12-1014

HOLTEC INTERNATIONAL

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BY OVERNIGHT MAIL

February 11, 1999

Mr. Joseph W. Shea
Project Manager
Spent Fuel Licensing Section, SFPO, NMSS
U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: USNRC Docket No. 72-1014
HI-STORM 100 Topical Safety Analysis Report, TAC No. L22221

Reference: Holtec Project No. 5014

Dear Mr. Shea,

Enclosed please find four (4) copies each of the following calculation packages which support Holtec International's HI-STORM 100 System application currently being reviewed under Docket No. 72-1014.

1. Holtec Report No. HI-971788, *Effective Property Evaluations of HI-STAR 100 and HI-STORM Dry Cask System Multi-Purpose Canister*, Rev. 2.

2. Holtec Report No. HI-971789, *Effective Thermal Conductivity Evaluations of LWR Fuel Assemblies in Dry Storage Casks*, Rev. 2.

3. Holtec Report No. HI-981928, *Structural Calculation Package for HI-STORM 100*, Rev. 3.

The enclosed calculations contain information which is commercially sensitive to Holtec International and is treated by us with strict confidentiality. This information is of the type described in 10CFR2.790(b)(4). The entirety of each calculation is considered proprietary to Holtec. The attached affidavit sets forth the bases for which the information is required to be withheld by the NRC from further disclosure, consistent with these considerations and pursuant to the provisions of 10CFR2.790(b)(1). It is therefore requested that the proprietary information enclosed be withheld from public disclosure in accordance with applicable NRC regulations.

NFPP

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Ltr. Enc

HOLTEC INTERNATIONAL

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Fax (609) 797-0909

If you have any questions or comments, please contact us.

Sincerely,

Bernard Gilligan
Project Manager, HI-STAR/HI-STORM Licensing

Document I.D.: 5014266

Attachment: As Stated

Approvals:

Brian Gutherman
Licensing Manager

K P Singh

K. P. Singh, Ph.D.
President and CEO

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Mr. Joseph W. Shea
U.S. Nuclear Regulatory Commission
Document ID 5014266
Attachment 1

AFFIDAVIT PURSUANT TO 10CFR2.790

I, Alan I Soler, being duly sworn, depose and state as follows:

(1) I am Executive Vice President of Holtec International and have reviewed the information described in paragraph (2) which is sought to be withheld, and am authorized to apply for its withholding.

(2) The information sought to be withheld is the following documents:

a. Holtec Report No. HI-971788, *Effective Property Evaluations of HI-STAR 100 and HI-STORM Dry Cask System Multi-Purpose Canister*, Revision 2.

b. Holtec Report No. HI-971789, *Effective Thermal Conductivity Evaluations of LWR Fuel Assemblies in Dry Storage Casks*, Revision 2.

c. Holtec Report No. HI-981928, *Structural Calculation Package for HI-STORM 100*, Revision 3.

(3) In making this application for withholding of proprietary information of which it is the owner, Holtec International relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC Sec. 552(b)(4) and the Trade Secrets Act, 18 USC Sec. 1905, and NRC regulations 10CFR Part 9.17(a)(4), 2.790(a)(4), and 2.790(b)(1) for "trade secrets and commercial or financial information obtained from a person and privileged or confidential" (Exemption 4). The material for which exemption from disclosure is here sought is all "confidential commercial information", and some portions also qualify under the narrower definition of "trade secret", within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, <u>Critical Mass Energy Project v. Nuclear Regulatory Commission</u>, 975F2d871 (DC Cir. 1992), and <u>Public Citizen Health Research Group v. FDA</u>, 704F2d1280 (DC Cir. 1983).

(4) Some examples of categories of information which fit into the definition of

AFFIDAVIT PURSUANT TO 10CFR2.790

proprietary information are:

a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by Holtec's competitors without license from Holtec International constitutes a competitive economic advantage over other companies;

b. Information which, if used by a competitor, would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product.

c. Information which reveals cost or price information, production, capacities, budget levels, or commercial strategies of Holtec International, its customers, or its suppliers;

d. Information which reveals aspects of past, present, or future Holtec International customer-funded development plans and programs of potential commercial value to Holtec International;

e. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraphs 4.a, 4.b, 4.d, and 4.e, above.

(5) The information sought to be withheld is being submitted to the NRC in confidence. The information (including that compiled from many sources) is of a sort customarily held in confidence by Holtec International, and is in fact so held. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by Holtec International. No public disclosure has been made, and it is not available in public sources. All disclosures to third parties, including any required transmittals to the NRC, have been made, or must be made, pursuant to

AFFIDAVIT PURSUANT TO 10CFR2.790

regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence. Its initial designation as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in paragraphs (6) and (7) following.

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge. Access to such documents within Holtec International is limited on a "need to know" basis.

(7) The procedure for approval of external release of such a document typically requires review by the staff manager, project manager, principal scientist or other equivalent authority, by the manager of the cognizant marketing function (or his designee), and by the Legal Operation, for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside Holtec International are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary agreements.

(8) The information classified as proprietary was developed and compiled by Holtec International at a significant cost to Holtec International. This information is classified as proprietary because it contains detailed descriptions of analytical approaches and methodologies not available elsewhere. This information would provide other parties, including competitors, with information from Holtec International's technical database and the results of evaluations performed by Holtec International. Release of this information would improve a competitor's position without the competitor having to expend similar resources for the development of the database. A substantial effort has been expended by Holtec International to develop this information.

(9) Public disclosure of the information sought to be withheld is likely to cause

AFFIDAVIT PURSUANT TO 10CFR2.790

substantial harm to Holtec International's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of Holtec International's comprehensive spent fuel storage technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes beyond the extensive physical database and analytical methodology, and includes development of the expertise to determine and apply the appropriate evaluation process.

The research, development, engineering, and analytical costs comprise a substantial investment of time and money by Holtec International.

The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial.

Holtec International's competitive advantage will be lost if its competitors are able to use the results of the Holtec International experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to Holtec International would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive Holtec International of the opportunity to exercise its competitive advantage to seek an adequate return on its large investment in developing these very valuable analytical tools.

Mr. Joseph W. Shea
U.S. Nuclear Regulatory Commission
Document ID 5014266
Attachment 1

AFFIDAVIT PURSUANT TO 10CFR2.790

STATE OF NEW JERSEY)
) ss:
COUNTY OF BURLINGTON)

Dr. Alan I Soler, being duly sworn, deposes and says:

That he has read the foregoing affidavit and the matters stated therein are true and correct to the best of his knowledge, information, and belief.

Executed at Marlton, New Jersey, this 11th day of February, 1999.

Alan Soler

Dr. Alan I Soler
Holtec International

Subscribed and sworn before me this 11th day of February, 1999.

Maria C. Pepe

MARIA C. PEPE
NOTARY PUBLIC OF NEW JERSEY
My Commission Expires April 25, 2000

72-1014 HOLTEC INTERNATIONAL

EFFECTIVE THERMAL CONDUCTIVITY EVALUATIONS OF LWR FUEL ASSEMBLIES IN DRY STORAGE CASKS
BOOK #2

REC'D W/LTR DTD 2/11/99...9903030227

APPENDIX I

Basket Supports Effective Thermal Conductivity without Rayleigh Effect

I.1 Introduction

In order to determine the magnitude of the Rayleigh effect on the basket supports region effective thermal conductivity, an evaluation is performed which takes no credit for this effect. The results of this non-Rayleigh analysis are then compared to the equivalent analysis with the Rayleigh effect enabled.

I.2 Methodology

The non-Rayleigh analysis is performed using the ANSYS finite-element code, as described in Section 2.3 of this report. The Rayleigh effect multipliers in the ANSYS script file are all set equal to 1.0, which eliminates the natural circulation effect.

I.3 Acceptance Criteria

The calculations presented in this appendix are performed to generate data for use in Comment Resolution Letter No. 26 (Document ID 5014227, dated August 20, 1998) to an NRC question on the HI-STAR 100 TSAR (HI-941184, Revision 7). The calculations comprise a sensitivity study performed for illustrative purposes, so no explicit acceptance criteria are applied.

I.4 Assumptions

All assumptions listed in Section 4.3 of this report are applicable to the calculations presented in this appendix.

I.5 Input Data

All input data listed in Section 4.3 of this report are applicable to the calculations presented in this appendix. The effective thermal conductivities for the basket support region, without Rayleigh effect, is calculated from the results of the finite-element evaluation. The input data and corresponding references for this calculation are presented within the calculation itself, and are not repeated here.

I.6 Calculations

The non-Rayleigh analysis is performed for an MPC-68. This non-Rayleigh analysis corresponds to the Rayleigh enabled analysis of scenario 6 in Section 6.3. With the Rayleigh effect excluded, the orientation of the MPC has no effect on the results of the calculations.

The same ANSYS geometry database is used for both the new evaluation included in this appendix and the existing scenario 6 evaluation. The ANSYS script file V68NR.INP for the new non-Rayleigh evaluation is included on pages I-4 through I-8. The corresponding ANSYS results file V68NR.RES, containing calculated maximum temperature values, is included on page I-9. The calculation of the basket supports region effective thermal conductivity values is included on pages I-10 through I-12.

I.7 Results and Conclusions

The basket supports region effective thermal conductivity values are summarized in the following table, along with the results of the scenario 6 evaluation.

Temperature	non-Rayleigh Effective Thermal Conductivity	Scenario 6 Effective Thermal Conductivity
(°F)	(Btu/hr×ft×°F)	(Btu/hr×ft×°F)
200	0.1142	0.1502
450	0.2019	0.2350
700	0.3322	0.3687

The ANSYS solution, however, does not include the effect of the helium conduction elements. These elements provide a parallel heat conduction path across the basket supports region, and their effective thermal conductivity (see Section 7.4) should be added to the ANSYS solution conductivity values. The total effective thermal conductivity results are presented in the following table.

Temperature	non-Rayleigh Effective Thermal Conductivity	Scenario 6 Effective Thermal Conductivity
(°F)	(Btu/hr×ft×°F)	(Btu/hr×ft×°F)
200	0.7762	0.8122
450	0.8639	0.8970
700	0.9942	1.0307

These results demonstrate that the overall effect of completely eliminating the Rayleigh effect is minor, with thermal conductivity reduction in the range of 3.5% to 4.4%.

I.8 Computer Files

```
 Volume in drive F is VOL1
 Volume Serial Number is 0000-0000

 Directory of F:\user\erosenba\5014\mpc\k_mpc

V68NR    INP             9,120 08/17/98   08:03p
V68NR    RES             1,712 08/17/98   08:19p
V68NR    MCD            10,512 08/19/98   01:51p
```

