associates, LLC., submitted to Fluor Hanford, Inc, Richland, Washington.

Epstein, M., 2009, *Correlations and Models in Support of FATE Computer Program Thermal Analyses of KOP Material During CVD and Shipping*, FAI/09-254, Rev. 1, Fauske & Associates, LLC, submitted to CH2M Hill Plateau Remediation Company, Richland, Washington.

HNF-SD-SNF-CN-023, 2000, *Thermal Analysis of Cold Vacuum Drying of Spent Nuclear Fuel*, Rev 3, Fluor Hanford, Inc, Richland, Washington.

HNF-SD-SNF-TI-015, 2002, *Spent Nuclear Fuel Project Technical Databook, Vol. 1*, Rev 7A, Fluor Hanford, Inc, Richland, Washington.

HNF-SD-SNF-TI-015, 2009, *Spent Nuclear Fuel Project Technical Databook, Vol. 2, Sludge*, Rev 14A, CH2MHILL, Plateau Remediation Company, Richland, Washington.

KBC-38156, *Conceptual Feasibility Report for KOP Accelerated Disposition*, Rev 0, Fluor Hanford, Inc, Richland, Washington.

Lee, S.J., and Plys, M.G. 2006, "FATE 2.057 Software Change Specification and Testing – Generic Models," FAI memorandum, August 25, Fauske & Associates, LLC., submitted to Fluor Hanford, Inc, Richland, Washington.

Lee, S.J., and Plys, M.G., 2009, *Cold Vacuum Drying of Knock Out Pot Material in Scrap Basket Insert Blocks*, FAI/09-366, Fauske & Associates, LLC, submitted to CH2M Hill Plateau Remediation Company, Richland, Washington.

Plys, M.G., and Lee, S.J. 2004, "FATE 2.0: Facility Flow, Aerosol, Thermal, and Explosion Model (Improved and Combined HANSF and HADCRT Models)", Fauske & Associates, LLC., submitted to Fluor Hanford, Inc, Richland, Washington.

Plys, M.G., and S.J. Lee, 2008, "CVD of KOP Material in an MCO Insert Basket," FAI memorandum to J. Sloughter, C. Miska, and N. Sullivan, June 23, 2008, Fauske & Associates, LLC., submitted to Fluor Hanford, Inc, Richland, Washington.

Sloughter, J. P., 2009, "Hydrate Analysis for Knock Out Pot Material", Interoffice Memorandum to N. J. Sullivan, 09STP-JPS-02, July 21, 2009, CH2MHill Plateau Remediation Company, Richland, Washington

SNF-23281, 2004, *FAI/04-71, Facility Flow, Aerosol, Thermal and Explosion Model (Improved and Combined HANSF and HADCRT Models), Vols. 1 & 2*FAI/04-71, Two Volumes, Fluor Hanford, Inc., Richland, WA, November.Washington.

SNF-7765, 2006, *Supporting Basis for Spent Nuclear Fuel Project Sludge Technical Databook*, Rev 3B3C, Fluor Hanford, Inc, Richland, Washington.

ATTACHMENT

Apthorpe, R. and M.G. Plys, 2010, *Cold Vacuum Drying of Knock Out Pot Material in Scrap Basket Insert Blocks,* FAI/10-28, Fauske & Associates, LLC, submitted to CH2M Hill Plateau Remediation Company, Richland, Washington.

FAUSKE & ASSOCIATES, LLC

WORLD LEADER IN NUCLEAR AND CHEMICAL PROCESS SAFETY

Report No.: FAI/10-28

Cold Vacuum Drying of Knock Out Pot Material in Scrap Basket Insert Blocks

Submitted to:

C2HM Hill Plateau Remediation Company

Richland, Washington

Prepared by:
Robert Apthorpe
Martin Plys

Reviewed by:
Sung Jin Lee

January, 2010

16W070 83rd STREET • BURR RIDGE, ILLINOIS 60527
(877) FAUSKE1 OR (630) 323-8750 • FAX: (630) 986-5481 • E-MAIL: INFO@FAUSKE.COM

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 SUMMARY

During the latter half of FY09 Fauske & Associates, LLC has worked interactively with the Sludge Treatment Project to evaluate the thermal and gas generation issues associated with placing Knock Out Pot (KOP) material into a Multi-Canister Overpack (MCO) for cold vacuum drying (CVD). On the design side, a number of potential designs, features, dimensions, and material loadings have been explored, and on the modeling side, physical models appropriate to the design have evolved and been assessed.

This report presents results for the current design using the most mature model approach. The crucial feature of results to be found is thermal stability of the KOP material under restrictive operating conditions and bounding design assumptions. Model features and inputs are selected to minimize the need for technical specifications that would require verification, so that results presented here are therefore conservative. Additionally, this conservative model is compared against a model using safety-basis parameters to illustrate the degree of conservatism in the conservative approach.

KOP material will be placed in a 1" wide slot within a copper block, six of which are loosely placed within the outer (coarse) sections of a Mark 1A scrap basket (see Section 3.) Three such baskets are loaded, in alternating positions (see Section 4.) Results using conservative KOP material properties are presented in Section 5 and results using safety basis KOP material properties are presented in Section 6.

In simulation of the normal CVD process using conservative, bounding values for the material characteristics, reaction rates, and MCO conditions, the KOP material is predicted to have stable temperature behavior and the MCO is expected to dry out after about 9.5 hours. Stable behavior is also predicted for one key accident scenario, loss of annulus water. Acceptable behavior is predicted for another key accident scenario, degraded vacuum pumping with no helium purge. In this case, the KOP material temperature is below 100 °C when the conservatively large residual water heel is evaporated after a duration of 18 hours. In theory, a similar case with even more water would eventually be thermally unstable. A case for MCO cooldown is also presented here for comparison to backfill conditions required for the canister storage building (CSB).

Using safety basis KOP material properties, the KOP material is predicted to have stable temperature behavior and MCO dryout is expected at 9 hours. Approximately 3.4 kg of uranium dioxide is predicted to be produced. Cases analyzed

using conservative KOP material properties bound those using safety basis material properties.

2.0 PURPOSE AND SCOPE

The purpose of this report is to describe the best available conceptual design calculation for CVD of KOP material, which represents the culmination of an interactive process between design, model refinement, and calculation during FY09. Normal CVD was considered in FY09, and in FY10 accident cases and new cases are now considered. The scope of this memorandum is to identify the design considered, summarize the models employed, list inputs related to KOP material and the CVD process, and present the calculation results for normal vacuum drying, two accident cases, and MCO cooldown. In a separate report, FAI/09-254 by M. Epstein, we describe analyses of phenomena during CVD, models, and stand-alone assessments in detail. In later FY10 work we will provide updates to the FATE documentation and Quality Assurance of model implementation.

3.0 CONCEPTUAL DESIGN FOR CVD OF KOP MATERIAL

3.1 Conceptual Design

The conceptual design for a copper insert block in a coarse sector of a Mark IA scrap basket is shown in Figures 3-1 and 3-2 [Dwg. KOP-SK-510]. Key aspects of the design that enter into analysis are the number of square inches of copper and KOP material in a cross section, because these translate to the volume and mass of materials. There is a nominal 3/16" gap between the insert block and the basket walls for practical issues of tolerance and block insertion. For conservatism, the analysis considers a gap of 3/8". Gases in the MCO can enter the KOP material region at the basket top and bottom, not via the copper sides. It is easily demonstrated that there is large flow resistance to this path compared to other paths, and the model is set up to be insensitive to flow split [Epstein, 2009].

3.2 Assumed Process and KOP Material Properties

It is assumed that a separation process will be used to remove most particles of less than 500 to 600 micron size. The purpose of the separations process is to eliminate very small particles that are known to prevent water draining and to greatly impede drying of the KOP material, and to eliminate material that was not part of the original KOP stream (which was all above 500 or 600 microns).

KOP material is presently categorized as a K Basins sludge stream. Sludge properties are summarized in the SNF Databook, Volume 2 [Schmidt, 2006] and supporting documents [Plys and Schmidt, 2006]. Limited KOP material sampling has confirmed that the density is less than that of fuel piece material, but due to the planned separations process, databook KOP material properties apply. In addition, for conservatism, we have been requested to assume a low water volume fraction of 0.25 (versus the commonly recognized minimum value of 0.40), and a limiting small particle diameter of 600 microns. Values used here are summarized in Table 3-1.

In the safety basis case, we assume a KOP material porosity of 0.40 and a particle diameter of 1500 microns. This particle diameter from the SNF Databook is a conservative estimate of the Sauter mean diameter, and it represents the correct reactive surface area for a particle size distribution. These and related values are summarized in Table 3-2.

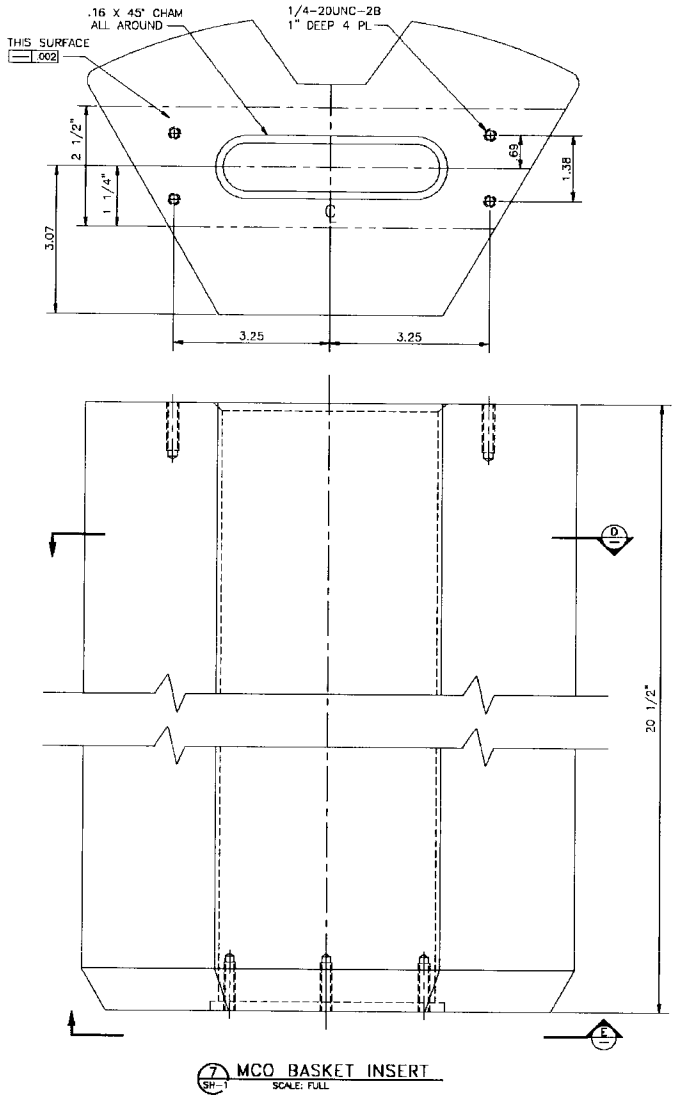


Figure 3-1: Copper insert block plan and elevation views.

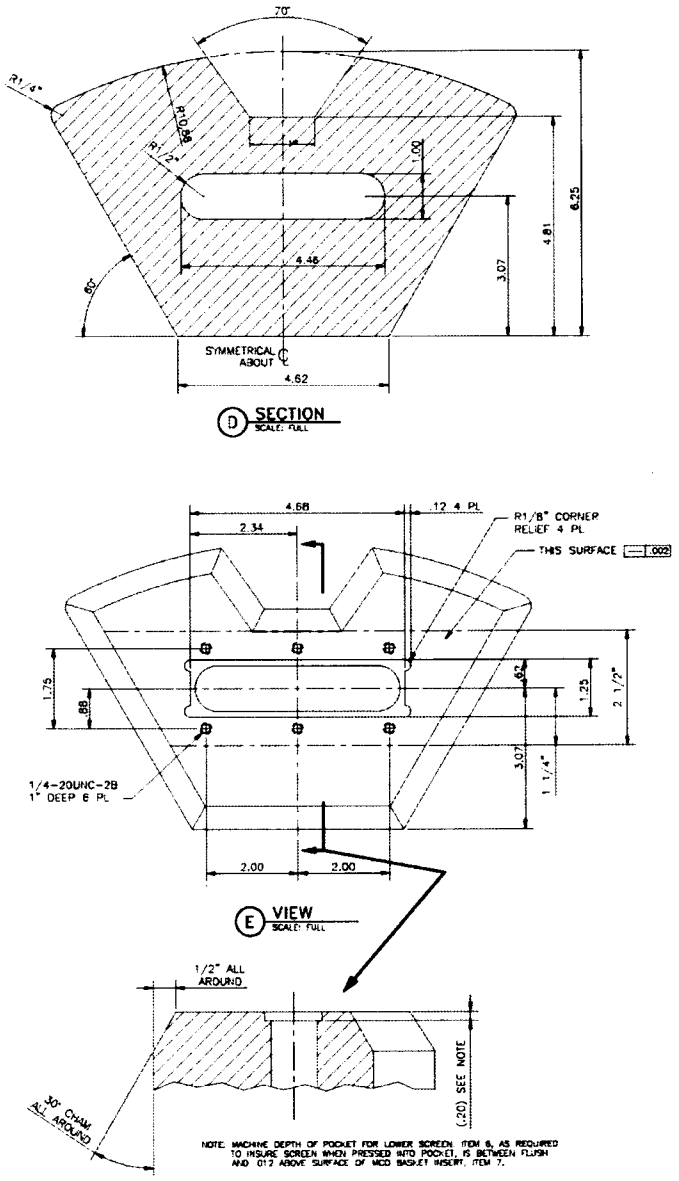


Figure 3-2: Copper insert block plan and section views.

Table 3-1: Conservative KOP Material Properties, Safety Basis Fuel Pieces			
Water Volume Fraction α	**Particle Density ρ_p (1)**	**Total U Concentration C_U (2)**	**U Metal Concentration C_{Umet} (2)**
0.25	16832 kg/m^3	11750 kg/m^3	11750 kg/m^3
Decay Power	**Decay Power Q_v (3)**	**Reactive Particle Size d_p**	**Reactive Area per Volume (4)**
117 W/MTU	1837 W/m^3 solids	600 µm	6184 m^2/m^3

(1) Databook KOP values are based upon a combination of U metal and Zr cladding at about η = 82.63 vol% U, 1- η = 17.37 vol% Zr. Therefore ρ_p = (19000*η + 6520*(1-η)) = 16832 kg/m^3. The equivalent KOP wet sludge value is ρ_{wet} = (1-α)ρ_p + 1000*α. = 12874 kg/m^3.

(2) Databook value adjusted for porosity: C_U = C_{Umet} = (0.75/0.60)*9400 = 11750.

(3) Q_v = 0.117*19000*0.8263 = 1837 W/m^3 solids.

(4) A/V = (6/d_p)(C_{Umet}/ρ_m) = (6/0.0006)*(11750/19000) = 6184.

Table 3-2: Nominal KOP Material Properties, Safety Basis Fuel Pieces			
Water Volume Fraction α	**Particle Density ρ_p (1)**	**Total U Concentration C_U (2)**	**U Metal Concentration C_{Umet} (2)**
0.40	16832 kg/m^3	9400 kg/m^3	9400 kg/m^3
Decay Power	**Decay Power Q_v (3)**	**Reactive Particle Size d_p**	**Reactive Area per Volume (4)**
117 W/MTU	1837 W/m^3 solids	1500 µm	1978 m^2/m^3

(1) Databook KOP values are based upon a combination of U metal and Zr cladding at about η = 82.63 vol% U, 1- η = 17.37 vol% Zr. Therefore ρ_p = (19000*η + 6520*(1-η)) = 16832 kg/m^3. The equivalent KOP wet sludge value is ρ_{wet} = (1-α)ρ_p + 1000*α. = 10499 kg/m^3.

(2) Databook value for 40% void fraction: C_U = C_{Umet} = 9400.

(3) Q_v = 0.117*19000*0.8263 = 1837 W/m^3 solids.

(4) A/V = (6/d_p)(C_{Umet}/ρ_m) = (6/0.0015)*(9400/19000) = 1978.

4.0 FATE MODEL REPRESENTATION AND PHYSICAL MODELS

4.1 Thermal Stability Concern Background

Fuel previously stored in the K Basins was fabricated from metallic uranium and zirconium cladding. Damage to cladding exposes metallic uranium, which chemically reacts with liquid water in the basins and with water vapor during CVD, producing hydrogen gas and heat. The greatest amount of reactive surface area is present in scrap baskets, designed to hold fuel pieces as small as ¼ inch. MCO scrap baskets were designed with a copper outer shroud and internal copper spokes to help remove the chemical reaction power. Most power is lost to the MCO wall, and a small amount is lost to gas leaving the MCO.

Because KOP material has greater reactive surface area per unit volume than scrap previously considered, a key concern is its thermal stability during any step of processing and storage. When generated heat can be removed and steady temperatures are maintained, this is known as thermal stability. If the heat source exceeds heat losses, then fuel will heat up, and reaction rates will increase, resulting in greater power generation. This is a positive feedback process known as thermal instability and fuel temperature can escalate considerably. Thermal instability and "ignition" of uranium has been observed under numerous circumstances at Hanford and throughout the DOE complex.

The technical safety basis for CVD of MCOs containing fuel and scrap baskets is documented in thermal analyses of design, off-normal, and accident conditions. These analyses used the HANSF and FATE computer programs which contained models specifically written and validated to calculate chemical reactions, heat transfer, and fluid flow within an MCO. Stability analysis for early KOP CVD conceptual design was performed by [Plys and Lee, 2009]. Earlier examples are contained in [Plys and Duncan, 2000] and [Plys and Malinovic, 1999]. The current computer program used for this work, FATE, is described in [Plys and Lee, 2004], and changes to the model will be documented under Quality Assurance in follow-on work.

4.2 Model Representation

The FATE model representation for CVD of KOP material is shown in Figure 4-1. Since the copper block is nearly isothermal, by symmetry the KOP material is modeled as a layer with ½ inch thickness insulated in what would be the middle of the 1 inch

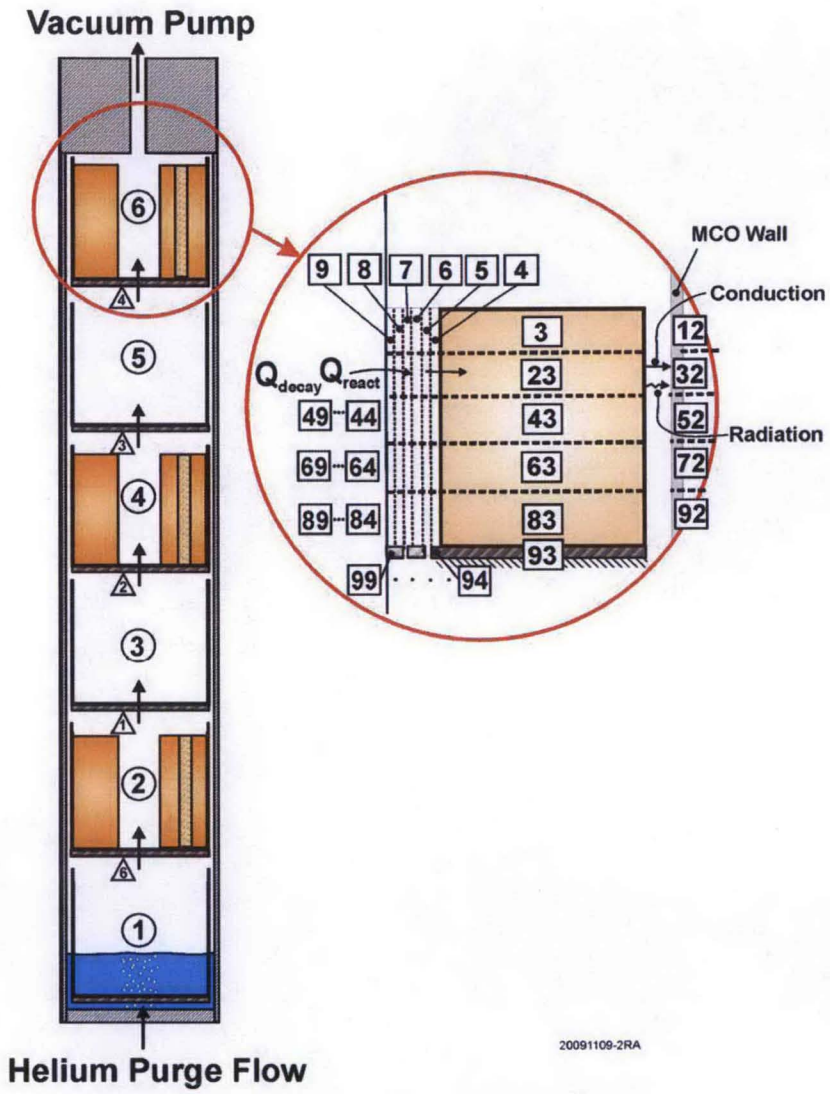


Figure 4-1: FATE model representation for CVD of KOP material in an insert block.

thick fuel section. In the base analysis (Cases 1 and 5) and in both postulated accident scenarios (Cases 2, 3, 6 and 7), the adjacent copper block is considered insulated on its opposite side, and no credit is taken for its ability to transfer heat to gas in the small surrounding gap, or across the gap to the scrap basket copper walls. In the cooldown scenario (Cases 4 and 8), credit is taken for heat transfer across the helium gap from the copper block to the scrap basket to the MCO wall, as described in Sections 5.4 and 6.4.

Within the KOP material, six different average temperatures are used to for the reaction rate, and each average temperature is found from a three-point temperature distribution, so that the node thickness for heat conduction is less than 1 mm. The KOP material and block are also axially divided into five levels.

Per the design, three baskets containing KOP material are separated by empty baskets with an empty basket in the bottom of the MCO. After draining, residual water remains in KOP material pores, and a heel of water remains on the MCO bottom, which can partially submerge KOP material if it is loaded in the bottom basket. Since the bottom basket is empty in the current design, submerged KOP material is not a concern in this analysis.

4.3 Model Inputs

Model inputs to FATE can be divided into five categories for the present purposes:

1. Regions. Control volume parameters are defined here, such as the free volume in each section of the MCO, elevation, and initial gas compositions.

2. Junctions. These are the flow path connections between MCO regions. A helium purge enters the MCO bottom, and a vacuum pump is modeled at the MCO top. The helium purge is allowed to evaporate water vapor from the MCO heel water pool when it exists, so the incoming gas flow is 100% relative humidity.

3. Heat Sinks. Solids with internal temperature distributions are specified here and include the MCO wall, bottom, and top, scrap basket structures, copper insert blocks, and KOP material. Dimensions, material properties, and boundary conditions are input.

4. MCO models. Inputs that are specific to describing how MCO-specific phenomena are applied to regions, junctions, and heat sinks are provided here.

5. General calculation control. Items here include time step selection, plot parameter selection, and general overhead, and are of secondary importance.

The following input values are used for both the conservative and nominal calculations:

- 50 °C initial temperature (all cases except MCO cooldown),
- 1.5 scfm Helium purge rate (normal CVD only),
- 1" effective KOP material thickness, (modeled as 1/2" KOP thickness with one side insulated boundary),
- 3/8" gap between copper insert and scrap basket copper shroud,
- 20 Liters free water heel at MCO bottom (all cases except MCO cooldown), and
- 10 X reaction rate law multiplier (literature rate multiplied by 10)

In the conservative case (25% void fraction), we use:

- 600 μm particle diameter for reactive surface area,
- 11.77 kg/liter uranium loading in the block,
- 75% volume fraction of uranium (25% free volume),
- 12 vol% residual free water in KOP material,

As mentioned previously, several values are used which are more conservative than those supplied by the SNF Databook, Volume 2 [Schmidt, 2006]. The free volume was reduced from 40% to 25% which tends to increase the surface area and thus increases the KOP material oxidation rate. The 600 micron particle size is less than half the safety basis size of 1500 microns, so it provides 2.5 times the reactive surface area per unit volume. This represents a bounding case so that results are not sensitive to variations of a separations process. The volume fraction of residual water was previously estimated at 7.5 vol% in the nominal case (see [Epstein, 2008]), however in the conservative case it is assumed to be 12 vol% pending further investigation.

