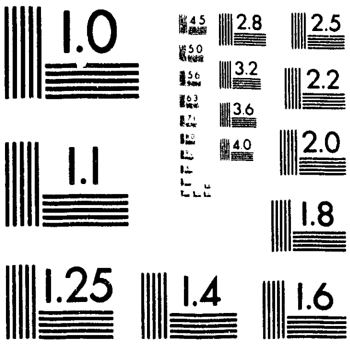
1.0
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WSRC-TR-91-372, REV 1

GAM-HEAT - A COMPUTER CODE TO COMPUTE HEAT TRANSFER IN COMPLEX ENCLOSURES (U)

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This paper was prepared in connection with work done under Contract No. DE-AC09-89SR18035 with the U. S. Department of Energy.

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P. O. Box 62, Oak Ridge, TN 37831; prices available from (615) 576-8401.

Available to the public from the National Technical Information Service, U. S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

Project: 90-064-1
Document:
Title: GAM_HEAT - A Computer Code To Compute Heat Transfer In Complex Enclosures

Revision Number: 01

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GAM_HEAT - A Computer Code To Compute Heat Transfer In Complex Enclosures

INTRODUCTION

The GAM_HEAT code was developed for heat transfer analyses associated with postulated Double Ended Guilliotine Break Loss Of Coolant Accidents (DEGB LOCA) resulting in a drained reactor vessel. In these analyses the gamma radiation resulting from fission product decay constitutes the primary source of energy as a function of time. This energy is deposited into the various reactor components and is re-radiated as thermal energy. The code accounts for all radiant heat exchanges within and leaving the reactor enclosure. The SRS reactors constitute complex radiant exchange enclosures since there are many assemblies of various types within the primary enclosure and most of the assemblies themselves constitute enclosures. GAM_HEAT accounts for this complexity by processing externally generated view factors and connectivity matrices as discussed below, and also accounts for convective, conductive, and advective heat exchanges. The code is structured such that it is applicable for many situations involving heat exchange between surfaces within a radiatively passive medium.

SUMMARY

The GAM_HEAT code has been exercised extensively for computing transient temperatures in SRS reactors with specific charges and control components (safety and control rods and septifoils). Results from these computations have been used to establish the need for and to evaluate hardware modifications designed to help mitigate results of postulated accident scenarios, and to assist in the specification of safe reactor operating power limits. The code utilizes temperature dependence on material properties, and the efficiency of the code has been significantly enhanced by the use of an iterative equation solver. Verification of the code to date consists of comparisons with parallel efforts at Los Alamos National Laboratory (Pasamehmetoglu, 1991), comparisons with similar efforts at Westinghouse Science and Technology Center in Pittsburgh, Pa., and benchmarked using problems with known analytical or iterated solutions. All comparisons and tests yield results that indicate the GAM_HEAT code performs as intended.

DISCUSSION

Revision History - Since the issuance of Rev 0 of this document the GAM_HEAT code has been extensively modified and extended to accommodate particular features of the SRS reactor components, and to account for temperature dependence on heat convection, emissivity, and heat capacity. The modifications necessary to account for temperature dependence for improved accuracy were made by incorporating functions for particular variables into special subroutines.

This makes the code less general for other applications, however generality is of less concern than code efficiency now that the temperature dependence has caused a significant increase in the computational effort compared to the original version. Before temperature dependence was augmented it was necessary to invert the chi matrix associated with radiant heat emissions only once for the entire transient. If this radiant heat transfer solution technique is continued, the chi matrix must be inverted at each time step. This is mildly inefficient for small problems but grossly inefficient for large problems which are necessary for further study. The code was therefore modified to use an iterative solution technique as discussed below for much improved efficiency.

Modeling Features - GAM_HEAT is a heat exchange code that accommodates radiative, convective, conductive, and advective heat transfer. The model requires as input radiation and conduction connectivity matrices. These matrices are vectorized, as described later, where only the non-zero entries are specified in a row-ordered format. For large systems this format results in very efficient mathematical manipulations with minimum storage and CPU requirements. As a consequence of this code structure the geometry and dimensionality of any problem is expressed in the vectorized connectivity matrices which are generated external to the computational model. The output of the code consists of temperature maxima and temperature solution vectors. These data may be post-processed independently as required. The current version of the code features the ability to compute transients of a specified time duration or to terminate the transient calculation immediately after all peak temperatures are reached. The code also may be executed for multiple power levels with the capability of generating statistical data useful for estimating uncertainties in the analyses. An Eulerian integration of the heat balance equations is performed as a cumulative summation within each time step. Other features and options will be introduced in discussions of the input parameters in later sections of this report.

The code is written in FORTRAN77 with some extensions that are all compatible with DIGITAL VAX systems and also compatible with the CRAY and IBM 6000 computers at SRL. The source code is extensively annotated. Appendix A contains several benchmark problems used to validate the code. Appendix B contains a sample input and output. The input is in ASCII format to provide a readable visual check of the input for any given problem. Appendix C contains the source code for the program which is stored under configuration control in SRLUSER7:[LOCA.COOPER.CMS_DIR.GAM_LIB]

Heat Balance Equations - The heat balance equations solved by this program are given as:

Component Surfaces

$$m_i c_i \frac{dT_i}{dt} = \Gamma_i + \sum_{j=1}^{J} \varepsilon_j A_j H_j - \sum_{j=1}^{J} \varepsilon_j A_j \Omega_j - \qquad \text{Eq(01)}$$

$$h_i A_i (T_i - T_a) - k_i \sum_{j=1}^{J} (T_i - T_j) / L_{i \to j}$$

Air Components

$$m_a c_a \frac{dT_a}{dt} = \sum_{j=1}^{N} \delta_{aj} h_j A_j (T_j - T_a) - u_a c_a (T_a - \Phi) \qquad \text{Eq(02)}$$

where
- m -- mass, lb-mass
- c --- Heat Capacity, Btu/(lb-mass °R)
- T --- Temperature, °R
- t --- Time, hr
- Γ --- Gamma Deposition, Btu/hr
- ε --- Emissivity, Dimensionless
- H --- Incident Surface Radiation, Btu/hr-ft^2
- A--- Surface Area, ft^2
- Ω --- Emissive Power, σT^4, Btu/hr-ft^2
- σ --- Stephan-Boltzman Constant, Btu/hr-ft^2-°R^4
- h --- Convective Heat Transfer Coeff, Btu/hr-ft^2-°F
- k --- Heat Conduction Coeff, Btu/hr-ft-°F
- L --- Conduction Length, ft
- δ --- Boolean Matrix for Convective Heat Transfer,
- u --- Air Mass Transport, lb/hr
- ϕ --- Incoming Air Reference Temperature, °R

The left side of Equation 1 is the mass heat storage term for the component associated with surface i. The first term on the right is the gamma energy deposition rate within the metal component associated with surface i, the second is the incident radiant energy absorption rate, and the third is the emissive power for surface i. The fourth term is the convective energy exchange rate and the last term is the conductive energy exchange rate. The left side of Equation 2 is the mass heat storage term for air component a. The first term on the right is the convective heat exchange rate and is seen to be the same as the fourth term in Equation 1 except for the Boolean matrix δ_{aj}. The Boolean value δ_{aj} is equal to 1 when surface j is convectively coupled to air component a and is zero otherwise. This is only symbolic representation however, the code performs the summation differently for reasons of computational efficiency. The last term in Equation 2 is the computation of heat exchange rate by mass transport. These equations are solved in a fully explicit manner by equating dT to (T^{n+1} - T^n) and solving for T^{n+1} where n denotes the nth time step. For the problems considered to date it has been observed that a time step of 0.25 seconds is about optimum to prevent numerical instability. It has also been verified that results are independent of time step size when the time step value is varied below 0.25 seconds.

Gamma Energy Deposition - Energy deposition into the various components of the enclosure are input quantities computed external to this code. In this application the energy is presumed to be in the form of gamma photons resulting from the decay of radioactive fission products built in during reactor operations. Therefore the Γ term refers to gamma energy that is deposited in the metal components. These data are supplied by using methods described in (Baumann, 1991). Since the gamma energy is deposited in the metal components there exists some possibility for confusion because the components have more than one surface, and it is the surfaces that radiate and convect energy. These energy exchanges are properly accounted for by the assignments of primary and secondary surfaces for the individual components, and temperature updates are not performed before both surfaces are considered.

A special program subroutine was written to compute the gamma loading to the various components as a function of time after the termination of reactor operations. If the energy deposition is by any means other than gamma heating this subroutine must be replaced. This routine, in addition to the initial gamma loading, requires the input of a pre-incident power level and a total gamma peaking factor (the product of radial and axial peaking) to compute maximum temperatures for a 2D input model. If a 3D model is input, the peaking factor should be set to unity. The algorithm for setting the gamma loading in each component at each time step is:

Set $\tau = \log(t_n)$ for each time step n,

$$F = \sum_{k=0}^{K} A_k \tau^k$$ for the K terms in the approximation, and

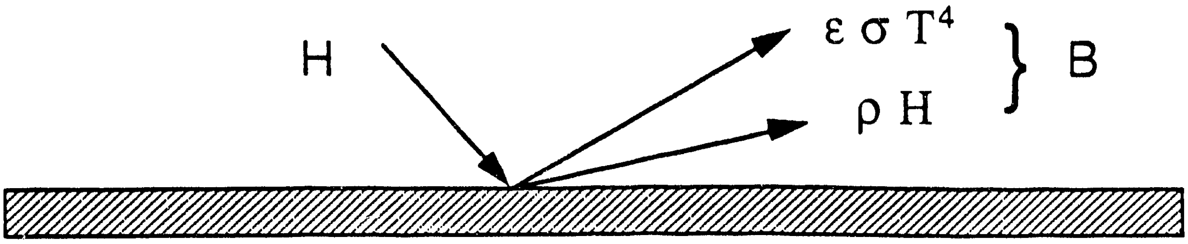
$$\Gamma_m = FPWD_m$$ for each component m Eq(03)

where the A_k are the polynomial coefficients to the deposition approximation, P is the total peaking factor, W is the power in watts, and D is the input deposition fraction.

Radiant Heat Exchange - It is noted in Equation 1 that the incident radiation term contains a product H_jA_j which is defined as the instantaneous total radiant energy arriving at surface i from all other surfaces in the complex enclosure. The value of H_i is therefore influenced by all surfaces j within the enclosure having optical coupling to surface i, including itself if the surface i is concave. The degree of influence surface j has upon i is proportional to the degree of optical coupling which is expressed as a view factor. View factors and their determination are discussed in Taylor(1991). A derivation of the H_i is developed in Sparrow (1978) as follows:

Figure 1

Radiant Energy at Any Surface



In the above Figure, H is the instantaneous total radiant energy in an enclosure impinging on any surface within the enclosure. Two radiative components emanate from the surface. The emissive power is represented by the $\varepsilon\sigma T^4$ term and the reflected energy is represented by the ρH term. A surface radiosity is now defined as B which is the sum of the emissive power and reflected energy. The mathematical relationship between the B and H vectors is given below.

$$B_i = \varepsilon_i \sigma T_i^4 + \rho_i H_i = \varepsilon_i \sigma T_i^4 + (1-\varepsilon_i) H_i \qquad \text{Eq(04)}$$

$$H_i = \sum_{j=1}^{N} B_j F_{i\to j} \qquad \text{Eq(05)}$$

$$B_i = \varepsilon_i \sigma T_i^4 + (1-\varepsilon_i) \sum_{j=1}^{N} B_j F_{j\to i} \qquad \text{Eq(06)}$$

In Equation 6 the gray-body assumption is invoked which specifies that the fraction of incident radiant energy that is reflected plus the fraction that is re-emitted must sum to 1.0, or

$$\rho = (1-\varepsilon) \qquad \text{Eq(07)}$$

Equation 5 states that the total energy $\mathbf{H}_i$ is the sum of energies from all surfaces. For a given surface the radiant energy is the product of radiosity and the associated view factors as discussed above. The view factors are determined as a function of geometrical relationships and are input to the computations. It is thus noted in Equation 6 that B is now the solution vector for the set of surface equations. Equation 6 is recast as in Equation 8 below and the chi coefficient matrix is determined by equation 9.

$$\sum_{j=1}^{N} \chi_{ij} B_j = \Omega_i \qquad \text{Eq(08)}$$

$$\chi_{ij} = \frac{\delta_{ij} - (1-\varepsilon_i) F_{i\to j}}{\varepsilon_i} \qquad \text{Eq(09)}$$

$$\Omega_i = \sigma T_i^4 \qquad \text{Eq(10)}$$

The B vector is now determined using an iterative equation solver based on successive over-relaxation (SOR). There is no method available to optimally determine the over-relaxation parameter ω, however, it known that the upper limit is about 1.25. This value is an input parameter for GAM_HEAT computations and a value of 1.15 has consistently been used with good results. This equation solver is also structured to utilize vectorized matrices with only non-zero components to eliminate the need for storing matrices. The emissivities that appear in the equation set are temperature dependent, therefore the process described above must be performed each time step as the temperatures are updated. This equation solver efficiency is shown to be about a factor of two greater than direct solvers for an 11 X 11 chi matrix, and more than a factor of 10 for a 54 X 54 matrix. For larger matrices the efficiency is expected to be even greater. The success of this algorithm is primarily due to the small time steps used (about 0.25 sec) such that the radiosity B vector is always near the correct solution and a minimum of iterations are required for convergence. The algorithm actually employed is structured as follows:

SOR Algorithm

Solve the linear system $Ax = b$ with $a_{ii} \neq 0$ for each $i = 1, 2, \ldots, n$

Set the ω parameter

Step 1 Set $k = 1$

Step 2 For each $i = 1, 2, \ldots, n$

$$x_i^k = (1-\omega)\, x_i^{k-1} + \left(b_i - \sum_{j=1}^{i-1} a_{ij} x_j^k - \sum_{j=i+1}^{n} a_{ij} x_j^{k-1} \right) \qquad \text{Eq(11)}$$

Step 3 Test for convergence

If converged, go to Step 4

If not, increment k and go to Step 2

Step 4 Iterations are complete

In the above algorithm the B vector is represented by the X vector of Equation 11. The B vector is initialized using input temperatures and material properties. After the B vector is known, the H vector is then determined from Equation 4 and the radiative components of Equation 1 are then available.