ANSYS Script File - V68NR.INP

```
! **********************************************************
! Input File for Vertical (Storage) Helium Backfilled MPC-68
!**********************************************************
/FILNAM,V68NR
/TITLE,MPC-68 Model
/UNITS,BIN

PI=ACOS(-1)

! ***********************
! Resume Database MPC68.DB
! ***********************
RESUME,MPC68,DB

! *****************
! Enter PreProcessor
! *****************
/PREP7

! ***************************************************
! Definition of Input Values
! All Dimensions are in inch, hour, Btu, Rankine units
! ***************************************************
KCA0 = 1.425E-2              ! Effective Thermal Conductivity
KCA1 = 2.249E-2              ! of Fuel Assembly Regions
KCA2 = 3.409E-2              ! at 660R, 910R and 1160R
!
KII0 = 1.087                 ! Along Panel Thermal Conductivity
KII1 = 1.205                 ! for Boral Basket Panels
KII2 = 1.294                 ! at 660R, 910R and 1160R
!
KOI0 = 0.192                 ! Through Panel Thermal Conductivity
KOI1 = 0.242                 ! for Boral Basket Panels
KOI2 = 0.286                 ! at 660R, 910R and 1160R
!
KAX0 = 0.700                 ! Alloy-X Thermal Conductivity
KAX1 = 0.816                 ! at 660R, 910R and 1160R
KAX2 = 0.916                 !
!
KHE0 = 8.133E-3              ! Helium Thermal Conductivity
KHE1 = 1.074E-2              ! EXCLUDING Rayleigh Effect
KHE2 = 1.312E-2              ! at 660R, 910R, and 1160R
!
MRA0 = 1.00                  ! Rayleigh Effect Helium Conductivity
MRA1 = 1.00                  ! Multiplier at 660R, 910R and 1160R
MRA2 = 1.00                  ! for Model Bottom Zones
!
MRB0 = 1.00                  ! Rayleigh Effect Helium Conductivity
MRB1 = 1.00                  ! Multiplier at 660R, 910R and 1160R
MRB2 = 1.00                  ! for Model Top Zones
!
MRC0 = 1.00                  ! Rayleigh Effect Helium Conductivity
MRC1 = 1.00                  ! Multiplier at 660R, 910R and 1160R
MRC2 = 1.00                  ! For Model Side Zones
!
ERAD = 0.36                  ! Emissivity of Radiating Surfaces
!
ASSYQ = 15.00                ! Total Heat Load per Inch Depth
```

```
TPER1 = 660                  ! Periphery Temperature for Load Case 1
TPER2 = 910                  ! Periphery Temperature for Load Case 2
TPER3 = 1160                 ! Periphery Temperature for Load Case 3

! **********************************
! Define Properties for All Materials
! **********************************
MPTEMP,,TPER1,TPER2,TPER3     ! Temperature Data Points
!
MPDATA,KXX,1,,KCA0,KCA1,KCA2  ! Fuel Assembly Regions
!
MPDATA,KXX,2,,KAX0,KAX1,KAX2  ! Alloy-X
!
MPDATA,KXX,3,,KII0,KII1,KII2  ! Boral Basket Panels, Along Panel
MPDATA,KYY,3,,KOI0,KOI1,KOI2  ! Boral Basket Panels, Through Panel
!
MPDATA,KXX,4,,KHE0,KHE1,KHE2
!
MPDATA,KXX,5,,KHE0*MRA0,KHE1*MRA1,KHE2*MRA2  ! Model Bottom Zones
!
MPDATA,KXX,6,,KHE0*MRB0,KHE1*MRB1,KHE2*MRB2  ! Model Top Zones
!
MPDATA,KXX,7,,KHE0*MRC0,KHE1*MRC1,KHE2*MRC2  ! Model Side Zones

! **************************************************************
! Exit the Preprocessor and Enter the Radiation Matrix Generator
! **************************************************************
FINISH
/AUX12

! ***************************
! Define Material Emissivities
! ***************************
EMIS,8,ERAD                   ! Radiating Surfaces Emissivity

! ******************************************
! Select Radiating Surface Elements and Nodes
! ******************************************
ALLSEL
ESEL,S,TYPE,,2
NSLE,S

! ********************************************
! Specify Options and Generate Radiation Matrix
! ********************************************
GEOM,1
VTYPE,0,1000
WRITE
ALLSEL

! **************************************************************
! Exit the Radiation Matrix Generator and Enter the PreProcessor
! **************************************************************
FINISH
/PREP7

! **************************************
! Define Radiation Matrix as Superelement
! **************************************
TYPE,3
```

```
SE

! ***************************************
! Set Heat Generation Boundary Conditions
! ***************************************
ESEL,S,MAT,,1                  ! Select All Fuel Region Elements
ESEL,R,TYPE,,1                 ! Reselect Only PLANE55 Elements
BFE,ALL,HGEN,,ASSYQ/2491.44    ! Apply Volumetric Heat Generation

! ******************************************************
! Exit the PreProcessor and Enter the Solution Processor
!******************************************************
FINISH
/SOLU

! ************************
! Perform Static Solutions
! ************************
ANTYPE,STAT                    ! Perform STATIC Solution
TUNIF,TPER1                    ! Set Initial, Uniform Temperature

CSYS,1                         ! Select Cylindrical Coordinates

TIME,1.0                       ! Load Case 1
NSEL,S,LOC,X,34.1875           ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER1               ! Set Constant Periphery Temperature
NALL                           ! Reselect All Nodes
EALL                           ! Reselect All Elements
ESEL,U,TYPE,,2                 ! Unselect Radiation Surface Elements
SOLVE

TIME,2.0                       ! Load Case 2
NSEL,S,LOC,X,34.1875           ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER2               ! Set Constant Periphery Temperature
NALL                           ! Reselect All Nodes
EALL                           ! Reselect All Elements
ESEL,U,TYPE,,2                 ! Unselect Radiation Surface Elements
SOLVE

TIME,3.0                       ! Load Case 3
NSEL,S,LOC,X,34.1875           ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER3               ! Set Constant Periphery Temperature
NALL                           ! Reselect All Nodes
EALL                           ! Reselect All Elements
ESEL,U,TYPE,,2                 ! Unselect Radiation Surface Elements
SOLVE

TIME,4.0
NSEL,S,LOC,X,34.1875           ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER1-1.0           ! Set Constant Periphery Temperature
NALL
D,BASKEDGE,TEMP,TPER1          ! Set Constant Periphery Temperature
EALL                           ! Reselect All Elements
ESEL,U,TYPE,,2                 ! Unselect Radiation Surface Elements
SOLVE

TIME,5.0
NSEL,S,LOC,X,34.1875           ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER2-1.0           ! Set Constant Periphery Temperature
NALL
D,BASKEDGE,TEMP,TPER2          ! Set Constant Periphery Temperature
```

```
EALL                               ! Reselect All Elements
ESEL,U,TYPE,,2                     ! Unselect Radiation Surface Elements
SOLVE

TIME,6.0
NSEL,S,LOC,X,34.1875               ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER3-1.0               ! Set Constant Periphery Temperature
NALL
D,BASKEDGE,TEMP,TPER3              ! Set Constant Periphery Temperature
EALL                               ! Reselect All Elements
ESEL,U,TYPE,,2                     ! Unselect Radiation Surface Elements
SOLVE

! **********************************************
! Exit Solution Processor and Enter PostProcessor
! **********************************************
FINISH
/POST1

! ********************************************
! Generate Calculated Temperature Results File
! ********************************************
SET,1
NSORT,TEMP                         ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX1,SORT,,MAX               ! Determine Maximum Temperature

SET,2
NSORT,TEMP                         ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX2,SORT,,MAX               ! Determine Maximum Temperature

SET,3
NSORT,TEMP                         ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX3,SORT,,MAX               ! Determine Maximum Temperature

SET,4
NSORT,TEMP                         ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX4,SORT,,MAX               ! Determine Maximum Temperature

SET,5
NSORT,TEMP                         ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX5,SORT,,MAX               ! Determine Maximum Temperature

SET,6
NSORT,TEMP                         ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX6,SORT,,MAX               ! Determine Maximum Temperature

/OUTPUT,,RES

/COM,Output File for Temperature Distribution Analysis
/COM,of a Vertical Helium Backfilled MPC-68

/COM
/COM
/COM,Maximum Temperature for 660R MPC Periphery Temperature
*STATUS,TMAX1

/COM
/COM
/COM,Maximum Temperature for 910R MPC Periphery Temperature
*STATUS,TMAX2
```

```
/COM
/COM
/COM,Maximum Temperature for 1160R MPC Periphery Temperature
*STATUS,TMAX3

/COM
/COM
/COM,Maximum Temperature for 660R Basket Periphery Temperature
*STATUS,TMAX4

/COM
/COM
/COM,Maximum Temperature for 910R Basket Periphery Temperature
*STATUS,TMAX5

/COM
/COM
/COM,Maximum Temperature for 1160R Basket Periphery Temperature
*STATUS,TMAX6

/OUTPUT,TERM

! ************************************
! Save Database and Exit PostProcessor
! ************************************
SAVE
FINISH
```

ANSYS Results File - V68NR.INP

```
Output File for Temperature Distribution Analysis
of a Vertical Helium Backfilled MPC-68


Maximum Temperature for 660R MPC Periphery Temperature

PARAMETER STATUS- TMAX1      (   46 PARAMETERS DEFINED)
                  (INCLUDING     11 INTERNAL PARAMETERS)

 NAME         VALUE          TYPE      DIMENSIONS
 TMAX1      688.259428      SCALAR


Maximum Temperature for 910R MPC Periphery Temperature

PARAMETER STATUS- TMAX2      (   46 PARAMETERS DEFINED)
                  (INCLUDING     11 INTERNAL PARAMETERS)

 NAME         VALUE          TYPE      DIMENSIONS
 TMAX2      929.592085      SCALAR


Maximum Temperature for 1160R MPC Periphery Temperature

PARAMETER STATUS- TMAX3      (   46 PARAMETERS DEFINED)
                  (INCLUDING     11 INTERNAL PARAMETERS)

 NAME         VALUE          TYPE      DIMENSIONS
 TMAX3      1174.58118      SCALAR


Maximum Temperature for 660R Basket Periphery Temperature

PARAMETER STATUS- TMAX4      (   46 PARAMETERS DEFINED)
                  (INCLUDING     11 INTERNAL PARAMETERS)

 NAME         VALUE          TYPE      DIMENSIONS
 TMAX4      674.938982      SCALAR


Maximum Temperature for 910R Basket Periphery Temperature

PARAMETER STATUS- TMAX5      (   46 PARAMETERS DEFINED)
                  (INCLUDING     11 INTERNAL PARAMETERS)

 NAME         VALUE          TYPE      DIMENSIONS
 TMAX5      922.058151      SCALAR


Maximum Temperature for 1160R Basket Periphery Temperature

PARAMETER STATUS- TMAX6      (   46 PARAMETERS DEFINED)
                  (INCLUDING     11 INTERNAL PARAMETERS)

 NAME         VALUE          TYPE      DIMENSIONS
 TMAX6      1170.00277      SCALAR
```

INTRODUCTION

This calculation is performed to calculate the effective planar thermal conductivity of the fuel basket and basket support region of a Holtec MPC-68 in a vertical (storage) orientation. The results of this calculation will become inputs to assembled HI-STAR and/or HI-STORM cask systems.

METHODOLOGY

Temperature distributions in a planar section perpendicular to the longitudinal axis of the Holtec MPC-68 have been calculated separately [1] using the ANSYS general-purpose finite element code. The temperature distributions are obtained for two separate boundary conditions:

1. Constant temperature MPC periphery
2. Constant temperature fuel basket periphery

The maximum calculated temperature for each condition is extracted from the results of the finite-element analyses. The differences between these calculated maximum temperatures and the boundary conditions can be used to determine the effective thermal conductivities of equivalent, homogeneous regions.

The fuel basket is reduced to a homogeneous cylinder with uniform heat generation. In a planar section for this idealized geometry, the effective thermal conductivity is given by:

$$k_{eff} = Q_{gen} / (4 \times \pi \times \Delta T_{bm})$$

where: k_{eff} is the effective thermal conductivity, Btu / (hr x in x F)
Q_{gen} is the heat generation per unit depth, Btu / (hr x in)
ΔT_{bm} is the basket periphery-to-maximum temperature difference, F

The basket support region is reduced to a homogeneous hollow cylinder with a known wall thickness. If the cylinder wall thickness is small compared to the cylinder radii, the thermal conductivity can be determined using the familiar Fourier equation for 1-D conduction:

$$keff = (Q \times L) / (A \times \Delta T_{pb})$$

where: Q is the total heat generation rate, Btu/hr
L is the conduction length (wall thickness), in
A is the conducting area, in^2
ΔT_{pb} is the temperature difference, F

The temperature difference (ΔT) must be determined from the planar temperature distribution. If the basket periphery-to-maximum temperature difference is subtracted from the MPC periphery-to-maximum temperature difference, the results is the temperature difference across the basket support region:

$$\Delta T_{pm} - \Delta T_{bm} = (T_p - T_m) - (T_b - T_m) = T_p - T_b = \Delta T_{pb}$$

Therefore, the fuel basket region effective thermal conductivity can be obtained as:

$$k_{eff} = (Q_{gen} \times L) / (A \times (\Delta T_{pm} - \Delta T_{bm}))$$

NOMENCLATURE

This calculation is performed using the Mathcad electronic scratchpad program. The built-in units of temperature are absolute units (i.e. Rankine). Temperature differences are identical in both Rankine and Fahrenheit units. All calculations in this worksheet utilize temperature differences only, so all temperatures will be specified in Rankine (R) units.

REFERENCES

[1] ANSYS Database MPC68.DB, ANSYS Input Script V68NR.INP and ANSYS Postprocessor Result File V68NR.RES.

[2] "HI-STAR 100 MPC-68 Construction," Holtec Drawing 1401, Sheet 1, Revision 5.