In the nominal safety-basis case (40% void fraction), we use:

- 1500 μm particle diameter for reactive surface area,
- 9.42 kg/liter uranium loading in the block,
- 60% volume fraction of uranium (40% free volume),
- 7.5 vol% residual free water in KOP material,

4.4 Physical Models

Thermal conductivity in the KOP material bed depends upon both gas composition and pressure, and a model for it is given and compared to data in [Plys and Lee, 2008]. The value of thermal conductivity at less than 10 mmHg can be an order of magnitude or more less than the value at near-atmospheric pressure.

The reaction of uranium with MCO gases is evaluated using the rate law in the SNF databook, Volume 1. For practical purposes, this is the oxygen-free Pearce correlation for the reaction between uranium and water vapor. That is,

$$R = 10 ** (4.33 - 2144 / T + 0.5 * log_{10}(P / 1000.0)) \ [mgO_2/cm^2/hr],$$

where T is in K and P is in Pa.

The reaction rate depends upon the square root of the water vapor pressure, so that at a given temperature, the reaction rate decreases with MCO pressure. Also, as water vapor attempts to enter a bed of KOP material, it will react, so its vapor pressure will decrease, and hence the reaction rate will decrease. In accord with bounding calculations for CVD, the literature rate is multiplied by a factor of 10.

In addition, 12% of the KOP material is assumed to be coved by residual water in the conservative case. Because material is water-covered and below 100 °C, the rate law that is used by the code for the covered area, following the logic for the databook implementation, is:

$$R = 10 ** (7.634 - 3016/ T) \ [mgO_2/cm^2/hr].$$

There is very little heat transfer resistance between the MCO bottom head and the water heel, per Section 2 of FAI/09-254, so most of the heat transfer resistance is due to conduction from circulating CVD water through the bottom head. This affects the

evaporation rate of the heel. Comparing the normally-calculated FATE heat transfer coefficient with the value for a shallow pool, a multiplier of 10 is used in this case.

Helium entering the MCO can pass through a water pool when present, and due to the geometry, it can spread over considerable area as bubbles. This allows evaporation of water into the helium, which is therefore available for reaction with uranium. Based on Section 3 of FAI/09-254, evaporation is allowed to proceed to 100% relative humidity.

Water vapor available for reaction with KOP material is either residual water initially present in the pores, or it is water vapor that diffuses inward from the local gas surrounding a copper insert. As water vapor diffuses into the relatively long and narrow porous bed, reacting with uranium, the water vapor mass fraction decreases. As mentioned above, the reaction rate depends upon the square root of the water vapor partial pressure, which is proportional to the water vapor mass fraction. A model for this phenomenon is described in Section 6 of FAI/09-254, and it provides a step-by-step prescription to evaluate the "reaction efficiency," which is the reduction of the reaction rate compared to what it would be if all the KOP material were exposed to water vapor at the pressure outside the copper block.

Note that if residual water remains on the KOP material, then steam is produced locally and the reaction is not limited by diffusion. If the saturation pressure of wetted KOP material, evaluated at the KOP material temperature, is above the MCO total pressure, this corresponds to boiling of the residual water. If the saturation pressure is below the MCO total pressure, then evaporation occurs just at the rate required to supply the reaction with uranium. This conservatively supplies reactant. If residual water has vanished, then the diffusion limitation applies.

A transient analysis of the conceptual design was performed using the FATE™ 2.0 computer code modified per the discussion above. FATE (trademark symbol dropped for brevity) is the successor code to the HANSF computer code that was used for design and safety analysis of MCOs during the Spent Nuclear Fuel Project. The code and its capabilities are discussed in the references.

5.0 SIMULATION OF CVD OF 25% VOID FRACTION KOP MATERIAL

Four cases using 600 μm diameter 25% void fraction KOP material are analyzed: a base CVD case, a degraded vacuum and loss of helium purge accident case, a loss of annulus cooling accident case, and a post-CVD cooldown case. The results of each analysis are discussed below.

5.1 Case 1: KOPC19 - CVD of 25% Void Fraction KOP Material

The results of simulating CVD on 25% void fraction KOP material are shown in Figures 5-1A and B. The results demonstrate thermal stability. Each page has four separate history plots as follows:

Page 1, Upper Left: MCO pressure (Pa). The pressure gradually decreases as residual water is evaporated from various scrap baskets, and it decreases suddenly when the bottom water heel dries out. The KOP material dries out in approximately 30 minutes and the bottom water heel has evaporated after about 9.7 hours.

Page 1, Lower Left: Reaction power per tier and decay power (W). Reaction power far exceeds decay power, while local surface water is available. After the KOP material dries out, the reaction rate is limited by diffusion of steam into the KOP material.

Page 1, Upper Right: KOP material temperature per tier, °C. Temperatures stay within about 12 degrees of the initial temperature. "Noise" in the temperature and steam concentration early in the calculation is during the period when water is boiling inside the KOP material, and the end of the "noise" corresponds to dry-out of the KOP material.

Page 1, Lower Right: Steam concentration per tier. Steam concentration shows the driving force for oxidant external to the KOP material, and it remains fairly steady until all water is evaporated. Since hydrogen is usually negligible compared to steam, the helium concentration is about one minus the steam concentration during drying.

Page 2, Upper Left: Tier 4 (middle basket) energy balance details. This is similar to the lower left plot of page 1, but includes the total source and heat

losses to the MCO wall. Losses increase steadily as the KOP material and inserts heat up.

Page 2, Lower Left: Reaction efficiency per tier. This illustrates the impact of the relative difficulty in supplying steam to KOP material, showing a reaction efficiency of about 30%, consistent with expected values from hand calculations [Epstein, 2009].

Page 2, Upper Right: Gas temperature per tier (°C). There is some minor instability due the small gas heat capacity compared to that of the solid structures.

Page 2, Lower Right: MCO water heel mass (kg). The water heel steadily evaporates and is gone after about 9.7 hours.

Detailed investigation has shown the copper blocks are nearly isothermal, which is essential to their feature in providing heat capacity to suppress temperature increases. Residual water on fuel is gone after about 30 minutes, so that for most of the drying period, water is supplied by the bottom heel but a diffusion limitation occurs within KOP material. Results shown here are influenced in a conservative manner by the large residual water heel, and drying would be faster with a smaller heel. Also, this case is truly thermally stable, because heat losses are able eventually to equal heat sources (to observe this requires an alternate scenario with a considerably larger water heel, and a duration of about 24 hours).

5.2 Case 2: KOP_VACXDG_19 - Degraded Vacuum Pumping with No Helium Purge

The degraded vacuum pumping accident case considers a low vacuum pumping rate, 13 scfm (compared to the normal rate of 30 scfm) and no helium injection flow. The degraded-vacuum case bounds all of the other vacuum cases in the original MCO accident calculations (HNF-SD-SNF-CN-023). Based upon this experience, if the degraded vacuum case for KOP material is benign, there is no reason to simulate the other vacuum cases.

Transient results histories for this case are shown in Figures 5-2A and 5-2B in the same format as described above for normal CVD. KOP material is thermally stable for this case. The pressure is lower compared to normal CVD with the helium purge, so water in the KOP material boils off faster. However, the water heel evaporates more

slowly without the helium purge, and dries out after about 18 hours. The KOP material temperature steadily rises while the heel evaporates, attaining about 88 °C in the lower basket. The reaction efficiency decreases as KOP material heats up, as expected. The nature of the temperature and heat balance results indicates that this case is not truly thermally stable, and that an alternative scenario with a larger water heel would lead eventually to thermal runaway.

5.3 Case 3: KOP_OVLOCXSP_19 - Open MCO with Loss of Annulus Water

In the loss of annulus water case, the annulus water is assumed to be suddenly drained and replaced by air, which severely degrades the main mechanism for removing heat from the MCO. The MCO is open to the vacuum pumping system at atmospheric pressure, but there is neither vacuum pumping nor helium injection, so the MCO atmosphere is stagnant. To eliminate the benefit of oxygen poisoning, no oxygen is included in the MCO atmosphere. Otherwise, initial and boundary conditions are the same as for normal CVD.

Transient results histories are shown in Figures 5-3A and -3B. Since the MCO is at a higher pressure than during normal CVD, there is no boiling. Residual water in KOP material evaporates and completely reacts with the uranium metal, leading to increased reaction power and temperature rise in the KOP material compared to normal CVD. The KOP material temperature stabilizes at 60°C shortly after the residual water in the material is consumed. The residual water heel remains intact.

5.4 Case 4: KOP_COOLSPRS_19 - Cooling of MCO and KOP Sludge After Vacuum Drying

The MCO cooldown case initial condition is an idealized state following vacuum drying and a final pressure rebound test. 200 g of free water are assumed to remain in the MCO, and initial fuel and copper block temperatures are derived from the long-term results of the normal CVD case. The MCO is pressurized with helium to 4 psig, and all components of the MCO are initialized to 60°C corresponding to the end of vacuum drying. The annulus water is initially at 50°C, and cooling water at 17°C is injected into the annulus at a rate of 15 gpm. The purpose of this case is to establish the maximum gas temperature after cooldown, so that the number of moles of helium can be separately compared to requirements for interim storage.

Transient results histories are shown in Figures 5-4A and 5-4B. After about 20 minutes, the KOP material has consumed all the residual water and quickly drops from

a peak temperature of about 72°C down to 60°C and thereafter slowly cools to about 30°C at the end of 10 hours.

5.5 Transient Results Figures

Results figures are given on the following pages.

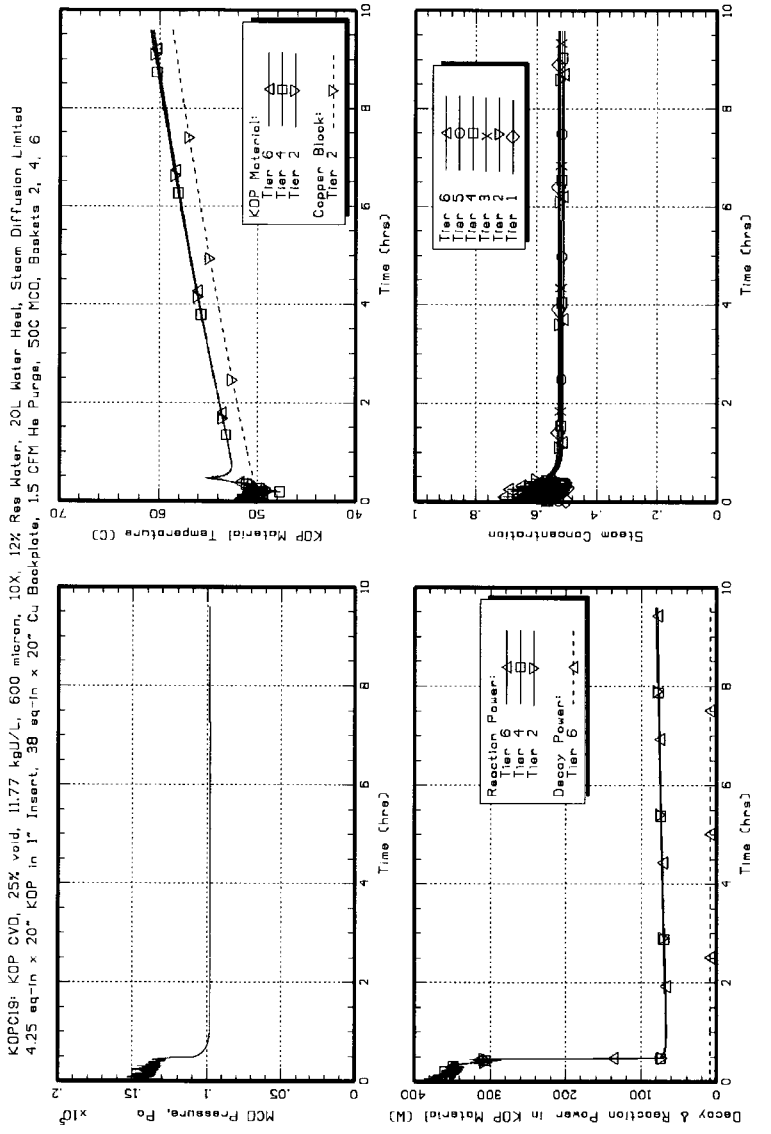


Figure 5-1A: Case 1: CVD of 25% Void Fraction KOP Material (1 of 2).

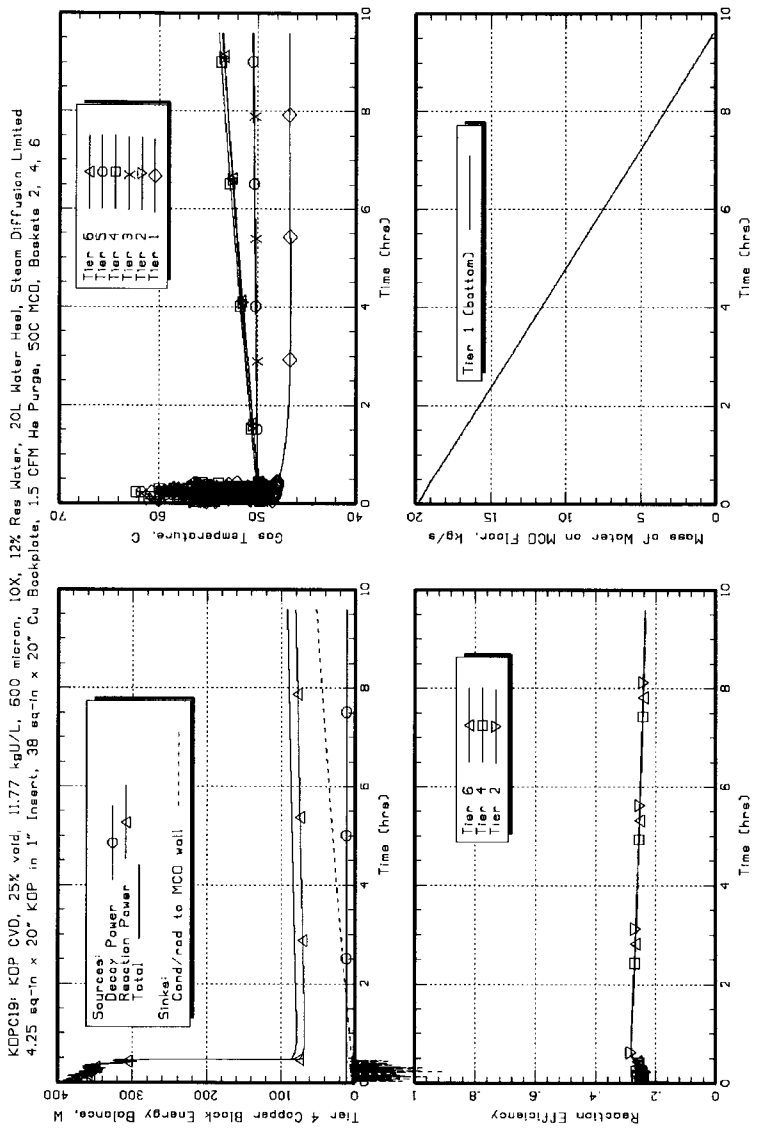


Figure 5-1B: Case 1: CVD of 25% Void Fraction KOP Material (2 of 2).

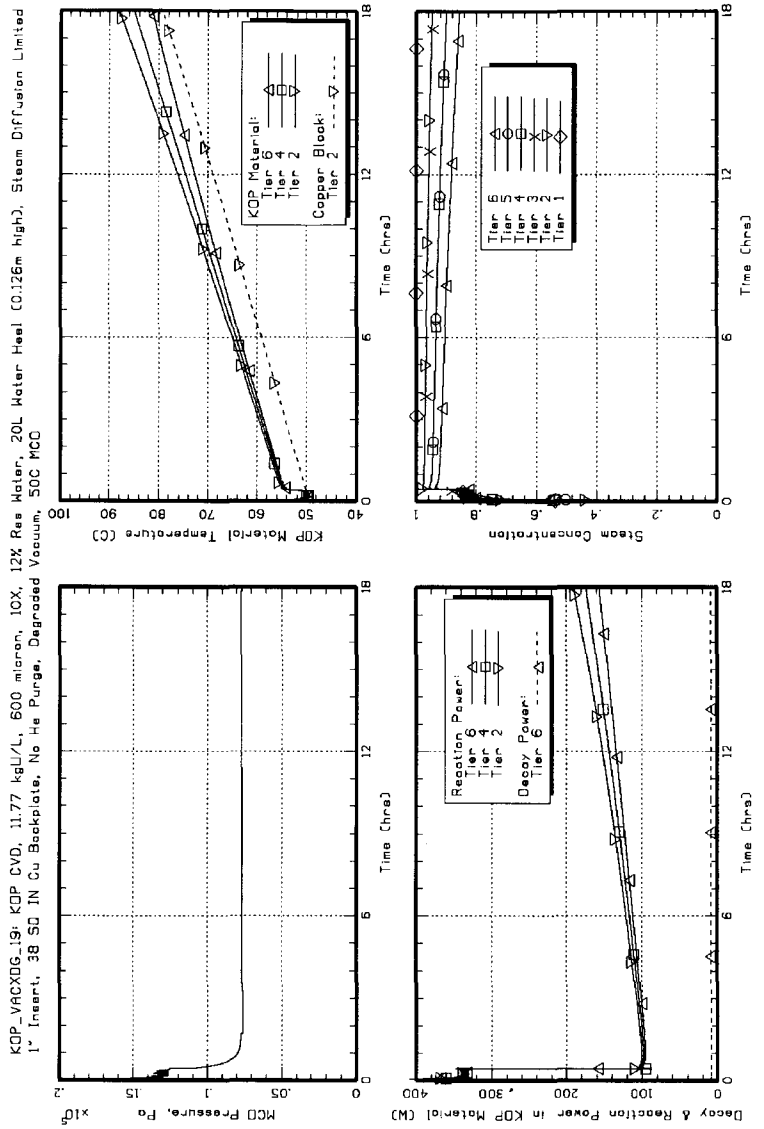


Figure 5-2A: Case 2: Degraded Vacuum Pumping With No Helium Purge (1 of 2).

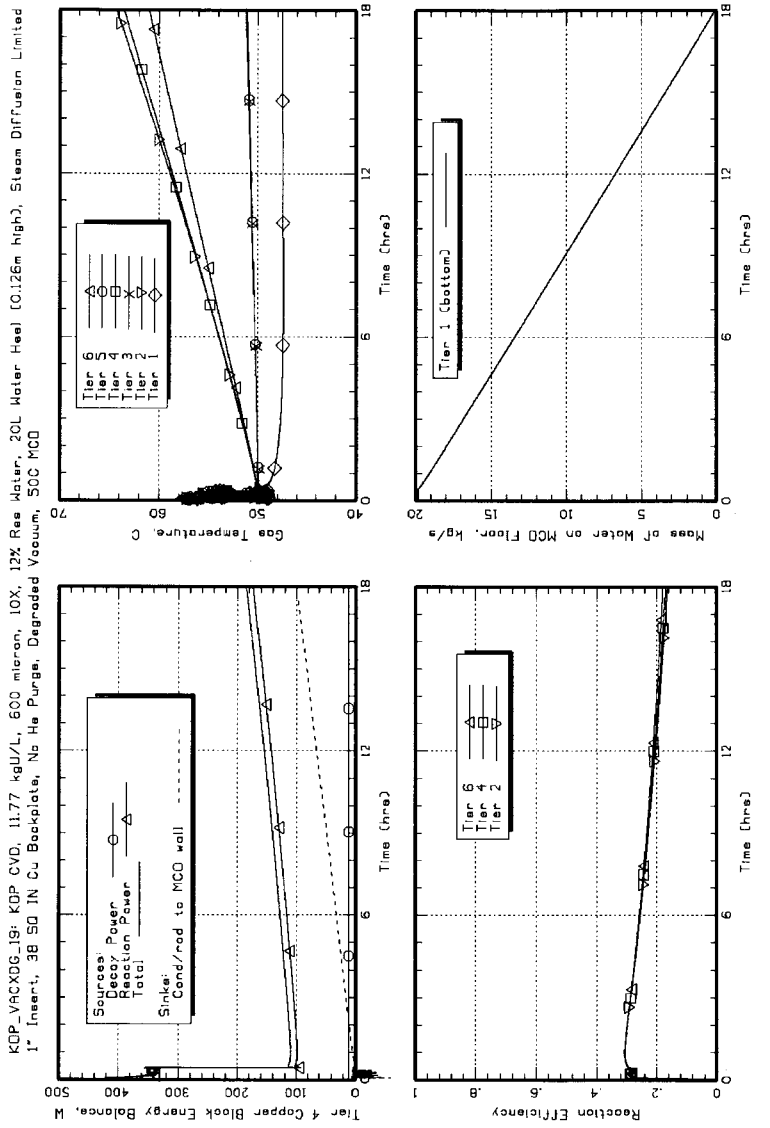


Figure 5-2B: Case 2: Degraded Vacuum Pumping With No Helium Purge (2 of 2).

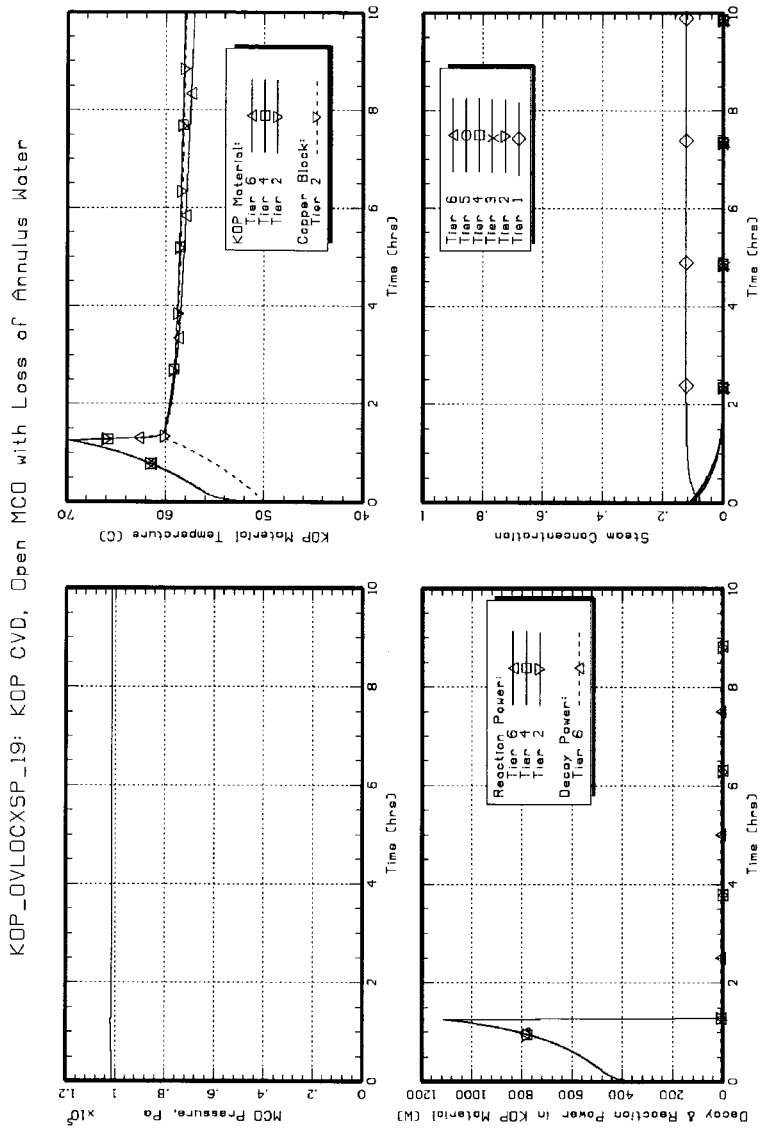


Figure 5-3A: Case 3: Open MCO With Loss of Annulus Water (1 of 2).