Convective Heat Exchange

Each surface can be convectively coupled to only one air component. However, a given air component may be convectively coupled to many surfaces. The convective coupling for each surface is therefore specified in the N by 5 control matrix of the basic control data as described below.

Convective heat exchange is facilitated by a special routine that is a combination of modified literature correlations and correlations developed at SRS for the special reactor components in use. Of particular concern is the safety rods which are inside an aluminum thimble with holes accounting for about 33% of the thimble surface area. The radiative heat transfer for the thimble and rod is accommodated by special considerations provided by input without detracting from the generality of the code. However, the convective heat transfer could not be facilitated by input without very special considerations. For this reason the parameters and algorithms used to compute convective transfer are contained in a special subroutine with no functional connection to input data except for the gap enhancement factor and indices used to direct the computations for the various components. The gap enhancement factor is used to vary the conductivity of air between the thimble and safety rod as a means of simulating special conditions.

Natural Convective Cooling Correlations - The following discussion describes the computation of heat transfer coefficients as used in the GAM_HEAT code for convective heat transfer between vertical reactor components and the air that would be inside the reactor tank after a large break LOCA. A more detailed description may be obtained from (Steimke, 1991) which is the source of the algorithms presented here. In this source the correlations developed are based on temperature differences between surfaces and ambient up to 500 °C. Therefore these algorithms are assumed applicable for temperatures over the range expected in gamma heating scenarios.

Temperature dependent heat transfer coefficients, h_i, are evaluated as follows:

$$h_i = k(Nu_L / L) \qquad \text{Eq(12)}$$

where k is the thermal conductivity of air, Nu_L is the Nusselt number for the component of interest, and L is the length of that component.

For large diameter assemblies such as contained in the SRS reactors, the Nusselt number is correlated as follows.

$$Nu_L = 0.12 \ Ra_L^{1/3} \qquad Eq(13)$$

$$Ra_L = L^3 g \ |T_w - T_\infty| \ Pr / (\upsilon^2 T_\infty)$$

where T_W represents surface temperature and T_∞ represents air temperature.

This Nusselt number correlation applies to the turbulent regime which is appropriate for most of the length of the safety rod and thimble combination. The air conductivity, Prandtl number, and kinematic viscosity, k, Pr and ν, are evaluated at the film temperature. All properties are evaluated under the assumption of dry air.

$$T_f = (T_w + T_\infty)/2$$

$$k = 3.486E-3 + 4.021E-5 \, T_f - 6.289E-9 \, T_f^2$$

$$Pr = 0.7178 + 2.314E-4 \, T_f - 9.979E-7 \, T_f^2 + 8.778E-10 \, T_f^3$$

$$\upsilon = -2.345E-5 + 2.718E-7 \, T_f + 1.3271E-9 \, T_f^2 - 2.881E-13 \, T_f^3 \qquad Eq(14)$$

The units in the above equations are °K, pcu/hr-ft -°K, dimensionless, and ft^2/sec, respectively.

Heat transfer from the outside of the thimble and the portion of the safety rod not covered by the thimble solid surface is computed from the following equations:

$$Nu_L = \left(0.12 \, \xi \, Ra_L^{1/3}\right) / \ln(1+\xi) \qquad Eq(15)$$

$$\xi = (2 \eta L) / (0.12 \ Ra_L^{1/3} \ D)$$

A fit to literature data and SRL data gave η equal to 2.56. T_f is computed separately for the thimble and safety rod.

The safety rod is assumed to be centered in the thimble, making no thermal contact. Heat transfer is by conduction through the air layer between them. It is to be noted again that this is a special case of heat transfer from surfaces since all other surfaces in the reactor are coupled to air components whereas this is a surface to surface coupling. This is facilitated by placing a minus sign on the coupling indices as discussed in the input description. The heat transfer coefficient in this case is:

$$h = k / \Delta R \qquad \text{Eq(16)}$$

The thermal conductivity k of air is evaluated at the average of the safety rod and thimble temperatures and ΔR is the gap width. The surface area to which this is applied is the average of the safety rod and thimble inner surface areas.

Conductive Heat Exchange - Components associated with each surface may be conductively coupled to any number of other components. The connectivity matrix for this coupling is also specified and stored in vectorized format as described above. Conductive heat transfer is computed as specified in the last term of Equation 1.

Air Compartment Energy Exchange - When running two-dimensional problems such as the infinite lattice configuration included as the sample problem in this report, there is no mechanism available to properly account for convective air flow (and consequently energy exchange) between various air regimes within the reactor. GAM_HEAT does provide for this exchange mechanism by the input of a matrix of coefficients that specify the exchange rate, in pounds per hour, between compartments. Although this is recognized as an over-simplification of reality, it is expected to facilitate the study of phenomena that would otherwise be impractical until such time that more rigorous analyses become available. The energy being transferred is given by the following algorithm:

$$E_j = \sum_{i=1}^{N} a_{i,j} m_i c_a (T_i - T_j) \quad \text{for } i \neq j, \text{ and} \qquad \text{Eq(17)}$$

$$\sum_{j=1}^{N} a_{i,j} m_i = \sum_{j=1}^{N} a_{j,i} m_j \quad \text{for all } i \qquad \text{Eq(18)}$$

where E is energy, Btu/hour, and the a's are mass transfer coefficients in mass fraction per hour.

Uncertainty Analyses; - Provisions are made in the GAM_HEAT code to automatically perform uncertainty analyses when uncertainty parameters are input for prescribed variables. The prescribed variables are:

01) Convection coefficients as programmed in a special subroutine
02) Boundary temperature conditions for all reactor components

03) Gamma deposition axial peaking to compute max temperatures
04) Total deposited gamma power as specified in ANSI/ANS-5.1 1979
05) Temperature dependent aluminum emissivity
06) Temperature dependent stainless steel emissivity
07) Safety thimble convective coefficients
08) Safety rod convection coefficients
09) Temperature dependent heat capacity of aluminum
10) Temperature dependent heat capacity of stainless steel

The rationale and development of these uncertainties are discussed in (Cooper et al., 1991)

Values for these variables are input in terms of one sigma standard deviation or as a fraction representing a one sigma percentage of the code calculated value. Uncertainty values may be input for any or all the variables listed. The objective of these analyses is to evaluate the overall temperature uncertainty based on critical components when all uncertainties are considered. For any given power level this is implemented in the code by first establishing a base or nominal case by performing the temperature transient computation with no uncertainty applied. The transient computation is then performed over a specified range of probit values P_{ij} which is defined as:

$$P_{ij} = (V_{ij} - \mu_i) / \sigma_i \qquad \text{Eq(19)}$$

where V_{ij} is the deviation from the best estimate value μ_i for each variable in turn, and σ_i is the input or computed standard deviation of the variable i. The subscript j represents the number of probit values specified for each variable i. The V_{ij} are specified such that the P_{ij} are equal for all j, and the range extends to $\pm$ the maximum value of P_{ij}. During each transient the current uncertainty variable will be augmented by adding the product $P_{ij}\sigma_i$ to the variable best estimate. Since a complete transient computation must be performed for each variable with uncertainty specified, and for each probit value specified, there will be (i x j + 1) transients computed for each reactor power specified, accounting for the nominal case.

After all uncertainty transients are computed yielding maximum temperatures for a given power level, the GAM_HEAT program then computes a combined uncertainty value in terms of temperature maxima by applying a root mean squared summation derived from linear error propagation analysis:

$$\sigma_{T,j} = \sqrt{\sum_{i=1}^{N} \left(T_{i,\pm j} - T_0\right)^2} \quad \text{for all } T_{i,\pm j} > T_0 \qquad \text{Eq(20)}$$

where $T_{i,\pm j}$ implies that results from ± values of P_{ij} are to be used in the summation, and T_0 is the maximum temperature from the nominal transient. This analysis assumes that the temperature maxima as a function of uncertainty are linear with respect to probit values for any given variable with uncertainties applied. For cases where the temperature response to uncertainties is significantly nonlinear, it may be necessary to use statistical sampling methods on these responses to determine the overall uncertainty. However, in investigations to date the responses to ± one standard deviation on the uncertainties has been sufficiently linear so that statistical sampling was not required.

Temperature Dependent Heat Capacity - Thermal properties of the various component materials are calculated for each time step based on temperatures computed at the previous time step. Temperature transient calculations for the components currently in the SRS reactors involve only three component materials for which thermal property functions are required to apply temperature dependence. These materials are aluminum, cadmium, and stainless steel. Property functions as specified in (Kielpinski, 1991) are presented in Table I. These functions are programmed as a special routine in the GAM_HEAT code.

Table I
Heat Capacity Functions of Temperature

General form, $c_p = A + B * T + C * T^2$
c_p in Btu / lbm-°R, T in °K

Material	A	B	C	1 Std Dev	Range, °K
Cd (solid)	4.5235E-02	3.0821E-05	-1.7862E-08	0.00112	300 - 594
Al	1.9688E-01	3.1042E-05	7.6250E-08	0.01150	300 - 920
304 SS	1.0396E-01	1.7512E-05	5.2190E-08	0.02070	300 - 1250
Cd (liq)	0.0617	0.0	0.0	0.0	594 - 1038

The safety rods currently in the K-Area reactor are expected to be replaced in the near future to allow operations at increased power levels. The new rods will be composed of stainless steel and boron carbide (B_4C) pellets enclosed in a sheath having the same diameter as rods currently in use. Heat capacity of B_4C as a function of temperature is given in a slightly different form than the other materials. The form of this function as derived from (Brandes) is given as:

$$c_p(B_4C) = 0.7495 + 1.759E\text{-}4 * T - 3.492E\text{+}4 * T^{-2} \qquad \text{Eq(21)}$$

where c_p is in units of Btu / (lb - °R). The range of this polynomial is from about 300 °K to 1100 °K.

Checks are performed in the GAM_HEAT program to provide warnings when computed temperatures are outside the ranges specified.

ECS Flow Throttling - Under current operating conditions coolant flow for the septifoils and control rods is upward with discharge through slots and holes near the top of the reactor. Under drained or partially drained tank conditions this discharge is depended upon to provide coolant to the universal sleeve housings (USH's) of the fuel assemblies surrounding control rod positions. If ECS flow is reduced beyond a certain value the flow to the septifoils will no longer exit the holes and slots. Under this condition there will be no wetting of the surrounding USH's of the fuel assemblies. This condition is simulated by running the transient calculation for a user specified time at which the bounding conditions of the USH's (and septifoils if considered appropriate) are turned off and they are allowed to heat up. This causes higher temperatures than would have prevailed otherwise. As the GAM_HEAT program currently exists the specified time for turning off the boundary conditions must be less than the time for the reactor components to have reached a peak.