INPUT DATA

$OD := 68.375 \cdot in$ — Outer Diameter of MPC-68, from [2]

$L_{unit} := 1.0 \cdot in$ — One Inch Unit Length

$Q_{gen} := 15.0 \cdot \frac{BTU}{hr}$ — Total Heat Generation per Unit Length, from [1]

$L := 1.815 \cdot in$ — Basket Support Region Cylinder Wall Thickness

CALCULATE OUTER SURFACE AREA PER UNIT LENGTH OF MPC

$A := \pi \cdot OD \cdot (1 \cdot in)$ $\qquad$ $A = 214.806 \cdot in^2$

CALCULATE EFFECTIVE THERMAL CONDUCTIVITIES AT 660 R

$\Delta T_{pm} := (688.259 - 660) \cdot R$ $\qquad$ $\Delta T_{pm} = 28.259 \cdot R$

$\Delta T_{bm} := (674.939 - 660) \cdot R$ $\qquad$ $\Delta T_{bm} = 14.939 \cdot R$

$k_{bm} := \frac{Q_{gen}}{L_{unit} \cdot 4 \cdot \pi \cdot \Delta T_{bm}}$ $\qquad$ $k_{bm} = 0.959 \cdot \frac{BTU}{hr \cdot ft \cdot R}$

$k_{supp} := \frac{Q_{gen} \cdot L}{A \cdot (\Delta T_{pm} - \Delta T_{bm})}$ $\qquad$ $k_{supp} = 0.1142 \cdot \frac{BTU}{hr \cdot ft \cdot R}$

CALCULATE EFFECTIVE THERMAL CONDUCTIVITIES AT 910 R

$\Delta T_{pm} := (929.592 - 910) \cdot R$ $\qquad$ $\Delta T_{pm} = 19.592 \cdot R$

$\Delta T_{bm} := (922.058 - 910) \cdot R$ $\qquad$ $\Delta T_{bm} = 12.058 \cdot R$

$k_{bm} := \dfrac{Q_{gen}}{L_{unit} \cdot 4 \cdot \pi \cdot \Delta T_{bm}}$ $\qquad k_{bm} = 1.188 \cdot \dfrac{BTU}{hr \cdot ft \cdot R}$

$k_{supp} := \dfrac{Q_{gen} \cdot L}{A \cdot \left(\Delta T_{pm} - \Delta T_{bm}\right)}$ $\qquad k_{supp} = 0.2019 \cdot \dfrac{BTU}{hr \cdot ft \cdot R}$

<u>CALCULATE EFFECTIVE THERMAL CONDUCTIVITIES AT 1160 R</u>

$\Delta T_{pm} := (1174.581 - 1160) \cdot R$ $\qquad \Delta T_{pm} = 14.581 \cdot R$

$\Delta T_{bm} := (1170.003 - 1160) \cdot R$ $\qquad \Delta T_{bm} = 10.003 \cdot R$

$k_{bm} := \dfrac{Q_{gen}}{L_{unit} \cdot 4 \cdot \pi \cdot \Delta T_{bm}}$ $\qquad k_{bm} = 1.432 \cdot \dfrac{BTU}{hr \cdot ft \cdot R}$

$k_{supp} := \dfrac{Q_{gen} \cdot L}{A \cdot \left(\Delta T_{pm} - \Delta T_{bm}\right)}$ $\qquad k_{supp} = 0.3322 \cdot \dfrac{BTU}{hr \cdot ft \cdot R}$

APPENDIX J

Conductivity of MPC-24 & 68 with Diluted He and MPC-24 without Rayleigh Effect

J.1 Introduction

Fuel rods are backfilled with helium during manufacture. During operation in a reactor gaseous fission products are produced, and are also contained within the fuel rods. If fuel rods were ruptured while in dry storage in a Holtec MPC, the fuel rod backfill helium and a portion of the gaseous fission products would be released into the MPC internal atmosphere, diluting the MPC backfill helium. The effects of dilution of the MPC backfill helium by the fuel rod gases on the thermal conductivity of the fuel basket and basket peripheral region are examined in this appendix.

In appendix I of this report, the thermal conductivity of an MPC-68 fuel basket peripheral region without Rayleigh effect is evaluated. An additional analysis for an MPC-24 under the same conditions is included in this appendix.

J.2 Methodology

The MPC helium dilution evaluations are performed using the ANSYS finite-element code, as described in Section 2.3 of this report, and modifying the thermal conductivity of the helium backfill gas and the effective thermal conductivity of the fuel assemblies.

The MPC-24 non-Rayleigh analysis is performed using the ANSYS finite-element code, as described in Section 2.3 of this report. The Rayleigh effect multipliers in the ANSYS script file are all set equal to 1.0, which eliminates the natural circulation effect.

J.3 Acceptance Criteria

The calculations presented in this appendix are performed to generate data for use in HI-STAR and HI-STORM Systems thermal analysis. No explicit acceptance criteria are applied.

J.4 Assumptions

All assumptions listed in Section 4.3 of this report are applicable to the calculations presented in this appendix.

J.5 Input Data

For the diluted helium calculations, both the helium and fuel assembly effective thermal conductivity values are obtained from Revision 1 of Holtec Report HI-971789, ("Effective Thermal Conductivity Evaluations of LWR Fuel Assemblies in Dry Storage Casks").

All input data listed in Section 4.3 of this report are applicable to the calculations presented in this appendix. The effective thermal conductivities for the basket support region, without Rayleigh effect, is calculated from the results of the finite-element evaluation. The input data and corresponding references for this calculation are presented within the calculation itself, and are not repeated here.

J.6 Calculations and Results

The same ANSYS geometry databases are used for both the new evaluations included in this appendix and the existing evaluations in Section 6.3. The ANSYS script files are listed in Appendix Section J.8.

The diluted helium calculations are performed for the following three different conditions:

Condition 1 - 100% fuel rod gas release, HI-STAR transportation cask with an MPC-24
Condition 2 - 10% fuel rod gas release, HI-STORM storage cask with an MPC-24
Condition 3 - 10% fuel rod gas release, HI-STORM storage cask with an MPC-68

As previously stated, the diluted helium and fuel assembly effective thermal conductivities for these analyses are obtained from Revision 1 of Holtec Report HI-971789.

These calculations are presented in this appendix on pages J-5 through J-38. The results of these calculations, along with the non-diluted baseline results previously calculated, are presented and compared in the following table. The first number in each cell is the fuel basket effective thermal conductivity and the second number is the fuel basket periphery region effective thermal conductivity.

	k_{eff} at 200°F (Btu/hr×ft°F)	**k_{eff} at 450°F (Btu/hr×ft°F)**	**k_{eff} at 700°F (Btu/hr×ft°F)**
MPC-24 Baseline Condition (Section 6.3 Scenario #1)	1.108 0.3136	1.495 0.4456	1.954 0.6459
MPC-24 Condition 1 (100% fuel rod gas release)	0.933 0.2286	1.303 0.3550	1.758 0.5538
MPC-24 Baseline Condition (Section 6.3 Scenario #4)	1.108 0.2643	1.495 0.4025	1.954 0.6080
MPC-24Condition 2 (MPC-24, 10% fuel rod gas release)	1.047 0.2506	1.425 0.3879	1.883 0.5902
MPC-68 Baseline Condition (Section 6.3 Scenario #6)	0.959 0.1481	1.188 0.2294	1.432 0.3543
Condition 3 (MPC-68, 10% fuel rod gas release)	0.941 0.1395	1.168 0.2203	1.404 0.3438

The non-Rayleigh analysis is performed for an MPC-24. This non-Rayleigh analysis corresponds to the Rayleigh enabled analysis of scenario 1 in Section 6.3. With the Rayleigh effect excluded, the orientation of the MPC has no effect on the results of the calculations.

The basket supports region effective thermal conductivity values are summarized in the following table, along with the results of the scenario 6 evaluation.

Temperature (°F)	non-Rayleigh Effective Thermal Conductivity (Btu/hr×ft×°F)	Section 6.3 Scenario 1 Effective Thermal Conductivity (Btu/hr×ft×°F)
200	0.2050	0.3136
450	0.3522	0.4456
700	0.5644	0.6459

The ANSYS solution, however, does not include the effect of the helium conduction elements. These elements provide a parallel heat conduction path across the basket supports region, and their effective thermal conductivity (see Section 7.4) should be added to the ANSYS solution conductivity values. The total effective thermal conductivity results are presented in the following table.

Temperature (°F)	non-Rayleigh Effective Thermal Conductivity (Btu/hr×ft×°F)	Section 6.3 Scenario 1 Effective Thermal Conductivity (Btu/hr×ft×°F)
200	0.4550	0.5636
450	0.6022	0.6956
700	0.8144	0.8959

These results demonstrate that the overall effect of completely eliminating the Rayleigh effect is a thermal conductivity reduction in the range of 19.3% at lower temperatures to 9.1% at higher temperatures.

J.7 Conclusions

As expected, helium dilution by the released fuel rod gases reduces the effective thermal conductivity of the MPC fuel basket and the basket periphery region. The elimination of the Rayleigh effect in the MPC-24 also reduces the fuel basket periphery region conductivity, but has no effect on the fuel basket periphery.

J.8 Computer Files

```
Volume in drive F is VOL1
Volume Serial Number is 0000-0000
```

```
Directory of F:\USER\EROSENBA\5014\MPC\K_MPC

11/20/98  01:27p            8,899 H24MG.INP
11/20/98  04:05p            1,722 H24MG.RES
12/30/98  03:32p            8,952 V24MG.INP
12/30/98  03:33p            9,411 V68MG.INP
12/30/98  04:54p            1,765 V24MG.RES
12/31/98  11:51a            1,765 V68MG.RES
01/19/99  03:37p            8,843 H24NR.INP
01/19/99  05:38p            1,714 H24NR.RES
02/01/99  03:37p           16,171 H24MG.MCD
02/01/99  03:38p           17,285 V24MG.MCD
02/01/99  03:39p           17,100 V68MG.MCD
02/01/99  03:40p           16,060 H24NR.MCD
```

ANSYS Script File H24MG.INP

```
! ***********************************************************
! Input File for Horizontal Diluted Helium Backfilled MPC-24
!   Helium Dilution is the Result of Fuel Rods Gas Release
!************************************************************
/FILNAM,H24MG
/TITLE,MPC-24 Model
/UNITS,BIN

PI=ACOS(-1)

! ************************
! Resume Database MPC24.DB
! ************************
RESUME,MPC24,DB

! ******************
! Enter PreProcessor
! ******************
/PREP7

! ***************************************************
! Definition of Input Values
! All Dimensions are in inch, hour, Btu, Rankine units
! ***************************************************
KCA0 = 1.334E-2              ! Effective Thermal Conductivity
KCA1 = 2.321E-2              ! of Fuel Assembly Regions
KCA2 = 3.813E-2              ! at 660R, 910R and 1160R
!
KII0 = 1.117                 ! Along Panel Thermal Conductivity
KII1 = 1.236                 ! for Boral Basket Panels
KII2 = 1.328                 ! at 660R, 910R and 1160R
!
KOI0 = 0.203                 ! Through Panel Thermal Conductivity
KOI1 = 0.255                 ! for Boral Basket Panels
KOI2 = 0.301                 ! at 660R, 910R and 1160R
!
KAX0 = 0.700                 ! Alloy-X Thermal Conductivity
KAX1 = 0.816                 ! at 660R, 910R and 1160R
KAX2 = 0.916                 !
!
KHE0 = 4.379E-3              ! Helium Thermal Conductivity
KHE1 = 5.780E-3              ! EXCLUDING Rayleigh Effect
KHE2 = 7.078E-3              ! at 660R, 910R, and 1160R
```

```
!
MRA0 = 5.45                    ! Rayleigh Effect Helium Conductivity
MRA1 = 4.09                    ! Multiplier at 660R, 910R and 1160R
MRA2 = 3.36                    !
!
ERAD1 = 0.36                   ! Emissivity of Flux Trap Surfaces
ERAD2 = 0.36                   ! Emissivity of Periphery Surfaces
!
ASSYQ = 15.00                  ! Total Heat Load per Inch Depth

TPER1 = 660                    ! Periphery Temperature for Load Case 1
TPER2 = 910                    ! Periphery Temperature for Load Case 2
TPER3 = 1160                   ! Periphery Temperature for Load Case 3

! ***********************************
! Define Properties for All Materials
! ***********************************
MPTEMP,,TPER1,TPER2,TPER3      ! Temperature Data Points
!
MPDATA,KXX,1,,KCA0,KCA1,KCA2   ! Fuel Assembly Regions
!
MPDATA,KXX,2,,KII0,KII1,KII2   ! Boral Basket Panels, Along Panel
MPDATA,KYY,2,,KOI0,KOI1,KOI2   ! Boral Basket Panels, Through Panel
!
MPDATA,KXX,3,,KAX0,KAX1,KAX2   ! Alloy-X
!
MPDATA,KXX,4,,KHE0,KHE1,KHE2
!
MPDATA,KXX,5,,KHE0*MRA0,KHE1*MRA1,KHE2*MRA2  ! Downcomer Regions

! **************************************************************
! Exit the Preprocessor and Enter the Radiation Matrix Generator
! **************************************************************
FINISH
/AUX12

! ***************************
! Define Material Emissivities
! ***************************
EMIS,6,ERAD1                   ! Emissivity in Flux Traps
EMIS,7,ERAD2                   ! Emissivity in Periphery

! *****************************************
! Select Radiating Surface Elements and Nodes
! *****************************************
ALLSEL
ESEL,S,TYPE,,2
NSLE,S

! *********************************************
! Specify Options and Generate Radiation Matrix
! *********************************************
GEOM,1
VTYPE,0,1000
WRITE
ALLSEL

! **************************************************************
! Exit the Radiation Matrix Generator and Enter the PreProcessor
! **************************************************************
FINISH
```

```
/PREP7

! ***************************************
! Define Radiation Matrix as Superelement
! ***************************************
TYPE,3
SE

! ***************************************
! Set Heat Generation Boundary Conditions
! ***************************************
ESEL,S,MAT,,1                    ! Select All Fuel Region Elements
BFE,ALL,HGEN,,ASSYQ/1837.5       ! Apply Volumetric Heat Generation

! *******************************************************
! Exit the PreProcessor and Enter the Solution Processor
!*******************************************************
FINISH
/SOLU

! ***********************
! Perform Static Solutions
! ***********************
ANTYPE,STAT                      ! Perform STATIC Solution
EQSLV,JCG                        ! Select JCG Solver
SOLCON,ON                        ! Automatic Solution Controls
NSUBST,1,10,1                    ! Set Substep Controls

TUNIF,TPER1                      ! Set Initial, Uniform Temperature
CSYS,1                           ! Select Cylindrical Coordinates

TIME,1.0                         ! Load Case 1
NSEL,S,LOC,X,34.1875             ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER1                 ! Set Constant Periphery Temperature
NALL                             ! Reselect All Nodes
EALL                             ! Reselect All Elements
ESEL,U,TYPE,,2                   ! Unselect Radiation Surface Elements
SOLVE

TIME,2.0                         ! Load Case 2
NSEL,S,LOC,X,34.1875             ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER2                 ! Set Constant Periphery Temperature
NALL                             ! Reselect All Nodes
EALL                             ! Reselect All Elements
ESEL,U,TYPE,,2                   ! Unselect Radiation Surface Elements
SOLVE

TIME,3.0                         ! Load Case 3
NSEL,S,LOC,X,34.1875             ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER3                 ! Set Constant Periphery Temperature
NALL                             ! Reselect All Nodes
EALL                             ! Reselect All Elements
ESEL,U,TYPE,,2                   ! Unselect Radiation Surface Elements
SOLVE

TIME,4.0
NSEL,S,LOC,X,34.1875             ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER1-1.0             ! Set Constant Periphery Temperature
NALL
D,BASKEDGE,TEMP,TPER1            ! Set Constant Periphery Temperature
EALL                             ! Reselect All Elements
```

```
ESEL,U,TYPE,,2                      ! Unselect Radiation Surface Elements
SOLVE

TIME,5.0
NSEL,S,LOC,X,34.1875                ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER2-1.0                ! Set Constant Periphery Temperature
NALL
D,BASKEDGE,TEMP,TPER2               ! Set Constant Periphery Temperature
EALL                                ! Reselect All Elements
ESEL,U,TYPE,,2                      ! Unselect Radiation Surface Elements
SOLVE

TIME,6.0
NSEL,S,LOC,X,34.1875                ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER3-1.0                ! Set Constant Periphery Temperature
NALL
D,BASKEDGE,TEMP,TPER3               ! Set Constant Periphery Temperature
EALL                                ! Reselect All Elements
ESEL,U,TYPE,,2                      ! Unselect Radiation Surface Elements
SOLVE

! ************************************************
! Exit Solution Processor and Enter PostProcessor
! ************************************************
FINISH
/POST1

! ********************************************
! Generate Calculated Temperature Results File
! ********************************************
SET,1
NSORT,TEMP                          ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX1,SORT,,MAX                ! Determine Maximum Temperature

SET,2
NSORT,TEMP                          ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX2,SORT,,MAX                ! Determine Maximum Temperature

SET,3
NSORT,TEMP                          ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX3,SORT,,MAX                ! Determine Maximum Temperature

SET,4
NSORT,TEMP                          ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX4,SORT,,MAX                ! Determine Maximum Temperature

SET,5
NSORT,TEMP                          ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX5,SORT,,MAX                ! Determine Maximum Temperature

SET,6
NSORT,TEMP                          ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX6,SORT,,MAX                ! Determine Maximum Temperature

/OUTPUT,,RES

/COM,Output File for Temperature Distribution Analysis
/COM,of a Horizontal Diluted Helium Backfilled MPC-24

/COM
/COM
```

```
/COM,Maximum Temperature for 660R MPC Periphery Temperature
*STATUS,TMAX1

/COM
/COM
/COM,Maximum Temperature for 910R MPC Periphery Temperature
*STATUS,TMAX2

/COM
/COM
/COM,Maximum Temperature for 1160R MPC Periphery Temperature
*STATUS,TMAX3

/COM
/COM
/COM,Maximum Temperature for 660R Basket Periphery Temperature
*STATUS,TMAX4

/COM
/COM
/COM,Maximum Temperature for 910R Basket Periphery Temperature
*STATUS,TMAX5

/COM
/COM
/COM,Maximum Temperature for 1160R Basket Periphery Temperature
*STATUS,TMAX6

/OUTPUT,TERM

! ************************************
! Save Database and Exit PostProcessor
! ************************************
SAVE
FINISH
```