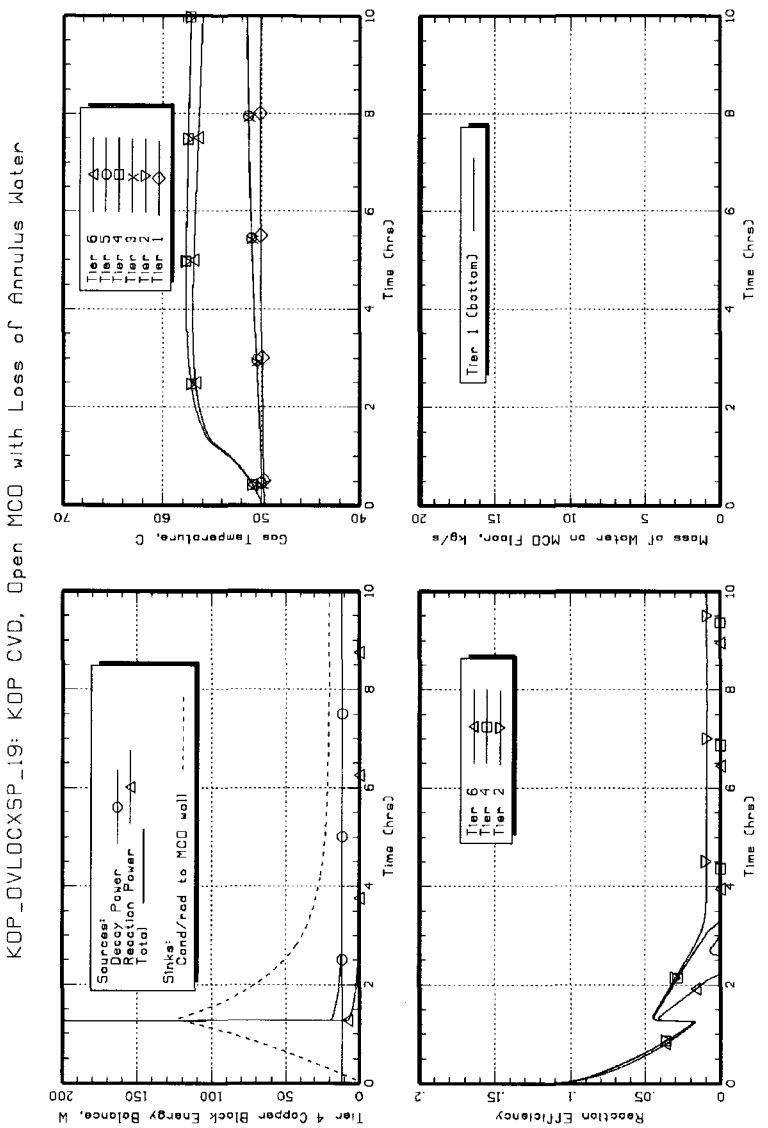


Figure 5-3B: Case 3: Open MCO With Loss of Annulus Water (2 of 2).

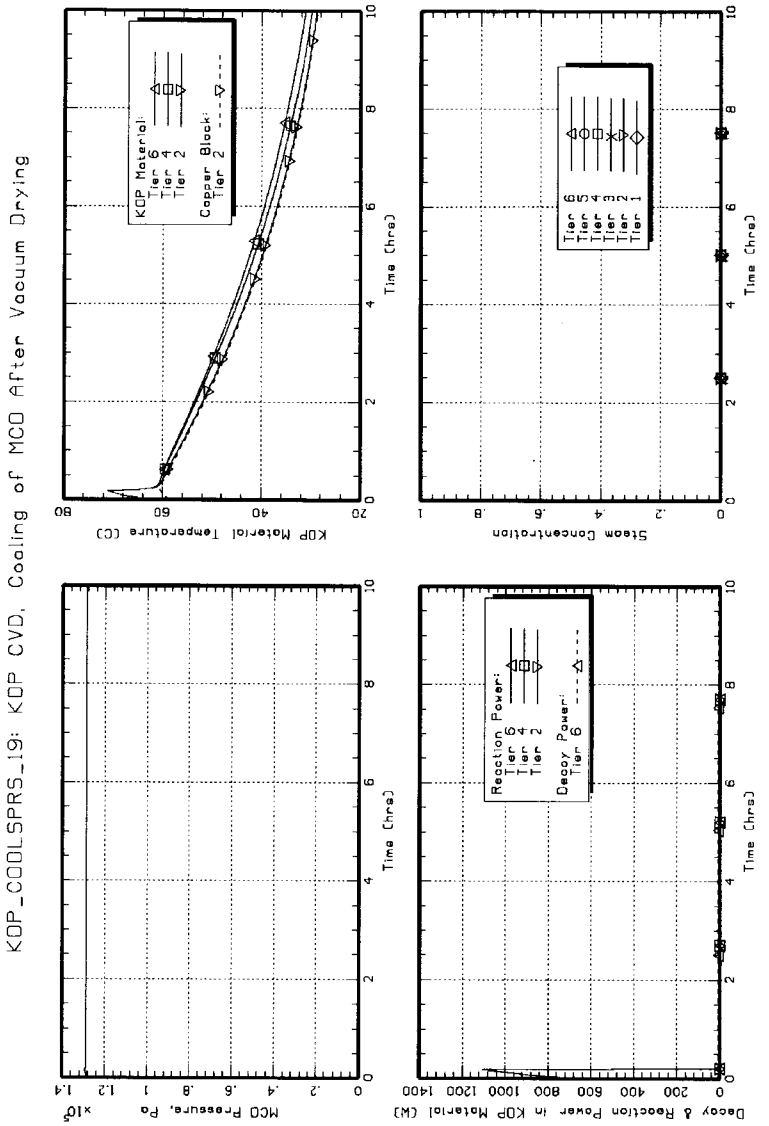


Figure 5-4A: Case 4: Cooling of MCO and KOP Sludge After Vacuum Drying (1 of 2).

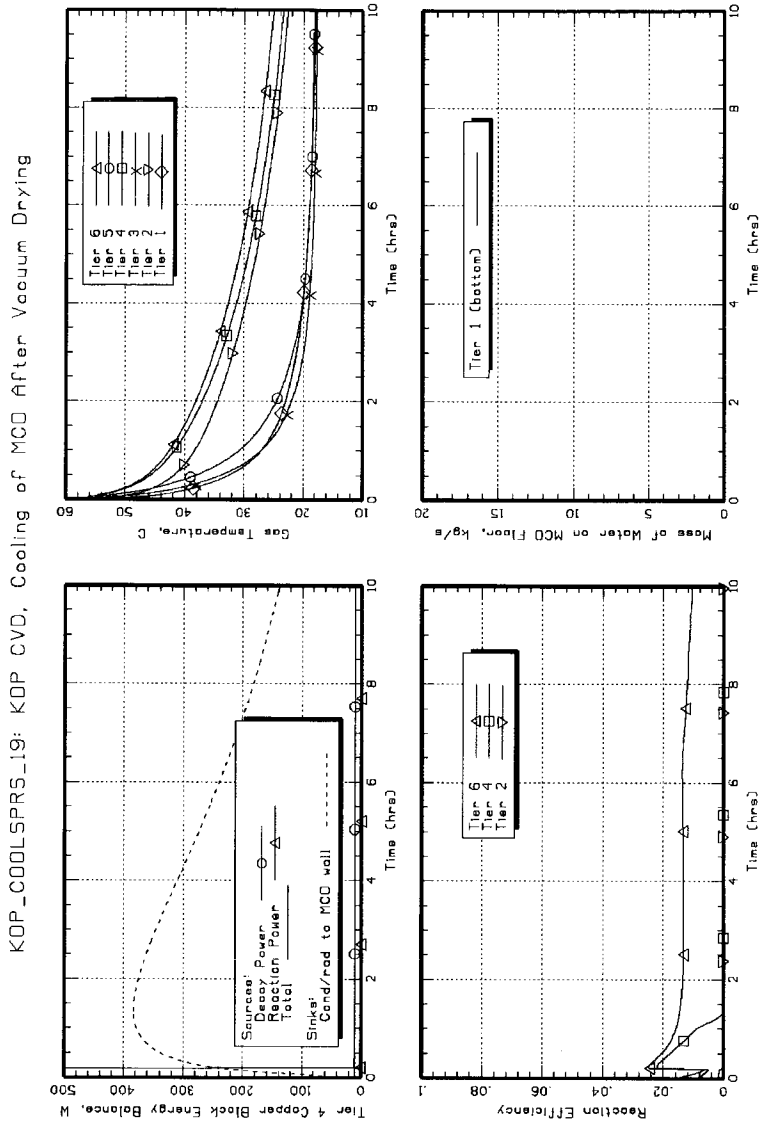


Figure 5-4B: Case 4: Cooling of MCO and KOP Sludge After Vacuum Drying (2 of 2).

6.0 SIMULATION OF CVD OF 40% VOID FRACTION KOP MATERIAL

The four cases described in Section 5.0 are re-analyzed here using safety basis KOP material properties (1500 μm diameter and 40% void fraction). The purpose of the this analysis is to document the safety basis results. An additional purpose of the baseline CVD case is to document the amount of particulate generated. The results of each analysis are discussed below. Results figures for each case are organized the same as in Section 4, with the exception that for Case 5, normal CVD, a third figure with generated particulate is provided.

Because results are similar between analogous cases, only a brief description of results is required. While water is available, reaction power is about half the value found for analogous cases in Section 5, and KOP material temperatures are commensurately somewhat lower.

6.1 Case 5: KOPC18 - CVD of Safety Basis KOP Material

The results of simulating CVD safety basis KOP material are shown in Figures 6-1A, B, and C. The results demonstrate thermal stability. Residual water in the scrap baskets boils away in slightly less than one hour, and the residual water heel evaporates in about 9.7 hours. Per Figure 6-1C, uranium dioxide is steadily produced with a maximum mass of 3.4 kg produced before the MCO is dry.

6.2 Case 6: KOP_VACXDG - Degraded Vacuum Pumping with No Helium Purge

Results for the safety basis degraded vacuum case are shown in Figures 6-2A and 6-2B KOP material is thermally stable, and the peak temperatures is 72 °C, about 6 °C lower than for the case in Section 5.2. The time for water heel evaporation is 18 hours.

6.3 Case 7: KOP_OVLOCXSP - Open MCO with Loss of Annulus Water

Results for the safety basis loss of annulus water are shown in Figures 6-3A and 6-3B. The time period for evaporation of water on KOP material, and its complete local reaction with uranium metal, is about 5 hours. This process leads to increased reaction power and temperature rise in the KOP material compared to normal CVD. The KOP material temperature stabilizes near 60°C shortly after the residual water in the material is consumed. The residual water heel remains intact.

6.4 Case 8: KOP_COOLSPRS - Cooling of MCO and KOP Sludge After Vacuum Drying

Results for the safety basis cooldown case are shown in Figures 6-4A and 6-4B. These results are nearly identical to those presented in Section 5.4. After residual water is consumed in about 45 minutes, KOP material slowly cools to about 30°C at the end of 10 hours.

6.5 Transient Results Figures

Results figures are given on the following pages.

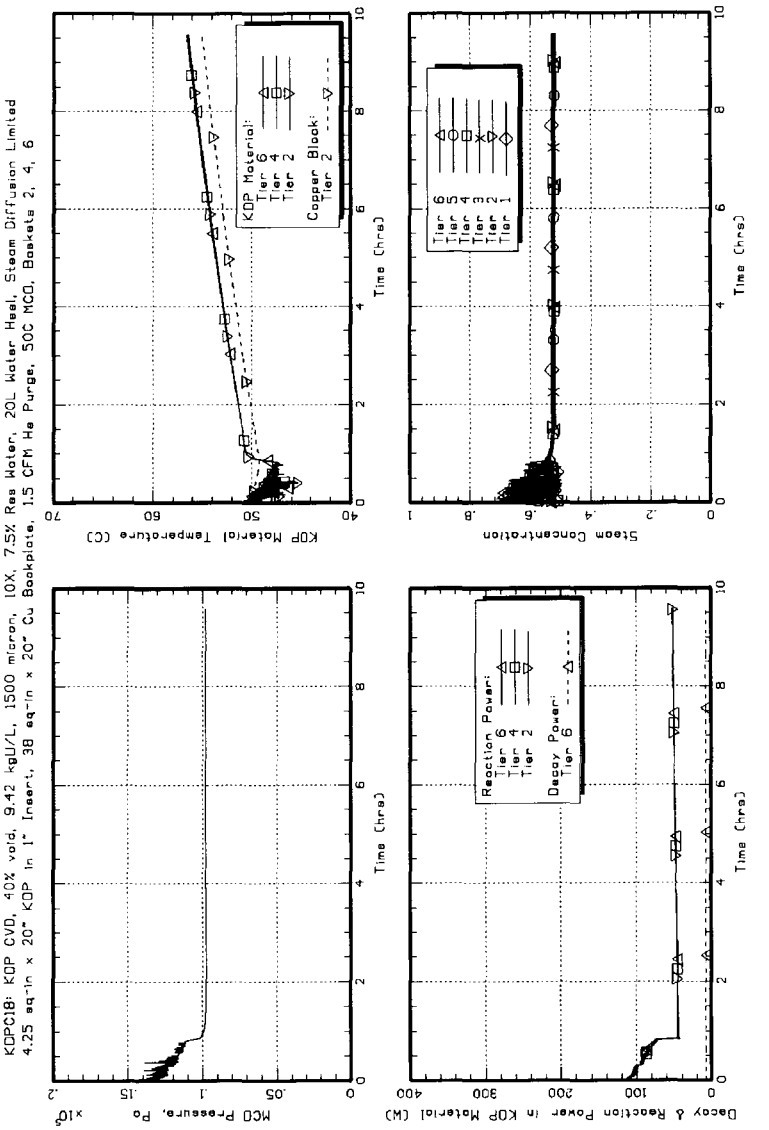


Figure 6-1A: Case 5: CVD of Safety Basis KOP Material (1 of 3).

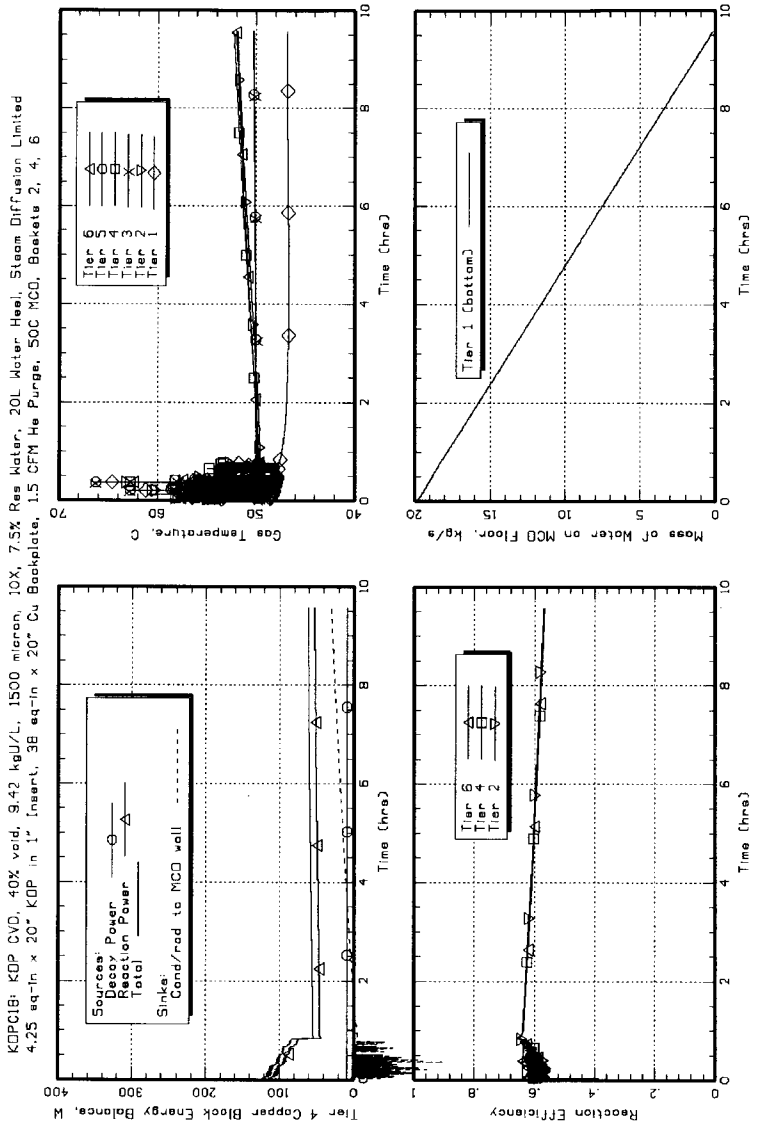


Figure 6-1B: Case 5: CVD of Safety Basis KOP Material (2 of 3).

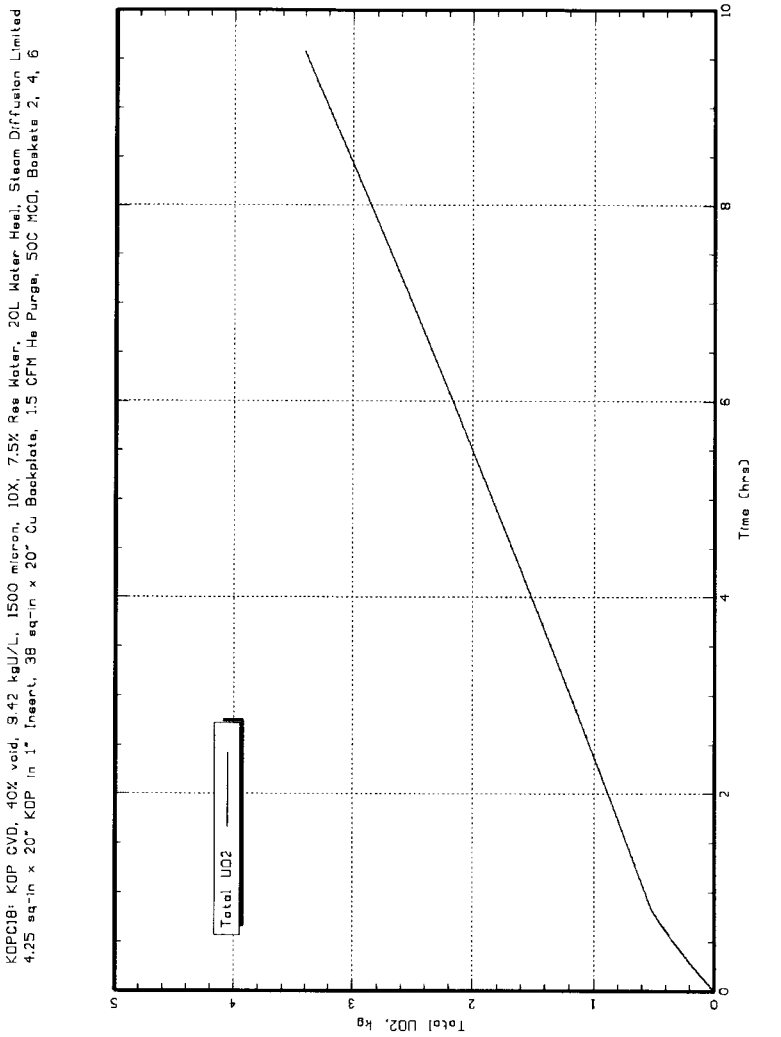


Figure 6-1C: Case 5: CVD of Safety Basis KOP Material (3 of 3).

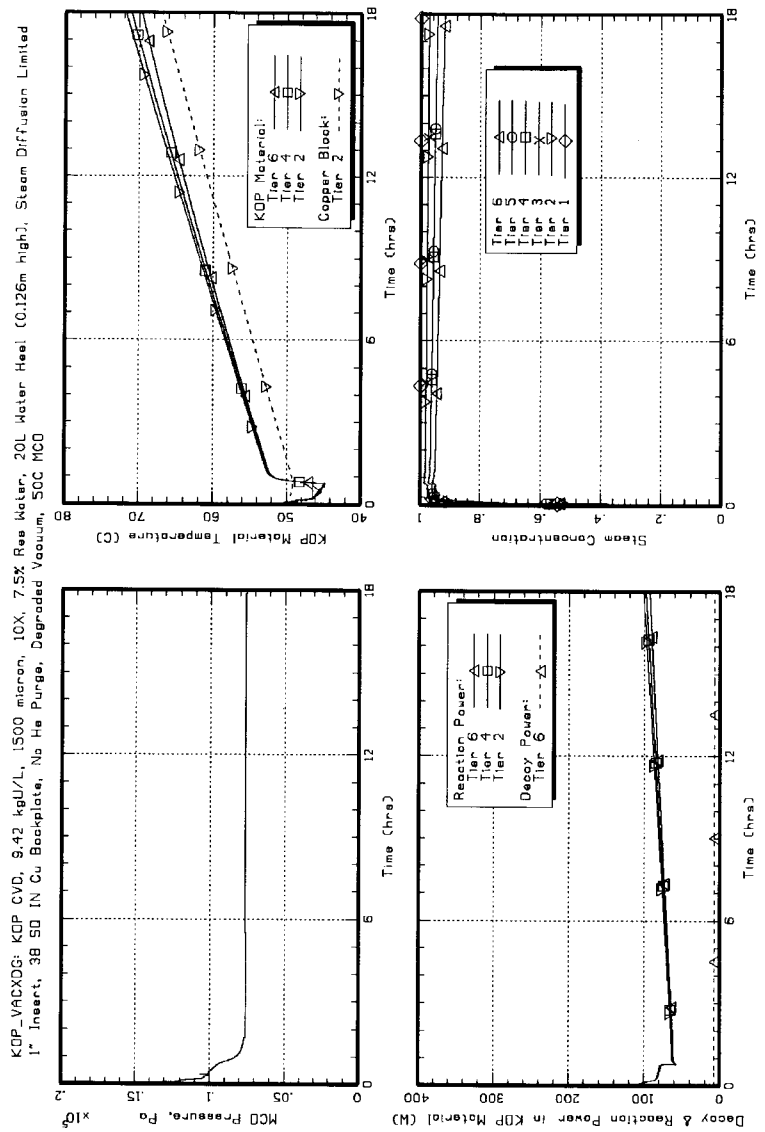


Figure 6-2A: Case 6: Degraded Vacuum Pumping With No Helium Purge (1 of 2).