Input Features - GAM_HEAT is designed to work with large systems of equations, therefore most of the input data are expected to be generated by peripheral programs written for specified purposes, although for small systems the data may be prepared manually. All input data are generated and placed in a data file to be input at run time. The GAM_HEAT code internally generates data that are temperature dependent such as emissivities, convection coefficients, and heat capacities. In addition, the gamma energy deposition rate is also updated as a function of time after reactor operation is terminated. The emissivity and gamma deposition updates are computed using polynomial expressions whose coefficients are part of the input data. The other updates are computed by algorithms that are programmed into the relevant subroutines since there is generally no reason to modify these algorithms.

Input requirements are discussed below.

Basic Control Data - The following data are written to a file in ASCII free-form format. The first two lines may contain any alphanumeric data to identify the output. The next lines are the basic input parameters, one entry per line. Where blank lines are specified to be entered, these may contain arbitrary alphanumeric information also, since these lines are not processed other than being included in the output for completeness.

charvar ---- Alphanumeric data,
blank line -- Blank line,

mxtim ----- Maximum run time, sec,
dt ------------ Time step increment, sec,
prt ---------- Print interval, sec,
tadd -------- Incident time delay after shutdown, sec,

The tadd parameter above is to account for fission product decay to properly compute gamma energies as a function of time when the incident is initiated at some time (tadd, sec) after shutdown.

throtl--------	Time after accident initiation that ECS throttling below a threshold value is simulated by removing temperature boundary conditions on USH's and septifoils, and allowing heatup,
nmatl ------	Number of different surface materials,
nmair ------	Number of different air materials,
view -------	View factor summation criterion, % error, discussed below
recip -------	Criterion for view factor reciprocity as discussed below, percent error allowed,
itmx -------	Maximum iterations for radiosity vector convergence,
cnvrg ------	Criterion for radiosity solution convergence,
rlax --------	Relaxation parameter for solution convergence,
nmet ------	Number of metal surfaces,
nair -------	Number of air components,
gapen -----	Gap conductivity enhancement factor,
sigmx -----	Sigma range for uncertainty limit, ± sigmx,
siginc -----	Sigma increment,

mtran ----- Flag to control transient duration

- mtran = 0 Terminate after all surfaces and air components reach peak temperatures.
- mtran = 1 Run full transient (mxtim sec)

mcon ----- Flag to specify the heat energy deposition mode.

- mcon = 0 Heating energy is transient
- mcon = 1 Heating energy is constant

Enter two blank lines

The next input data specify output variables. If the entry is a positive integer the output variable is a surface temperature whose index corresponds to the entry. If the integer is preceded by a minus sign the output variable is the temperature of an air component. For each entry a maximum temperature will be output and, if uncertainties are specified, the uncertainty analyses will be performed and output.

nout ------	Number of entries for output
indx, varnam	The index associated with the entry, (surface or air index as input below), and a name to be associated (arbitrary). One entry pair per line.

Enter two blank lines

The next entries are on a single line that specifies the number of power levels, and the power levels in megawatts.

npow, pow_i	Num of power levels, and levels for i = 1,..., npow

Enter two blank lines

Next a group of parameters associated with gamma deposition are entered.

axpeak -----	Total peaking factor, dimensionless
core_len ------	Active core length, feet
dep_1 -------	Gamma deposition fraction 1st minute after shutdown
npoly ------	Number of coefficients in polynomial, Eq(03)

Enter two blank lines

gdep -----	Deposition polynomial coefficients, in ascending order

Enter two blank lines

The next control data are contained in an N by 5 control matrix where N is the total number of metal surfaces, including boundary condition surfaces associated with components where the temperature is held constant. This matrix establishes the coupling between surface and air components according to entries in the third column. These entries generally specify air components, however, if an entry is preceded by a minus sign the entry specifies another surface with conductive air coupling instead of convective coupling.

There is one line for each surface. The data contained on each line is:

nc ---------	Surface number,
matno -----	Material number,
npath(1) ---	Conductivity coupling ? 0 for no, 1 for yes
npath(2) ---	Convective coupling air component index,
npath(3) ---	Radiative coupling ? 0 for no, 1 for yes
npath(4) ---	Fixed temperature ? 0 for no, 1 for yes
npath(5) ---	Secondary surface index, or zero for no secondary surface,

Secondary surfaces referred to above are generally the inside surface of a cylindrical component where the outside surface is considered primary. These roles may be reversed so long as the numbering scheme is such that all primary surfaces are input before secondary surfaces are listed.

Enter two blank lines

The final control data specify the index of the air material properties to be used for each air component. There will be one line for each air component.

nc, namat -- Air component number, and associated index to specify the air material as input below.

Enter two blank lines

Material Properties - Material properties must now be specified for as many different types of materials as are specified by the material indices in the above control parameters. The number of different materials is not expected to be large, therefore these data are input as ASCII data in the same file as the control parameters.

Surface Materials - Due to the number of different parameters associated with each surface these data are input in two groups as follows. There will be one line in each group for each material specified. The following entries are on a single line.

First Group

mn ----------	Material number,	
metnam ---	Surface name for edit and ID information	
cv ------------	Material heat capacity,	Btu/(lb-R)
tmelt -------	Melting temperature,	°R
cmelt -------	Heat of fusion,	Btu/lb
ipc -----------	Index for computing heat capacity,	dimensionless
imiss -------	Surface emissivity index,	dimensionless
xmiss ------	Boundary condition emissivity,	dimensionless
area --------	Surface area,	ft^2
xmass -----	Mass associated with this surface	lb_mass

The xmiss entry above will be used for the material with index (mn) if a surface is specified as a boundary condition. Otherwise an emissivity will be computed at each transient time step according to current temperature. The ipc parameter specifies the correct path within the temperature dependent heat capacity (cpc) subroutine according to the following values:

ipc = 1, Material is assumed to be all aluminum,
2, Material is old safety rod homogenized,
3, Material is B4C safety rod homogenized
4, Material is all stainless steel.

Comments for the first group above also apply for the second group.

Second Group

mn -----------	Material number,	
metnam ----	Material name for edit and ID information	
ttmat --------	Initial temperature,	°R

phi -----------	Reference temperature,	°R
convnam---	Convection uncertainty parameter name	
conda -------	Cross-sectional area for conduction,	ft^2
condk -------	Conductivity coefficient,	Btu/(hr-ft-°R)
condl --------	Conduction length	ft
nu_indx ----	Nusselt index for computing Ra number,	dimensionless

Enter two blank lines

The convnam above is a character variable used in the code to compute an uncertainty index to point to the correct uncertainty variable for the specified material associated with a given surface. This name is not arbitrary, it must correspond exactly to one of the convective uncertainty names as specified below if uncertainties are specified. If no uncertainties are specified this name will not be used and becomes arbitrary, but must be entered to satisfy the free format read request.

Air Materials

mn ----------	Material number,	
airnam-----	Material name for edit and ID info	
cp ------------	Heat capacity, constant pressure,	Btu/(lb-°R)
amass -----	Air mass per component,	lb_mass
uair --------	Air mass flow rate,	lb_mass/hr
ttair --------	Initial air temperature,	°F
phair -------	Incoming air temperature,	°F

Enter two blank lines

Air Compartment Specs - The following input is used for computing the exchange of energy between partitioned air regions within the main tank enclosure. The input is in the form of a matrix whose elements are exchange coefficients with units of lb/hour. Exchange is allowed from any compartment to any other compartment, The coefficients must be determined external to the GAM_HEAT program and it is incumbent upon the user to ensure a balanced set of coefficients such that mass and energy is conserved. This requirement is checked in the code and if an imbalance is detected the program will terminate with an appropriate message. The first entry is the number of compartments to be input. Succeeding lines, one line for each compartment, contain all the coefficients for a particular compartment which specifies exchange with all other compartments.

ntnk -------- Number of tank air compartments

tcoef(i,j) --- Energy exchange coefficients from compartment i to compartment j for j = 1,2,· · ·,ntnk

Enter two blank lines

Uncertainty Parameters - The first uncertainty parameter is a specification of the number of entries to be made. If the number is zero then no further entries are necessary. Otherwise make one uncertainty entry per line until the proper number of entries are made. The error parameters for emissivities are input as 0.0 followed by the name because these parameters are computed from polynomial coefficients supplied below. Uncertainty estimates will be performed only for the input entries.

nval -------	Number of uncertainty parameters to be input
error, devnam	One sigma uncertainty followed by the name of the uncertainty variable. This name must be in quotes and must be one of the following names:

'convect'	For general convective surfaces
'bnd_tmp'	Input initial and boundary condition temperatures
'peaking'	Gamma peaking factors, axial and radial combined
'gam_dep'	Initial gamma source from fission products
'emis_al'	Aluminum emissivity
'emis_ss'	Stainless steel emissivity
'thim_h '	Safety thimble convection coefficient
'srod_h '	Safety rod convection coefficient
'cp_thim'	Thimble heat capacity
'cp_srod'	Rod heat capacity

Enter two blank lines

Emissivity Coefficients - Emissivities as a function of temperature are computed in the code by the use of input coefficients associated with polynomials approximating the temperature dependence. The range of the polynomials used to date extends from about 0 °C to 1000 °C. These coefficients are included in the input because emissivity data are not as firm as other engineering data and therefore subject to change. In addition the emissivity is subject to change as components are changed although the components may be identical except for differences in exposure to the reactor environment. Since these polynomials are input, there are no checks made in the code to ensure operation within a specific range. In the input below the first integer is the emissivity index associated with a specific material type and entered as the sixth entry in the first group of material parameters above. The second entry is the number of coefficients to be entered including the zero degree coefficient. Thus, there will be one more coefficient than the degree of the polynomial being used. This entry is followed by the coefficients. All entries for each polynomial are on a single line. If uncertainties are input for the emissivity associated with the emissivity index, then the uncertainty polynomial data must appear on the next line. The format will be as described above for the emissivity polynomial.

ndx, neco, ecoef(i), i=1,· · ·,ndx	Always entered
ndx, nsco, scoef(i), i=1,· · ·,ndx	Enter only for specified uncertainty

Repeat the above input for all emissivity indices in the first group of material inputs above.

Insert two blank lines

Initial Heat Generation - For the reactor problem an internal heat generation rate in watts is determined for each component with surfaces. This calculation is performed in a routine that is custom designed to compute these data as a function of time for each component. The basis of this routine is the (Baumann, 1991) document. The following data, three entries per line, provide the initial power distribution fractions.

nc --------- Component number,
id ---------- Component identification,
gamnit ---- Initial fractional power distribution

Repeat the above input until all components associated with primary surfaces have been input.

Insert two blank lines

Coupling Data Storage Format - For radiative and conductive heat transfer, each surface will be coupled to a specified number of other surfaces through view factors or conductivity coefficients. When all surfaces are considered, the couplings constitute a connectivity matrix where the dimension of the matrix is the total number of surfaces. For large systems the connectivity matrices are expected to be sparse because each surface is connected to a small number of other surfaces relative to the total number in the system. To store and manipulate such matrices would be wasteful of computer resources, and may not be affordable because of resource demands. Expected applications of this program include large systems with complex geometry and surface coupling conditions, therefore it was necessary to adopt a data storage format that minimizes storage and computational effort. The method chosen is described, for example, in (Axelsson and Barker, 1984), and can be described best in terms of matrices and vectors and is structured as follows:

The coupling information within each mode is expressed mathematically as a matrix. Diagonal entries in the matrix denote self-coupling, and off-diagonal entries denote coupling to other components. The sparsity pattern of the matrix is symmetric. However, the values of the entries in general are not symmetric with respect to the diagonal. Each matrix as described above is stored as three vectors. The first vector contains the row-ordered non-zero entries of the matrix, another vector having the same length contains the column numbers of each non-zero entry, and the third vector is a pointer vector having the same dimension as the matrix. The entries of this vector specify the vector position (sequence number within the first vector) of the first non-zero entry of each row of the matrix. This vector also specifies the corresponding column number within the second vector since these vectors have direct correspondence relative to position. In actual application the pointer vector length is augmented by one to facilitate the use of an efficient algorithm for computing indices. This method of storage also provides a means of efficiently performing the matrix algebra associated with the system solution. With the three vectors described above the required elements of the matrices may be extracted as needed without having to deal with computations involving zero quantities.

View Factors - The view factors associated with component surfaces are the essential means of specifying the geometry for radiant heat exchange. There are generally several view factors associated with a given surface, and the totality of all view factors constitute an N x N connectivity matrix where N is the total number of surfaces in the system. However, in large systems the matrix generally will also be sparse. The GAM_HEAT program uses the method of storing all matrices described above to minimize storage and CPU requirements.