ANSYS Script File V24MG.INP

```
! ************************************************************
! Input File for Vertical (Storage) MPC-24 with Diluted Helium
!  Dilution of Helium is from a Hypothetical 10% Rod Rupture
!************************************************************
/FILNAM,V24MG
/TITLE,MPC-24 Model
/UNITS,BIN

PI=ACOS(-1)

! ************************
! Resume Database MPC24.DB
! ************************
RESUME,MPC24,DB

! *****************
! Enter PreProcessor
! *****************
/PREP7

! ***************************************************
! Definition of Input Values
```

```
! All Dimensions are in inch, hour, Btu, Rankine units
! ****************************************************
KCA0 = 1.772E-2               ! Effective Thermal Conductivity
KCA1 = 2.894E-2               ! of Fuel Assembly Regions
KCA2 = 4.473E-2               ! at 660R, 910R and 1160R
!
KII0 = 1.117                  ! Along Panel Thermal Conductivity
KII1 = 1.236                  ! for Boral Basket Panels
KII2 = 1.328                  ! at 660R, 910R and 1160R
!
KOI0 = 0.203                  ! Through Panel Thermal Conductivity
KOI1 = 0.255                  ! for Boral Basket Panels
KOI2 = 0.301                  ! at 660R, 910R and 1160R
!
KAX0 = 0.700                  ! Alloy-X Thermal Conductivity
KAX1 = 0.816                  ! at 660R, 910R and 1160R
KAX2 = 0.916                  !
!
KHE0 = 7.336E-3               ! Helium Thermal Conductivity
KHE1 = 9.687E-3               ! EXCLUDING Rayleigh Effect
KHE2 = 1.184E-2               ! at 660R, 910R, and 1160R
!
MRA0 = 3.17                   ! Rayleigh Effect Helium Conductivity
MRA1 = 2.56                   ! Multiplier at 660R, 910R and 1160R
MRA2 = 2.21                   !
!
ERAD1 = 0.36                  ! Emissivity of Flux Trap Surfaces
ERAD2 = 0.36                  ! Emissivity of Periphery Surfaces
!
ASSYQ = 15.00                 ! Total Heat Load per Inch Depth

TPER1 = 660                   ! Periphery Temperature for Load Case 1
TPER2 = 910                   ! Periphery Temperature for Load Case 2
TPER3 = 1160                  ! Periphery Temperature for Load Case 3

! **********************************
! Define Properties for All Materials
! **********************************
MPTEMP,,TPER1,TPER2,TPER3     ! Temperature Data Points
!
MPDATA,KXX,1,,KCA0,KCA1,KCA2  ! Fuel Assembly Regions
!
MPDATA,KXX,2,,KII0,KII1,KII2  ! Boral Basket Panels, Along Panel
MPDATA,KYY,2,,KOI0,KOI1,KOI2  ! Boral Basket Panels, Through Panel
!
MPDATA,KXX,3,,KAX0,KAX1,KAX2  ! Alloy-X
!
MPDATA,KXX,4,,KHE0,KHE1,KHE2
!
MPDATA,KXX,5,,KHE0*MRA0,KHE1*MRA1,KHE2*MRA2  ! Downcomer Regions

! ***************************************************************
! Exit the Preprocessor and Enter the Radiation Matrix Generator
! ***************************************************************
FINISH
/AUX12

! **************************
! Define Material Emissivities
! **************************
EMIS,6,ERAD1                  ! Emissivity in Flux Traps
```

```
EMIS,7,ERAD2                    ! Emissivity in Periphery

! *******************************************
! Select Radiating Surface Elements and Nodes
! *******************************************
ALLSEL
ESEL,S,TYPE,,2
NSLE,S

! *********************************************
! Specify Options and Generate Radiation Matrix
! *********************************************
GEOM,1
VTYPE,0,1000
WRITE
ALLSEL

! ************************************************************
! Exit the Radiation Matrix Generator and Enter the PreProcessor
! ************************************************************
FINISH
/PREP7

! ***************************************
! Define Radiation Matrix as Superelement
! ***************************************
TYPE,3
SE

! ***************************************
! Set Heat Generation Boundary Conditions
! ***************************************
ESEL,S,MAT,,1                   ! Select All Fuel Region Elements
BFE,ALL,HGEN,,ASSYQ/1837.5      ! Apply Volumetric Heat Generation

! *****************************************************
! Exit the PreProcessor and Enter the Solution Processor
!*****************************************************
FINISH
/SOLU

! ***********************
! Perform Static Solutions
! ***********************
ANTYPE,STAT                     ! Perform STATIC Solution
EQSLV,JCG                       ! Select JCG Solver
SOLCON,ON                       ! Automatic Solution Controls
NSUBST,1,10,1                   ! Set Substep Controls

TUNIF,TPER1                     ! Set Initial, Uniform Temperature
CSYS,1                          ! Select Cylindrical Coordinates

TIME,1.0                        ! Load Case 1
NSEL,S,LOC,X,34.1875            ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER1                ! Set Constant Periphery Temperature
NALL                            ! Reselect All Nodes
EALL                            ! Reselect All Elements
ESEL,U,TYPE,,2                  ! Unselect Radiation Surface Elements
SOLVE

TIME,2.0                        ! Load Case 2
```

```
NSEL,S,LOC,X,34.1875              ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER2                  ! Set Constant Periphery Temperature
NALL                              ! Reselect All Nodes
EALL                              ! Reselect All Elements
ESEL,U,TYPE,,2                    ! Unselect Radiation Surface Elements
SOLVE

TIME,3.0                          ! Load Case 3
NSEL,S,LOC,X,34.1875              ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER3                  ! Set Constant Periphery Temperature
NALL                              ! Reselect All Nodes
EALL                              ! Reselect All Elements
ESEL,U,TYPE,,2                    ! Unselect Radiation Surface Elements
SOLVE

TIME,4.0
NSEL,S,LOC,X,34.1875              ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER1-1.0              ! Set Constant Periphery Temperature
NALL
D,BASKEDGE,TEMP,TPER1             ! Set Constant Periphery Temperature
EALL                              ! Reselect All Elements
ESEL,U,TYPE,,2                    ! Unselect Radiation Surface Elements
SOLVE

TIME,5.0
NSEL,S,LOC,X,34.1875              ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER2-1.0              ! Set Constant Periphery Temperature
NALL
D,BASKEDGE,TEMP,TPER2             ! Set Constant Periphery Temperature
EALL                              ! Reselect All Elements
ESEL,U,TYPE,,2                    ! Unselect Radiation Surface Elements
SOLVE

TIME,6.0
NSEL,S,LOC,X,34.1875              ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER3-1.0              ! Set Constant Periphery Temperature
NALL
D,BASKEDGE,TEMP,TPER3             ! Set Constant Periphery Temperature
EALL                              ! Reselect All Elements
ESEL,U,TYPE,,2                    ! Unselect Radiation Surface Elements
SOLVE

! ***********************************************
! Exit Solution Processor and Enter PostProcessor
! ***********************************************
FINISH
/POST1

! ********************************************
! Generate Calculated Temperature Results File
! ********************************************
SET,1
NSORT,TEMP                        ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX1,SORT,,MAX              ! Determine Maximum Temperature

SET,2
NSORT,TEMP                        ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX2,SORT,,MAX              ! Determine Maximum Temperature

SET,3
NSORT,TEMP                        ! Sort Nodal Temps From Highest to Lowest
```

```
*GET,TMAX3,SORT,,MAX            ! Determine Maximum Temperature

SET,4
NSORT,TEMP                      ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX4,SORT,,MAX            ! Determine Maximum Temperature

SET,5
NSORT,TEMP                      ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX5,SORT,,MAX            ! Determine Maximum Temperature

SET,6
NSORT,TEMP                      ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX6,SORT,,MAX            ! Determine Maximum Temperature

/OUTPUT,,RES

/COM,Output File for Temperature Distribution Analysis
/COM,of a Vertical MPC-24 Backfilled with Helium Gas
/COM,Diluted by 10% of Released Fuel Rod Gases

/COM
/COM
/COM,Maximum Temperature for 660R MPC Periphery Temperature
*STATUS,TMAX1

/COM
/COM
/COM,Maximum Temperature for 910R MPC Periphery Temperature
*STATUS,TMAX2

/COM
/COM
/COM,Maximum Temperature for 1160R MPC Periphery Temperature
*STATUS,TMAX3

/COM
/COM
/COM,Maximum Temperature for 660R Basket Periphery Temperature
*STATUS,TMAX4

/COM
/COM
/COM,Maximum Temperature for 910R Basket Periphery Temperature
*STATUS,TMAX5

/COM
/COM
/COM,Maximum Temperature for 1160R Basket Periphery Temperature
*STATUS,TMAX6

/OUTPUT,TERM

! ***********************************
! Save Database and Exit PostProcessor
! ***********************************
SAVE
FINISH
```