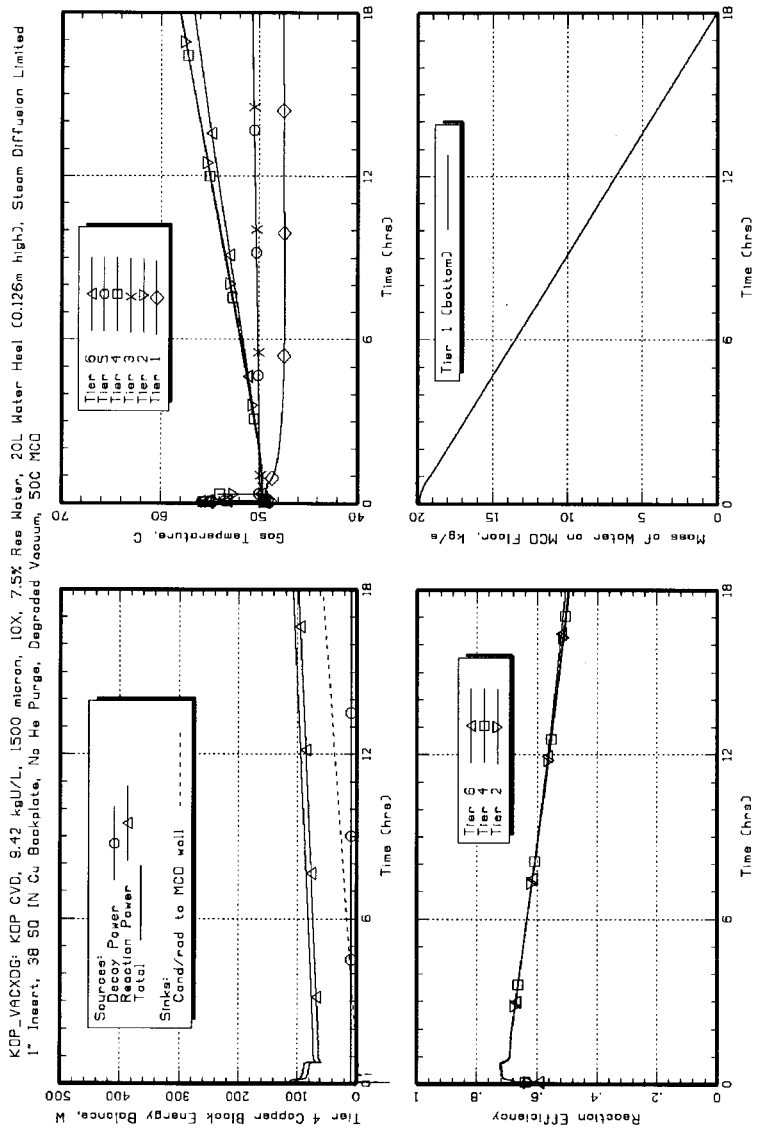


Figure 6-2B: Case 6: Degraded Vacuum Pumping With No Helium Purge (2 of 2).

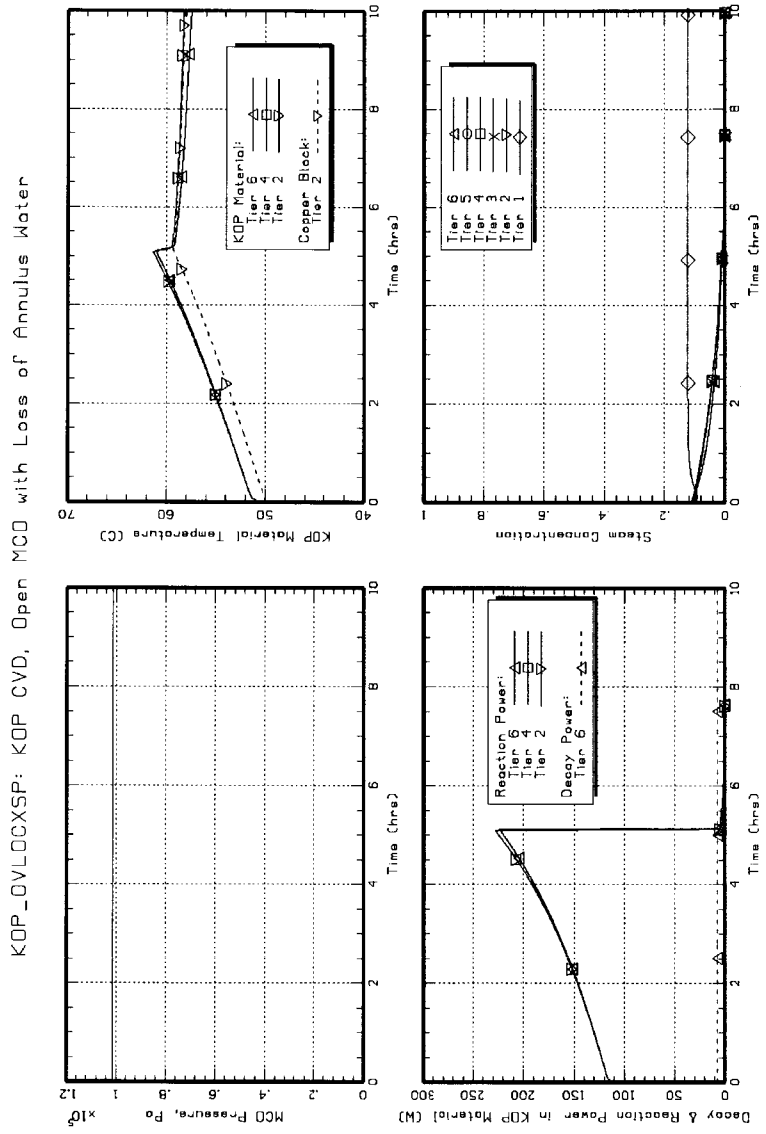


Figure 6-3A: Case 7: Open MCO With Loss of Annulus Water (1 of 2).

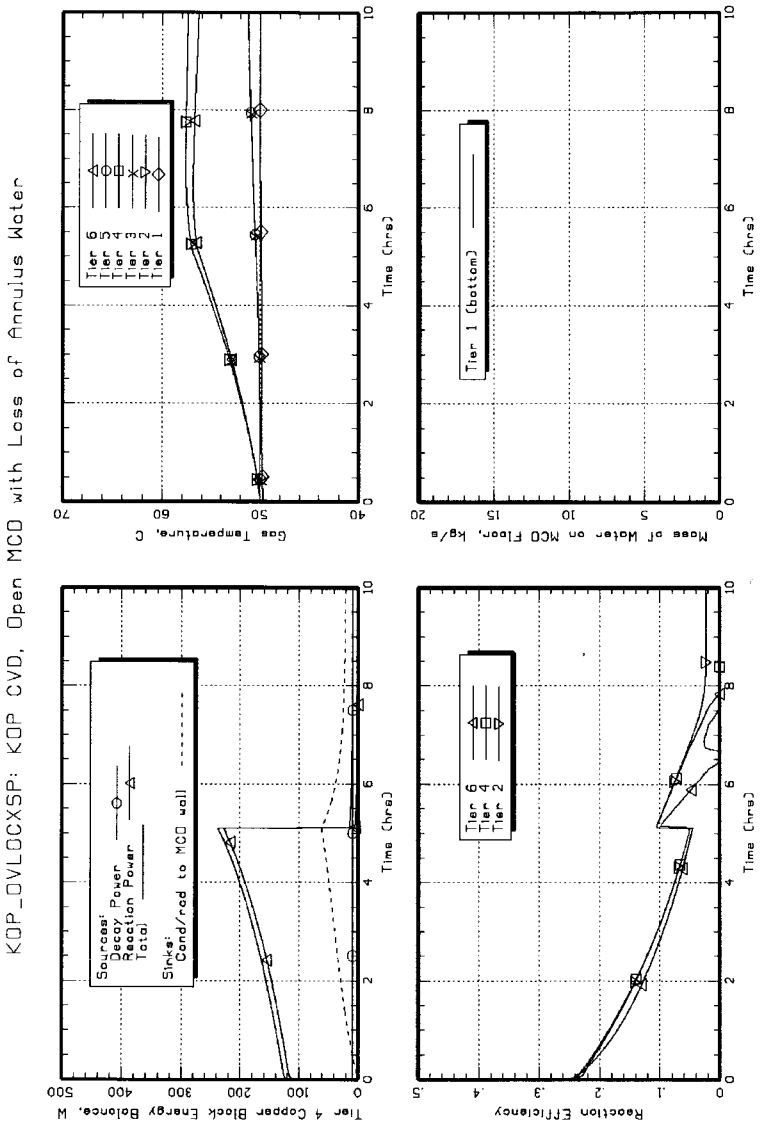


Figure 6-3B: Case 7: Open MCO With Loss of Annulus Water (2 of 2).

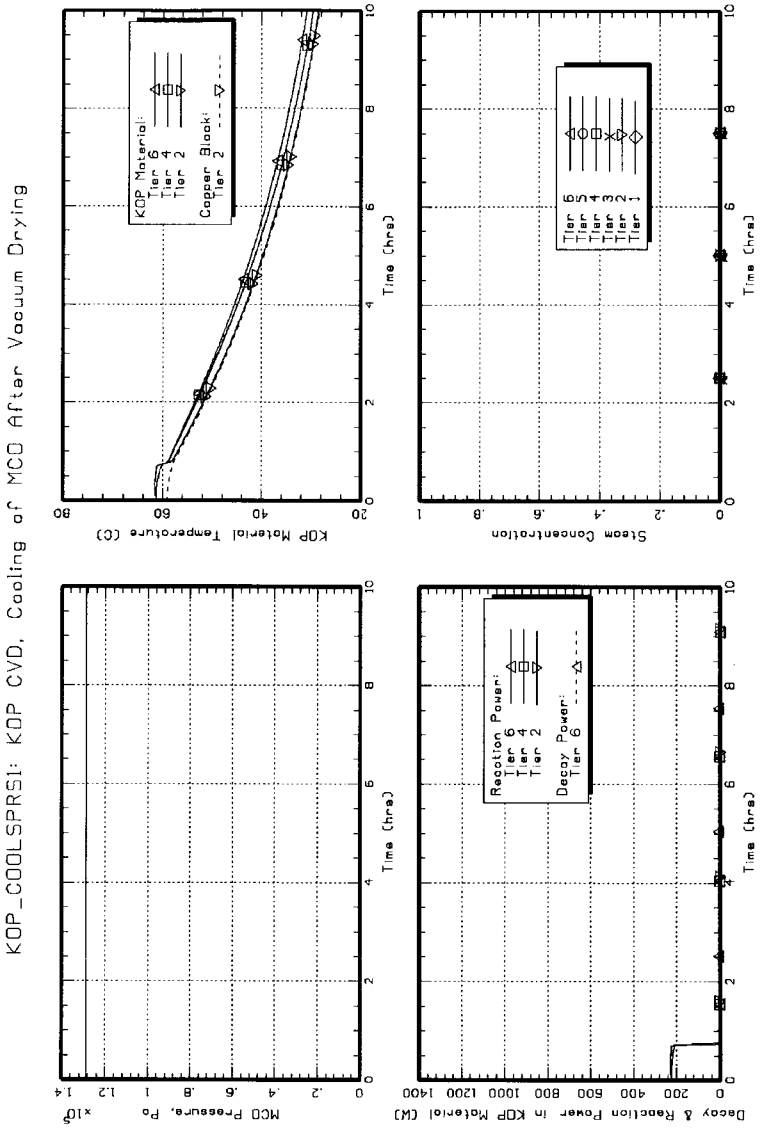


Figure 6-4A: Case 8: Cooling of MCO and KOP Sludge After Vacuum Drying (1 of 2).

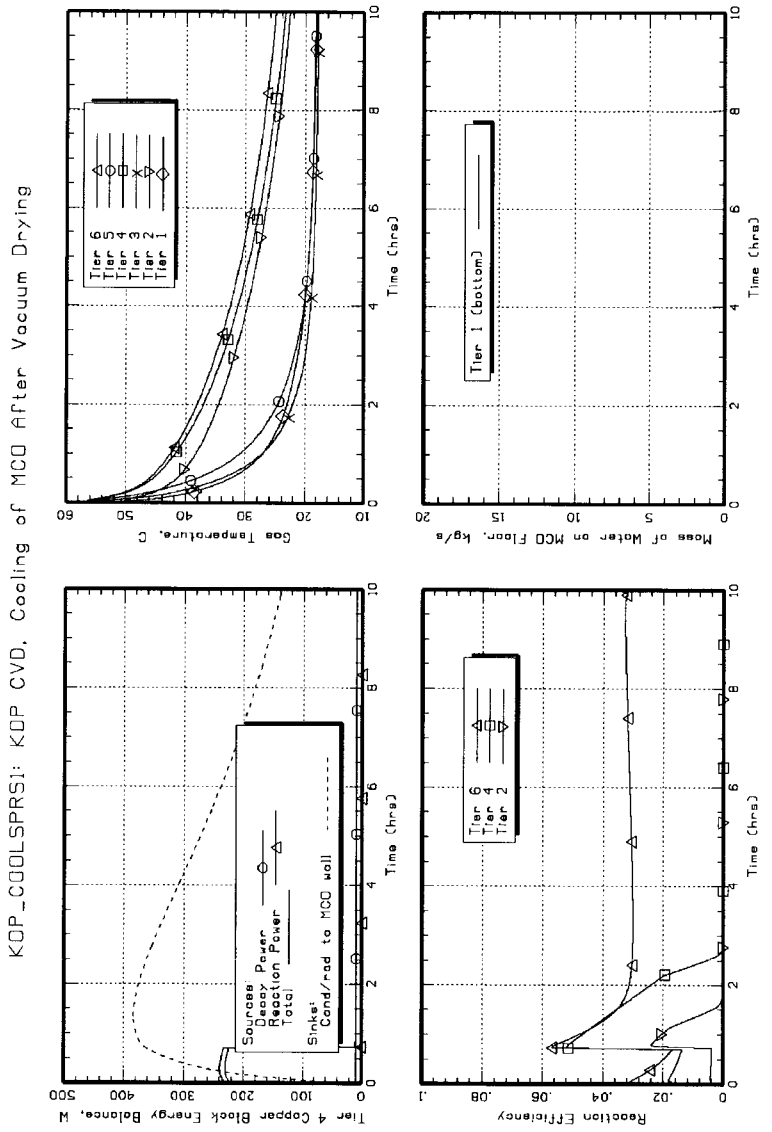


Figure 6-4B: Case 8: Cooling of MCO and KOP Sludge After Vacuum Drying (2 of 2).

7.0 REFERENCES

Dwg. KOP-SK-510, Rev. 0, Sheet 4, KOP MCO Basket Insert Assembly, CHPRC Engineering Sketch, dated 8/14/09.

Epstein, M., 2008, "Residual Saturation Measurements," FAI Internal Memorandum to M.G. Plys, September 2, Fauske & Associates, LLC.

Epstein, M., 2009, Correlations and Models in Support of FATE Computer Program Thermal Analyses of KOP Material During CVD and Shipping, FAI/09-254, Rev. 1, Fauske & Associates, LLC, submitted to CH2M Hill Plateau Remediation Company, Richland, WA, December.

Plys, M.G. and B. Malinovic, 1999, IWTS Metal-Water Reaction Rate Evaluation (Fauske & Associates Report FAI/99-26), SNF-4266, Rev.0, Duke Engineering and Services Hanford, Inc., Richland, WA.

Plys, M.G. and D.R. Duncan, 2000, Uranium Pyrophoricity Phenomena and Prediction (FAI/00-39), SNF-6781, Rev. 0, EDT 629783, Fluor Hanford, Richland, WA, October.

Plys, M.G., and S.J. Lee, 2004, FATE 2.0: Facility Flow, Aerosol, Thermal, and Explosion Model (Improved and Combined HANSF and HADCRT Models), SNF-23281, FAI/04-71, 2 volumes, Fluor Hanford, Inc., Richland, WA, November.

Plys, M.G., and S.J. Lee, 2008, "CVD of KOP Material in an MCO Insert Basket," FAI memorandum to J. Sloughter, C. Miska, and N. Sullivan, June 23, 2008.

Plys, M.G., and A.J. Schmidt, Supporting Basis for Spent Nuclear Fuel Project Sludge Technical Databook, SNF-7765, Revision 3B, released January, 2006.

Schmidt, A.J., 2006, Spent Nuclear Fuel Project Technical Databook, Vol. 2, Sludge, HNF-SD-SNF-TI-015, Revision 13A, Fluor Hanford, Richland, WA, June.