For small problems it is feasible to include the view factor data in the same ASCII file with the other input data. To date the largest problem has been a model with 54 surfaces and all input data has been from a single file. When larger models are being investigated the view factor data will be transferred to a separate binary file for more efficient input. Once a view factor model has been established and verified for a given model it is not likely to change.

For each surface view factors are entered in the following format:

kcom, kcc ----- Where kcom is the surface index, and kcc is the number of other surfaces viewed by this surface.

kcf, fff ------- Kcf is the index of the surface for which this view factor, fff, applies. This line must be repeated until kcc view factors have been entered. One entry must be a self-view factor even if the surface is not concave in order to prevent numerical difficulties. In this instance enter a very small number such as 1.0E-20

This format must be repeated for each surface in the model.

Since all surface to surface interactions are specified there is no need for additional geometry for the execution of the GAM_HEAT code.

There are two basic requirements associated with view factors. The first and most important requirement is that the sum of all view factors originating from a given surface must be unity which forces energy conservation,

$$\sum_{j=1}^{J} F_{i \to j} = 1.0$$

If this condition is not met for any component the solution obtained will be in error. The code checks to determine if this condition is met and if not, the program is terminated. Another condition that should prevail is the reciprocity relationship for view factor and area products,

$$A_i F_{i \to j} = A_j F_{j \to i}$$

If this condition does not prevail it indicates incorrect energy exchanges, but stability of the equation set may not be affected. This condition is checked for all surfaces but the program is not terminated unless the magnitude of any inequality exceeds the specified reciprocity criterion in the input.

Conductive Coupling - The format for conductive coupling is the same as for view factors described above although the connectivity matrix generally will be different.

Problem Size Limitations - The size limitation on any given problem is determined by dimensioning parameters within PARAMETER statements located at the beginning of the source code. When large systems are modeled it would be prudent to adjust these parameters to assure that enough computer space is allocated without unduly taxing facilities. At the beginning of each program execution the storage requirements for various parameters are computed, checked for adequacy, and reported to the default system output file. If any dimensional demand is greater than allocated, the program will terminate. This output may also be used to check for excessive storage.

Output Data - All input data are included in the output as a verification check. Additional output is controlled by input control data which specifies the frequency at which all temperature data will be output to an external file for postprocessing. The bulk of the output data is in binary form that is written to a file to be postprocessed for specific requirements. The first record of this output is the number of surface temperatures to be printed and the control information described above that is needed to sort the data. This is followed by records of all temperatures at the specified time intervals. Maximum temperatures of all surfaces and air components are output to a separate file in the ASCII format that may be used to evaluate the execution.

Sample I/O - A sample input and output is included as Appendix B. This input is a simulation of the SRS reactors where a supercell with periodic boundary conditions is modeled. The supercell consists of 6 Mark-22 assemblies, a septifoil, and a safety rod. Infinite axial length is also assumed, therefore the model represents a lattice extending to infinity in all directions. Output from processing this model is tabulated in Table B1 which contains peak temperatures of selected variables. Transients for these same variables are shown in Figure B3.

References

Axelsson, O. and V. A. Barker, "Finite Element Solution of Boundary Value Problems, Theory and Computation", Academic Press, 1984.

Baumann, N. P., and W. R. Ferrara, "Gamma Energy Deposition in the Mark 22 Lattice", SCS-RPG-91-0052, March 15, 1991.

Brandes, E. A., Ed., "Smithells Metals Reference Book", Sixth Edition, Buttersworth, London England.

Kielpinski, A. L. "Temperature Dependent Heat Capacity Functions For Use In Gamma Heating Analyses", NES-CDG-910229, Nov. 1991.

Sparrow, E. M., and R. D. Cess, "Radiation Heat Transfer", Hemisphere Publishing Corp., 1978.

Steimke, J. L., "Heat Transfer for Safety Rod and Thimble", WSRC-TR-91-600, Oct. 1991.

Taylor, J. R., "Radiation View Factors For Gamma Heating", WSRC-TR-91-371, May, 1991.

APPENDIX A

Model Verification and Benchmarking

No experimental data currently exist to directly verify these gamma heating computations, nor is any likely to be available in the near future. It is therefore necessary to rely on theoretical considerations to verify that the computer program is performing adequately. Even in the presence of experimental data it is necessary to verify correct algorithm behavior. To that end a suite of benchmark problems has been processed to compare the theoretical and numerical solutions. These benchmark problems were obtained from the Los Alamos National Laboratory (Pasamehmetoglu, 1991) as they were used in their benchmarking efforts. These efforts were related to a computer program that was developed in parallel with the SRL program to investigate the gamma heating problem. Analytical solutions to each of these problems, when such solutions exist, were also given in the reference document and independently verified. Steady state solutions are available for all problems and each problem is designed to test various aspects of the computer programming as indicated below.

In some instances it was necessary to use a modified version of the GAM_HEAT code to accommodate necessary boundary conditions such as constant convective transfer coefficients,constant heat capacities, and constant medium temperatures. In the code these parameters are generally considered temperature dependent. However, the modifications in all cases were trivial so that all the tests indicated below are directly applicable to the GAM_HEAT code as used for critical applications.

Problem 1 - Rod Enclosed By A Cylinder - This is a radiation only problem consisting of two concentric cylinders of infinite length with parameters as specified in Figure A1. The SRL GAM_HEAT code computed a steady state temperature of 620.0 compared to the analytical solution of 620.1 °C. These results are shown in Figure A2.

Problem 2 - Rod Enclosed By Two Concentric Cylinders - This is also a radiation only problem with multiple enclosures consisting of three concentric cylinders. The geometry, boundary conditions and heat generation are the same as in Problem 1 with the addition of the outer cylinder. All pertinent parameters are shown in Figure A3. The GAM HEAT code computed steady state values for the heated rod and intermediate cylinder of 724.1 and 507.8 °C compared to the analytic solution of 724.2 and 507.9 °C. Results for this problem are shown in Figure A4.

Problem 3 - Multiple Surface Enclosure - Figure A5 shows an enclosure with multiple surfaces represented by a square channel of infinite length. As indicated, surface 1 is supplied with a constant power of 1000 watts per unit length while surface 3 is kept at a constant temperature of 100 °C. For this problem the GAM_HEAT code estimated a steady state temperature of 563.1 °C for side 1 and 479.2 ° C for sides 2 and 4 as shown in Figure A6. This compares with the analytic steady state of 563.2 and 479.2 °C.

Problem 4 - Two Infinite Parallel Plates - This problem is designed to test transient radiative cooling using two parallel plates of infinite length as shown in Figure A7. One plate is assigned an initial temperature of 1000 °K while the other is maintained at 0.0 °K. Transient temperatures for three cases are shown in Figure A8: 1) the numerical solution with a Δt of 0.05 seconds, 2) the numerical solution with a Δt of 0.25 seconds, and 3) the exact analytic solution. It is noted that for practical purposes the solutions are all identical, although there are slight differences as noted in Table A1, with the shorter time step yielding the most accurate solution as expected.

Table A1
Problem 4 - Computed Transients

Time, Sec	Δt = 0.05 Sec	Δt = 0.25 Sec	Analytical
0	726.84	726.84	726.84
20	122.19	118.65	122.75
40	44.24	42.54	44.39
60	5.21	4.12	5.24
80	-19.74	-20.52	-19.76
90	-37.62	-38.22	-37.67
100	-51.32	-51.82	-51.40
120	-62.31	-62.72	-62.39
140	-71.40	-71.75	-71.49
160	-79.10	-79.41	-79.19
180	-85.74	-86.02	-85.84
200	-91.56	-91.81	-91.66
220	-96.72	-96.94	-96.82
240	-101.34	-101.54	-101.44

Problem 5 - Two Parallel Plates with Convection - In this problem convective cooling is tested in combination with radiative cooling. Figure A9 shows two infinitely long plates with a convective fluid in between. The fluid is held at a constant temperature of 100 °C with other pertinent parameters as indicated. The problem is first solved numerically with radiative cooling only, which yielded a GAM_HEAT estimate of 530.0 °C compared to an analytic steady state of 530.1 °C. For the combined heat transfer, GAM-HEAT estimated a steady state of 452.0 °C compared to an analytic solution of 452.0. These results are shown in Figure A10.

Problem 6 - Three Parallel Plates with Convection - This problem consists of three infinitely long plates with a convective fluid in the channels between the plates. This is shown in Figure A11 with other pertinent parameters as indicated. Fluid properties are held constant and plate 3 is held at a constant temperature of 0.0 °C. Numerical solution using GAM_HEAT yields steady state temperatures of 493.9 °C for plate 1 and 297.0 °C for plate 2 as shown in Figure A12. This compares to analytic steady state temperatures of 491.9 and 291.0 °C

Problem 7- Plate Immersion Transient - Figure A13 schematically shows a plate immersed in a fluid with the fluid held at a constant temperature of 0.0 °C. At time zero 1000 watts is applied to the plate with the resulting GAM_HEAT transient shown in Figure 14 which also shows the exact solution. Again, for practical purposes the graphs are identical indicating the adequacy of the code.

Problem 8 - Convective Fluid Transient - The last test problem is designed to test the fluid energy equation solution. In this problem a quantity of fluid is enclosed between two plates with constant temperature boundary conditions and the fluid is allowed to convectively heat up. A schematic of this problem is shown in Figure A15. The transient is show in Figure A16 along with the exact solution where it is noted that again the graphs are essentially identical.

Results of the above tests give strong support to the adequacy and accuracy of the GAM_HEAT code for use in critical applications. However, it must be noted that the setup of a model (all input associated with a particular problem) is just as important as the code itself since computational accuracy can only be obtained from quality input. A sample problem is included as Appendix B representing an infinite lattice model, and it will be noted that although this is only a small part of the reactor core, the input can be significantly complex and subtle in some aspects. It is for this reason that the GAM_HEAT code is not recommended for the casual user, nor for would be users unfamiliar with the concepts and modeling of heat exchange phenomena.

References

Pasamehmetoglu, K. O., "Heat-Transfer Analysis For Gamma Heating In A Savannah River Reactor Core Exposed To Air", Draft Report, Los Alamos National Laboratory, Sep., 1991.