ANSYS Script File V68MG.INP

```
! ***********************************************************
! Input File for Vertical (Storage) MPC-68 with Diluted Helium
!  Dilution of Helium is from a Hypothetical 10% Rod Rupture
!***********************************************************
/FILNAM,V68MG
/TITLE,MPC-68 Model
/UNITS,BIN

PI=ACOS(-1)

! ***********************
! Resume Database MPC68.DB
! ***********************
RESUME,MPC68,DB

! *****************
! Enter PreProcessor
! *****************
/PREP7

! ***************************************************
! Definition of Input Values
! All Dimensions are in inch, hour, Btu, Rankine units
! ***************************************************
KCA0 = 1.314E-2                ! Effective Thermal Conductivity
KCA1 = 2.119E-2                ! of Fuel Assembly Regions
KCA2 = 3.212E-2                ! at 660R, 910R and 1160R
!
KII0 = 1.087                   ! Along Panel Thermal Conductivity
KII1 = 1.205                   ! for Boral Basket Panels
KII2 = 1.294                   ! at 660R, 910R and 1160R
!
KOI0 = 0.192                   ! Through Panel Thermal Conductivity
KOI1 = 0.242                   ! for Boral Basket Panels
KOI2 = 0.286                   ! at 660R, 910R and 1160R
!
KAX0 = 0.700                   ! Alloy-X Thermal Conductivity
KAX1 = 0.816                   ! at 660R, 910R and 1160R
KAX2 = 0.916                   !
!
KHE0 = 7.157E-3                ! Helium Thermal Conductivity
KHE1 = 9.451E-3                ! EXCLUDING Rayleigh Effect
KHE2 = 1.155E-2                ! at 660R, 910R, and 1160R
!
MRA0 = 2.41                    ! Rayleigh Effect Helium Conductivity
MRA1 = 1.95                    ! Multiplier at 660R, 910R and 1160R
MRA2 = 1.68                    ! for Model Bottom Zones
!
MRB0 = 2.41                    ! Rayleigh Effect Helium Conductivity
MRB1 = 1.95                    ! Multiplier at 660R, 910R and 1160R
MRB2 = 1.68                    ! for Model Top Zones
!
MRC0 = 2.41                    ! Rayleigh Effect Helium Conductivity
MRC1 = 1.95                    ! Multiplier at 660R, 910R and 1160R
MRC2 = 1.68                    ! For Model Side Zones
!
ERAD = 0.36                    ! Emissivity of Radiating Surfaces
!
```

```
ASSYQ = 15.00                  ! Total Heat Load per Inch Depth

TPER1 = 660                    ! Periphery Temperature for Load Case 1
TPER2 = 910                    ! Periphery Temperature for Load Case 2
TPER3 = 1160                   ! Periphery Temperature for Load Case 3

! **********************************
! Define Properties for All Materials
! **********************************
MPTEMP,,TPER1,TPER2,TPER3      ! Temperature Data Points
!
MPDATA,KXX,1,,KCA0,KCA1,KCA2   ! Fuel Assembly Regions
!
MPDATA,KXX,2,,KAX0,KAX1,KAX2   ! Alloy-X
!
MPDATA,KXX,3,,KII0,KII1,KII2   ! Boral Basket Panels, Along Panel
MPDATA,KYY,3,,KOI0,KOI1,KOI2   ! Boral Basket Panels, Through Panel
!
MPDATA,KXX,4,,KHE0,KHE1,KHE2
!
MPDATA,KXX,5,,KHE0*MRA0,KHE1*MRA1,KHE2*MRA2   ! Model Bottom Zones
!
MPDATA,KXX,6,,KHE0*MRB0,KHE1*MRB1,KHE2*MRB2   ! Model Top Zones
!
MPDATA,KXX,7,,KHE0*MRC0,KHE1*MRC1,KHE2*MRC2   ! Model Side Zones

! *********************************************************
! Exit the Preprocessor and Enter the Radiation Matrix Generator
! *********************************************************
FINISH
/AUX12

! ***************************
! Define Material Emissivities
! ***************************
EMIS,8,ERAD                    ! Radiating Surfaces Emissivity

! ****************************************
! Select Radiating Surface Elements and Nodes
! ****************************************
ALLSEL
ESEL,S,TYPE,,2
NSLE,S

! ******************************************
! Specify Options and Generate Radiation Matrix
! ******************************************
GEOM,1
VTYPE,0,1000
WRITE
ALLSEL

! *********************************************************
! Exit the Radiation Matrix Generator and Enter the PreProcessor
! *********************************************************
FINISH
/PREP7

! **************************************
! Define Radiation Matrix as Superelement
! **************************************
```

```
TYPE,3
SE

! **************************************
! Set Heat Generation Boundary Conditions
! **************************************
ESEL,S,MAT,,1                   ! Select All Fuel Region Elements
ESEL,R,TYPE,,1                  ! Reselect Only PLANE55 Elements
BFE,ALL,HGEN,,ASSYQ/2491.44     ! Apply Volumetric Heat Generation

! *****************************************************
! Exit the PreProcessor and Enter the Solution Processor
!*****************************************************
FINISH
/SOLU

! ***********************
! Perform Static Solutions
! ***********************
ANTYPE,STAT                     ! Perform STATIC Solution
EQSLV,JCG                       ! Select JCG Solver
SOLCON,ON                       ! Automatic Solution Controls
NSUBST,1,10,1                   ! Set Substep Controls

TUNIF,TPER1                     ! Set Initial, Uniform Temperature
CSYS,1                          ! Select Cylindrical Coordinates

TIME,1.0                        ! Load Case 1
NSEL,S,LOC,X,34.1875            ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER1                ! Set Constant Periphery Temperature
NALL                            ! Reselect All Nodes
EALL                            ! Reselect All Elements
ESEL,U,TYPE,,2                  ! Unselect Radiation Surface Elements
SOLVE

TIME,2.0                        ! Load Case 2
NSEL,S,LOC,X,34.1875            ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER2                ! Set Constant Periphery Temperature
NALL                            ! Reselect All Nodes
EALL                            ! Reselect All Elements
ESEL,U,TYPE,,2                  ! Unselect Radiation Surface Elements
SOLVE

TIME,3.0                        ! Load Case 3
NSEL,S,LOC,X,34.1875            ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER3                ! Set Constant Periphery Temperature
NALL                            ! Reselect All Nodes
EALL                            ! Reselect All Elements
ESEL,U,TYPE,,2                  ! Unselect Radiation Surface Elements
SOLVE

TIME,4.0
NSEL,S,LOC,X,34.1875            ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER1-1.0            ! Set Constant Periphery Temperature
NALL
D,BASKEDGE,TEMP,TPER1           ! Set Constant Periphery Temperature
EALL                            ! Reselect All Elements
ESEL,U,TYPE,,2                  ! Unselect Radiation Surface Elements
SOLVE

TIME,5.0
```

```
NSEL,S,LOC,X,34.1875            ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER2-1.0            ! Set Constant Periphery Temperature
NALL
D,BASKEDGE,TEMP,TPER2           ! Set Constant Periphery Temperature
EALL                            ! Reselect All Elements
ESEL,U,TYPE,,2                  ! Unselect Radiation Surface Elements
SOLVE

TIME,6.0
NSEL,S,LOC,X,34.1875            ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER3-1.0            ! Set Constant Periphery Temperature
NALL
D,BASKEDGE,TEMP,TPER3           ! Set Constant Periphery Temperature
EALL                            ! Reselect All Elements
ESEL,U,TYPE,,2                  ! Unselect Radiation Surface Elements
SOLVE

! ***********************************************
! Exit Solution Processor and Enter PostProcessor
! ***********************************************
FINISH
/POST1

! ********************************************
! Generate Calculated Temperature Results File
! ********************************************
SET,1
NSORT,TEMP                      ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX1,SORT,,MAX            ! Determine Maximum Temperature

SET,2
NSORT,TEMP                      ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX2,SORT,,MAX            ! Determine Maximum Temperature

SET,3
NSORT,TEMP                      ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX3,SORT,,MAX            ! Determine Maximum Temperature

SET,4
NSORT,TEMP                      ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX4,SORT,,MAX            ! Determine Maximum Temperature

SET,5
NSORT,TEMP                      ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX5,SORT,,MAX            ! Determine Maximum Temperature

SET,6
NSORT,TEMP                      ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX6,SORT,,MAX            ! Determine Maximum Temperature

/OUTPUT,,RES

/COM,Output File for Temperature Distribution Analysis
/COM,of a Vertical MPC-68 Backfilled with Helium Gas
/COM,Diluted by 10% of Released Fuel Rod Gases

/COM
/COM
/COM,Maximum Temperature for 660R MPC Periphery Temperature
*STATUS,TMAX1
```

```
/COM
/COM
/COM,Maximum Temperature for 910R MPC Periphery Temperature
*STATUS,TMAX2

/COM
/COM
/COM,Maximum Temperature for 1160R MPC Periphery Temperature
*STATUS,TMAX3

/COM
/COM
/COM,Maximum Temperature for 660R Basket Periphery Temperature
*STATUS,TMAX4

/COM
/COM
/COM,Maximum Temperature for 910R Basket Periphery Temperature
*STATUS,TMAX5

/COM
/COM
/COM,Maximum Temperature for 1160R Basket Periphery Temperature
*STATUS,TMAX6

/OUTPUT,TERM

! ***********************************
! Save Database and Exit PostProcessor
! ***********************************
SAVE
FINISH
```