APPENDIX A: FATE INPUT DECKS

A.1 Case 1: KOPC19.DAT Simulation of CVD of 25% Void Fraction KOP Material

```
*********************************************************************
*
*   CASE KOPC19
*   INDEFINITE VACUUM CYCLE
*   SIX KOP SCRAP BASKETS (SSSSSS)
*
************************************************************
* KOPC19   11.77 KG/l  600 micron 10X 20L                  *
*          1.5 CFM He Purge                                *
*          50 C MCO                                        *
*          6 x 38 SQ-In x 20 In Copper Backplate           *
*          6 x 4.25 SQ-In x 20 In KOP Material in 1" Insert *
*          MCO Heel water    =  20 L                       *
*          Basket water      =  12% of void                 *
*          Top, 3rd, and 5th baskets contain KOP material  *
************************************************************
*
*--------------------------------------------------------------------
CONTROL    ! Major keyword group
*--------------------------------------------------------------------
*
*
 TITLE     ! Keyword; next line is title, title can be any length
 KOPC19   11.77 KG/l  600 micron 10X 20L
          1.5 CFM He Purge
          50 C MCO
          6 x 38 SQ-In x 20 In Copper Backplate
          6 x 4.25 SQ-In x 20 In KOP Material in 1" Insert
          MCO Heel water    =  20 L
          Basket water      =  12% of void
          Top, 3rd, and 5th baskets contain KOP material
 END TITLE ! Anything after END is a comment
*
*
 TIMING    ! Keyword
  TSTART         0.          !  START TIME, >0 FOR RESTART RUN
*  RESTART_FILE   VCKOP1.RER  !  RESTART FILE NAME FOR RESTART RUN
                              !  IF NOT SPECIFIED, READ FROM
                              !  'input deck name'.RER
  TLAST      36000.          !  END TIME (Seconds) - 36 HOURS
* 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 mimium 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       0.001       !  MIN TIMESTEP (Seconds)
   DTMAX                   !  MAX TIMESTEP (Seconds)
    0.         0.02
    100.       0.2
    1600.      0.02
    6120       0.2
   DTPRIN      1800.       !  PRINT INTERVAL (Seconds)
   PLTMIN        10.       !  MIN PLOT INTERVAL (Seconds)
   PLTMAX       100.       !  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    0.2           !  MAXIMUM TIME STEP WHEN THE CORROSION IS
                            !  STEAM STARVED
 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  1  677
  HS  5   3  23  34  43  63  83
  HS  5 203 223 234 243 263 283
  HS  5 403 423 434 443 463 483
  HS  5  12  32  52  72  92
  HS  5 212 232 252 272 292
  HS  5 412 432 452 472 492
 END PRINT  ! PRINT is a comment
*
 PLOT 1    ! 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        6    1   2   3   4   5   6      ! Temperature in MCO
  LIQ-T        1    6                          ! Liq Temperature in MCO
  LIQ-MASS STEAM   1    6                          ! Liq MASS
  HS-TA        5    9   49  69  89  99            ! Tier 6 (top), vertical thru scrap
  HS-TA        10   63  64  65  66  67  68  69  70  71  72  ! Tier 6, back-plate, scrap, spoke,
shroud, MCO
  HS-TA        5    209 249 269 289 299           ! Tier 4, vertical thru scrap
  HS-TA        10   263 264 265 266 267 268 269 270 271 272 ! Tier 4, back-plate, scrap, spoke,
shroud, MCO
  HS-TA        5    409 449 469 489 499           ! Tier 2, vertical thru scrap
  HS-TA        10   463 464 465 466 467 468 469 470 471 472 ! Tier 2, back-plate, scrap, spoke,
shroud, MCO
```

```
  HS-TA        3    676 677 678                    ! Cask, MCO bott & lid
 END PLOT
 *
 PLOT 2
  GAS-X  NITROGEN    6   1   2   3   4   5   6   ! N2 %
  GAS-X  OXYGEN      6   1   2   3   4   5   6   ! O2 %
  GAS-X  STEAM       6   1   2   3   4   5   6   ! H2O %
  GAS-X  HYDROGEN    6   1   2   3   4   5   6   ! H2 %
  GAS-X  HELIUM      6   1   2   3   4   5   6   ! He %
  GAS-W              6   1   2   3   4   5   6   ! Junc. flow
  GAS-WV             6   1   2   3   4   5   6   ! Junc. flow
  GAS-WX             6   1   2   3   4   5   6   ! Junc. cc flow
  GAS-MASS  HYDROGEN     1   8                     ! H2 release
  GAS-MASS  STEAM        1   8                     ! H2O release
 END PLOT
*
 PLOT 3
  QGAS-HSO 5  23, 43,  3, 63, 83
  QGAS-HSO 5 223,243,203,263,283
  QGAS-HSO 5 423,443,403,463,483
  QGAS-HSI 5  12  32  52  72  92
  QGAS-HSI 5 212 232 252 272 292
  QGAS-HSI 5 412 432 452 472 492
  QRAD-HSO 5  23, 43,  3, 63, 83
  QRAD-HSO 5 223,243,203,263,283
  QRAD-HSO 5 423,443,403,463,483
  QRAD-HSI 5  12  32  52  72  92
  QRAD-HSI 5 212 232 252 272 292
  QRAD-HSI 5 412 432 452 472 492
 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
  IHXPOL  1    ! Heat and Mass transfer on liquid pool
  IASED   0    ! Aerosol Sedimentation
  IALEAK  0    ! Aerosol Leakage
  IFOG    0    ! Fog formation
  ISRC    1    ! User-defined sources
  IMCO    1    ! MCO models
  ISENS   0    ! Sensitivity runs
  IPLTYP  2    ! 1=wrap around, 2=no wrap (spreadsheet format)
 END ACTIVE MODELS ! ACTIVE MODELS  is a comment
*
 MODEL         ! keyword for model parameters
* multipliers for region gas conductivities
* syntax:
*   FKGAS  fkgas1  fkgas2  fkgas3  ...
 FLOWKBED  0.0066
 FLANGM    0.1
* Multiplier to heat sink to liquid pool hx coefficient.
* There should be very little hx resistance between the MCO bottom
* and water heel because of He sparging and/or boiling during
* vacuum drying.
  FHHSL    10.0
 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:
* 1.5 FT^3/MIN * 1 MIN/60 SEC * 0.02832 M^3/1 FT^3 = 0.0007080 M^3/SEC
* He density @ stp is 0.16 kg/m^3, hence 1.13e-4 kg/s
 SOURCES 1                  !-- KEYWORD AND # SOURCE GROUPS
  REGION  6  GASES 1        !-- REGION #, # GASES
  SPARGE  0.00761  0.0      !   GAS SPARGE, RADIUS, ELEVATION
  HELIUM                    !-- GAS NAMES MUST BE ON NEXT LINE
   0.0  45  1.13E-4    0.E0
```

```
   1.E6 45  1.13E-4    0.E0
  END REGION                  !-- ENDS A REGION SOURCE
 END SOURCE                   !-- ENDS ALL SOURCE INPUT
*
END CONTROL    ! End of CONTROL keyword group
*
EVENTS
 SET 1 WHEN PR(1) < 1000
 CONTROL
  ACTIVE MODELS
   IHXPOL   0          ! Turn off Pool Evaporation
  END ACTIVE
 END CONTROL
 END WHEN

 SET 2 WHEN PR(1) < 6600
 CONTROL
  ACTIVE MODELS
   ISRC   0           ! Turn off He source
  END ACTIVE
 END CONTROL
 END WHEN
END EVENTS
*
*-----------------------------------------------------------------------
VOLUMES
*-----------------------------------------------------------------------
* total free volume in MCO is 0.9544 m^3
* volume of six scrap baskets is 6*0.0348 = 0.2088 m^3
* volume of KOP material in one basket = 6*0.00139 m^3 = 0.00834 m^3
* volume of copper block in one basket = 6*0.01245 m^3 = 0.07470 m^3
* Therefore, gas volume in MCO = 0.9544-0.2088-3*(0.00834+0.07470)
*                              = 0.49648 m^3
* Distribute the volume equally among six tiers:
*    VOLUME = 0.49648/6 = 0.08275 m^3 per tier
*
* 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 6 each contain a basket, top to bottom
*              scrap1     scrap2      scrap3      scrap4      scrap5
 REGIONS         1          2           3           4           5
  VOLUME       0.08275     0.08275     0.08275     0.08275     0.08275
  SED_AREA     0.172       0.172       0.172       0.172       0.172
  ZTOP         0.7643      0.5881      0.5881      0.5881      0.5881
  ELEVATION    2.9405      2.3524      1.7643      1.1762      0.5881
  TEMP_GAS     40.0        40.0        40.0        40.0        40.0
  PRESSURE     1.013E5   1.013E5     1.013E5     1.013E5     1.013E5
 END REGIONS
*
* Note on scrap6 Z_LIQ estimate:
* Liquid in this region is displaced by a 1.5" thick basket bottom plate, a
* 6-5/8" diameter center post and six trapezoidal outer posts having a total
* cross-sectional area of 17.34 sq-in. For 20 liters of water, the elevation
* of the water surface (Z_LIQ) is the the basket bottom plate thickness (1.5")
* plus the basket volume divided by the basket cross-sectional area less the
* area occupied by the center and outer posts. For a basket diameter of
* 22.675", the liquid level turns out to be 4.9672".
*
* r_basket          11.3375 [in]      0.2880 [m]
* r_cpost            3.3125 [in]      0.0841 [m]
* h_heel             1.5    [in]      0.0381 [m]
* bt_minor_opost     1.23   [in]      0.0312 [m]
* bt_major_opost     2.757  [in]      0.0700 [m]
* ht_opost           1.45   [in]      0.0368 [m]
* z_top             23.167  [in]      0.5884 [m]
* m_liq             20      [kg]
* rho_liq            1      [g/cm3]
*
* h_post            21.667  [in]      0.5503 [m] = z_top - h_heel
```

```
*
* A_basket        403.8169 [in2]     0.2605 [m2] = pi * r_basket^2
* A_cpost          34.4716 [in2]     0.0222 [m2] = pi * r_cpost^2
* A_oposts         17.3435 [in2]     0.0112 [m2]
*          = 6 * (bt_minor_opost + bt_major_opost)/2 * ht_opost
*
* V_heel          605.73   [in3]     0.0099 [m3] = A_basket * h_heel
* V_liq          1220.4    [in3]     0.0200 [m3]
*
* z_liq_noposts     4.5223 [in]      0.1149 [m]
*              = h_heel + V_liq / A_basket
* z_liq             4.9672 [in]      0.1262 [m]
*              = h_heel + V_liq / (A_basket - Acpost - A_oposts)
*
* This also requires a change to VOLUME:
*
* VOLUME = V_liq * ZTOP / Z_LIQ = 0.0933 [m^3]
*
*             scrap6      gap     environment
 REGIONS          6          7          8
  VOLUME       0.0933    0.25         1.E9
  SED_AREA     0.172      0.0          0.0
  ZTOP         0.5881     4.4069       1.E3
  ELEVATION   -0.03048   -0.01452      0.0
  TEMP_GAS     40.0       40.0        40.0
  Z_LIQ        0.1262     0.0          0.0
  TEMP_LIQ     40.0       40.0        40.0
  PRESSURE     1.013E5    1.013E5     1.013E5
  HPLGR        5.E0      -1.E0       -1.E0
 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
 END GASES
*
* If there are more than five regions, continue here.
* Gap is artificial here, MCO wall will be set to 40 C
*
  GASES          6         7         8
   HELIUM       0.89      0.0       0.0
   STEAM        0.11      0.01      0.0
   OXYGEN       0.0       0.20      0.21
   NITROGEN     0.0       0.79      0.79
  END GASES           ! GASES is a comment
*
 LIQUIDS        6
  STEAM        1.0
 END LIQUIDS
*
* 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         8
*  STEAM       0.0       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_TIMETG
*   EXTRAPOLATION_TIMEPG
*   TIMEP  IREG  TIME1, TIME2...
*   PRFIX  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
*  TIMEP 1   0.0    100.     200.
*  PRFIX  1   1.E5   1.2E5    1.4E5
*
END VOLUMES ! VOLUMES is a comment
*
*
* Major keyword-----------------------------------------------------------
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/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 cylindrical, thickness(m) for planar
* AHS     One-sided average 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. Use 1 for lumped heat sink
* 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)
*
```

```
*****************************************************************
*
* scrap basket # 1 - Tier 6, top tier
*
*****************************************************************
*
* scrap basket # 1 - sludge
*
* Preserve half the thickenss of the sludge, 1 inch.
* That is, XRO of HS-9 - XRI of HS-4 = 0.2842 - 0.2715 = 0.0127 m
*
* Determine AHS to preserve the volume of sludge.
* That is, AHS*0.0127 = 6*0.00139 or AHS = 0.6567
*
SINKS          4
*
 IGEOM         0
 IORIHS        0
 IMATHS        1
 IREGI         1
 IREGO         1
 XRI         0.2715
 XRO         0.2736
 AHS         0.6567
 XZHS        0.5080
 TIINIT      50.0
 TOINIT      50.0
 IMSLAB        3
 XLHS        0.5080
 ZTHS        3.4485
 ZBHS        2.9405
END
*
SINKS          5            6            7            8            9
*
 SAME_AS       4            4            4            4            4
 XRI         0.2736       0.2757       0.2779       0.2800       0.2821
 XRO         0.2757       0.2779       0.2800       0.2821       0.2842
 AHS         0.6567       0.6567       0.6567       0.6567       0.6567
 ZTHS        3.4485       3.4485       3.4485       3.4485       3.4485
 ZBHS        2.9405       2.9405       2.9405       2.9405       2.9405
END
*
* scrap basket # 1 - bottom plate - 1.25" (0.03175 m) thick
SINKS          93           94
*
 SAME_AS       4            4
 IMATHS        2            2
 IREGI         0            0
 IREGO         0            0
 XRI         0.1647       0.2715
 XRO         0.2715       0.2736
 AHS         0.04373      0.04373
 IMSLAB        5            3
 XZHS        0.03175      0.03175
 XLHS        0.03175      0.03175
 ZTHS        2.9405       2.9405
 ZBHS        2.9100       2.9100
END
*
SINKS          95           96           97           98           99
*
 SAME_AS       93           93           93           93           93
 XRI         0.2736       0.2757       0.2779       0.2800       0.2821
 XRO         0.2757       0.2779       0.2800       0.2821       0.2842
 IMSLAB        3            3            3            3            3
 AHS         0.04373      0.04373      0.04373      0.04373      0.04373
 ZTHS        2.9405       2.9405       2.9405       2.9405       2.9405
 ZBHS        2.9100       2.9100       2.9100       2.9100       2.9100
END
*
```

```
* scrap basket # 1 - insert
*
SINKS          1
*
 SAME_AS       4
 IMATHS        2
 XRI        0.02223
 XRO        0.03493
 AHS        0.1191
 XZHS       0.5881
 IMSLAB        3
 XZHS       0.5564
 XLHS       0.5564
 ZTHS       3.4969
 ZBHS       2.9405
END
*
* scrap basket # 1 - dip tube
* height= 0.6631 m
* AHS= pi x (0.00761+0.01670) x 0.6631 = 0.05064
*
SINKS          2
*
 SAME_AS       1
 IMATHS        2
 XRI        0.00761
 XRO        0.01670
 AHS        0.05064
 XZHS       0.5564
 XLHS       0.5564
 ZTHS       3.4969
 ZBHS       2.9405
END
*
* scrap basket # 1 - 6*38 SQ-IN*20 IN Copper Block
*
* XRO = same as XRI of sludge = 0.2715
* AHS = same as sludge = 0.6567
* Determine XRI to preserve the volume of copper block
* i.e. 0.6567*(0.2715 - XRI) = 6*38*20*0.0254^3
* Or, XRI = 0.1577
*
* SET GAP DISTANCE XDHSO TO 0.0143M,
* 0.00476M BETWEEN MCO WALL AND BASKET WALL PLUS
* TWO 3/16" GAP BETWEEN BASKET WALL AND COPPER BLOCK,
* TO MODEL HEAT FLOW ACROSS THE GAP
*
* ASHSO = 2*ph*(0.2921 - 0.0143)*0.5080 = 0.8867
*
SINKS          3
*
 SAME_AS       4
 IREGI         0
 IREGO         1
 IMATHS        3
 XRI        0.1577
 XRO        0.2715
 AHS        0.6567
 ASHSO      0.8867
 XZHS       0.508
 IMSLAB        5
 XLHS       0.508
 XDHSO      0.0143
 ZTHS       3.4485
 ZBHS       2.9405
END
*
* scrap basket # 1 - copper spoke
* width = 6*2*1/8" = 0.0381 m
* AHS= 0.5423 x 0.0381 = 0.02066
* AHSS1= (0.2842-0.2365)*0.5423 = 0.02589
```

```
*
SINKS         10
*
 SAME_AS       3
 IGEOM         1
 IREGO         1
 IMATHS        3
 XRI         0.0
 XRO         0.169
 AHS         0.02066
 IREGS1        1
 AHSS1       0.02589
 IMSLAB       20
 XLHS        0.541
 XZHS        0.541
 ZTHS        3.4815
 ZBHS        2.9405
END
*
* scrap basket # 1 - basket shroud
* Make EHSO very small to stop radiation to MCO wall
* Copper block to MCO wall ht across the gap
* is modeled separately
*
SINKS         11
*
 SAME_AS       1
 IREGI         1
 IREGO         1
 IMATHS        3
 EHSO        1.E-6
 XRI         0.2842
 XRO         0.2874
 AHS         0.9720
 IMSLAB        3
 XLHS        0.541
 XZHS        0.541
 ZTHS        3.4815
 ZBHS        2.9405
END
*
* scrap basket # 1 - MCO wall
*
* SET GAP DISTANCE XDHSI TO 0.0143M,
* 0.00476M BETWEEN MCO WALL AND BASKET WALL PLUS
* TWO 3/16" GAP BETWEEN BASKET WALL AND COPPER BLOCK,
* TO MODEL HEAT FLOW ACROSS THE GAP
*
SINKS         12
*
 SAME_AS      11
 IREGI         1
! IREGO         7
! Set MCO outer wall temperature
 IREGO        -1
 TOHS        50.0
 IMATHS        2
 XRI         0.2921
 XRO         0.3048
 AHS         1.1026
 XLHS        0.5881
 XDHSI       0.0143
 XZHS        0.5881
 ZTHS        3.4981
 ZBHS        2.9405
END
*********************************************************************
*
* scrap basket # 2 - Tier 5
*
*********************************************************************
```

```
*
* scrap basket # 2 - bottom plate
*
SINKS       193         194         195
*
 SAME_AS     93          94          95
 IREGI        0           0           0
 IREGO        0           0           0
 ZTHS        2.3524      2.3524      2.3524
 ZBHS        2.3207      2.3207      2.3207
END
*
SINKS       196         197         198         199
*
 SAME_AS     96          97          98          99
 IREGI        0           0           0           0
 IREGO        0           0           0           0
 ZTHS        2.3524      2.3524      2.3524      2.3524
 ZBHS        2.3207      2.3207      2.3207      2.3207
END
*
* scrap basket # 2 - insert
*
SINKS       101
*
 SAME_AS      1
 IREGI        2
 IREGO        2
 ZTHS         2.9088
 ZBHS         2.3524
END
*
* scrap basket # 2 - dip tube
*
SINKS       102
*
 SAME_AS      2
 IREGI        2
 IREGO        2
 ZTHS         2.9088
 ZBHS         2.3524
END
*
* scrap basket # 2 - copper spoke
*
SINKS       110
*
 SAME_AS     10
 IREGI        2
 IREGO        2
 IREGS1       2
 ZTHS         2.8934
 ZBHS         2.3524
END
*
* scrap basket # 2 - basket shroud
*
SINKS       111
*
 SAME_AS     11
 IREGI        2
 IREGO        2
 ZTHS         2.8934
 ZBHS         2.3524
END
*
* scrap basket # 2 - MCO wall
*
SINKS       112
*
 SAME_AS     12
```

```
 IREGI        2
 ZTHS         2.9405
 ZBHS         2.3524
END
*****************************************************************
*
* scrap basket # 3 - Tier 4
*
*****************************************************************
*
*
* scrap basket # 3 - sludge
*
SINKS       204         205
*
 SAME_AS      4           5
 IREGI        3           3
 IREGO        3           3
 ZTHS         2.2723      2.2723
 ZBHS         1.7643      1.7643
END
*
SINKS       206         207         208         209
*
 SAME_AS      6           7           8           9
 IREGI        3           3           3           3
 IREGO        3           3           3           3
 ZTHS         2.2723      2.2723      2.2723      2.2723
 ZBHS         1.7643      1.7643      1.7643      1.7643
END
*
* scrap basket # 3 - bottom plate
*
SINKS       293         294         295
*
 SAME_AS     93          94          95
 ZTHS         1.7643      1.7643      1.7643
 ZBHS         1.7326      1.7326      1.7326
END
*
SINKS       296         297         298         299
*
 SAME_AS     96          97          98          99
 ZTHS         1.7643      1.7643      1.7643      1.7643
 ZBHS         1.7326      1.7326      1.7326      1.7326
END
*
* scrap basket # 3 - insert
*
SINKS       201

 SAME_AS      1
 IREGI        3
 IREGO        3
 ZTHS         2.3207
 ZBHS         1.7643
END
*
* scrap basket # 3 - dip tube
*
SINKS       202
*
 SAME_AS      2
 IREGI        3
 IREGO        3
 ZTHS         2.3207
 ZBHS         1.7643
END
*
* scrap basket # 3 - copper back plate (block)
*
```

```
SINKS       203
*
 SAME_AS      3
 IREGO        3
 ZTHS         2.2723
 ZBHS         1.7643
END
*
* scrap basket # 3 - copper spoke
*
SINKS       210
*
 SAME_AS     10
 IREGI        3
 IREGO        3
 IREGS1       3
 ZTHS         2.3053
 ZBHS         1.7643
END
*
* scrap basket # 3 - basket shroud
*
SINKS       211
*
 SAME_AS     11
 IREGI        3
 IREGO        3
 ZTHS        2.3053
 ZBHS        1.7643
END
*
* scrap basket # 3 - MCO wall
*
SINKS       212
*
 SAME_AS     12
 IREGI        3
 ZTHS        2.3524
 ZBHS        1.7643
END
*
*****************************************************************
*
* scrap basket # 4 - Tier 3
*
*****************************************************************
*
* scrap basket # 4 - bottom plate
*
SINKS       393         394         395
*
 SAME_AS     93          94          95
 ZTHS        1.1762      1.1762      1.1762
 ZBHS        1.1457      1.1457      1.1457
END
*
SINKS       396         397         398         399
*
 SAME_AS     96          97          98          99
 ZTHS        1.1762      1.1762      1.1762      1.1762
 ZBHS        1.1457      1.1457      1.1457      1.1457
END
*
* scrap basket # 4 - insert
*
SINKS       301
*
 SAME_AS      1
 IREGI        4
 IREGO        4
 ZTHS         1.8393
```

```
 ZBHS          1.1457
END
*
* scrap basket # 4 - dip tube
*
SINKS        302
*
 SAME_AS       2
 IREGI         4
 IREGO         4
 ZTHS          1.8393
 ZBHS          1.1457
END
*
* scrap basket # 4 - copper spoke
*
SINKS        310
*
 SAME_AS      10
 IREGI         4
 IREGO         4
 IREGS1        4
 ZTHS          1.8393
 ZBHS          1.1762
END
*
* scrap basket # 4 - basket shroud
*
SINKS        311
*
 SAME_AS      11
 IREGI         4
 IREGO         4
 ZTHS         1.8393
 ZBHS         1.1762
END
*
* scrap basket # 4 - MCO wall
*
SINKS        312
*
 SAME_AS      12
 IREGI         4
 ZTHS         1.8393
 ZBHS         1.1762
END
*
**********************************************************************
*
* scrap basket # 5 - Tier 2
*
**********************************************************************
*
* scrap basket # 5 - sludge
*
SINKS        404          405
*
 SAME_AS       4            5
 IREGI         5            5
 IREGO         5            5
 ZTHS          1.0961       1.0961
 ZBHS          0.5881       0.5881
END
*
SINKS        406          407          408          409
*
 SAME_AS       6            7            8            9
 IREGI         5            5            5            5
 IREGO         5            5            5            5
 ZTHS          1.0961       1.0961       1.0961       1.0961
 ZBHS          0.5881       0.5881       0.5881       0.5881
```

```
END
*
* scrap basket # 5 - bottom plate
*
SINKS        493          494          495
*
 SAME_AS      93           94           95
 ZTHS         0.5881       0.5881       0.5881
 ZBHS         0.5564       0.5564       0.5564
END
*
SINKS        496          497          498          499
*
 SAME_AS      96           97           98           99
 ZTHS         0.5881       0.5881       0.5881       0.5881
 ZBHS         0.5564       0.5564       0.5564       0.5564
END
*
* scrap basket # 5 - insert
*
SINKS        401
*
 SAME_AS       1
 IREGI         5
 IREGO         5
 ZTHS          1.1445
 ZBHS          0.5881
END
*
* scrap basket # 5 - dip tube
*
SINKS        402
*
 SAME_AS       2
 IREGI         5
 IREGO         5
 ZTHS          1.1445
 ZBHS          0.5881
END
*
* scrap basket # 5 - Copper Back Plate
*
SINKS        403
*
 SAME_AS       3
 IREGO         5
 ZTHS          1.0961
 ZBHS          0.5881
END
*
* scrap basket # 5 - copper spoke
*
SINKS        410
*
 SAME_AS      10
 IREGI         5
 IREGO         5
 IREGS1        5
 ZTHS          1.1291
 ZBHS          0.5881
END
*
* scrap basket # 5 - basket shroud
*
SINKS        411
*
 SAME_AS      11
 IREGI         5
 IREGO         5
 ZTHS         1.1291
 ZBHS         0.5881
```

```
END
*
* scrap basket # 5 - MCO wall
*
SINKS        412
*
 SAME_AS      12
 IREGI         5
 ZTHS         1.1762
 ZBHS         0.5881
END
*
*********************************************************************
*
* scrap basket # 6 - Tier 1, bottom tier
*
*********************************************************************
*
* scrap basket # 6 - bottom plate
*
SINKS        593          594          595
*
 SAME_AS      93           94           95
 ZTHS         0            0            0
 ZBHS        -0.03048     -0.03048     -0.03048
END
*
SINKS        596          597          598          599
*
 SAME_AS      96           97           98           99
 ZTHS         0            0            0            0
 ZBHS        -0.03048     -0.03048     -0.03048     -0.03048
END
*
* scrap basket # 6 - insert
*
SINKS        501
*
 SAME_AS       1
 IREGI         6
 IREGO         6
 ZTHS          0.5564
 ZBHS          0.0
END
*
* scrap basket # 6 - dip tube
*
SINKS        502
*
 SAME_AS       2
 IREGI         6
 IREGO         6
 ZTHS          0.5564
 ZBHS          0.0
END
*
* scrap basket # 6 - copper spoke
*
SINKS        510
*
 SAME_AS      10
 IREGI         6
 IREGO         6
 IREGS1        6
 ZTHS          0.541
 ZBHS          0
END
*
* scrap basket # 6 - basket shroud
*
SINKS        511
```

```
*
 SAME_AS      11
 IREGI         6
 IREGO         6
 ZTHS          0.541
 ZBHS          0
END
*
* scrap basket # 6 - MCO wall
*
SINKS        512
*
 SAME_AS      12
 IREGI         6
 ZTHS          0.5881
 ZBHS          0
END
*
*          CASK WALL     MCO BOT      MCO LID
SINKS        676           677          678
*
 IGEOM         0             1            1
 IORIHS        0             1            2
 IMATHS        2             2            2
 XRI          0.3199        0.0          0.0
 XRO          0.5056        0.0508       0.29
 AHS          10.24         0.29         0.29
 XZHS         3.95          0.3          0.3
 TIINIT       50.00         50.00        50.00
 TOINIT       50.00         50.00        50.00
 IMSLAB       10            5            20
 IREGI         7             6            1
 TIHS         0.0           0.0          0.0
 IREGO         8            -1            8
 TOHS         0.0           50.0         0.0
 XIHS         0.02          0.001        0.02
 XLHS         3.95          0.3          0.3
 EHSI         0.3           0.3          1.0
 EHSO         0.3           0.3          0.3
 ZTHS          4.3924       -0.03048     3.9948
 ZBHS         -0.01452      -0.08128     3.7048
END
*
MATERIAL LIBRAY
*
* MATERIAL LIBRARY - SPECIFY MATERIAL PROPERTIES FOR MATERIAL 'imaths'
* UPTO 20 (INMAT) MATERIALS CAN BE SPECIFIED
* SYNTAX:
*
* URANIUM         1       17102.   26.9    130.    1957.     0.7       0.7
* OLD INPUTS:
* decay power per unit sludge volume for fuel piece sludge is 1100 W/m^3
* in the code, decay power = qv*(1-porosity)*volhs
* therefore, qv= 1100 W/m^3 / (1-porosity) = 1100 / (1 - 0.50526) = 2223.4 W/m^3
* URANIUM         1       19000.   26.9    130.    2223.4    0.7       0.7
* NEW METHOD:
* Will use 40% void for SB KOP material.
* True solid density = 16.8 MT/m**3 is consistent
* Preserve U metal khs, cp
* Preserve SB decay power Qm=117W/MTU
* Qv = Qm [W/MTU]*fu[MTU/MT]*rho[MT/m**3]
*    = 117 * 0.825 * 15.667 = 1512.3
*
* NEW METHOD FOR 25% VOID:
* KOP material solid particles are 82.63% uraninum and 17.37% zirconium by volume.
* f_void    =   0.25;   // vol-%
* f_metal   = 1.0 - f_void;
* fv_Zr     = 0.1737;   // vol-%
* fv_U      = 1 - fv_Zr
*           = 0.8263
* rho_Zr    =   6520;   // kg/m^3
```

```
* rho_U      =  19000;   // kg/m^3
* cp_Zr      =    278;   // J/kg/k
* cp_U       =    120;   // J/kg/k
* q_m        =  0.117;   // W/kg
*
* q_v        = q_m * rho_U * fv_U
*            = 1836.8649  // W/m^3
*
* rho_metal = fv_U * rho_U + fv_Zr * rho_Zr
*           = 16832.224  // kg/m^3
*
* cp_metal  = (fv_U * rho_U * cp_U + fv_Zr * rho_Zr * cp_Zr) / rho_metal
*           = 130.63073  // J/kg/k
*
* name          imaths     rho      khs      cp       qv      ehsi      ehso
  URANIUM          1       16832.   26.9    131.    1837.     0.7       0.7
  STAINLESS-STEEL 2         8000.   16.0    500.       0.     0.3       0.3
  COPPER           3        8954.  398.0    384.       0.     0.7       0.7
END
*
* 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
*
* 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
*
* 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  hs1  hgap1  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
* 0.005524 M.  THEREFORE, THE GAP CONDUCTANCE IS 0.03/0.005524=5.4 W/m^2/C
*
* 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 #278)
*  COND_NETWORK NET=1 -278  22
*                            77
*                           132
*                           187
*                           242
* MODEL CONTIGUOUS INSERT
*  COND_NETWORK NET=2        21
*                            76
*                           131
*                           186
*                           241
* MODEL CONTIGUOUS MCO WALL CONNECTED TO THE SHIELD PLUG(HS #278)
*  COND_NETWORK NET=3 -278  51  106   161   216   271
```

```
*
*
* BETWEEN THE INSERT AND THE DIP TUBE, THERE IS A AIR GAP OF THICKNESS
* 0.005524 M.  THEREFORE, THE GAP CONDUCTANCE IS 0.03/0.005524=5.4 W/m^2/C
  SANDWICH   1 5.4   2
  SANDWICH 201 5.4 202
  SANDWICH 401 5.4 402
*
* BETWEEN COPPER BLOCK AND SLUDGE
  SANDWICH  3  1000  4
  SANDWICH 23  1000 24
  SANDWICH 43  1000 44
  SANDWICH 63  1000 64
  SANDWICH 83  1000 84
  SANDWICH 203  1000 204
  SANDWICH 223  1000 224
  SANDWICH 243  1000 244
  SANDWICH 263  1000 264
  SANDWICH 283  1000 284
  SANDWICH 403  1000 404
  SANDWICH 423  1000 424
  SANDWICH 443  1000 444
  SANDWICH 463  1000 464
  SANDWICH 483  1000 484
* NETWORKS
*
* BASKET 1 -  FUEL PIECE SLUDGE
  COND_NETWORK NET=1    4  94
  COND_NETWORK NET=2    5  95
  COND_NETWORK NET=3    6  96
  COND_NETWORK NET=4    7  97
  COND_NETWORK NET=5    8  98
  COND_NETWORK NET=6    9  99
* BASKET 1 - SS-BACK-PLATE
  COND_NETWORK NET=7    3  93
*
* BASKET 3 -  FUEL PIECE SLUDGE
  COND_NETWORK NET=8  204  294
  COND_NETWORK NET=9  205  295
  COND_NETWORK NET=10 206  296
  COND_NETWORK NET=11 207  297
  COND_NETWORK NET=12 208  298
  COND_NETWORK NET=13 209  299
* BASKET 3 - SS-BACK-PLATE
  COND_NETWORK NET=14 203  293
*
* BASKET 5 -  FUEL PIECE SLUDGE
  COND_NETWORK NET=15  404  494
  COND_NETWORK NET=16  405  495
  COND_NETWORK NET=17  406  496
  COND_NETWORK NET=18  407  497
  COND_NETWORK NET=19  408  498
  COND_NETWORK NET=20  409  499
* BASKET 5 - SS-BACK-PLATE
  COND_NETWORK NET=21  403  493
*
END HEAT_SINKS ! HEAT_SINKS is a comment
*-------------------------------------------------------------------------
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 faiure 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 faiure junction, it is the pressure differential required
*          to fail from the downstream compartment to the uptream compt.
*          for check valve junction, it is the differential pressure
*          at which the opened check valve closes
*  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        5          4          3          2          1
        IR2        4          3          2          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     0.01       0.01       0.01       0.01      10.
        AJN      0.025      0.025      0.025      0.025      0.0
        Z1JN     0.5781     0.5781     0.5781     0.5781    10.
        Z2JN     0.0        0.0        0.0        0.0       12.65
        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
        SAME_AS    1
        IR1        6
        IR2        5
        Z1JN      0.60859
     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  0        ! =0, no diversion heat transfer calculation
                   ! =1, normal diversion heat transfer calculation
                   ! =2, suppress the individual diversion when
                   !         QTDVRT>0 but Tfi<Tgas, or
                   !         QTDVRT<0 but Tfi>Tgas
                   ! =3, suppress the individual diversion when
                   !         QTDVRT>0 but Tfi<Tgas
  IEVAP   1        ! =1, do evaporation/condensation of water
                   ! =0, do not do evaporation/condensation
```

```
  ILAW    3       ! oxidation rate law, 0 - McGillivrary/Ritchie
                  !                     1 - Pearce
                  !                     2 - Trimble
                  !                     3 - Databook
                  !                     4 - Databook + oxygen free Trimble
  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  0       ! =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
  ILIMITDIF 1     ! =1, steam flow in scrap bed is diffusion limited
                  !     if there is no water on fuel surface,
                  !        steam needs to diffuse into the bed to react with U
                  !     if there is water on fuel surface,
                  !        steam for reaction is provided locally by evaporated water
                  !     water on fuel surface evaporates at the same rate as reaction
                  !     consumption unless it is boiling
                  ! =0, steam flow in scrap bed is not diffusion limited
                  !
  XTFMIN  1.E-3   ! minimum water film thickness below which the the wetted
                  ! surface starts to uncover
   IHSCSK 0       ! define the cask heat sink
                  ! set to zero to enable fix T boundary condition on MCO wall
   IRGAP   7       ! 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 raditive heat transfer between the
                   !     fuel/scrap and the lid/floor
                  ! =1, fully account for the radiative heat transfer
   HCONTACTSC 1.0E-7  ! scrap to scrap basket wall contact conductance
*
* 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, overides 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
   PUMP  1       8       0      0    1.652E-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
*
* Automatically generate the basket structure heat sinks with AXIAL command
*
   AUTO_INSERT     1
   AUTO_DIPTUBE    1
   AUTO_BACKPLATE  1
```

```
   AUTO_SPOKE      1
   AUTO_SHROUD     1
   AUTO_MCOWALL    1
*
 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 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
* WH2Fl 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
* QEVPFL, QEVPSC, 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
*
    CORRODH2
    WH2TT
    MH2TT
    QDECSC 5  1  2  3  4  5
    QDECSC 5  6  7  8  9 10
    QDECSC 5 11 12 13 14 15
    QDECTT
    UDECTT
    QOXOTT
    UOXOTT
    QOXWSC 5  1  2  3  4  5
    QOXWSC 5  6  7  8  9 10
    QOXWSC 5 11 12 13 14 15
    QOXWTT
    UOXWTT
    QINTT
    UINTT
    QLIDTT
    ULIDTT
```

```
    QGASTT
    UGASTT
    QEVPSC 5  1  2  3  4  5
    QEVPSC 5  6  7  8  9 10
    QEVPSC 5 11 12 13 14 15
    QEVPTT
    UEVPTT
    QCNDTT
    UCNDTT
    QOUTTT
    UOUTTT
    UINTGT
    UMCO
    FUERR
    TOTUO2
    ERCSC  6  1 2  3  4  5  6
 END PLOT
*
 SOLAR_RAD
*
* pointers to heat sinks representing the cask wall and the top
* solar radiation impinges on these
* set IHCASK to zero to impose 40 C water jacket temperature on MCO wall
* otherwise the code sets IREGO(imco) to zero
*
  IHCASK   0
  IHTOP    278
*
* 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
 END SOLAR_RAD
*
 SCRAP_BSKT  3    ! Total number of scrap baskets
*
* First scrap basket (top)
*
  IHSSC    4  5  6  7  8  9   ! radial outward
*
   ISCINS   1     ! define the adjacent center insert heat sink,
                  ! 0 for no insert
   ISCBPT   3     ! define the back plate heat sink
   ISCSPK  10     ! define the spoke heat sink
   ISCFIN  11     ! define copper fin heat sink
   ISCMCO  12     ! define the adjacent MCO wall heat sink
   ISCLID   0     ! define the lid or floor heat sink to which the scrap
                  ! radiate to, negative to radiate to floor
* mulitiplier for effective conductivity in scrap basket in the order read in
* (only conduction part)
   FKSC  1.0  1.0  1.0  1.0  1.0  1.0
* mulitiplier for effective conductivity in scrap basket in the order read in
* (only radiation part)
   FRSC  1.0  1.0  1.0  1.0  1.0  1.0
* porosity of the scrap for each heat sink in the order read in
* OLD:
* to match Umet of 9400 kg/m^3, (1 - FPOROS)*19000 = 9400, or FPOROS= 0.50526
* note: FPOROS includes volume of water, gas, and non-Umetal
* NEW:
* FPOROS=true porosity; adjust URANIUM properties for solids
   FPOROS  0.25  0.25  0.25  0.25  0.25  0.25
* particle size for thermal conductivity in the order read in (m)
   XDSCRP  0.001   0.001   0.001   0.001   0.001   0.001
```

```
   XRSCBK  0.2842  ! radius of scrap basket (m)
   XHSCBK  0.5413  ! 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.
* f_metal    = 1 - f_void;
*            =     0.75;
* d_particle = 1500.E-6;   // m
* f_sat      =     0.08;
* rho_w      =     1000;   // kg/m^3
*
* for 25% void, Cumet = (1-0.25)/0.6*9400 = 11750 kg/m^3
* C_U = (f_metal / 0.6) * 9400 // kg/m^3
*     = 11750.
*
* Hence, 6 Cumet / D / rhom = 6 * 11750 / 0.0006 / 19000 = 6184/m
* AdV_ox = 6 * C_U / d_particle / rho_U // m^-1
* 6 Cumet / D / rhom = 6 * 11750 / 0.0006 / 19000 = 6184/m
   AVOXSC  6184.  6184.  6184.  6184.  6184.  6184.
   FOXSC   10  0     ! multiplier for AVOXSC
*
* Sat * porosity * rhow = 0.12 * 0.25 * 1000 = 30 kg/m^3
* mvw_scrap_0 = f_sat * f_void * rho_w // kg/m^3
   MVWSC0  30.0  ! 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  1.E3  ! disable insert to scrap micro-convection
*   XSCMCO  0.00476 ! gap distance between scrap basket and MCO wall
   XSCMCO  1.E3  ! disable hx between scrap basket and MCO wall
*
* axial conduction tracked in the scrap basket
*
* top to bottom axial partition
   AXIAL          0.2    0.2    0.2    0.2    0.2
   AXIAL_INDEX      0     21     41     61     81
   AXIAL_FUEL       1      1      1      1      1
* multiplier for FPOROS(porosity of scrap) for each axial basket
   FFPOR  1.0    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    1.0
* multiplier for MVWSC0(initial amount of water per unit volume) for each
* axial basket.
   FMVWSC 1.0    1.0    1.0    1.0    1.0
* multiplier for XDSCR(characteristic scrap size) for each axial basket
   FXDSC  1.0    1.0    1.0    1.0    1.0
* multiplier for FKSC(multiplier for effective conductivity (conduction)
* in scrap)
   FFKSC  1.0    1.0    1.0    1.0    1.0
* multiplier for FRSC(multiplier for effective conductivity (radiation)
* in scrap)
   FFRSC  1.0    1.0    1.0    1.0    1.0
  END IHSSC for 1st scrap basket
*
* Third scrap basket (third from top)
*
  SAME AS SCRAP BASKET 1
*
  IHSSC    204  205  206  207  208  209     ! radial outward
*
   ISCINS  201    ! define the adjacent center insert heat sink,
                  ! 0 for no insert
   ISCBPT  203    ! define the back plate heat sink
   ISCSPK  210    ! define the spoke heat sink
   ISCFIN  211    ! define copper fin heat sink
   ISCMCO  212    ! define the adjacent MCO wall heat sink
```

```
   ISCLID   0      ! define the lid or floor heat sink to which the scrap
                   ! radiate to, negative to radiate to floor
   AXIAL_INDEX    0    221  241   261    281
  END IHSSC for 3rd scrap basket
*
* Fifth scrap basket (fifth from top, second to bottom)
*
  SAME AS SCRAP BASKET 1
*
  IHSSC   404  405  406  407  408  409     ! radial outward
*
   ISCINS 401     ! define the adjacent center insert heat sink,
                  ! 0 for no insert
   ISCBPT 403     ! define the back plate heat sink
   ISCSPK 410     ! define the spoke heat sink
   ISCFIN 411     ! define copper fin heat sink
   ISCMCO 412     ! define the adjacent MCO wall heat sink
   ISCLID   0     ! define the lid or floor heat sink to which the scrap
                  ! radiate to, negative to radiate to floor
   AXIAL_INDEX    0   421  441   461    481
  END IHSSC for 5th scrap basket
END SCRAP_BSKT
END MCO
```