Figure A1 - Problem #1
Infinite Concentric Cylinders

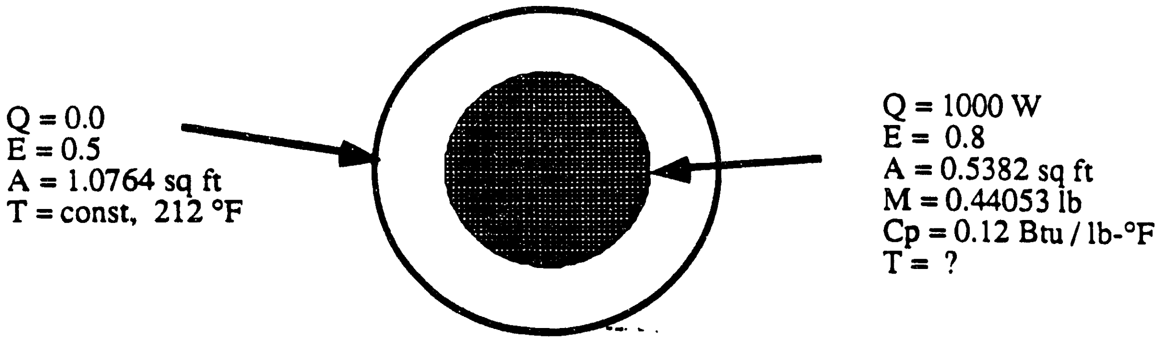


Figure A2
Bench Mark Problem # 1

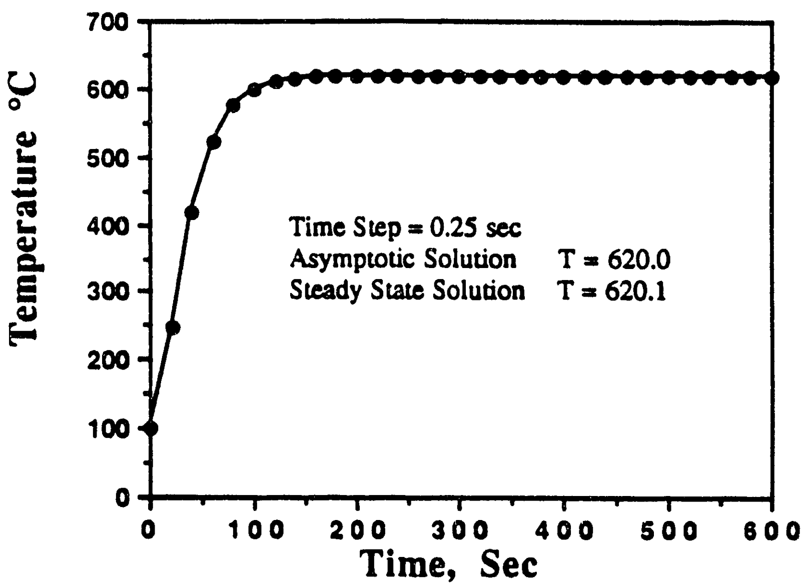


Figure A3 - Problem #2
Infinite Concentric Cylinders

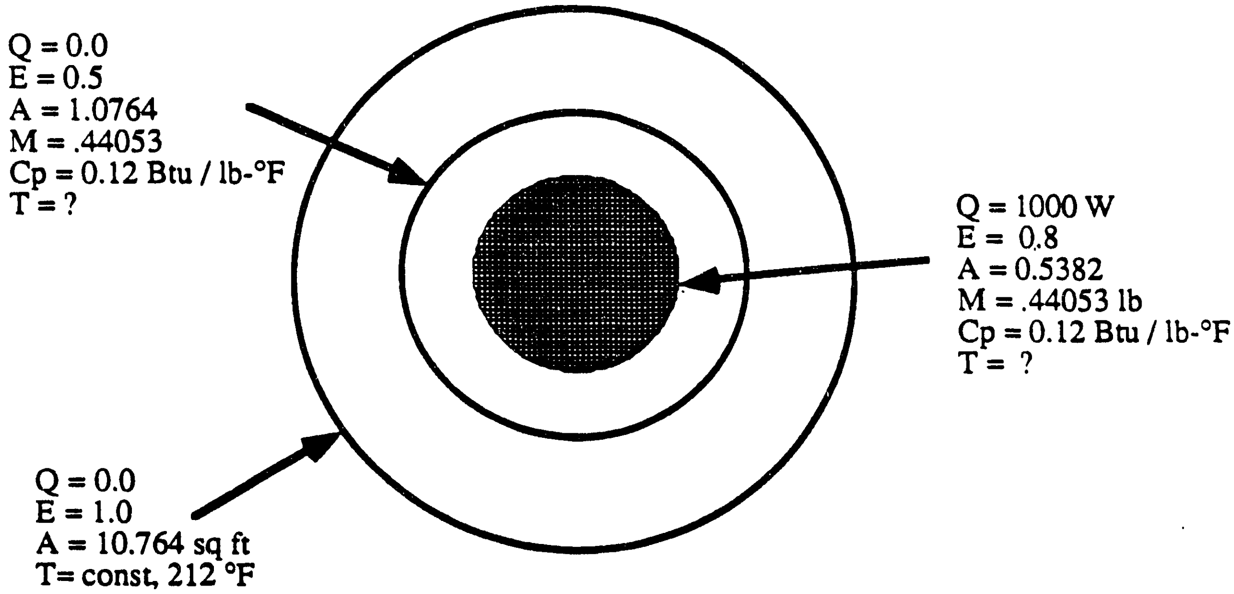


Figure A4
Bench Mark Problem #2

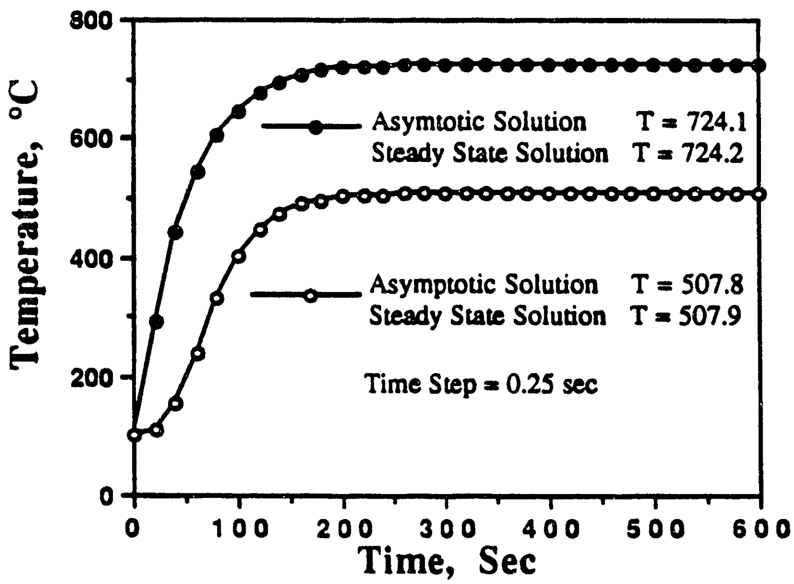


Figure A5 - Problem #3
Infinite Equalateral Rectangle

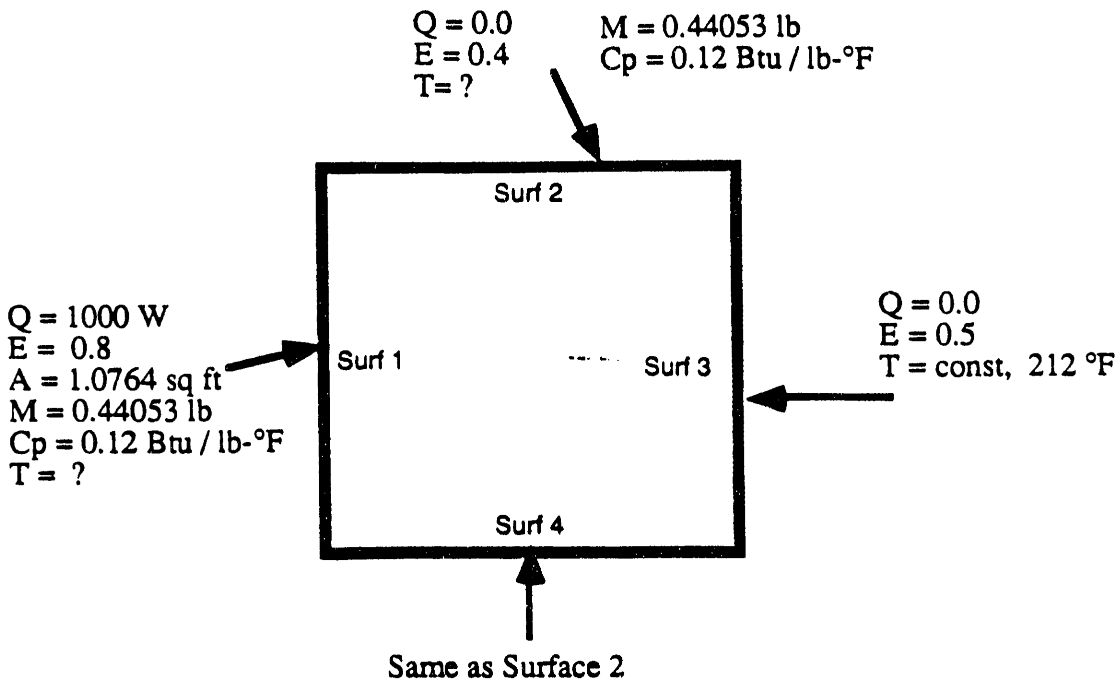


Figure A6
Bench Mark Problem #3

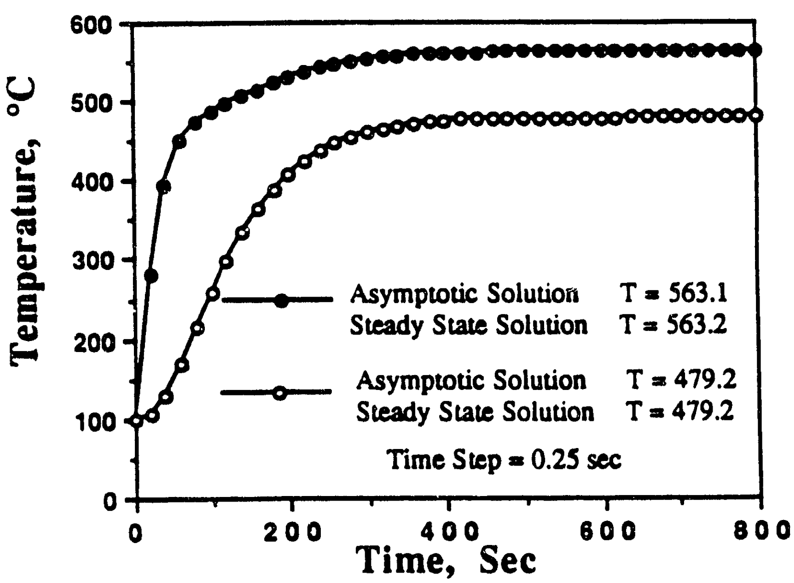


Figure A7 - Problem #4
Infinite Parallel Plates

Figure A8
Bench Mark Problem #4

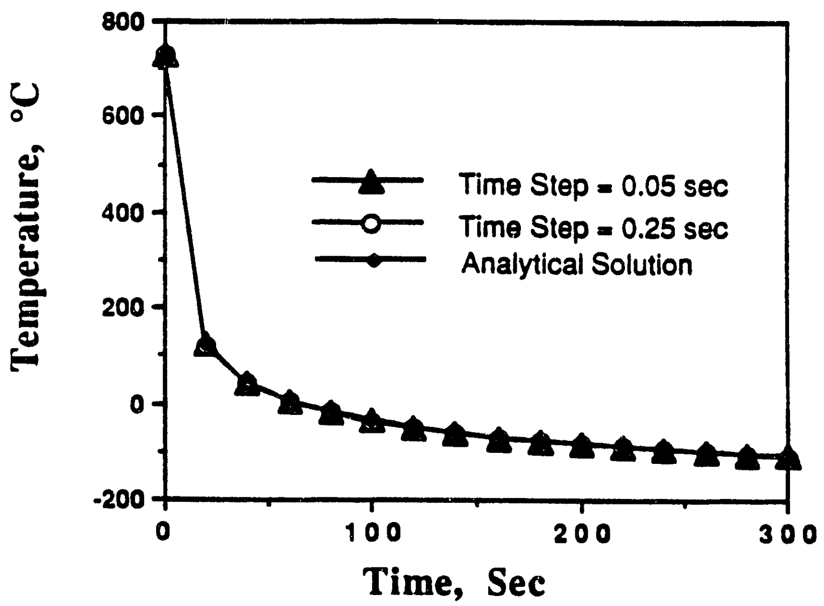


Figure A9 - Problem #5
Infinite Parallel Plates

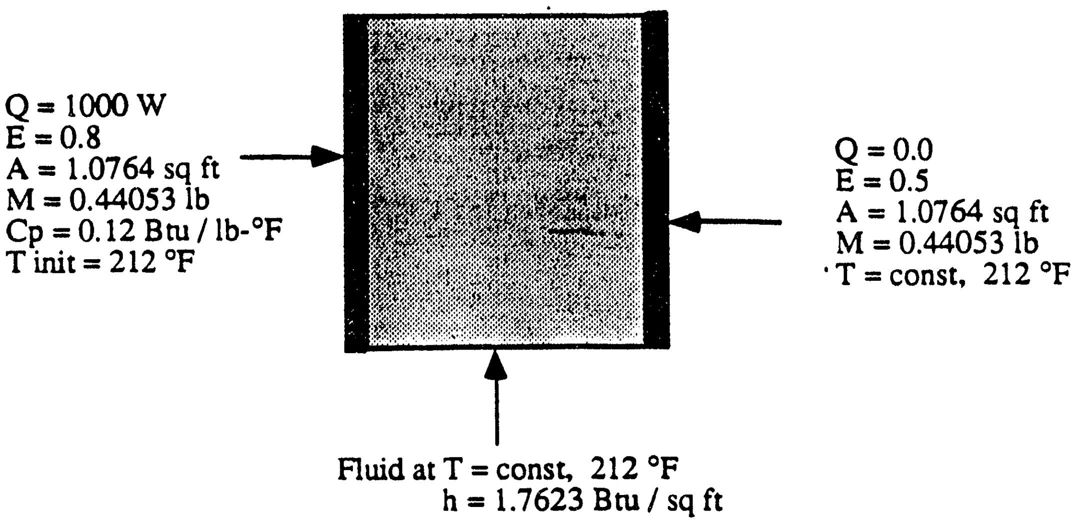


Figure A10
Bench Mark Problem #5

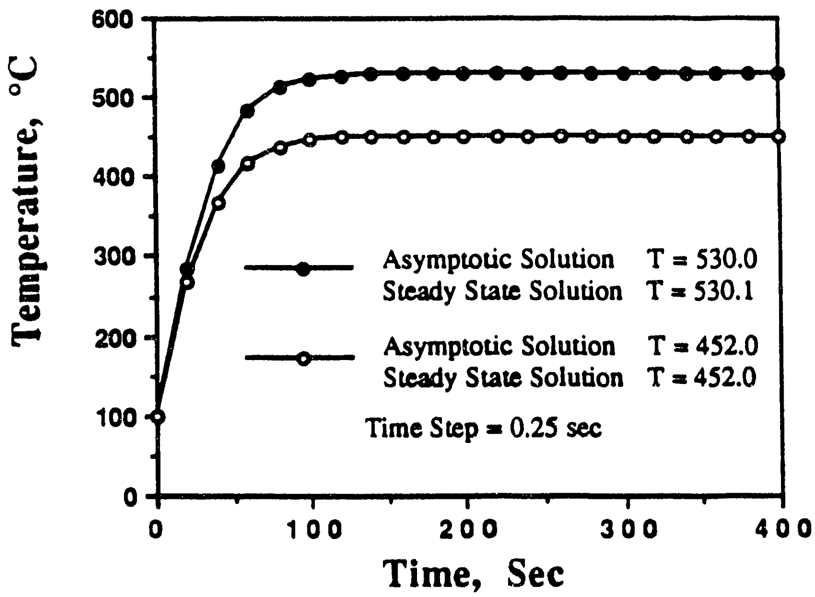


Figure A11 - Problem #6
Infinite Parallel Plates

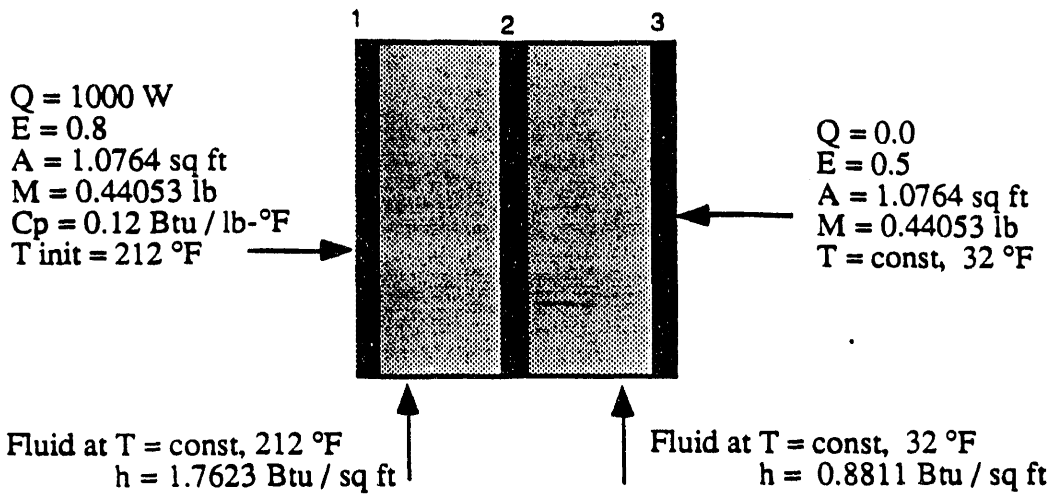


Figure A12
Bench Mark Problem #6

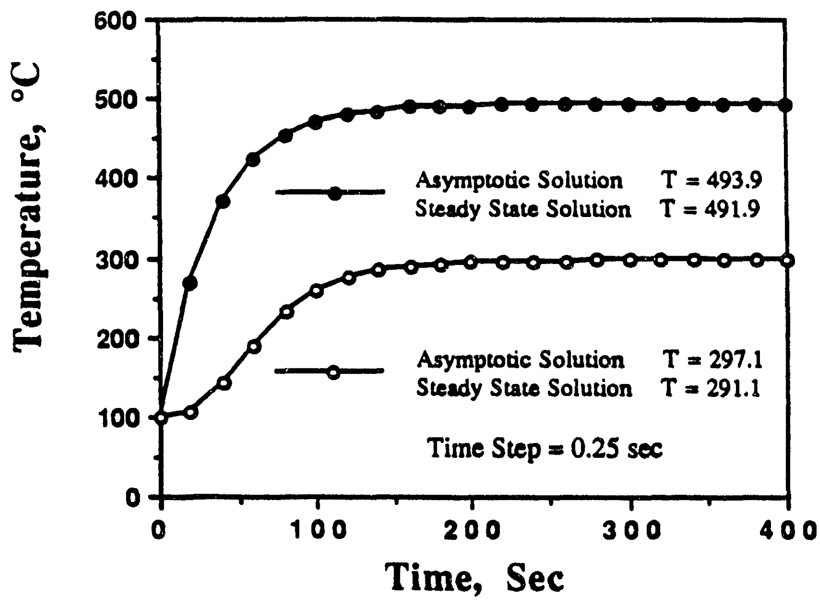


Figure A13 - Problem #7
Convective Cooling

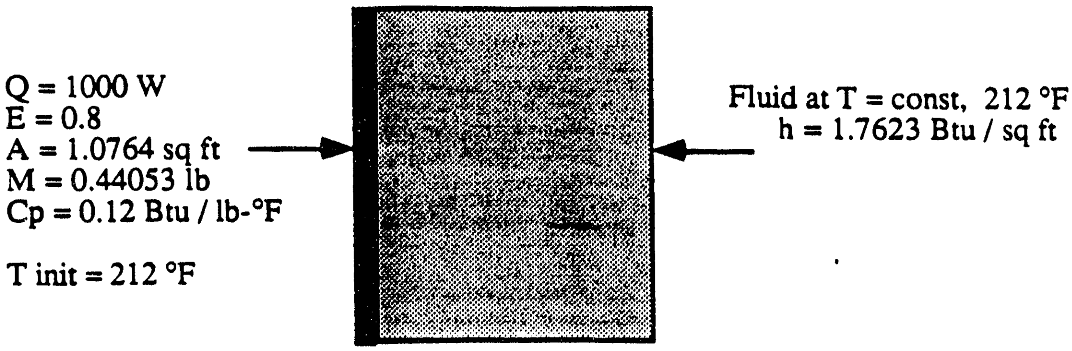


Figure A14
Bench Mark Problem #7

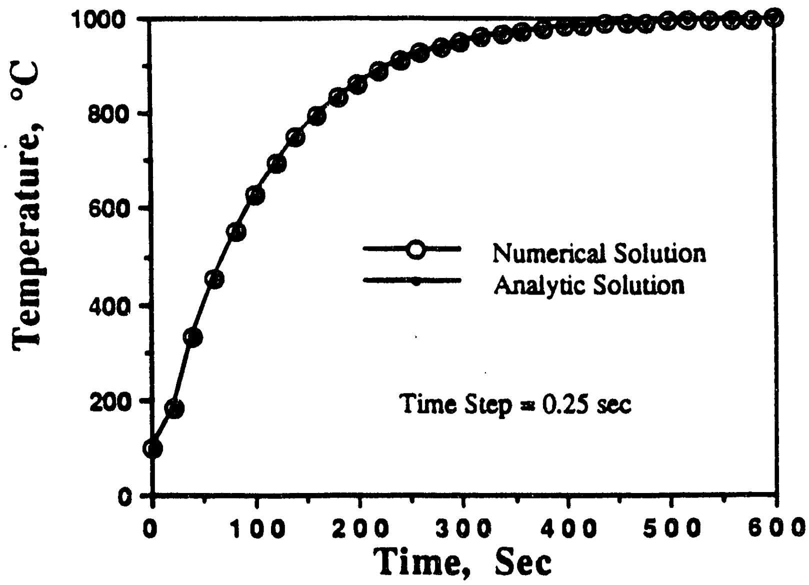


Figure A15 - Problem #8
Convective Heatup

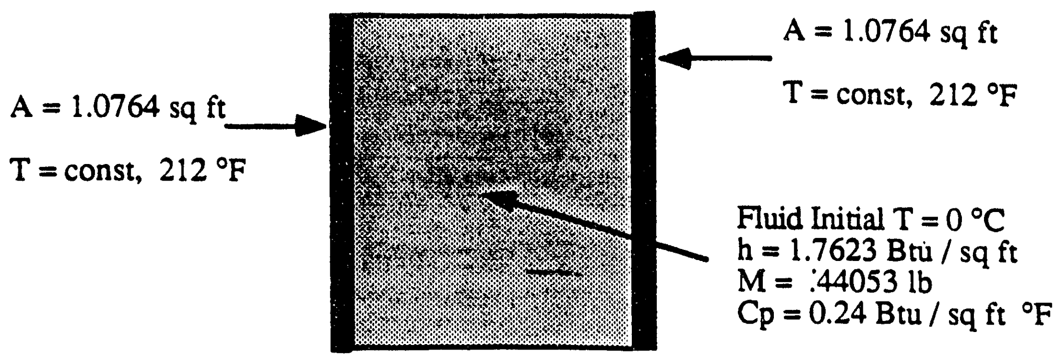
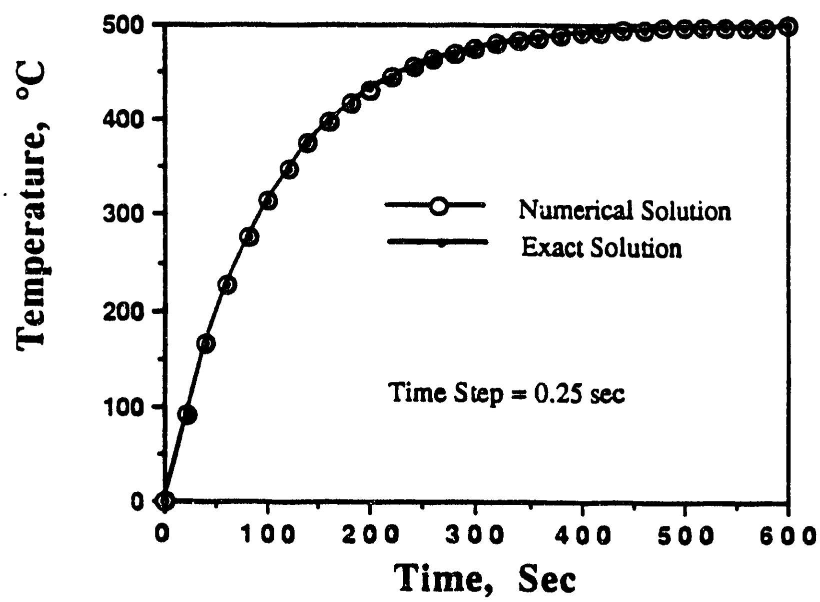


Figure A16
Bench Mark Problem #8



APPENDIX B

Sample Reactor Problem

Supercell - Infinite Lattice Model

(With Pre-Modified Septifoil Hardware)