ANSYS Script File H24NR.INP

```
! ***********************************************************
! Input File for Horizontal (Transport) Helium Backfilled MPC-24
!************************************************************
/FILNAM,H24NR
/TITLE,MPC-24 Model
/UNITS,BIN

PI=ACOS(-1)

! ***********************
! Resume Database MPC24.DB
! ***********************
RESUME,MPC24,DB

! *****************
! Enter PreProcessor
! *****************
/PREP7

! **************************************************
! Definition of Input Values
! All Dimensions are in inch, hour, Btu, Rankine units
! **************************************************
KCA0 = 2.138E-2             ! Effective Thermal Conductivity
KCA1 = 3.375E-2             ! of Fuel Assembly Regions
```

```
KCA2 = 5.022E-2                       ! at 660R, 910R and 1160R
!
KII0 = 1.117                          ! Along Panel Thermal Conductivity
KII1 = 1.236                          ! for Boral Basket Panels
KII2 = 1.328                          ! at 660R, 910R and 1160R
!
KOI0 = 0.203                          ! Through Panel Thermal Conductivity
KOI1 = 0.255                          ! for Boral Basket Panels
KOI2 = 0.301                          ! at 660R, 910R and 1160R
!
KAX0 = 0.700                          ! Alloy-X Thermal Conductivity
KAX1 = 0.816                          ! at 660R, 910R and 1160R
KAX2 = 0.916                          !
!
KHE0 = 8.133E-3                       ! Helium Thermal Conductivity
KHE1 = 1.074E-2                       ! EXCLUDING Rayleigh Effect
KHE2 = 1.312E-2                       ! at 660R, 910R, and 1160R
!
MRA0 = 1.00                           ! Rayleigh Effect Helium Conductivity
MRA1 = 1.00                           ! Multiplier at 660R, 910R and 1160R
MRA2 = 1.00                           !
!
ERAD1 = 0.36                          ! Emissivity of Flux Trap Surfaces
ERAD2 = 0.36                          ! Emissivity of Periphery Surfaces
!
ASSYQ = 15.00                         ! Total Heat Load per Inch Depth

TPER1 = 660                           ! Periphery Temperature for Load Case 1
TPER2 = 910                           ! Periphery Temperature for Load Case 2
TPER3 = 1160                          ! Periphery Temperature for Load Case 3

! ***********************************
! Define Properties for All Materials
! ***********************************
MPTEMP,,TPER1,TPER2,TPER3             ! Temperature Data Points
!
MPDATA,KXX,1,,KCA0,KCA1,KCA2          ! Fuel Assembly Regions
!
MPDATA,KXX,2,,KII0,KII1,KII2          ! Boral Basket Panels, Along Panel
MPDATA,KYY,2,,KOI0,KOI1,KOI2          ! Boral Basket Panels, Through Panel
!
MPDATA,KXX,3,,KAX0,KAX1,KAX2          ! Alloy-X
!
MPDATA,KXX,4,,KHE0,KHE1,KHE2
!
MPDATA,KXX,5,,KHE0*MRA0,KHE1*MRA1,KHE2*MRA2   ! Downcomer Regions

! ***************************************************************
! Exit the Preprocessor and Enter the Radiation Matrix Generator
! ***************************************************************
FINISH
/AUX12

! ***************************
! Define Material Emissivities
! ***************************
EMIS,6,ERAD1                          ! Emissivity in Flux Traps
EMIS,7,ERAD2                          ! Emissivity in Periphery

! ******************************************
! Select Radiating Surface Elements and Nodes
```

```
! *******************************************
ALLSEL
ESEL,S,TYPE,,2
NSLE,S

! *********************************************
! Specify Options and Generate Radiation Matrix
! *********************************************
GEOM,1
VTYPE,0,1000
WRITE
ALLSEL

! ****************************************************************
! Exit the Radiation Matrix Generator and Enter the PreProcessor
! ****************************************************************
FINISH
/PREP7

! ***************************************
! Define Radiation Matrix as Superelement
! ***************************************
TYPE,3
SE

! ***************************************
! Set Heat Generation Boundary Conditions
! ***************************************
ESEL,S,MAT,,1                   ! Select All Fuel Region Elements
BFE,ALL,HGEN,,ASSYQ/1837.5      ! Apply Volumetric Heat Generation

! ******************************************************
! Exit the PreProcessor and Enter the Solution Processor
!******************************************************
FINISH
/SOLU

! ***********************
! Perform Static Solutions
! ***********************
ANTYPE,STAT                     ! Perform STATIC Solution
EQSLV,JCG                       ! Select JCG Solver
SOLCON,ON                       ! Automatic Solution Controls
NSUBST,1,10,1                   ! Set Substep Controls

TUNIF,TPER1                     ! Set Initial, Uniform Temperature
CSYS,1                          ! Select Cylindrical Coordinates

TIME,1.0                        ! Load Case 1
NSEL,S,LOC,X,34.1875            ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER1                ! Set Constant Periphery Temperature
NALL                            ! Reselect All Nodes
EALL                            ! Reselect All Elements
ESEL,U,TYPE,,2                  ! Unselect Radiation Surface Elements
SOLVE

TIME,2.0                        ! Load Case 2
NSEL,S,LOC,X,34.1875            ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER2                ! Set Constant Periphery Temperature
NALL                            ! Reselect All Nodes
EALL                            ! Reselect All Elements
```

```
ESEL,U,TYPE,,2                  ! Unselect Radiation Surface Elements
SOLVE

TIME,3.0                        ! Load Case 3
NSEL,S,LOC,X,34.1875            ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER3                ! Set Constant Periphery Temperature
NALL                            ! Reselect All Nodes
EALL                            ! Reselect All Elements
ESEL,U,TYPE,,2                  ! Unselect Radiation Surface Elements
SOLVE

TIME,4.0
NSEL,S,LOC,X,34.1875            ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER1-1.0            ! Set Constant Periphery Temperature
NALL
D,BASKEDGE,TEMP,TPER1           ! Set Constant Periphery Temperature
EALL                            ! Reselect All Elements
ESEL,U,TYPE,,2                  ! Unselect Radiation Surface Elements
SOLVE

TIME,5.0
NSEL,S,LOC,X,34.1875            ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER2-1.0            ! Set Constant Periphery Temperature
NALL
D,BASKEDGE,TEMP,TPER2           ! Set Constant Periphery Temperature
EALL                            ! Reselect All Elements
ESEL,U,TYPE,,2                  ! Unselect Radiation Surface Elements
SOLVE

TIME,6.0
NSEL,S,LOC,X,34.1875            ! Select Outer Periphery Nodes
D,ALL,TEMP,TPER3-1.0            ! Set Constant Periphery Temperature
NALL
D,BASKEDGE,TEMP,TPER3           ! Set Constant Periphery Temperature
EALL                            ! Reselect All Elements
ESEL,U,TYPE,,2                  ! Unselect Radiation Surface Elements
SOLVE

! ***********************************************
! Exit Solution Processor and Enter PostProcessor
! ***********************************************
FINISH
/POST1

! ******************************************
! Generate Calculated Temperature Results File
! ******************************************
SET,1
NSORT,TEMP                      ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX1,SORT,,MAX            ! Determine Maximum Temperature

SET,2
NSORT,TEMP                      ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX2,SORT,,MAX            ! Determine Maximum Temperature

SET,3
NSORT,TEMP                      ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX3,SORT,,MAX            ! Determine Maximum Temperature

SET,4
NSORT,TEMP                      ! Sort Nodal Temps From Highest to Lowest
```

```
*GET,TMAX4,SORT,,MAX               ! Determine Maximum Temperature

SET,5
NSORT,TEMP                         ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX5,SORT,,MAX               ! Determine Maximum Temperature

SET,6
NSORT,TEMP                         ! Sort Nodal Temps From Highest to Lowest
*GET,TMAX6,SORT,,MAX               ! Determine Maximum Temperature

/OUTPUT,,RES

/COM,Output File for Temperature Distribution Analysis
/COM,of a Horizontal Helium Backfilled MPC-24

/COM
/COM
/COM,Maximum Temperature for 660R MPC Periphery Temperature
*STATUS,TMAX1

/COM
/COM
/COM,Maximum Temperature for 910R MPC Periphery Temperature
*STATUS,TMAX2

/COM
/COM
/COM,Maximum Temperature for 1160R MPC Periphery Temperature
*STATUS,TMAX3

/COM
/COM
/COM,Maximum Temperature for 660R Basket Periphery Temperature
*STATUS,TMAX4

/COM
/COM
/COM,Maximum Temperature for 910R Basket Periphery Temperature
*STATUS,TMAX5

/COM
/COM
/COM,Maximum Temperature for 1160R Basket Periphery Temperature
*STATUS,TMAX6

/OUTPUT,TERM

! ************************************
! Save Database and Exit PostProcessor
! ************************************
SAVE
FINISH
```

ANSYS Results File H24MG.RES

```
Output File for Temperature Distribution Analysis
of a Horizontal Diluted Helium Backfilled MPC-24


Maximum Temperature for 660R MPC Periphery Temperature

PARAMETER STATUS- TMAX1      (  41 PARAMETERS DEFINED)
                 (INCLUDING     11 INTERNAL PARAMETERS)

 NAME         VALUE          TYPE      DIMENSIONS
 TMAX1     684.766329       SCALAR

Maximum Temperature for 910R MPC Periphery Temperature

PARAMETER STATUS- TMAX2      (  41 PARAMETERS DEFINED)
                 (INCLUDING     11 INTERNAL PARAMETERS)

 NAME         VALUE          TYPE      DIMENSIONS
 TMAX2     927.061906       SCALAR

Maximum Temperature for 1160R MPC Periphery Temperature

PARAMETER STATUS- TMAX3      (  41 PARAMETERS DEFINED)
                 (INCLUDING     11 INTERNAL PARAMETERS)

 NAME         VALUE          TYPE      DIMENSIONS
 TMAX3     1172.03713       SCALAR

Maximum Temperature for 660R Basket Periphery Temperature

PARAMETER STATUS- TMAX4      (  41 PARAMETERS DEFINED)
                 (INCLUDING     11 INTERNAL PARAMETERS)

 NAME         VALUE          TYPE      DIMENSIONS
 TMAX4     675.345887       SCALAR

Maximum Temperature for 910R Basket Periphery Temperature

PARAMETER STATUS- TMAX5      (  41 PARAMETERS DEFINED)
                 (INCLUDING     11 INTERNAL PARAMETERS)

 NAME         VALUE          TYPE      DIMENSIONS
 TMAX5     920.997519       SCALAR

Maximum Temperature for 1160R Basket Periphery Temperature

PARAMETER STATUS- TMAX6      (  41 PARAMETERS DEFINED)
                 (INCLUDING     11 INTERNAL PARAMETERS)

 NAME         VALUE          TYPE      DIMENSIONS
 TMAX6     1168.14820       SCALAR
```

ANSYS Results File V24MG.RES

```
Output File for Temperature Distribution Analysis
of a Vertical MPC-24 Backfilled with Helium Gas
Diluted by 10% of Released Fuel Rod Gases


Maximum Temperature for 660R MPC Periphery Temperature

PARAMETER STATUS- TMAX1      (  41 PARAMETERS DEFINED)
                  (INCLUDING    11 INTERNAL PARAMETERS)

 NAME         VALUE          TYPE     DIMENSIONS
 TMAX1     682.276281       SCALAR


Maximum Temperature for 910R MPC Periphery Temperature

PARAMETER STATUS- TMAX2      (  41 PARAMETERS DEFINED)
                  (INCLUDING    11 INTERNAL PARAMETERS)

 NAME         VALUE          TYPE     DIMENSIONS
 TMAX2     925.604334       SCALAR


Maximum Temperature for 1160R MPC Periphery Temperature

PARAMETER STATUS- TMAX3      (  41 PARAMETERS DEFINED)
                  (INCLUDING    11 INTERNAL PARAMETERS)

 NAME         VALUE          TYPE     DIMENSIONS
 TMAX3     1171.25536       SCALAR


Maximum Temperature for 660R Basket Periphery Temperature

PARAMETER STATUS- TMAX4      (  41 PARAMETERS DEFINED)
                  (INCLUDING    11 INTERNAL PARAMETERS)

 NAME         VALUE          TYPE     DIMENSIONS
 TMAX4     673.680698       SCALAR


Maximum Temperature for 910R Basket Periphery Temperature

PARAMETER STATUS- TMAX5      (  41 PARAMETERS DEFINED)
                  (INCLUDING    11 INTERNAL PARAMETERS)

 NAME         VALUE          TYPE     DIMENSIONS
 TMAX5     920.051728       SCALAR


Maximum Temperature for 1160R Basket Periphery Temperature

PARAMETER STATUS- TMAX6      (  41 PARAMETERS DEFINED)
                  (INCLUDING    11 INTERNAL PARAMETERS)

 NAME         VALUE          TYPE     DIMENSIONS
 TMAX6     1167.60587       SCALAR
```

ANSYS Results File V68MG.RES

```
Output File for Temperature Distribution Analysis
of a Vertical MPC-68 Backfilled with Helium Gas
Diluted by 10% of Released Fuel Rod Gases


Maximum Temperature for 660R MPC Periphery Temperature

PARAMETER STATUS- TMAX1      (  46 PARAMETERS DEFINED)
                   (INCLUDING    11 INTERNAL PARAMETERS)

 NAME          VALUE          TYPE      DIMENSIONS
 TMAX1      686.123699       SCALAR

Maximum Temperature for 910R MPC Periphery Temperature

PARAMETER STATUS- TMAX2      (  46 PARAMETERS DEFINED)
                   (INCLUDING    11 INTERNAL PARAMETERS)

 NAME          VALUE          TYPE      DIMENSIONS
 TMAX2      929.168846       SCALAR

Maximum Temperature for 1160R MPC Periphery Temperature

PARAMETER STATUS- TMAX3      (  46 PARAMETERS DEFINED)
                   (INCLUDING    11 INTERNAL PARAMETERS)

 NAME          VALUE          TYPE      DIMENSIONS
 TMAX3      1174.62596       SCALAR

Maximum Temperature for 660R Basket Periphery Temperature

PARAMETER STATUS- TMAX4      (  46 PARAMETERS DEFINED)
                   (INCLUDING    11 INTERNAL PARAMETERS)

 NAME          VALUE          TYPE      DIMENSIONS
 TMAX4      675.222983       SCALAR

Maximum Temperature for 910R Basket Periphery Temperature

PARAMETER STATUS- TMAX5      (  46 PARAMETERS DEFINED)
                   (INCLUDING    11 INTERNAL PARAMETERS)

 NAME          VALUE          TYPE      DIMENSIONS
 TMAX5      922.264018       SCALAR

Maximum Temperature for 1160R Basket Periphery Temperature

PARAMETER STATUS- TMAX6      (  46 PARAMETERS DEFINED)
                   (INCLUDING    11 INTERNAL PARAMETERS)

 NAME          VALUE          TYPE      DIMENSIONS
 TMAX6      1170.20171       SCALAR
```

ANSYS Results File H24NR.RES

```
Output File for Temperature Distribution Analysis
of a Horizontal Helium Backfilled MPC-24


Maximum Temperature for 660R MPC Periphery Temperature

PARAMETER STATUS- TMAX1       (  41 PARAMETERS DEFINED)
                  (INCLUDING     11 INTERNAL PARAMETERS)

 NAME         VALUE           TYPE      DIMENSIONS
 TMAX1     683.427684        SCALAR


Maximum Temperature for 910R MPC Periphery Temperature

PARAMETER STATUS- TMAX2       (  41 PARAMETERS DEFINED)
                  (INCLUDING     11 INTERNAL PARAMETERS)

 NAME         VALUE           TYPE      DIMENSIONS
 TMAX2     925.702689        SCALAR


Maximum Temperature for 1160R MPC Periphery Temperature

PARAMETER STATUS- TMAX3       (  41 PARAMETERS DEFINED)
                  (INCLUDING     11 INTERNAL PARAMETERS)

 NAME         VALUE           TYPE      DIMENSIONS
 TMAX3     1171.14740        SCALAR


Maximum Temperature for 660R Basket Periphery Temperature

PARAMETER STATUS- TMAX4       (  41 PARAMETERS DEFINED)
                  (INCLUDING     11 INTERNAL PARAMETERS)

 NAME         VALUE           TYPE      DIMENSIONS
 TMAX4     672.923586        SCALAR


Maximum Temperature for 910R Basket Periphery Temperature

PARAMETER STATUS- TMAX5       (  41 PARAMETERS DEFINED)
                  (INCLUDING     11 INTERNAL PARAMETERS)

 NAME         VALUE           TYPE      DIMENSIONS
 TMAX5     919.587697        SCALAR


Maximum Temperature for 1160R Basket Periphery Temperature

PARAMETER STATUS- TMAX6       (  41 PARAMETERS DEFINED)
                  (INCLUDING     11 INTERNAL PARAMETERS)

 NAME         VALUE           TYPE      DIMENSIONS
 TMAX6     1167.33115        SCALAR
```

INTRODUCTION

This calculation is performed to calculate the effective planar thermal conductivity of the fuel basket and basket support region of a Holtec MPC-24 in a horizontal (transport) orientation with diluted helium. The dilution of the helium is due to a hypothetical rupture of all fuel rods and subsequent release of the rod fill gas and gaseous fission products. The results of this calculation will become inputs to an assembled HI-STAR cask system model.