A.2 Case 2: KOP_VACXDG_19.DAT KOP with Degraded Vacuum Pumping and No Helium Purge

```
*-----------------------------------------------------------------------
CONTROL     ! Major keyword group
*-----------------------------------------------------------------------
*
 TITLE      ! Keyword; next line is title, title can be any length
    KOP_VACXDG_19
       Degraded Vacuum Pumping with No Helium Purge
       Case file to be run with the base file KOPC19.DAT
 END TITLE ! Anything after END is a comment
*
 TIMING
    TLAST  64800.0
 END
*
 ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
  ISRC    0     ! User-defined sources
 END ACTIVE MODELS ! ACTIVE MODELS  is a comment
*
END CONTROL     ! End of CONTROL keyword group
*
*-----------------------------------------------------------------------
MCO       ! MCO Major Keyword
*-----------------------------------------------------------------------
 GENERAL          ! Keyword for general inputs
* 13 FT^3/MIN * 1 MIN/60 SEC * 0.02832 M^3/1 FT^3 = 0.006136 M^3/SEC
 PUMP IRIPUM  IROPUM  ICONPM ITFEED  WVPUMP   WVFEED  TGFEED  TCONPM
   PUMP  1       8       0      0    6.136E-3  0.0      0.0     0.0
 END GENERAL          ! GENERAL is a comment
END MCO
```

A.3 Case 3: KOP_OVLOCXSP_19.DAT Open MCO with Loss of Annulus Water

```
*-----------------------------------------------------------------------
CONTROL    ! Major keyword group
*-----------------------------------------------------------------------
*
 TITLE     ! Keyword; next line is title, title can be any length
    KOP_OVLOCXSP_19
       Open MCO with Loss of Annulus Water
       Case file to be run with the base file KOPC19.DAT
 END TITLE ! Anything after END is a comment
*
 ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
  ISRC    0    ! User-defined sources
 END ACTIVE MODELS ! ACTIVE MODELS  is a comment
*
END CONTROL    ! End of CONTROL keyword group
*
* Major keyword-----------------------------------------------------
HEAT_SINKS
*-----------------------------------------------------------------------
SINKS         12   112   212   312   412
 IREGO         7     7     7     7     7
END
*
SINKS        512
 IREGO         7
END
END HEAT_SINKS
```