The Savannah River Site nuclear production reactors are sufficiently large and with regular geometry such that it is feasible to characterize basic operating parameters by investigating a relatively small part of the core. Generally, the reactor cores contain repeating assembly patterns except at the periphery of the lattice which is of reduced nuclear significance. Of particular interest is the current K-Area reactor charge with a repeating pattern, referred to as a supercell, consisting of six Mark 22 fuel assemblies, a septifoil containing seven control rods, a safety rod and the containing safety thimble. Using appropriate boundary conditions it is feasible to represent an infinitely large lattice using only one supercell. This model is appropriate for conservatively estimating operating characteristics with computational economy. A schematic representation of the infinite lattice model is shown as Figure B1. The mathematical representation of this model effects extensions without bounds in all directions horizontally and vertically, and any one of the outlined patches represents the computational domain of the sample problem. An expanded version of this lattice is included as Figure B2 which shows more detail and the identity of the individual assemblies. These details help to reveal the actual complexity of the sample problem. A large portion of the complexity in this problem is due to the modeling of septifoils which were not designed to provide cooling for the control rod assembly nor coolant for adjacent assemblies. As a result of studies such as this the septifoils have been modified to provide internal flow to cool the total control rod assembly and to provide spray cooling to adjacent assemblies in the event of a drained tank scenario. For details on this modification see Shadday, 1991.