METHODOLOGY

Temperature distributions in a planar section perpendicular to the longitudinal axis of the Holtec MPC-24 have been calculated separately [1] using the ANSYS general-purpose finite element code. The temperature distributions are obtained for two separate boundary conditions:

1. Constant temperature MPC periphery
2. Constant temperature fuel basket periphery

The maximum calculated temperature for each condition is extracted from the results of the finite-element analyses. The differences between these calculated maximum temperatures and the boundary conditions can be used to determine the effective thermal conductivities of equivalent, homogeneous regions.

The fuel basket is reduced to a homogeneous cylinder with uniform heat generation. In a planar section for this idealized geometry, the effective thermal conductivity is given by:

$$k_{eff} = Q_{gen} / (4 \times \pi \times \Delta T_{bm})$$

where: k_{eff} is the effective thermal conductivity, Btu / (hr x in x F)
Q_{gen} is the heat generation per unit depth, Btu / (hr x in)
ΔT_{bm} is the basket periphery-to-maximum temperature difference, F

The basket support region is reduced to a homogeneous hollow cylinder with a known wall thickness. If the cylinder wall thickness is small compared to the cylinder radii, the thermal conductivity can be determined using the familiar Fourier equation for 1-D conduction:

$$keff = (Q \times L) / (A \times \Delta T_{pb})$$

where: Q is the total heat generation rate, Btu/hr
L is the conduction length (wall thickness), in
A is the conducting area, in^2
ΔT_{pb} is the temperature difference, F

The temperature difference (ΔT) must be determined from the planar temperature distribution. If the basket periphery-to-maximum temperature difference is subtracted from the MPC periphery-to-maximum temperature difference, the results is the temperature difference across the basket support region:

$$\Delta T_{pm} - \Delta T_{bm} = (T_p - T_m) - (T_b - T_m) = T_p - T_b = \Delta T_{pb}$$

Therefore, the fuel basket region effective thermal conductivity can be obtained as:

$$k_{eff} = (Q_{gen} \times L) / (A \times (\Delta T_{pm} - \Delta T_{bm}))$$

NOMENCLATURE

This calculation is performed using the Mathcad electronic scratchpad program. The built-in units of temperature are absolute units (i.e. Rankine). Temperature differences are identical in both Rankine and Fahrenheit units. All calculations in this worksheet utilize temperature differences only, so all temperatures will be specified in Rankine (R) units.

REFERENCES

[1] ANSYS Database MPC24.DB, ANSYS Input Script H24MG.INP and ANSYS Postprocessor Result File H24MG.RES.

[2] "HI-STAR 100 MPC-24 Construction," Holtec Drawing 1395, Sheet 1, Revision 5.

INPUT DATA

$OD := 68.375 \cdot in$ — Outer Diameter of MPC-24, from [2]

$L_{unit} := 1.0 \cdot in$ — One Inch Unit Length

$Q_{gen} := 15.0 \cdot \frac{BTU}{hr}$ — Total Heat Generation per Unit Length, from [1]

$L := 2.57 \cdot in$ — Basket Support Region Cylinder Wall Thickness

CALCULATE OUTER SURFACE AREA PER UNIT LENGTH OF MPC

$A := \pi \cdot OD \cdot (1 \cdot in)$ $\qquad A = 214.806 \, in^2$

CALCULATE EFFECTIVE THERMAL CONDUCTIVITIES AT 660 R

$\Delta T_{pm} := (684.766 - 660) \cdot R$ $\qquad \Delta T_{pm} = 24.766 \, R$

$\Delta T_{bm} := (675.346 - 660) \cdot R$ $\qquad \Delta T_{bm} = 15.346 \, R$

$$k_{bm} := \frac{Q_{gen}}{L_{unit} \cdot 4 \cdot \pi \cdot \Delta T_{bm}} \qquad k_{bm} = 0.933 \, \frac{BTU}{hr \cdot ft \cdot R}$$

$$k_{supp} := \frac{Q_{gen} \cdot L}{A \cdot \left(\Delta T_{pm} - \Delta T_{bm}\right)} \qquad k_{supp} = 0.2286 \, \frac{BTU}{hr \cdot ft \cdot R}$$

CALCULATE EFFECTIVE THERMAL CONDUCTIVITIES AT 910 R

$\Delta T_{pm} := (927.062 - 910) \cdot R$ $\qquad \Delta T_{pm} = 17.062 \, R$

$\Delta T_{bm} := (920.996 - 910) \cdot R$ $\qquad \Delta T_{bm} = 10.996 \, R$

$$k_{bm} := \frac{Q_{gen}}{L_{unit} \cdot 4 \cdot \pi \cdot \Delta T_{bm}} \qquad k_{bm} = 1.303 \circ \frac{BTU}{hr \cdot ft \cdot R}$$

$$k_{supp} := \frac{Q_{gen} \cdot L}{A \cdot \left(\Delta T_{pm} - \Delta T_{bm}\right)} \qquad k_{supp} = 0.355 \circ \frac{BTU}{hr \cdot ft \cdot R}$$

CALCULATE EFFECTIVE THERMAL CONDUCTIVITIES AT 1160 R

$$\Delta T_{pm} := (1172.037 - 1160) \cdot R \qquad \Delta T_{pm} = 12.037 \circ R$$

$$\Delta T_{bm} := (1168.148 - 1160) \cdot R \qquad \Delta T_{bm} = 8.148 \circ R$$

$$k_{bm} := \frac{Q_{gen}}{L_{unit} \cdot 4 \cdot \pi \cdot \Delta T_{bm}} \qquad k_{bm} = 1.758 \circ \frac{BTU}{hr \cdot ft \cdot R}$$

$$k_{supp} := \frac{Q_{gen} \cdot L}{A \cdot \left(\Delta T_{pm} - \Delta T_{bm}\right)} \qquad k_{supp} = 0.5538 \circ \frac{BTU}{hr \cdot ft \cdot R}$$

INTRODUCTION

This calculation is performed to calculate the effective planar thermal conductivity of the fuel basket and basket support region of a Holtec MPC-24, backfilled with helium gas diluted by gases released from 10% of the stored fuel rods, in a vertical (storage) orientation. The results of this calculation will become inputs to assembled HI-STAR and/or HI-STORM cask systems thermal models.

METHODOLOGY

Temperature distributions in a planar section perpendicular to the longitudinal axis of the Holtec MPC-24 have been calculated separately [1] using the ANSYS general-purpose finite element code. The temperature distributions are obtained for two separate boundary conditions:

1. Constant temperature MPC periphery
2. Constant temperature fuel basket periphery

The maximum calculated temperature for each condition is extracted from the results of the finite-element analyses. The differences between these calculated maximum temperatures and the boundary conditions can be used to determine the effective thermal conductivities of equivalent, homogeneous regions.

The fuel basket is reduced to a homogeneous cylinder with uniform heat generation. In a planar section for this idealized geometry, the effective thermal conductivity is given by:

$$k_{eff} = Q_{gen} / (4 \times \pi \times \Delta T_{bm})$$

where: k_{eff} is the effective thermal conductivity, Btu / (hr x in x F)
Q_{gen} is the heat generation per unit depth, Btu / (hr x in)
ΔT_{bm} is the basket periphery-to-maximum temperature difference, F

The basket support region is reduced to a homogeneous hollow cylinder with a known wall thickness. If the cylinder wall thickness is small compared to the cylinder radii, the thermal conductivity can be determined using the familiar Fourier equation for 1-D conduction:

$$keff = (Q \times L) / (A \times \Delta T_{pb})$$

where: Q is the total heat generation rate, Btu/hr
L is the conduction length (wall thickness), in
A is the conducting area, in^2
ΔT_{pb} is the temperature difference, F

The temperature difference (ΔT) must be determined from the planar temperature distribution. If the basket periphery-to-maximum temperature difference is subtracted from the MPC periphery-to-maximum temperature difference, the results is the temperature difference across the basket support region:

$$\Delta T_{pm} - \Delta T_{bm} = (T_p - T_m) - (T_b - T_m) = T_p - T_b = \Delta T_{pb}$$

Therefore, the fuel basket region effective thermal conductivity can be obtained as:

$$k_{eff} = (Q_{gen} \times L) / (A \times (\Delta T_{pm} - \Delta T_{bm}))$$

NOMENCLATURE

This calculation is performed using the Mathcad electronic scratchpad program. The built-in units of temperature are absolute units (i.e. Rankine). Temperature differences are identical in both Rankine and Fahrenheit units. All calculations in this worksheet utilize temperature differences only, so all temperatures will be specified in Rankine (R) units.

REFERENCES

[1] ANSYS Database MPC24.DB, ANSYS Input Script V24MG.INP and ANSYS Postprocessor Result File V24MG.RES.

[2] "HI-STAR 100 MPC-24 Construction," Holtec Drawing 1395, Sheet 1, Revision 10.

INPUT DATA

$OD := 68.375 \cdot in$ Outer Diameter of MPC-24, from [2]

$L_{unit} := 1.0 \cdot in$ One Inch Unit Length

$Q_{gen} := 15.0 \cdot \frac{BTU}{hr}$ Total Heat Generation per Unit Length, from [1]

$L := 2.57 \cdot in$ Basket Support Region Cylinder Wall Thickness

CALCULATE OUTER SURFACE AREA PER UNIT LENGTH OF MPC

$A := \pi \cdot OD \cdot (1 \cdot in)$ $A = 214.806 \circ in^2$

CALCULATE EFFECTIVE THERMAL CONDUCTIVITIES AT 660 R

$\Delta T_{pm} := (682.276 - 660) \cdot R$ $\Delta T_{pm} = 22.276 \circ R$

$\Delta T_{bm} := (673.681 - 660) \cdot R$ $\Delta T_{bm} = 13.681 \circ R$

$k_{bm} := \frac{Q_{gen}}{L_{unit} \cdot 4 \cdot \pi \cdot \Delta T_{bm}}$ $k_{bm} = 1.047 \circ \frac{BTU}{hr \cdot ft \cdot R}$ $k_{bm} = 1.812 \circ \frac{watt}{m \cdot K}$

$k_{supp} := \frac{Q_{gen} \cdot L}{A \cdot \left(\Delta T_{pm} - \Delta T_{bm}\right)}$ $k_{supp} = 0.2506 \circ \frac{BTU}{hr \cdot ft \cdot R}$ $k_{supp} = 0.434 \circ \frac{watt}{m \cdot K}$

CALCULATE EFFECTIVE THERMAL CONDUCTIVITIES AT 910 R

$\Delta T_{pm} := (925.604 - 910) \cdot R$ $\Delta T_{pm} = 15.604 \circ R$

$\Delta T_{bm} := (920.052 - 910) \cdot R$ $\Delta T_{bm} = 10.052 \circ R$

$$k_{bm} := \frac{Q_{gen}}{L_{unit} \cdot 4 \cdot \pi \cdot \Delta T_{bm}} \qquad k_{bm} = 1.425 \circ \frac{BTU}{hr \cdot ft \cdot R} \qquad k_{bm} = 2.466 \circ \frac{watt}{m \cdot K}$$

$$k_{supp} := \frac{Q_{gen} \cdot L}{A \cdot \left(\Delta T_{pm} - \Delta T_{bm}\right)} \qquad k_{supp} = 0.3879 \circ \frac{BTU}{hr \cdot ft \cdot R} \qquad k_{supp} = 0.671 \circ \frac{watt}{m \cdot K}$$

CALCULATE EFFECTIVE THERMAL CONDUCTIVITIES AT 1160 R

$$\Delta T_{pm} := (1171.255 - 1160) \cdot R \qquad \Delta T_{pm} = 11.255 \circ R$$

$$\Delta T_{bm} := (1167.606 - 1160) \cdot R \qquad \Delta T_{bm} = 7.606 \circ R$$

$$k_{bm} := \frac{Q_{gen}}{L_{unit} \cdot 4 \cdot \pi \cdot \Delta T_{bm}} \qquad k_{bm} = 1.883 \circ \frac{BTU}{hr \cdot ft \cdot R} \qquad k_{bm} = 3.259 \circ \frac{watt}{m \cdot K}$$

$$k_{supp} := \frac{Q_{gen} \cdot L}{A \cdot \left(\Delta T_{pm} - \Delta T_{bm}\right)} \qquad k_{supp} = 0.5902 \circ \frac{BTU}{hr \cdot ft \cdot R} \qquad k_{supp} = 1.021 \circ \frac{watt}{m \cdot K}$$

INTRODUCTION

This calculation is performed to calculate the effective planar thermal conductivity of the fuel basket and basket support region of a Holtec MPC-68, backfilled with helium gas diluted by gases released from 10% of the stored fuel rods, in a vertical (storage) orientation. The results of this calculation will become inputs to assembled HI-STAR and/or HI-STORM cask systems thermal models.