A.4 Case 4: KOP_COOLSPRS_19.DAT Cooling of MCO and KOP Sludge After Vacuum Drying

```
*---------------------------------------------------------------------
CONTROL    ! Major keyword group
*---------------------------------------------------------------------
*
*
 TITLE     ! Keyword; next line is title, title can be any length
    KOP_COOLSPRS_19
       Cooling of MCO with KOP sludge after Vacuum Drying
       200 g of free water
       MCO pressurized with helium to a pressure of 4 psig
       17 C cooling water injected to the annulus at a rate of 15 gpm

       At the end of vacuum cycle, the copper blocks are 58.8 C.
       The KOP sludge center temperature is 60.9 C.
 END TITLE ! Anything after END is a comment
*
*
 TIMING    ! Keyword
  TSTART         0.          !  START TIME, >0 FOR RESTART RUN
*  RESTART_FILE    VCKOP1.RER  !  RESTART FILE NAME FOR RESTART RUN
                              !  IF NOT SPECIFIED, READ FROM
                              !  'input deck name'.RER
  TLAST      36000.           !  END TIME (Seconds) - 36 HOURS
* 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 mimium 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       0.001        !  MIN TIMESTEP (Seconds)
   DTMAX                    !  MAX TIMESTEP (Seconds)
   0.           0.001
    .100        0.01
   1.000        0.1
  10.000        1.0
    DTPRIN       1800.       !  PRINT INTERVAL (Seconds)
   PLTMIN        10.         !  MIN PLOT INTERVAL (Seconds)
   PLTMAX       100.         !  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     0.2           !  MAXIMUM TIME STEP WHEN THE CORROSION IS
                             !  STEAM STARVED
 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  1  677
  HS  5   3  23  34  43  63  83
  HS  5 203 223 234 243 263 283
```

```
  HS  5 403 423 434 443 463 483
 END PRINT  ! PRINT is a comment
*
 PLOT 1    ! 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        6    1   2   3   4   5   6          ! Temperature in MCO
  LIQ-T        1    6                              ! Liq Temperature in MCO
  LIQ-MASS STEAM   1    6                              ! Liq MASS
  HS-TA        5    9   49  69  89  99                 ! Tier 6 (top), vertical thru scrap
  HS-TA        10   63  64  65  66  67  68  69  70  71  72  ! Tier 6, back-plate, scrap, spoke,
shroud, MCO
  HS-TA        5    209 249 269 289 299                ! Tier 4, vertical thru scrap
  HS-TA        10   263 264 265 266 267 268 269 270 271 272 ! Tier 4, back-plate, scrap, spoke,
shroud, MCO
  HS-TA        5    409 449 469 489 499                ! Tier 2, vertical thru scrap
  HS-TA        10   463 464 465 466 467 468 469 470 471 472 ! Tier 2, back-plate, scrap, spoke,
shroud, MCO
  HS-TA        3    676 677 678                    ! Cask, MCO bott & lid
 END PLOT
 *
 PLOT 2
  GAS-X  NITROGEN   6   1   2   3   4   5   6   ! N2 %
  GAS-X  OXYGEN     6   1   2   3   4   5   6   ! O2 %
  GAS-X  STEAM      6   1   2   3   4   5   6   ! H2O %
  GAS-X  HYDROGEN   6   1   2   3   4   5   6   ! H2 %
  GAS-X  HELIUM     6   1   2   3   4   5   6   ! He %
  GAS-W             6   1   2   3   4   5   6   ! Junc. flow
  GAS-WV            6   1   2   3   4   5   6   ! Junc. flow
  GAS-WX            6   1   2   3   4   5   6   ! Junc. cc flow
  GAS-MASS  HYDROGEN    1   8                   ! H2 release
  GAS-MASS  STEAM       1   8                   ! H2O release
 END PLOT
*
 PLOT 3
  QGAS-HSO 5  23, 43,  3, 63, 83
  QGAS-HSO 5 223,243,203,263,283
  QGAS-HSO 5 423,443,403,463,483
  QGAS-HSI 5  12  32  52  72  92
  QGAS-HSI 5 212 232 252 272 292
```

```
  QGAS-HSI 5 412 432 452 472 492
  QRAD-HSO 5  23, 43,  3, 63, 83
  QRAD-HSO 5 223,243,203,263,283
  QRAD-HSO 5 423,443,403,463,483
  QRAD-HSI 5  12  32  52  72  92
  QRAD-HSI 5 212 232 252 272 292
  QRAD-HSI 5 412 432 452 472 492
 END PLOT  ! PLOT is a comment
*
 PLOT 4
  GAS-T 7    8  9  10  11  12  13  14          ! gap water temp.
  HS-TA 5    12  32  52  72  92                ! MCO wall temp., tier 6
  HS-TA 1   112                                ! MCO wall temp., tier 5
  HS-TA 5   212 232 252 272 292                ! MCO wall temp., tier 4
  HS-TA 1   312                                ! MCO wall temp., tier 3
  HS-TA 5   412 432 452 472 492                ! MCO wall temp., tier 2
  HS-TA 1   512                                ! MCO wall temp., tier 1
 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
  IHXPOL  1    ! Heat and Mass transfer on liquid pool
  IASED   0    ! Aerosol Sedimentation
  IALEAK  0    ! Aerosol Leakage
  IFOG    0    ! Fog formation
  ISRC    1    ! User-defined sources
  IMCO    1    ! MCO models
  ISENS   0    ! Sensitivity runs
  IPLTYP  2    ! 1=wrap around, 2=no wrap (spreadsheet format)
 END ACTIVE MODELS ! ACTIVE MODELS  is a comment
*
 MODEL         ! keyword for model parameters
* multipliers for region gas conductivities
* syntax:
*   FKGAS  fkgas1  fkgas2  fkgas3  ...
 FLOWKBED  0.0066
 FLANGM    0.1
* multiplier to heat sink to liquid pool hx coefficient
 FHHSL    10.0
 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:
* 1.5 FT^3/MIN * 1 MIN/60 SEC * 0.02832 M^3/1 FT^3 = 0.0007080 M^3/SEC
* He density @ stp is 0.16 kg/m^3, hence 1.13e-4 kg/s
*
 SOURCES 1                    !-- KEYWORD AND # SOURCE GROUPS
*
* 17 C cooling water injected to the annulus at a rate of 15 gpm
*
  REGION  9  GASES 1          !-- REGION #, # GASES
  WATER                       !-- GAS NAMES MUST BE ON NEXT LINE
   0    17.0 0.95  0.E0
   1.E6 17.0 0.95  0.E0
  END REGION                  !-- ENDS A REGION SOURCE
 END SOURCE                   !-- ENDS ALL SOURCE INPUT
*
END CONTROL    ! End of CONTROL keyword group
*
EVENTS
 SET 1 WHEN PR(1) < 1000
 CONTROL
  ACTIVE MODELS
   IHXPOL   0          ! Turn off Pool Evaporation
  END ACTIVE
```

```
 END CONTROL
 END WHEN

 SET 2 WHEN PR(1) < 6600
 CONTROL
  ACTIVE MODELS
   ISRC   0          ! Turn off He source
  END ACTIVE
 END CONTROL
 END WHEN
END EVENTS
*
*-------------------------------------------------------------------------
VOLUMES
*-------------------------------------------------------------------------
* total free volume in MCO is 0.9544 m^3
* volume of six scrap baskets is 6*0.0348 = 0.2088 m^3
* volume of KOP material in one basket = 6*0.00139 m^3 = 0.00834 m^3
* volume of copper block in one basket = 6*0.01245 m^3 = 0.07470 m^3
* Therefore, gas volume in MCO = 0.9544-0.2088-3*(0.00834+0.07470)
*                              = 0.49648 m^3
* Distribute the volume equally among six tiers:
*    VOLUME = 0.49648/6 = 0.08275 m^3 per tier
*
* 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 6 each contain a basket, top to bottom
*              scrap1     scrap2      scrap3      scrap4      scrap5
 REGIONS        1          2           3           4           5
  VOLUME       0.08275    0.08275     0.08275     0.08275     0.08275
  SED_AREA     0.172      0.172       0.172       0.172       0.172
  ZTOP         0.7643     0.5881      0.5881      0.5881      0.5881
  ELEVATION    2.9405     2.3524      1.7643      1.1762      0.5881
  TEMP_GAS     58.8       58.8        58.8        58.8        58.8
  PRESSURE     1.013E5    1.013E5     1.013E5     1.013E5     1.013E5
 END REGIONS
*
* Note on scrap6 Z_LIQ estimate:
* Liquid in this region is displaced by a 1.5" thick basket bottom plate, a
* 6-5/8" diameter center post and six trapezoidal outer posts having a total
* cross-sectional area of 17.34 sq-in. For 20 liters of water, the elevation
* of the water surface (Z_LIQ) is the the basket bottom plate thickness (1.5")
* plus the basket volume divided by the basket cross-sectional area less the
* area occupied by the center and outer posts. For a basket diameter of
* 22.675", the liquid level turns out to be 4.9672".
*
* r_basket         11.3375 [in]      0.2880 [m]
* r_cpost           3.3125 [in]      0.0841 [m]
* h_heel            1.5    [in]      0.0381 [m]
* bt_minor_opost    1.23   [in]      0.0312 [m]
* bt_major_opost    2.757  [in]      0.0700 [m]
* ht_opost          1.45   [in]      0.0368 [m]
* z_top            23.167  [in]      0.5884 [m]
* m_liq            20      [kg]
* rho_liq           1      [g/cm3]
*
* h_post           21.667  [in]      0.5503 [m] = z_top - h_heel
*
* A_basket        403.8169 [in2]     0.2605 [m2] = pi * r_basket^2
* A_cpost          34.4716 [in2]     0.0222 [m2] = pi * r_cpost^2
* A_oposts         17.3435 [in2]     0.0112 [m2]
*          = 6 * (bt_minor_opost + bt_major_opost)/2 * ht_opost
*
* V_heel          605.73   [in3]     0.0099 [m3] = A_basket * h_heel
* V_liq          1220.4    [in3]     0.0200 [m3]
*
* z_liq_noposts     4.5223 [in]      0.1149 [m]
*               = h_heel + V_liq / A_basket
* z_liq             4.9672 [in]      0.1262 [m]
```

```
*               = h_heel + V_liq / (A_basket - Acpost - A_oposts)
*
* This also requires a change to VOLUME:
*
* VOLUME = V_liq * ZTOP / Z_LIQ = 0.0933 [m^3]
*
*              scrap6      gap      environment
 REGIONS          6          7           8
  VOLUME       0.0933     0.25         1.E9
  SED_AREA     0.172       0.0          0.0
  ZTOP         0.5881     4.4069        1.E3
  ELEVATION   -0.03048    -0.01452      0.0
  TEMP_GAS     58.8       50.0         40.0
  Z_LIQ        0.0        0.0          0.0
  PRESSURE     1.013E5    1.013E5      1.013E5
  HPLGR        5.E0      -1.E0        -1.E0
 END REGIONS  ! REGIONS is a comment
*
*              newCoolGap NewEnviron
 REGIONS          9          10
  VOLUME       0.00365     1.E9
  SED_AREA     0.0         0.0
  ZTOP         3.7048      1.E3
  ELEVATION    0.0         0.0
  TEMP_GAS     50.0        45.5
  PRESSURE     1.013E5    1.289E5
 END REGIONS
*
 REGIONS          11          12          13          14
  VOLUME       0.0168      0.0168      0.0168      0.0365
  SED_AREA     0.0         0.0         0.0         0.0
  ZTOP         2.205       0.5881      0.5881      1.9405
  ELEVATION   -0.03048     0.5881      1.1762      1.7643
  TEMP_GAS     50.0        50.0        50.0        50.0
  PRESSURE     1.013E5    1.013E5     1.013E5     1.013E5
 END REGIONS
*
* 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       1.0        1.0        1.0        1.0        1.0
 END GASES
*
* If there are more than five regions, continue here.
* Gap is artificial here, MCO wall will be set to 40 C
*
  GASES           6          7          8
   HELIUM       1.0        0.0        0.0
   STEAM        0.0        0.01       0.0
   OXYGEN       0.0        0.20       0.21
   NITROGEN     0.0        0.79       0.79
  END GASES          ! GASES is a comment
*
 GASES            9          10
  HELIUM         0.0        0.995
  STEAM          0.0        0.005
  WATER          1.0        0.0
 END GASES
*
 GASES           11          12          13          14
  WATER          1.0         1.0         1.0         1.0
 END GASES
*
 LIQUIDS         6
  STEAM        1.0
 END LIQUIDS
*
* 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          8
*  STEAM        0.0        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_TIMETG
*   EXTRAPOLATION_TIMEPG
*   TIMEP  IREG  TIME1, TIME2...
*   PRFIX  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
*  TIMEP 1   0.0    100.     200.
*  PRFIX  1   1.E5   1.2E5    1.4E5
*
END VOLUMES ! VOLUMES is a comment
*
*
* Major keyword-----------------------------------------------------------
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/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 cylindrical, thickness(m) for planar
```

```
* AHS     One-sided average 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. Use 1 for lumped heat sink
* 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)
*
*********************************************************************
*
* scrap basket # 1 - Tier 6, top tier
*
*********************************************************************
*
* scrap basket # 1 - sludge
*
* Preserve half the thickenss of the sludge, 1 inch.
* That is, XRO of HS-9 - XRI of HS-4 = 0.2842 - 0.2715 = 0.0127 m
*
* Determine AHS to preserve the volume of sludge.
* That is, AHS*0.0127 = 6*0.00139 or AHS = 0.6567
*
SINKS         4
*
 IGEOM        0
 IORIHS       0
 IMATHS       1
 IREGI        1
 IREGO        1
 XRI       0.2715
 XRO       0.2736
 AHS       0.6567
 XZHS      0.5080
 TIINIT    60.9
 TOINIT    60.9
 IMSLAB       3
 XLHS      0.5080
 ZTHS      3.4485
 ZBHS      2.9405
END
*
SINKS         5           6           7           8           9
*
 SAME_AS      4           4           4           4           4
 XRI       0.2736      0.2757      0.2779      0.2800      0.2821
 XRO       0.2757      0.2779      0.2800      0.2821      0.2842
 AHS       0.6567      0.6567      0.6567      0.6567      0.6567
 ZTHS      3.4485      3.4485      3.4485      3.4485      3.4485
 ZBHS      2.9405      2.9405      2.9405      2.9405      2.9405
END
*
* scrap basket # 1 - bottom plate - 1.25" (0.03175 m) thick
SINKS         93          94
*
 SAME_AS      4           4
 IMATHS       2           2
 IREGI        0           0
 IREGO        0           0
 XRI       0.1647      0.2715
 XRO       0.2715      0.2736
 AHS       0.04373     0.04373
 IMSLAB       5           3
 XZHS      0.03175     0.03175
 XLHS      0.03175     0.03175
 ZTHS      2.9405      2.9405
 ZBHS      2.9100      2.9100
```

```
END
*
SINKS          95          96          97          98          99
*
 SAME_AS       93          93          93          93          93
 XRI        0.2736      0.2757      0.2779      0.2800      0.2821
 XRO        0.2757      0.2779      0.2800      0.2821      0.2842
 IMSLAB          3           3           3           3           3
 AHS        0.04373     0.04373     0.04373     0.04373     0.04373
 ZTHS        2.9405      2.9405      2.9405      2.9405      2.9405
 ZBHS        2.9100      2.9100      2.9100      2.9100      2.9100
END
*
* scrap basket # 1 - insert
*
SINKS          1
*
 SAME_AS       4
 IMATHS        2
 XRI        0.02223
 XRO        0.03493
 AHS        0.1191
 XZHS       0.5881
 IMSLAB         3
 TIINIT     58.8
 TOINIT     58.8
 XZHS       0.5564
 XLHS       0.5564
 ZTHS       3.4969
 ZBHS       2.9405
END
*
* scrap basket # 1 - dip tube
* height= 0.6631 m
* AHS= pi x (0.00761+0.01670) x 0.6631 = 0.05064
*
SINKS          2
*
 SAME_AS       1
 IMATHS        2
 XRI        0.00761
 XRO        0.01670
 AHS        0.05064
 TIINIT     58.8
 TOINIT     58.8
 XZHS       0.5564
 XLHS       0.5564
 ZTHS       3.4969
 ZBHS       2.9405
END
*
* scrap basket # 1 - 6*38 SQ-IN*20 IN Copper Block
*
* XRO = same as XRI of sludge = 0.2715
* AHS = same as sludge = 0.6567
* Determine XRI to preserve the volume of copper block
* i.e. 0.6567*(0.2715 - XRI) = 6*38*20*0.0254^3
* Or, XRI = 0.1577
*
* SET GAP DISTANCE XDHSO TO 0.0143M,
* 0.00476M BETWEEN MCO WALL AND BASKET WALL PLUS
* TWO 3/16" GAP BETWEEN BASKET WALL AND COPPER BLOCK,
* TO MODEL HEAT FLOW ACROSS THE GAP
*
* ASHSO = 2*ph*(0.2921 - 0.0143)*0.5080 = 0.8867
*
SINKS          3
*
 SAME_AS       4
 IREGI         0
 IREGO         1
```

```
 IMATHS       3
 XRI        0.1577
 XRO        0.2715
 AHS        0.6567
 ASHSO      0.8867
 XZHS       0.508
 IMSLAB       5
 TIINIT     58.8
 TOINIT     58.8
 XLHS       0.508
 XDHSO      0.0143
 ZTHS       3.4485
 ZBHS       2.9405
END
*
* scrap basket # 1 - copper spoke
* width = 6*2*1/8" = 0.0381 m
* AHS= 0.5423 x 0.0381 = 0.02066
* AHSS1= (0.2842-0.2365)*0.5423 = 0.02589
*
SINKS        10
*
 SAME_AS      3
 IGEOM        1
 IREGO        1
 IMATHS       3
 XRI        0.0
 XRO        0.169
 AHS        0.02066
 IREGS1       1
 AHSS1      0.02589
 IMSLAB      20
 TIINIT     58.8
 TOINIT     58.8
 XLHS       0.541
 XZHS       0.541
 ZTHS       3.4815
 ZBHS       2.9405
END
*
* scrap basket # 1 - basket shroud
* Make EHSO very small to stop radiation to MCO wall
* Copper block to MCO wall ht across the gap
* is modeled separately
*
SINKS        11
*
 SAME_AS      1
 IREGI        1
 IREGO        1
 IMATHS       3
 EHSO       1.E-6
 XRI        0.2842
 XRO        0.2874
 AHS        0.9720
 IMSLAB       3
 TIINIT     58.8
 TOINIT     58.8
 XLHS       0.541
 XZHS       0.541
 ZTHS       3.4815
 ZBHS       2.9405
END
*
* scrap basket # 1 - MCO wall
*
* SET GAP DISTANCE XDHSI TO 0.0143M,
* 0.00476M BETWEEN MCO WALL AND BASKET WALL PLUS
* TWO 3/16" GAP BETWEEN BASKET WALL AND COPPER BLOCK,
* TO MODEL HEAT FLOW ACROSS THE GAP
*
```

```
SINKS        12
*
 SAME_AS     11
 IREGI        1
 IREGO       14
 IMATHS       2
 TIINIT     50.0
 TOINIT     50.0
 XRI        0.2921
 XRO        0.3048
 AHS        1.1026
 XLHS       0.5881
 XDHSI      0.0143
 XZHS       0.5881
 ZTHS       3.4981
 ZBHS       2.9405
END
*****************************************************************
*
* scrap basket # 2 - Tier 5
*
*****************************************************************
*
* scrap basket # 2 - bottom plate
*
SINKS       193          194          195
*
 SAME_AS     93           94           95
 IREGI        0            0            0
 IREGO        0            0            0
 ZTHS        2.3524       2.3524       2.3524
 ZBHS        2.3207       2.3207       2.3207
END
*
SINKS       196          197          198          199
*
 SAME_AS     96           97           98           99
 IREGI        0            0            0            0
 IREGO        0            0            0            0
 ZTHS        2.3524       2.3524       2.3524       2.3524
 ZBHS        2.3207       2.3207       2.3207       2.3207
END
*
* scrap basket # 2 - insert
*
SINKS       101
*
 SAME_AS      1
 IREGI        2
 IREGO        2
 ZTHS         2.9088
 ZBHS         2.3524
END
*
* scrap basket # 2 - dip tube
*
SINKS       102
*
 SAME_AS      2
 IREGI        2
 IREGO        2
 ZTHS         2.9088
 ZBHS         2.3524
END
*
* scrap basket # 2 - copper spoke
*
SINKS       110
*
 SAME_AS     10
 IREGI        2
```

```
 IREGO        2
 IREGS1       2
 ZTHS         2.8934
 ZBHS         2.3524
END
*
* scrap basket # 2 - basket shroud
*
SINKS       111
*
 SAME_AS     11
 IREGI        2
 IREGO        2
 ZTHS         2.8934
 ZBHS         2.3524
END
*
* scrap basket # 2 - MCO wall
*
SINKS       112
*
 SAME_AS     12
 IREGI        2
 IREGO       14
 ZTHS         2.9405
 ZBHS         2.3524
END
*********************************************************************
*
* scrap basket # 3 - Tier 4
*
*********************************************************************
*
*
* scrap basket # 3 - sludge
*
SINKS       204          205
*
 SAME_AS      4            5
 IREGI        3            3
 IREGO        3            3
 ZTHS         2.2723       2.2723
 ZBHS         1.7643       1.7643
END
*
SINKS       206          207          208          209
*
 SAME_AS      6            7            8            9
 IREGI        3            3            3            3
 IREGO        3            3            3            3
 ZTHS         2.2723       2.2723       2.2723       2.2723
 ZBHS         1.7643       1.7643       1.7643       1.7643
END
*
* scrap basket # 3 - bottom plate
*
SINKS       293          294          295
*
 SAME_AS     93           94           95
 ZTHS         1.7643       1.7643       1.7643
 ZBHS         1.7326       1.7326       1.7326
END
*
SINKS       296          297          298          299
*
 SAME_AS     96           97           98           99
 ZTHS         1.7643       1.7643       1.7643       1.7643
 ZBHS         1.7326       1.7326       1.7326       1.7326
END
*
* scrap basket # 3 - insert
```

```
*
SINKS       201

 SAME_AS      1
 IREGI        3
 IREGO        3
 ZTHS         2.3207
 ZBHS         1.7643
END
*
* scrap basket # 3 - dip tube
*
SINKS       202
*
 SAME_AS      2
 IREGI        3
 IREGO        3
 ZTHS         2.3207
 ZBHS         1.7643
END
*
* scrap basket # 3 - copper back plate (block)
*
SINKS       203
*
 SAME_AS      3
 IREGO        3
 ZTHS         2.2723
 ZBHS         1.7643
END
*
* scrap basket # 3 - copper spoke
*
SINKS       210
*
 SAME_AS     10
 IREGI        3
 IREGO        3
 IREGS1       3
 ZTHS         2.3053
 ZBHS         1.7643
END
*
* scrap basket # 3 - basket shroud
*
SINKS       211
*
 SAME_AS     11
 IREGI        3
 IREGO        3
 ZTHS        2.3053
 ZBHS        1.7643
END
*
* scrap basket # 3 - MCO wall
*
SINKS       212
*
 SAME_AS     12
 IREGI        3
 IREGO       14
 ZTHS        2.3524
 ZBHS        1.7643
END
*
*********************************************************************
*
* scrap basket # 4 - Tier 3
*
*********************************************************************
*
```

```
* scrap basket # 4 - bottom plate
*
SINKS        393          394          395
*
 SAME_AS      93           94           95
 ZTHS         1.1762       1.1762       1.1762
 ZBHS         1.1457       1.1457       1.1457
END
*
SINKS        396          397          398          399
*
 SAME_AS      96           97           98           99
 ZTHS         1.1762       1.1762       1.1762       1.1762
 ZBHS         1.1457       1.1457       1.1457       1.1457
END
*
* scrap basket # 4 - insert
*
SINKS        301
*
 SAME_AS       1
 IREGI         4
 IREGO         4
 ZTHS          1.8393
 ZBHS          1.1457
END
*
* scrap basket # 4 - dip tube
*
SINKS        302
*
 SAME_AS       2
 IREGI         4
 IREGO         4
 ZTHS          1.8393
 ZBHS          1.1457
END
*
* scrap basket # 4 - copper spoke
*
SINKS        310
*
 SAME_AS      10
 IREGI         4
 IREGO         4
 IREGS1        4
 ZTHS          1.8393
 ZBHS          1.1762
END
*
* scrap basket # 4 - basket shroud
*
SINKS        311
*
 SAME_AS      11
 IREGI         4
 IREGO         4
 ZTHS         1.8393
 ZBHS         1.1762
END
*
* scrap basket # 4 - MCO wall
*
SINKS        312
*
 SAME_AS      12
 IREGI         4
 IREGO        13
 ZTHS         1.8393
 ZBHS         1.1762
END
```

```
*
*********************************************************************
*
* scrap basket # 5 - Tier 2
*
*********************************************************************
*
* scrap basket # 5 - sludge
*
SINKS       404         405
*
 SAME_AS      4           5
 IREGI        5           5
 IREGO        5           5
 ZTHS         1.0961      1.0961
 ZBHS         0.5881      0.5881
END
*
SINKS       406         407         408         409
*
 SAME_AS      6           7           8           9
 IREGI        5           5           5           5
 IREGO        5           5           5           5
 ZTHS         1.0961      1.0961      1.0961      1.0961
 ZBHS         0.5881      0.5881      0.5881      0.5881
END
*
* scrap basket # 5 - bottom plate
*
SINKS       493         494         495
*
 SAME_AS     93          94          95
 ZTHS         0.5881      0.5881      0.5881
 ZBHS         0.5564      0.5564      0.5564
END
*
SINKS       496         497         498         499
*
 SAME_AS     96          97          98          99
 ZTHS         0.5881      0.5881      0.5881      0.5881
 ZBHS         0.5564      0.5564      0.5564      0.5564
END
*
* scrap basket # 5 - insert
*
SINKS       401
*
 SAME_AS      1
 IREGI        5
 IREGO        5
 ZTHS         1.1445
 ZBHS         0.5881
END
*
* scrap basket # 5 - dip tube
*
SINKS       402
*
 SAME_AS      2
 IREGI        5
 IREGO        5
 ZTHS         1.1445
 ZBHS         0.5881
END
*
* scrap basket # 5 - Copper Back Plate
*
SINKS       403
*
 SAME_AS      3
 IREGO        5
```

```
 ZTHS          1.0961
 ZBHS          0.5881
END
*
* scrap basket # 5 - copper spoke
*
SINKS        410
*
 SAME_AS      10
 IREGI         5
 IREGO         5
 IREGS1        5
 ZTHS          1.1291
 ZBHS          0.5881
END
*
* scrap basket # 5 - basket shroud
*
SINKS        411
*
 SAME_AS      11
 IREGI         5
 IREGO         5
 ZTHS          1.1291
 ZBHS          0.5881
END
*
* scrap basket # 5 - MCO wall
*
SINKS        412
*
 SAME_AS      12
 IREGI         5
 IREGO        12
 ZTHS          1.1762
 ZBHS          0.5881
END
*
*****************************************************************
*
* scrap basket # 6 - Tier 1, bottom tier
*
*****************************************************************
*
* scrap basket # 6 - bottom plate
*
SINKS        593          594          595
*
 SAME_AS      93           94           95
 ZTHS         0            0            0
 ZBHS        -0.03048     -0.03048     -0.03048
END
*
SINKS        596          597          598          599
*
 SAME_AS      96           97           98           99
 ZTHS         0            0            0            0
 ZBHS        -0.03048     -0.03048     -0.03048     -0.03048
END
*
* scrap basket # 6 - insert
*
SINKS        501
*
 SAME_AS       1
 IREGI         6
 IREGO         6
 ZTHS          0.5564
 ZBHS          0.0
END
*
```

```
* scrap basket # 6 - dip tube
*
SINKS       502
*
 SAME_AS      2
 IREGI        6
 IREGO        6
 ZTHS         0.5564
 ZBHS         0.0
END
*
* scrap basket # 6 - copper spoke
*
SINKS       510
*
 SAME_AS     10
 IREGI        6
 IREGO        6
 IREGS1       6
 ZTHS         0.541
 ZBHS         0
END
*
* scrap basket # 6 - basket shroud
*
SINKS       511
*
 SAME_AS     11
 IREGI        6
 IREGO        6
 ZTHS         0.541
 ZBHS         0
END
*
* scrap basket # 6 - MCO wall
*
SINKS       512
*
 SAME_AS     12
 IREGI        6
 IREGO       11
 ZTHS         0.5881
 ZBHS         0
END
*
*         MCO BOT     MCO LID
SINKS       677         678
*
 IGEOM        1           1
 IORIHS       1           2
 IMATHS       2           2
 XRI          0.0         0.0
 XRO          0.0508      0.29
 AHS          0.29        0.29
 XZHS         0.3         0.3
 TIINIT       64.7        64.7
 TOINIT       64.7        64.7
 IMSLAB       5          20
 IREGI        6           1
 TIHS         0.0         0.0
 IREGO       11           8
 XIHS         0.001       0.02
 XLHS         0.3         0.3
 EHSI         0.3         1.0
 EHSO         0.3         0.3
 ZBHS        -0.08128     3.7048
 ZTHS        -0.03048     3.9948
END
*
*         topCASK WALL  2nd FB-Csk  3rd FB-Csk  4th FB-Csk
SINKS       676         679         680          681
```

```
*
 IGEOM        0           0           0           0
 IORIHS       0           0           0           0
 IMATHS       2           2           2           2
 XRI        0.3199      0.3199      0.3199      0.3199
 XRO        0.5056      0.5056      0.5056      0.5056
 AHS        4.36        1.944       1.944       1.944
 XZHS       1.88522     0.84057     0.84057     0.84057
 TIINIT     67.7        67.7        67.7        67.7
 TOINIT     67.7        67.7        67.7        67.7
 IMSLAB     10          10          10          10
 IREGI      14          13          12          11
 IREGO      10          10          10          10
 XLHS       3.95        3.95        3.95        3.95
 ZTHS       4.3924      2.50718     1.66662     0.82605
 ZBHS       2.50718     1.66662     0.82605    -0.01452
END
*
MATERIAL LIBRAY
*
* MATERIAL LIBRARY - SPECIFY MATERIAL PROPERTIES FOR MATERIAL 'imaths'
* UPTO 20 (INMAT) MATERIALS CAN BE SPECIFIED
* SYNTAX:
*
* URANIUM         1       17102.   26.9    130.    1957.     0.7       0.7
* OLD INPUTS:
* decay power per unit sludge volume for fuel piece sludge is 1100 W/m^3
* in the code, decay power = qv*(1-porosity)*volhs
* therefore, qv= 1100 W/m^3 / (1-porosity) = 1100 / (1 - 0.50526) = 2223.4 W/m^3
* URANIUM         1       19000.   26.9    130.    2223.4    0.7       0.7
* NEW METHOD:
* Will use 40% void for SB KOP material.
* True solid density = 16.8 MT/m**3 is consistent
* Preserve U metal khs, cp
* Preserve SB decay power Qm=117W/MTU
* Qv = Qm [W/MTU]*fu[MTU/MT]*rho[MT/m**3]
*    = 117 * 0.825 * 15.667 = 1512.3
*
* NEW METHOD FOR 25% VOID:
* KOP material solid particles are 82.63% uraninum and 17.37% zirconium by volume.
* f_void    =   0.25;   // vol-%
* f_metal   = 1.0 - f_void;
* fv_Zr     = 0.1737;   // vol-%
* fv_U      = 1 - fv_Zr
*           = 0.8263
* rho_Zr    =   6520;   // kg/m^3
* rho_U     =  19000;   // kg/m^3
* cp_Zr     =    278;   // J/kg/k
* cp_U      =    120;   // J/kg/k
* q_m       =  0.117;   // W/kg
*
* q_v       = q_m * rho_U * fv_U
*           = 1836.8649  // W/m^3
*
* rho_metal = fv_U * rho_U + fv_Zr * rho_Zr
*           = 16832.224  // kg/m^3
*
* cp_metal  = (fv_U * rho_U * cp_U + fv_Zr * rho_Zr * cp_Zr) / rho_metal
*           = 130.63073  // J/kg/k
*
* name          imaths     rho      khs      cp      qv      ehsi      ehso
  URANIUM          1       16832.   26.9    131.    1837.     0.7       0.7
  STAINLESS-STEEL 2         8000.   16.0    500.       0.     0.3       0.3
  COPPER           3        8954.  398.0    384.       0.     0.7       0.7
END
*
* 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
*
* 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
*
* 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  hs1  hgap1  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
* 0.005524 M.  THEREFORE, THE GAP CONDUCTANCE IS 0.03/0.005524=5.4 W/m^2/C
*
* 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 #278)
*  COND_NETWORK NET=1 -278  22
*                           77
*                          132
*                          187
*                          242
* MODEL CONTIGUOUS INSERT
*  COND_NETWORK NET=2       21
*                           76
*                          131
*                          186
*                          241
* MODEL CONTIGUOUS MCO WALL CONNECTED TO THE SHIELD PLUG(HS #278)
*  COND_NETWORK NET=3 -278  51  106   161   216   271
*
*
* BETWEEN THE INSERT AND THE DIP TUBE, THERE IS A AIR GAP OF THICKNESS
* 0.005524 M.  THEREFORE, THE GAP CONDUCTANCE IS 0.03/0.005524=5.4 W/m^2/C
  SANDWICH   1 5.4   2
  SANDWICH 201 5.4 202
  SANDWICH 401 5.4 402
*
* BETWEEN COPPER BLOCK AND SLUDGE
  SANDWICH  3  1000  4
  SANDWICH 23  1000 24
  SANDWICH 43  1000 44
  SANDWICH 63  1000 64
  SANDWICH 83  1000 84
  SANDWICH 203  1000 204
  SANDWICH 223  1000 224
  SANDWICH 243  1000 244
  SANDWICH 263  1000 264
  SANDWICH 283  1000 284
  SANDWICH 403  1000 404
  SANDWICH 423  1000 424
  SANDWICH 443  1000 444
  SANDWICH 463  1000 464
  SANDWICH 483  1000 484
* NETWORKS
```

```
*
* BASKET 1 -  FUEL PIECE SLUDGE
  COND_NETWORK NET=1    4  94
  COND_NETWORK NET=2    5  95
  COND_NETWORK NET=3    6  96
  COND_NETWORK NET=4    7  97
  COND_NETWORK NET=5    8  98
  COND_NETWORK NET=6    9  99
* BASKET 1 - SS-BACK-PLATE
  COND_NETWORK NET=7    3  93
*
* BASKET 3 -  FUEL PIECE SLUDGE
  COND_NETWORK NET=8  204  294
  COND_NETWORK NET=9  205  295
  COND_NETWORK NET=10 206  296
  COND_NETWORK NET=11 207  297
  COND_NETWORK NET=12 208  298
  COND_NETWORK NET=13 209  299
* BASKET 3 - SS-BACK-PLATE
  COND_NETWORK NET=14 203  293
*
* BASKET 5 -  FUEL PIECE SLUDGE
  COND_NETWORK NET=15  404  494
  COND_NETWORK NET=16  405  495
  COND_NETWORK NET=17  406  496
  COND_NETWORK NET=18  407  497
  COND_NETWORK NET=19  408  498
  COND_NETWORK NET=20  409  499
* BASKET 5 - SS-BACK-PLATE
  COND_NETWORK NET=21  403  493
* Cask Wall
  COND_NETWORK NET=22  676 679 680 681
END HEAT_SINKS ! HEAT_SINKS is a comment
*-----------------------------------------------------------------------
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 faiure 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 faiure junction, it is the pressure differential required
*          to fail from the downstream compartment to the uptream compt.
*          for check valve junction, it is the differential pressure
*          at which the opened check valve closes
*  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         5          4          3          2          1
        IR2         4          3          2          1         10
        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     0.01       0.01       0.01       0.01      9.211
        AJN      0.025      0.025      0.025      0.025    3.17E-5
        Z1JN     0.5781     0.5781     0.5781     0.5781    9.211
        Z2JN     0.0        0.0        0.0        0.0      12.65
        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
        SAME_AS     1
        IR1         6
        IR2         5
        Z1JN     0.60859
     END PATHS
*
     PATHS          7          8          9         10         11
*
        IJTYP       1          1          1          1          1
        IR1         9         11         12         13         14
        IR2        11         12         13         14          8
        IHORIZ      1          1          1          1          1
        XWJN     1.02       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      1.0        1.0        1.0        1.0        0.01
        Z1JN     0.0        0.0        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
     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  0       ! =0, no diversion heat transfer calculation
                  ! =1, normal diversion heat transfer calculation
                  ! =2, suppress the individual diversion when
                  !         QTDVRT>0 but Tfi<Tgas, or
                  !         QTDVRT<0 but Tfi>Tgas
                  ! =3, suppress the individual diversion when
                  !         QTDVRT>0 but Tfi<Tgas
  IEVAP   1       ! =1, do evaporation/condensation of water
                  ! =0, do not do evaporation/condensation
  ILAW    3       ! oxidation rate law, 0 - McGillivrary/Ritchie
                  !                     1 - Pearce
                  !                     2 - Trimble
                  !                     3 - Databook
                  !                     4 - Databook + oxygen free Trimble
  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  0       ! =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
  ILIMITDIF 1     ! =1, steam flow in scrap bed is diffusion limited
                  !     if there is no water on fuel surface,
                  !        steam needs to diffuse into the bed to react with U
                  !     if there is water on fuel surface,
                  !        steam for reaction is provided locally by evaporated water
                  !     water on fuel surface evaporates at the same rate as reaction
                  !     consumption unless it is boiling
                  ! =0, steam flow in scrap bed is not diffusion limited
                  !
  XTFMIN  1.E-3   ! minimum water film thickness below which the the wetted
                  ! surface starts to uncover
   IHSCSK 0       ! define the cask heat sink
                  ! set to zero to enable fix T boundary condition on MCO wall
   IRGAP   7       ! 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 raditive heat transfer between the
                   !     fuel/scrap and the lid/floor
                   ! =1, fully account for the radiative heat transfer
   HCONTACTSC 1.0E-7  ! scrap to scrap basket wall contact conductance
*
* 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, overides 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
*   PUMP  1       8       0      0    1.652E-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
*
* Automatically generate the basket structure heat sinks with AXIAL command
*
   AUTO_INSERT     1
   AUTO_DIPTUBE    1
   AUTO_BACKPLATE  1
   AUTO_SPOKE      1
   AUTO_SHROUD     1
   AUTO_MCOWALL    1
*
 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 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
* WH2Fl 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
* QEVPFL, QEVPSC, 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
*
    CORRODH2
    WH2TT
    MH2TT
    QDECSC 5  1  2  3  4  5
    QDECSC 5  6  7  8  9 10
    QDECSC 5 11 12 13 14 15
    QDECTT
    UDECTT
    QOXOTT
    UOXOTT
    QOXWSC 5  1  2  3  4  5
    QOXWSC 5  6  7  8  9 10
    QOXWSC 5 11 12 13 14 15
    QOXWTT
    UOXWTT
    QINTT
    UINTT
    QLIDTT
    ULIDTT
    QGASTT
    UGASTT
    QEVPSC 5  1  2  3  4  5
    QEVPSC 5  6  7  8  9 10
    QEVPSC 5 11 12 13 14 15
    QEVPTT
    UEVPTT
    QCNDTT
    UCNDTT
```

```
    QOUTTT
    UOUTTT
    UINTGT
    UMCO
    FUERR
    TOTUO2
    ERCSC  6  1 2  3  4  5  6
 END PLOT
*
 SOLAR_RAD
*
* pointers to heat sinks representing the cask wall and the top
* solar radiation impinges on these
* set IHCASK to zero to impose 40 C water jacket temperature on MCO wall
* otherwise the code sets IREGO(imco) to zero
*
  IHCASK   0
  IHTOP    278
*
* 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
 END SOLAR_RAD
*
 SCRAP_BSKT  3    ! Total number of scrap baskets
*
* First scrap basket (top)
*
  IHSSC    4  5  6  7  8  9   ! radial outward
*
   ISCINS   1     ! define the adjacent center insert heat sink,
                  ! 0 for no insert
   ISCBPT   3     ! define the back plate heat sink
   ISCSPK  10     ! define the spoke heat sink
   ISCFIN  11     ! define copper fin heat sink
   ISCMCO  12     ! define the adjacent MCO wall heat sink
   ISCLID   0     ! define the lid or floor heat sink to which the scrap
                  ! radiate to, negative to radiate to floor
* mulitiplier for effective conductivity in scrap basket in the order read in
* (only conduction part)
   FKSC  1.0  1.0  1.0  1.0  1.0  1.0
* mulitiplier for effective conductivity in scrap basket in the order read in
* (only radiation part)
   FRSC  1.0  1.0  1.0  1.0  1.0  1.0
* porosity of the scrap for each heat sink in the order read in
* OLD:
* to match Umet of 9400 kg/m^3, (1 - FPOROS)*19000 = 9400, or FPOROS= 0.50526
* note: FPOROS includes volume of water, gas, and non-Umetal
* NEW:
* FPOROS=true porosity; adjust URANIUM properties for solids
   FPOROS  0.30  0.30  0.30  0.30  0.30  0.30
* particle size for thermal conductivity in the order read in (m)
   XDSCRP  0.001   0.001   0.001   0.001   0.001   0.001
   XRSCBK  0.2842  ! radius of scrap basket (m)
   XHSCBK  0.5413  ! 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.
* 6 Cumet / D / rhom = 6 * 9400 / 0.0006 / 19000 = 4947/m
* for 30% void, Cumet = 0.7/0.6*9400 = 10967 kg/m^3
* hence, 6 Cumet / D / rhom = 6 * 10967 / 0.0006 / 19000 = 5772/m
```

```
   AVOXSC  5772.  5772.  5772.  5772.  5772.  5772.
   FOXSC   10  0     ! multiplier for AVOXSC
* Sat * porosity * rhow = 0.10 * 0.3 * 1000 = 30 kg/m^3
* 30 kg/m^3 gives a total free water of 1 kg in KOP.
* After the rebound test, no more than 200 g of water are left in the MCO.
* Therefore, set MVWSC0 to 200/1000*30=6.0 kg/m^3
   MVWSC0  6.0     ! 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  1.E3    ! disable insert to scrap micro-convection
*   XSCMCO  0.00476 ! gap distance between scrap basket and MCO wall
   XSCMCO  1.E3    ! disable hx between scrap basket and MCO wall
*
* axial conduction tracked in the scrap basket
*
* top to bottom axial partition
   AXIAL          0.2    0.2    0.2    0.2    0.2
   AXIAL_INDEX      0     21     41     61     81
   AXIAL_FUEL       1      1      1      1      1
* multiplier for FPOROS(porosity of scrap) for each axial basket
   FFPOR  1.0     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    1.0
* multiplier for MVWSC0(initial amount of water per unit volume) for each
* axial basket.
   FMVWSC 1.0     1.0    1.0    1.0    1.0
* multiplier for XDSCR(characteristic scrap size) for each axial basket
   FXDSC  1.0     1.0    1.0    1.0    1.0
* multiplier for FKSC(multiplier for effective conductivity (conduction)
* in scrap)
   FFKSC  1.0     1.0    1.0    1.0    1.0
* multiplier for FRSC(multiplier for effective conductivity (radiation)
* in scrap)
   FFRSC  1.0     1.0    1.0    1.0    1.0
  END IHSSC for 1st scrap basket
*
* Third scrap basket (third from top)
*
  SAME AS SCRAP BASKET 1
*
  IHSSC    204  205  206  207  208  209     ! radial outward
*
   ISCINS  201     ! define the adjacent center insert heat sink,
                   ! 0 for no insert
   ISCBPT  203     ! define the back plate heat sink
   ISCSPK  210     ! define the spoke heat sink
   ISCFIN  211     ! define copper fin heat sink
   ISCMCO  212     ! define the adjacent MCO wall heat sink
   ISCLID   0      ! define the lid or floor heat sink to which the scrap
                   ! radiate to, negative to radiate to floor
   AXIAL_INDEX    0    221  241   261    281
  END IHSSC for 3rd scrap basket
*
* Fifth scrap basket (fifth from top, second to bottom)
*
  SAME AS SCRAP BASKET 1
*
  IHSSC   404  405  406  407  408  409     ! radial outward
*
   ISCINS 401      ! define the adjacent center insert heat sink,
                   ! 0 for no insert
   ISCBPT 403      ! define the back plate heat sink
   ISCSPK 410      ! define the spoke heat sink
   ISCFIN 411      ! define copper fin heat sink
   ISCMCO 412      ! define the adjacent MCO wall heat sink
   ISCLID   0      ! define the lid or floor heat sink to which the scrap
```

```
                ! radiate to, negative to radiate to floor
   AXIAL_INDEX    0   421  441   461    481
  END IHSSC for 5th scrap basket
END SCRAP_BSKT
END MCO
```