The input model assumes that the bulk moderator is suddenly drained from the reactor tank after sustained operation at a specified power. It is further assumed that no coolant is available for any assembly except within the coolant channels of the fuel assemblies. The reactor components will then proceed to heat up from gamma energy being continuously deposited within the components. In this model the fuel assemblies contained within universal sleeve housings become both the source of gamma energy and the ultimate heat sink since these are the only components receiving coolant.

Output from the GAM_HEAT program is written to three files. The first is an ASCII file that contains a repeat of all input, peak temperatures for selected components, and basic statistical data if uncertainties were specified. The output to the other files contain relatively large amounts of data that generally need to be postprocessed for presentation. One file contains the transient data for all components, and the other contains the data required for statistical sampling to accurately evaluate response uncertainties. Table B1 is taken directly from the ASCII file and in this instance only the peak temperatures for the selected components were output since no uncertainty variables were specified.

References

Shadday, M. A. Jr, "Hydraulic Characteristics of the Type Q Septifoil", WSRC-TR-91-612, November, 1991

Table B1
Peak Temperatures for Selected Components
(Pre-Modified Septifoil Hardware)

Component	Temperature	Peak Time, min
Mark 22 USH	221.88	62.22
Safety Thimble	354.18	37.37
Safety Rod	473.29	27.86
Central Cntrl Rod	630.86	73.83
Al Cntrl Rod	569.36	79.41
Tank Air	268.63	65.27

The corresponding transients obtained by postprocessing the transient file are shown in Figure B3.

Figure B1
Infinite Lattice Configuration

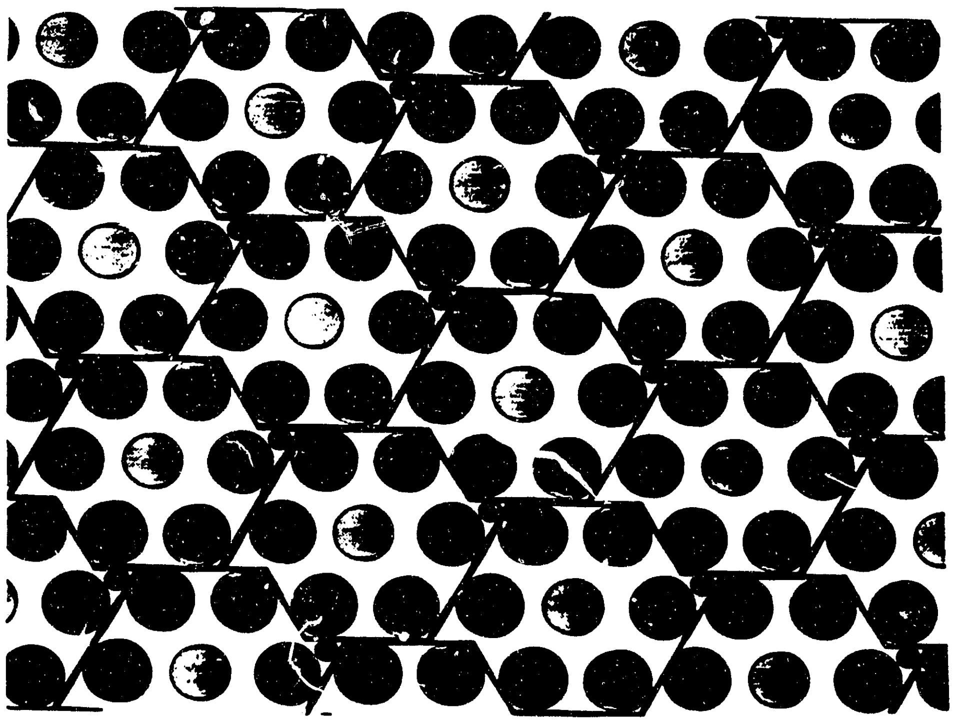


Figure B2
Detailed Lattice Components

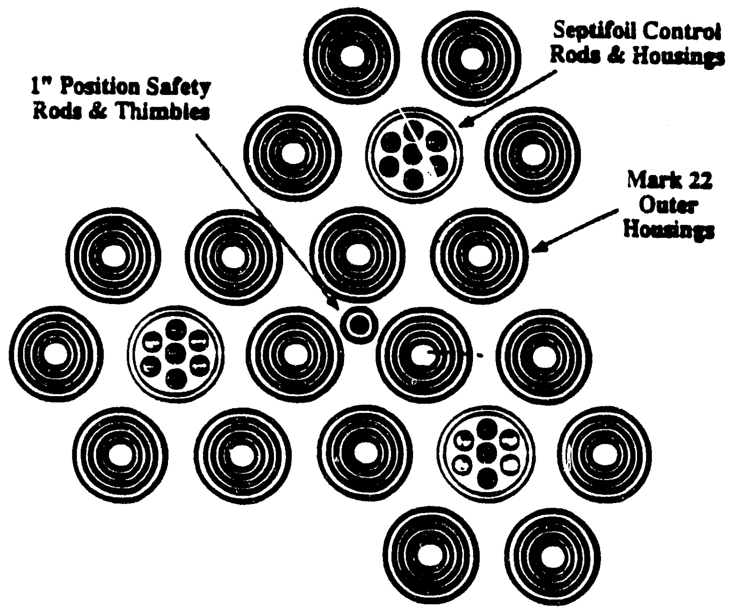
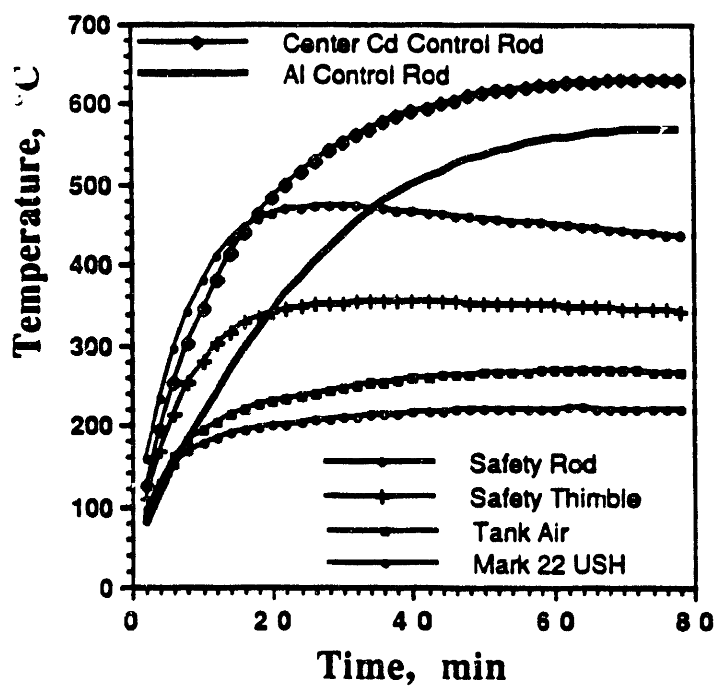


Figure B3
Selected Component Temperatures



Sample Problem Input Listing

Infinite Lattice With Dry Septifoils

```
 720  MW  Base Case with  Dry Septifoils

  6001                   ! Maximum run time, seconds
   .25                   ! Transient time step increment, seconds
   120.                  ! Edit time interval, seconds
   0.0                   ! Incident time delay after shutdown, seconds
  9000.                  ! Time to throttling
    13                   ! Number of different metal materials
     3                   ! Number of different air materials
  1.e-2                  ! View factor sum criterion, % error
     0.                  ! View factor reciprocity, % error
    30                   ! Max iterations to radiosity convergence
1.000E-6                 ! Convergence criterion for radiosity vector
  1.10                   ! Over-relax factor for iteration algorithm
    55                   ! Number of radiant heat surfaces
     8                   ! Number of air components
   1.0                   ! Gap enhancement factor
   0.0                   ! Sigma range = + and - sigmx
   0.0                   ! Sigma increment
     0                   ! 1 = Full trans,    0 = run to peak only
     0                   ! 1 = Const Power,  0 = transient power

 Output Variables
  06
  02  ' Mk22 USH '
  08  ' Saf Thim '
  09  ' Saf Rod  '
  10  ' Cen Cad  '
  14  ' Al Rod   '
 -01  ' Tank Air '

 Num of Power Levels      Pre-Incident Power Levels, MW
        01                     720.

  Gamma Deposition Parameters
  1.396                            ! Axial peaking
   12.5                            ! Active reactor core length
 0.020165                          ! 1 day, mid-cycle
     6                             ! Num of deposition coefficients

----------- Gamma Deposition Transient Coefficients ------------
1.70273e-02  -9.448e-03  +5.9107e-03  -4.4087e-03  +1.4693e-03  -1.656e-04

 comp  matl  cond?  conv?  ther?  Bnd?  Secnd?
  01    01     0     01      1     0     36      ! Septifoil Outer
```

02	02	0	01	1	0	37	! MK22-1 Outer
03	02	0	01	1	0	38	! MK22-2 Outer
04	02	0	01	1	0	39	! MK22-3 Outer
05	02	0	01	1	0	40	! MK22-4 Outer
06	02	0	01	1	0	41	! MK22-5 Outer
07	02	0	01	1	0	42	! MK22-6 Outer
08	03	0	01	1	0	35	! Saft Thim Outer
09	04	0	01	1	0	55	! Safety Rod
10	07	0	08	1	0	00	! Central Cadmium
11	07	0	08	1	0	00	! Outer Cadmium
12	08	0	08	1	0	00	! Aluminum Rod-1
13	08	0	08	1	0	00	! Aluminum Rod-2
14	08	0	08	1	0	00	! Aluminum Rod-3
15	08	0	08	1	0	00	! Aluminum Rod-4
16	08	0	08	1	0	00	! Aluminum Rod-5
17	05	0	08	1	0	43	! Web Spoke 1
18	05	0	08	1	0	44	! Web Spoke 2
19	05	0	08	1	0	45	! Web Spoke 3
20	05	0	08	1	0	46	! Web Spoke 4
21	05	0	08	1	0	47	! Web Spoke 5
22	05	0	08	1	0	48	! Web Spoke 6
23	06	0	08	1	0	49	! Web Hex Side 1
24	06	0	08	1	0	50	! Web Hex Side 2
25	06	0	08	1	0	51	! Web Hex Side 3
26	06	0	08	1	0	52	! Web Hex Side 4
27	06	0	08	1	0	53	! Web Hex Side 5
28	06	0	08	1	0	54	! Web Hex Side 6
29	09	0	02	1	1	00	! MK22-1 Targ
30	09	0	03	1	1	00	! MK22-2 Targ
31	09	0	04	1	1	00	! MK22-3 Targ
32	09	0	05	1	1	00	! MK22-4 Targ
33	09	0	06	1	1	00	! MK22-5 Targ
34	09	0	07	1	1	00	! MK22-6 Targ
35	10	0	-09	0	0	00	! Saft Thim Inner
36	11	0	08	0	0	00	! Septifoil Inner
37	12	0	02	0	0	00	! MK22-1 Inner
38	12	0	03	0	0	00	! MK22-2 Inner
39	12	0	04	0	0	00	! MK22-3 Inner
40	12	0	05	0	0	00	! MK22-4 Inner
41	12	0	06	0	0	00	! MK22-5 Inner
42	12	0	07	0	0	00	! MK22-6 Inner
43	05	0	08	0	0	00	! Web Spoke 1 Inner
44	05	0	08	0	0	00	! Web Spoke 2 Inner
45	05	0	08	0	0	00	! Web Spoke 3 Inner
46	05	0	08	0	0	00	! Web Spoke 4 Inner
47	05	0	08	0	0	00	! Web Spoke 5 Inner
48	05	0	08	0	0	00	! Web Spoke 6 Inner
49	06	0	08	0	0	00	! Web Hex Side 1 Inr
50	06	0	08	0	0	00	! Web Hex Side 2 Inr
51	06	0	08	0	0	00	! Web Hex Side 3 Inr
52	06	0	08	0	0	00	! Web Hex Side 4 Inr
53	06	0	08	0	0	00	! Web Hex Side 5 Inr
54	06	0	08	0	0	00	! Web Hex Side 6 Inr
55	13	0	-08	0	0	00	! Sec Saf Rod

comp	matl	
01	01	! Tank Air
02	02	! MK22 Air
03	02	! MK22 Air
04	02	! MK22 Air
05	02	! MK22 Air
06	02	! MK22 Air
07	02	! MK22 Air
08	03	! Septifoil Air