METHODOLOGY

Temperature distributions in a planar section perpendicular to the longitudinal axis of the Holtec MPC-68 have been calculated separately [1] using the ANSYS general-purpose finite element code. The temperature distributions are obtained for two separate boundary conditions:

1. Constant temperature MPC periphery
2. Constant temperature fuel basket periphery

The maximum calculated temperature for each condition is extracted from the results of the finite-element analyses. The differences between these calculated maximum temperatures and the boundary conditions can be used to determine the effective thermal conductivities of equivalent, homogeneous regions.

The fuel basket is reduced to a homogeneous cylinder with uniform heat generation. In a planar section for this idealized geometry, the effective thermal conductivity is given by:

$$k_{eff} = Q_{gen} / (4 \times \pi \times \Delta T_{bm})$$

where: k_{eff} is the effective thermal conductivity, Btu / (hr x in x F)
Q_{gen} is the heat generation per unit depth, Btu / (hr x in)
ΔT_{bm} is the basket periphery-to-maximum temperature difference, F

The basket support region is reduced to a homogeneous hollow cylinder with a known wall thickness. If the cylinder wall thickness is small compared to the cylinder radii, the thermal conductivity can be determined using the familiar Fourier equation for 1-D conduction:

$$keff = (Q \times L) / (A \times \Delta T_{pb})$$

where: Q is the total heat generation rate, Btu/hr
L is the conduction length (wall thickness), in
A is the conducting area, in^2
ΔT_{pb} is the temperature difference, F

The temperature difference (ΔT) must be determined from the planar temperature distribution. If the basket periphery-to-maximum temperature difference is subtracted from the MPC periphery-to-maximum temperature difference, the results is the temperature difference across the basket support region:

$$\Delta T_{pm} - \Delta T_{bm} = (T_p - T_m) - (T_b - T_m) = T_p - T_b = \Delta T_{pb}$$

Therefore, the fuel basket region effective thermal conductivity can be obtained as:

$$k_{eff} = (Q_{gen} \times L) / (A \times (\Delta T_{pm} - \Delta T_{bm}))$$

NOMENCLATURE

This calculation is performed using the Mathcad electronic scratchpad program. The built-in units of temperature are absolute units (i.e. Rankine). Temperature differences are identical in both Rankine and Fahrenheit units. All calculations in this worksheet utilize temperature differences only, so all temperatures will be specified in Rankine (R) units.

REFERENCES

[1] ANSYS Database MPC68.DB, ANSYS Input Script V68MG.INP and ANSYS Postprocessor Result File V68MG.RES.

[2] "HI-STAR 100 MPC-68 Construction," Holtec Drawing 1401, Sheet 1, Revision 11.

INPUT DATA

$OD := 68.375 \cdot in$ Outer Diameter of MPC-68, from [2]

$L_{unit} := 1.0 \cdot in$ One Inch Unit Length

$Q_{gen} := 15.0 \cdot \frac{BTU}{hr}$ Total Heat Generation per Unit Length, from [1]

$L := 1.815 \cdot in$ Basket Support Region Cylinde: Wall Thickness

CALCULATE OUTER SURFACE AREA PER UNIT LENGTH OF MPC

$A := \pi \cdot OD \cdot (1 \cdot in)$ $A = 214.806 \cdot in^2$

CALCULATE EFFECTIVE THERMAL CONDUCTIVITIES AT 660 R

$\Delta T_{pm} := (686.124 - 660) \cdot R$ $\Delta T_{pm} = 26.124 \cdot R$

$\Delta T_{bm} := (675.223 - 660) \cdot R$ $\Delta T_{bm} = 15.223 \cdot R$

$k_{bm} := \frac{Q_{gen}}{L_{unit} \cdot 4 \cdot \pi \cdot \Delta T_{bm}}$ $k_{bm} = 0.941 \cdot \frac{BTU}{hr \cdot ft \cdot R}$ $k_{bm} = 1.628 \cdot \frac{watt}{m \cdot K}$

$k_{supp} := \frac{Q_{gen} \cdot L}{A \cdot (\Delta T_{pm} - \Delta T_{bm})}$ $k_{supp} = 0.1395 \cdot \frac{BTU}{hr \cdot ft \cdot R}$ $k_{supp} = 0.241 \cdot \frac{watt}{m \cdot K}$

CALCULATE EFFECTIVE THERMAL CONDUCTIVITIES AT 910 R

$\Delta T_{pm} := (929.169 - 910) \cdot R$ $\Delta T_{pm} = 19.169 \cdot R$

$\Delta T_{bm} := (922.264 - 910) \cdot R$ $\quad \Delta T_{bm} = 12.264 \circ R$

$k_{bm} := \dfrac{Q_{gen}}{L_{unit} \cdot 4 \cdot \pi \cdot \Delta T_{bm}}$ $\quad k_{bm} = 1.168 \circ \dfrac{BTU}{hr \cdot ft \cdot R}$ $\quad k_{bm} = 2.021 \circ \dfrac{watt}{m \cdot K}$

$k_{supp} := \dfrac{Q_{gen} \cdot L}{A \cdot \left(\Delta T_{pm} - \Delta T_{bm}\right)}$ $\quad k_{supp} = 0.2203 \circ \dfrac{BTU}{hr \cdot ft \cdot R}$ $\quad k_{supp} = 0.381 \circ \dfrac{watt}{m \cdot K}$

CALCULATE EFFECTIVE THERMAL CONDUCTIVITIES AT 1160 R

$\Delta T_{pm} := (1174.626 - 1160) \cdot R$ $\quad \Delta T_{pm} = 14.626 \circ R$

$\Delta T_{bm} := (1170.202 - 1160) \cdot R$ $\quad \Delta T_{bm} = 10.202 \circ R$

$k_{bm} := \dfrac{Q_{gen}}{L_{unit} \cdot 4 \cdot \pi \cdot \Delta T_{bm}}$ $\quad k_{bm} = 1.404 \circ \dfrac{BTU}{hr \cdot ft \cdot R}$ $\quad k_{bm} = 2.43 \circ \dfrac{watt}{m \cdot K}$

$k_{supp} := \dfrac{Q_{gen} \cdot L}{A \cdot \left(\Delta T_{pm} - \Delta T_{bm}\right)}$ $\quad k_{supp} = 0.3438 \circ \dfrac{BTU}{hr \cdot ft \cdot R}$ $\quad k_{supp} = 0.595 \circ \dfrac{watt}{m \cdot K}$

INTRODUCTION

This calculation is performed to calculate the effective planar thermal conductivity of the fuel basket and basket support region of a Holtec MPC-24. The Reyleigh effect is neglected, so the solution is independent of orientation. The results of this calculation will become input to assembled HI-STAR and/or HI-STORM cask system models.

METHODOLOGY

Temperature distributions in a planar section perpendicular to the longitudinal axis of the Holtec MPC-24 have been calculated separately [1] using the ANSYS general-purpose finite element code. The temperature distributions are obtained for two separate boundary conditions:

1. Constant temperature MPC periphery
2. Constant temperature fuel basket periphery

The maximum calculated temperature for each condition is extracted from the results of the finite-element analyses. The differences between these calculated maximum temperatures and the boundary conditions can be used to determine the effective thermal conductivities of equivalent, homogeneous regions.

The fuel basket is reduced to a homogeneous cylinder with uniform heat generation. In a planar section for this idealized geometry, the effective thermal conductivity is given by:

$$k_{eff} = Q_{gen} / (4 \times \pi \times \Delta T_{bm})$$

where:
k_{eff} is the effective thermal conductivity, Btu / (hr x in x F)
Q_{gen} is the heat generation per unit depth, Btu / (hr x in)
ΔT_{bm} is the basket periphery-to-maximum temperature difference, F

The basket support region is reduced to a homogeneous hollow cylinder with a known wall thickness. If the cylinder wall thickness is small compared to the cylinder radii, the thermal conductivity can be determined using the familiar Fourier equation for 1-D conduction:

$$keff = (Q \times L) / (A \times \Delta T_{pb})$$

where:
Q is the total heat generation rate, Btu/hr
L is the conduction length (wall thickness), in
A is the conducting area, in^2
ΔT_{pb} is the temperature difference, F

The temperature difference (ΔT) must be determined from the planar temperature distribution. If the basket periphery-to-maximum temperature difference is subtracted from the MPC periphery-to-maximum temperature difference, the results is the temperature difference across the basket support region:

$$\Delta T_{pm} - \Delta T_{bm} = (T_p - T_m) - (T_b - T_m) = T_p - T_b = \Delta T_{pb}$$

Therefore, the fuel basket region effective thermal conductivity can be obtained as:

$$k_{eff} = (Q_{gen} \times L) / (A \times (\Delta T_{pm} - \Delta T_{bm}))$$

NOMENCLATURE

This calculation is performed using the Mathcad electronic scratchpad program. The built-in units of temperature are absolute units (i.e. Rankine). Temperature differences are identical in both Rankine and Fahrenheit units. All calculations in this worksheet utilize temperature differences only, so all temperatures will be specified in Rankine (R) units.

REFERENCES

[1] ANSYS Database MPC24.DB, ANSYS Input Script H24NR.INP and ANSYS Postprocessor Result File H24NR.RES.

[2] "HI-STAR 100 MPC-24 Construction," Holtec Drawing 1395, Sheet 1, Revision 5.

INPUT DATA

$OD := 68.375 \cdot in$ Outer Diameter of MPC-24, from [2]

$L_{unit} := 1.0 \cdot in$ One Inch Unit Length

$Q_{gen} := 15.0 \cdot \frac{BTU}{hr}$ Total Heat Generation per Unit Length, from [1]

$L := 2.57 \cdot in$ Basket Support Region Cylinder Wall Thickness

CALCULATE OUTER SURFACE AREA PER UNIT LENGTH OF MPC

$A := \pi \cdot OD \cdot (1 \cdot in)$ $A = 214.806 \, in^2$

CALCULATE EFFECTIVE THERMAL CONDUCTIVITIES AT 660 R

$\Delta T_{pm} := (683.428 - 660) \cdot R$ $\Delta T_{pm} = 23.428 \, R$

$\Delta T_{bm} := (672.924 - 660) \cdot R$ $\Delta T_{bm} = 12.924 \, R$

$k_{bm} := \frac{Q_{gen}}{L_{unit} \cdot 4 \cdot \pi \cdot \Delta T_{bm}}$ $k_{bm} = 1.108 \, \frac{BTU}{hr \cdot ft \cdot R}$

$k_{supp} := \frac{Q_{gen} \cdot L}{A \cdot (\Delta T_{pm} - \Delta T_{bm})}$ $k_{supp} = 0.205 \, \frac{BTU}{hr \cdot ft \cdot R}$

CALCULATE EFFECTIVE THERMAL CONDUCTIVITIES AT 910 R

$\Delta T_{pm} := (925.703 - 910) \cdot R$ $\Delta T_{pm} = 15.703 \, R$

$\Delta T_{bm} := (919.588 - 910) \cdot R$ $\Delta T_{bm} = 9.588 \, R$

$$k_{bm} := \frac{Q_{gen}}{L_{unit} \cdot 4 \cdot \pi \cdot \Delta T_{bm}} \qquad k_{bm} = 1.494 \circ \frac{BTU}{hr \cdot ft \cdot R}$$

$$k_{supp} := \frac{Q_{gen} \cdot L}{A \cdot \left(\Delta T_{pm} - \Delta T_{bm}\right)} \qquad k_{supp} = 0.3522 \circ \frac{BTU}{hr \cdot ft \cdot R}$$

CALCULATE EFFECTIVE THERMAL CONDUCTIVITIES AT 1160 R

$$\Delta T_{pm} := (1171.147 - 1160) \cdot R \qquad \Delta T_{pm} = 11.147 \circ R$$

$$\Delta T_{bm} := (1167.331 - 1160) \cdot R \qquad \Delta T_{bm} = 7.331 \circ R$$

$$k_{bm} := \frac{Q_{gen}}{L_{unit} \cdot 4 \cdot \pi \cdot \Delta T_{bm}} \qquad k_{bm} = 1.954 \circ \frac{BTU}{hr \cdot ft \cdot R}$$

$$k_{supp} := \frac{Q_{gen} \cdot L}{A \cdot \left(\Delta T_{pm} - \Delta T_{bm}\right)} \qquad k_{supp} = 0.5644 \circ \frac{BTU}{hr \cdot ft \cdot R}$$