A.5 Difference between Case 1: KOPC19.DAT and Case 5: KOPC18.DAT

```
Comparing files ..\REV3_25\KOPC19.DAT and KOPC18.DAT
***** ..\REV3_25\KOPC19.DAT
*
*   CASE KOPC19
*   INDEFINITE VACUUM CYCLE
***** KOPC18.DAT
*
*   CASE KOPC18
*   INDEFINITE VACUUM CYCLE
*****

***** ..\REV3_25\KOPC19.DAT
*************************************************************
* KOPC19    11.77 KG/l  600 micron 10X 20L                  *
*           1.5 CFM He Purge                                *
***** KOPC18.DAT
*************************************************************
* KOPC18    9.42 KG/l  1500 micron 10X 20L                  *
*           1.5 CFM He Purge                                *
*****

***** ..\REV3_25\KOPC19.DAT
*           MCO Heel water     =  20 L                      *
*           Basket water       =  12% of void                *
*           Top, 3rd, and 5th baskets contain KOP material  *
***** KOPC18.DAT
*           MCO Heel water     =  20 L                      *
*           Basket water       =  7.5% of void              *
*           Top, 3rd, and 5th baskets contain KOP material  *
*****

***** ..\REV3_25\KOPC19.DAT
 TITLE      ! Keyword; next line is title, title can be any length
 KOPC19    11.77 KG/l  600 micron 10X 20L
           1.5 CFM He Purge
***** KOPC18.DAT
 TITLE      ! Keyword; next line is title, title can be any length
 KOPC18    9.42 KG/l  1500 micron 10X 20L
           1.5 CFM He Purge
*****

***** ..\REV3_25\KOPC19.DAT
           MCO Heel water     =  20 L
           Basket water       =  12% of void
           Top, 3rd, and 5th baskets contain KOP material
***** KOPC18.DAT
           MCO Heel water     =  20 L
           Basket water       =  7.5% of void
           Top, 3rd, and 5th baskets contain KOP material
*****

***** ..\REV3_25\KOPC19.DAT
*
* NEW METHOD FOR 25% VOID:
* KOP material solid particles are 82.63% uraninum and 17.37% zirconium by volume.
* f_void     =   0.25;   // vol-%
* f_metal    = 1.0 - f_void;
***** KOPC18.DAT
*
* NEW METHOD FOR 40% VOID:
* KOP material solid particles are 82.63% uraninum and 17.37% zirconium by volume.
* f_void     =   0.40;   // vol-%
* f_metal    = 1.0 - f_void;
*****

***** ..\REV3_25\KOPC19.DAT
* FPOROS=true porosity; adjust URANIUM properties for solids
   FPOROS  0.25  0.25  0.25  0.25  0.25  0.25
```

```
* particle size for thermal conductivity in the order read in (m)
***** KOPC18.DAT
* FPOROS=true porosity; adjust URANIUM properties for solids
   FPOROS  0.40  0.40  0.40  0.40  0.40  0.40
* particle size for thermal conductivity in the order read in (m)
*****

***** ..\REV3_25\KOPC19.DAT
* f_metal    = 1 - f_void;
*            =     0.75;
* d_particle =  600.E-6;   // m
* f_sat      =     0.08;
* rho_w      =     1000;   // kg/m^3
***** KOPC18.DAT
* f_metal    = 1 - f_void;
*            =     0.6;
* d_particle = 1500.E-6;   // m
* f_sat      =      0.075;
* rho_w      =     1000;   // kg/m^3
*****

***** ..\REV3_25\KOPC19.DAT
*
* for 25% void, Cumet = (1-0.25)/0.6*9400 = 11750 kg/m^3
* C_U = (f_metal / 0.6) * 9400 // kg/m^3
*     = 11750.
*
* Hence, 6 Cumet / D / rhom = 6 * 11750 / 0.0006 / 19000 = 6184/m
* AdV_ox = 6 * C_U / d_particle / rho_U // m^-1
* 6 Cumet / D / rhom = 6 * 11750 / 0.0006 / 19000 = 6184/m
   AVOXSC  6184.  6184.  6184.  6184.  6184.  6184.
   FOXSC   10  0     ! multiplier for AVOXSC
***** KOPC18.DAT
*
* for 40% void, Cumet = (1-0.4)/0.6*9400 = 9400 kg/m^3
* C_U = (f_metal / 0.6) * 9400 // kg/m^3
*     = 9400.
*
* Hence, 6 Cumet / D / rhom = 6 * 9400 / 0.0015 / 19000 = 1979/m
* AdV_ox = 6 * C_U / d_particle / rho_U // m^-1
*
   AVOXSC  1979.  1979.  1979.  1979.  1979.  1979.
   FOXSC   10  0     ! multiplier for AVOXSC
*****

***** ..\REV3_25\KOPC19.DAT
*
* Sat * porosity * rhow = 0.12 * 0.25 * 1000 = 30 kg/m^3
* mvw_scrap_0 = f_sat * f_void * rho_w // kg/m^3
   MVWSC0  30.0  ! initial amount (kg) of water per unit bulk volume
***** KOPC18.DAT
*
* Sat * porosity * rhow = 0.075 * 0.4 * 1000 = 30 kg/m^3
* mvw_scrap_0 = f_sat * f_void * rho_w // kg/m^3
*
   MVWSC0  30.0  ! initial amount (kg) of water per unit bulk volume
*****
```

A.6 Case 6: KOP_VACXDG.DAT KOP with Degraded Vacuum Pumping and No Helium Purge

```
*-----------------------------------------------------------------------
CONTROL    ! Major keyword group
*-----------------------------------------------------------------------
*
 TITLE     ! Keyword; next line is title, title can be any length
    KOP_VACXDG
       Degraded Vacuum Pumping with No Helium Purge
       Case file to be run with the base file KOPC18.DAT
 END TITLE ! Anything after END is a comment
*
 TIMING
    TLAST  64800.0
 END
*
 ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
  ISRC    0    ! User-defined sources
 END ACTIVE MODELS ! ACTIVE MODELS  is a comment
*
END CONTROL    ! End of CONTROL keyword group
*
*-----------------------------------------------------------------------
MCO      ! MCO Major Keyword
*-----------------------------------------------------------------------
 GENERAL          ! Keyword for general inputs
* 13 FT^3/MIN * 1 MIN/60 SEC * 0.02832 M^3/1 FT^3 = 0.006136 M^3/SEC
 PUMP IRIPUM  IROPUM  ICONPM ITFEED  WVPUMP   WVFEED  TGFEED  TCONPM
   PUMP  1       8       0      0    6.136E-3  0.0      0.0     0.0
 END GENERAL          ! GENERAL is a comment
END MCO
```

A.7 Case 7: KOP_OVLOCXSP.DAT Open MCO with Loss of Annulus Water

```
*-----------------------------------------------------------------------
CONTROL     ! Major keyword group
*-----------------------------------------------------------------------
*
 TITLE      ! Keyword; next line is title, title can be any length
    KOP_OVLOCXSP
       Open MCO with Loss of Annulus Water
       Case file to be run with the base file KOPC18.DAT
 END TITLE ! Anything after END is a comment
*
 ACTIVE MODELS ! Keyword; MODELS is a comment; 1 = on, 0 = off
  ISRC    0    ! User-defined sources
 END ACTIVE MODELS ! ACTIVE MODELS  is a comment
*
END CONTROL     ! End of CONTROL keyword group
*
* Major keyword-------------------------------------------------------
HEAT_SINKS
*-----------------------------------------------------------------------
SINKS         12   112   212   312   412
 IREGO         7     7     7     7     7
END
*
SINKS        512
 IREGO         7
END
END HEAT_SINKS
*-----------------------------------------------------------------------
JUNCTIONS
*-----------------------------------------------------------------------
     PATHS         5
*
        AJN       3.17E-5
```

A.8 Difference between Case 4: KOP_COOLSPRS_19.DAT and Case 8: KOP_COOLSPRS1.DAT

```
Comparing files ..\REV3_25\KOP_COOLSPRS_19.DAT and KOP_COOLSPRS1.DAT
***** ..\REV3_25\KOP_COOLSPRS_19.DAT
 TITLE      ! Keyword; next line is title, title can be any length
    KOP_COOLSPRS_19
       Cooling of MCO with KOP sludge after Vacuum Drying
***** KOP_COOLSPRS1.DAT
 TITLE      ! Keyword; next line is title, title can be any length
    KOP_COOLSPRS1
       Cooling of MCO with KOP sludge after Vacuum Drying
*****

***** ..\REV3_25\KOP_COOLSPRS_19.DAT
*
*
 TIMING     ! Keyword
***** KOP_COOLSPRS1.DAT
*
 TIMING     ! Keyword
*****

***** ..\REV3_25\KOP_COOLSPRS_19.DAT
 FLANGM     0.1
* multiplier to heat sink to liquid pool hx coefficient
 FHHSL    10.0
***** KOP_COOLSPRS1.DAT
 FLANGM     0.1
* Multiplier to heat sink to liquid pool hx coefficient.
* There should be very little hx resistance between the MCO bottom
* and water heel because of He sparging and/or boiling during
* vacuum drying.
  FHHSL     10.0
*****

***** ..\REV3_25\KOP_COOLSPRS_19.DAT
*
EVENTS
***** KOP_COOLSPRS1.DAT
*
*
EVENTS
*****

***** ..\REV3_25\KOP_COOLSPRS_19.DAT
*
* NEW METHOD FOR 25% VOID:
* KOP material solid particles are 82.63% uraninum and 17.37% zirconium by volume.
* f_void     =   0.25;   // vol-%
* f_metal    = 1.0 - f_void;
***** KOP_COOLSPRS1.DAT
*
* NEW METHOD FOR 40% VOID:
* KOP material solid particles are 82.63% uraninum and 17.37% zirconium by volume.
* f_void     =   0.40;   // vol-%
* f_metal    = 1.0 - f_void;
*****

***** ..\REV3_25\KOP_COOLSPRS_19.DAT
* FPOROS=true porosity; adjust URANIUM properties for solids
   FPOROS  0.30  0.30  0.30  0.30  0.30  0.30
* particle size for thermal conductivity in the order read in (m)
***** KOP_COOLSPRS1.DAT
* FPOROS=true porosity; adjust URANIUM properties for solids
   FPOROS  0.40  0.40  0.40  0.40  0.40  0.40
* particle size for thermal conductivity in the order read in (m)
*****
```

```
***** ..\REV3_25\KOP_COOLSPRS_19.DAT
* each scrap basket heat sink in the order read in.
* 6 Cumet / D / rhom = 6 * 9400 / 0.0006 / 19000 = 4947/m
* for 30% void, Cumet = 0.7/0.6*9400 = 10967 kg/m^3
* hence, 6 Cumet / D / rhom = 6 * 10967 / 0.0006 / 19000 = 5772/m
   AVOXSC  5772.  5772.  5772.  5772.  5772.  5772.
   FOXSC   10  0     ! multiplier for AVOXSC
* Sat * porosity * rhow = 0.10 * 0.3 * 1000 = 30 kg/m^3
* 30 kg/m^3 gives a total free water of 1 kg in KOP.
* After the rebound test, no more than 200 g of water are left in the MCO.
***** KOP_COOLSPRS1.DAT
* each scrap basket heat sink in the order read in.
* f_metal    = 1 - f_void;
*            =     0.6;
* d_particle = 1500.E-6;   // m
* f_sat      =      0.075;
* rho_w      =     1000;   // kg/m^3
*
* for 40% void, Cumet = (1-0.4)/0.6*9400 = 9400 kg/m^3
* C_U = (f_metal / 0.6) * 9400 // kg/m^3
*     = 9400.
*
* Hence, 6 Cumet / D / rhom = 6 * 9400 / 0.0015 / 19000 = 1979/m
* AdV_ox = 6 * C_U / d_particle / rho_U // m^-1
*
   AVOXSC  1979.  1979.  1979.  1979.  1979.  1979.
   FOXSC   10  0     ! multiplier for AVOXSC
*
* Sat * porosity * rhow = 0.075 * 0.4 * 1000 = 30 kg/m^3
* mvw_scrap_0 = f_sat * f_void * rho_w // kg/m^3
*
* After the rebound test, no more than 200 g of water are left in the MCO.
*****

***** ..\REV3_25\KOP_COOLSPRS_19.DAT
* Therefore, set MVWSC0 to 200/1000*30=6.0 kg/m^3
   MVWSC0  6.0    ! initial amount (kg) of water per unit bulk volume
***** KOP_COOLSPRS1.DAT
* Therefore, set MVWSC0 to 200/1000*30=6.0 kg/m^3
*
   MVWSC0  6.0    ! initial amount (kg) of water per unit bulk volume
*****
```