	ID	cv	tmelt	cmelt	imiss	icpc	emiss	area	mass
01	'SepHsg'	.21	1140.	169.	1	1	0.850	0.878	0.610
02	'M22USH'	.21	1140.	169.	1	1	0.850	1.076	0.750
03	'SafThm'	.21	1140.	169.	1	1	0.600	0.237	0.280
04	'ExpRod'	.135	1220.	169.	2	2	0.300	0.095	1.417
05	'SepSpk'	.21	1220.	169.	1	1	0.600	0.038	0.075
06	'SepHex'	.21	1220.	169.	1	1	0.600	0.021	0.043
07	'CadRod'	.135	2550.	115.	2	2	0.300	0.246	1.417
08	'AluRod'	.21	1112.	169.	1	1	0.600	0.246	0.814
09	'M22Tar'	.21	1190.	169.	1	1	0.600	0.969	1.244
10	'ThmInn'	.21	1140.	169.	1	1	0.600	0.188	0.280
11	'SepInn'	.21	1220.	169.	1	1	0.600	0.942	0.664
12	'USHInn'	.21	1140.	169.	1	1	0.600	1.050	0.750
13	'InnRod'	.135	1220.	169.	2	2	0.300	0.151	1.417

	ID	tt	phi	uncert nam	conda	condk	condl	nu_indx
01	'SepHsg'	73.4	73.4	'convect'	.00361	139.	1.0E20	1
02	'M22USH'	82.4	82.4	'convect'	.00443	139.	1.0E20	1
03	'SafThm'	105.8	105.8	'thim_h '	.00165	139.	1.0E20	2
04	'ExpRod'	105.8	105.8	'srod_h '	.00482	139.	1.0E20	2
05	'SepSpk'	73.4	73.4	'convect'	.00013	139.	1.0E20	1
06	'SepHex'	73.4	73.4	'convect'	.00025	139.	1.0E20	1
07	'CadRod'	73.4	73.4	'convect'	.00482	139.	1.0E20	1
08	'AluRod'	73.4	73.4	'convect'	.00482	139.	1.0E20	1
09	'M22Tar'	82.4	82.4	'convect'	.00000	139.	1.0E20	1
10	'ThmInn'	105.8	105.8	'convect'	.16900	139.	.00583	1
11	'SepInn'	73.4	73.4	'convect'	.00393	139.	1.0E20	1
12	'USHInn'	82.4	82.4	'convect'	.00443	139.	1.0E20	1
13	'InnRod'	105.8	105.8	'convect'	.16900	139.	.00583	1

	ID	cp	mass	uair	tt	phi
01	'TnkAir'	.24	0.090	0.00	105.8	105.8
02	'M22Air'	.24	.00087	0.00	82.4	82.4
03	'SepAir'	.24	.00103	0.00	73.4	105.8

Number of tank compartments participating in air exchange
0

Number of variables with uncertainty parameters
0

E Type	Num	Coefficients					
01	06	.99695	-3.534e-4	-8.4074e-7	1.1687e-9	-5.4448e-13	8.7253e-17

02	04	2.290890e-1	2.294730e-4	-2.411490e-7	9.525770e-11

	ID	GAM PWR	FRAC
01	'SepHsg'	9.2222E-05	9.2222E-05
02	'M22-01'	1.3123E-04	1.3123E-04
03	'M22-02'	1.3123E-04	1.3123E-04
04	'M22-03'	1.3123E-04	1.3123E-04
05	'M22-04'	1.3123E-04	1.3123E-04
06	'M22-05'	1.3123E-04	1.3123E-04
07	'M22-06'	1.3123E-04	1.3123E-04
08	'SafThm'	4.3194E-05	1.3123E-04
09	'SafRod'	2.4653E-04	2.4653E-04
10	'CadRdC'	2.0621E-04	2.0621E-04
11	'CadRdO'	2.1323E-04	2.1323E-04
12	'AluRd1'	9.8197E-05	9.8197E-05
13	'AluRd2'	9.9600E-05	9.9600E-05
14	'AluRd3'	1.0100E-04	1.0100E-04
15	'AluRd4'	9.9600E-05	9.9600E-05
16	'AluRd5'	9.8197E-05	9.8197E-05
17	'WbSpk1'	4.9099E-06	4.9099E-06
18	'WbSpk2'	4.9099E-06	4.9099E-06
19	'WbSpk3'	4.9099E-06	4.9099E-06
20	'WbSpk4'	4.9099E-06	4.9099E-06
21	'WbSpk5'	4.9099E-06	4.9099E-06
22	'WbSpk6'	4.9099E-06	4.9099E-06
23	'WbHex1'	2.8084E-06	2.8084E-06
24	'WbHex2'	2.8084E-06	2.8084E-06
25	'WbHex3'	2.8084E-06	2.8084E-06
26	'WbHex4'	2.8084E-06	2.8084E-06
27	'WbHex5'	2.8084E-06	2.8084E-06
28	'WbHex6'	2.8084E-06	2.8084E-06
29	'M22Tg1'	1.9680E-03	1.9680E-03
30	'M22Tg2'	1.9680E-03	1.9680E-03
31	'M22Tg3'	1.9680E-03	1.9680E-03
32	'M22Tg4'	1.9680E-03	1.9680E-03
33	'M22Tg5'	1.9680E-03	1.9680E-03
34	'M22Tg6'	1.9600E-03	1.9680E-03

comp #	# Couplings	Coupling #	Form Factor	Radiative Coupling
01	10			
		02	1.58238E-01	! SepHsg ---> M22Hs1
		03	1.59058E-01	! SepHsg ---> M22Hs2
		04	1.57418E-01	! SepHsg ---> M22Hs3
		05	1.59206E-01	! SepHsg ---> M22Hs4
		06	1.57802E-01	! SepHsg ---> M22Hs5
		07	1.59046E-01	! SepHsg ---> M22Hs6
		08	4.82806E-03	! SepHsg ---> ThmOut
		09	1.55202E-03	! SepHsg ---> SafRod
		01	4.26365E-02	! SepHsg ---> SepHsg
		35	2.16003E-04	! SepHsg ---> ThmInn
02	10			
		02	4.46732E-02	! M22Hs1 ---> M22Hs1
		03	1.61301E-01	! M22Hs1 ---> M22Hs2
		04	1.56192E-01	! M22Hs1 ---> M22Hs3

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                        05   1.55704E-01   ! M22Hs1 ---> M22Hs4
                        06   1.55420E-01   ! M22Hs1 ---> M22Hs5
                        07   1.39512E-01   ! M22Hs1 ---> M22Hs6
                        08   4.20932E-02   ! M22Hs1 ---> ThmOut
                        09   1.40324E-02   ! M22Hs1 ---> SafRod
                        01   1.28796E-01   ! M22Hs1 ---> SepHsg
                        35   2.27606E-03   ! M22Hs1 ---> ThmInn
03        10
                        02   1.61384E-01   ! M22Hs2 ---> M22Hs1
                        03   5.77148E-02   ! M22Hs2 ---> M22Hs2
                        04   1.39379E-01   ! M22Hs2 ---> M22Hs3
                        05   1.61188E-01   ! M22Hs2 ---> M22Hs4
                        06   1.56412E-01   ! M22Hs2 ---> M22Hs5
                        07   1.60992E-01   ! M22Hs2 ---> M22Hs6
                        08   2.39932E-02   ! M22Hs2 ---> ThmOut
                        09   7.60437E-03   ! M22Hs2 ---> SafRod
                        01   1.30014E-01   ! M22Hs2 ---> SepHsg
                        35   1.32006E-03   ! M22Hs2 ---> ThmInn
04        10
                        02   1.55734E-01   ! M22Hs3 ---> M22Hs1
                        03   1.40017E-01   ! M22Hs3 ---> M22Hs2
                        04   4.46456E-02   ! M22Hs3 ---> M22Hs3
                        05   1.61706E-01   ! M22Hs3 ---> M22Hs4
                        06   1.55406E-01   ! M22Hs3 ---> M22Hs5
                        07   1.55790E-01   ! M22Hs3 ---> M22Hs6
                        08   4.21975E-02   ! M22Hs3 ---> ThmOut
                        09   1.35285E-02   ! M22Hs3 ---> SafRod
                        01   1.28673E-01   ! M22Hs3 ---> SepHsg
                        35   2.30408E-03   ! M22Hs3 ---> ThmInn
05        10
                        02   1.55629E-01   ! M22Hs4 ---> M22Hs1
                        03   1.61421E-01   ! M22Hs4 ---> M22Hs2
                        04   1.61537E-01   ! M22Hs4 ---> M22Hs3
                        05   5.77978E-02   ! M22Hs4 ---> M22Hs4
                        06   1.39328E-01   ! M22Hs4 ---> M22Hs5
                        07   1.61329E-01   ! M22Hs4 ---> M22Hs6
                        08   2.34768E-02   ! M22Hs4 ---> ThmOut
                        09   7.90425E-03   ! M22Hs4 ---> SafRod
                        01   1.30240E-01   ! M22Hs4 ---> SepHsg
                        35   1.33604E-03   ! M22Hs4 ---> ThmInn
06        10
                        02   1.55833E-01   ! M22Hs5 ---> M22Hs1
                        03   1.55973E-01   ! M22Hs5 ---> M22Hs2
                        04   1.55509E-01   ! M22Hs5 ---> M22Hs3
                        05   1.39104E-01   ! M22Hs5 ---> M22Hs4
                        06   4.47454E-02   ! M22Hs5 ---> M22Hs5
                        07   1.62081E-01   ! M22Hs5 ---> M22Hs6
                        08   4.25894E-02   ! M22Hs5 ---> ThmOut
                        09   1.33924E-02   ! M22Hs5 ---> SafRod
                        01   1.28600E-01   ! M22Hs5 ---> SepHsg
                        35   2.17207E-03   ! M22Hs5 ---> ThmInn
07        10
                        02   1.39312E-01   ! M22Hs6 ---> M22Hs1
                        03   1.61133E-01   ! M22Hs6 ---> M22Hs2
```

		04	1.55993E-01	! M22Hs6 ---> M22Hs3
		05	1.61837E-01	! M22Hs6 ---> M22Hs4
		06	1.61617E-01	! M22Hs6 ---> M22Hs5
		07	5.76818E-02	! M22Hs6 ---> M22Hs6
		08	2.38368E-02	! M22Hs6 ---> ThmOut
		09	7.50824E-03	! M22Hs6 ---> SafRod
		01	1.29656E-01	! M22Hs6 ---> SepHsg
		35	1.42405E-03	! M22Hs6 ---> ThmInn
08	10			
		02	2.07458E-01	! ThmOut ---> M22Hs1
		03	1.17064E-01	! ThmOut ---> M22Hs2
		04	2.08407E-01	! ThmOut ---> M22Hs3
		05	1.17284E-01	! ThmOut ---> M22Hs4
		06	2.07682E-01	! ThmOut ---> M22Hs5
		07	1.17456E-01	! ThmOut ---> M22Hs6
		08	4.01475E-03	! ThmOut ---> ThmOut
		09	1.17280E-03	! ThmOut ---> SafRod
		01	1.92372E-02	! ThmOut ---> SepHsg
		35	2.24153E-04	! ThmOut ---> ThmInn
09	09			
		01	1.94798E-02	! SafHol ---> SepHsg
		02	2.09002E-01	! SafHol ---> M22Hs1
		03	1.15649E-01	! SafHol ---> M22Hs2
		04	2.07677E-01	! SafHol ---> M22Hs3
		05	1.16568E-01	! SafHol ---> M22Hs4
		06	2.09444E-01	! SafHol ---> M22Hs5
		07	1.17153E-01	! SafHol ---> M22Hs6
		08	3.81957E-03	! SafHol ---> ThmOut
		09	1.20555E-03	! SafHol ---> SafRod
10	26			
		10	1.00000E-20	! CntrCd ---> CntrCd
		11	6.72000E-02	! CntrCd ---> OutrCd
		12	6.84000E-02	! CntrCd ---> AlRod1
		13	6.77000E-02	! CntrCd ---> AlRod2
		14	7.09000E-02	! CntrCd ---> AlRod3
		15	7.02000E-02	! CntrCd ---> AlRod4
		16	6.54000E-02	! CntrCd ---> AlRod5
		17	2.50000E-03	! CntrCd ---> WbSpk1
		18	2.70000E-03	! CntrCd ---> WbSpk2
		19	2.90000E-03	! CntrCd ---> WbSpk3
		20	3.10000E-03	! CntrCd ---> WbSpk4
		21	2.90000E-03	! CntrCd ---> WbSpk5
		22	2.40000E-03	! CntrCd ---> WbSpk6
		36	3.68000E-02	! CntrCd ---> SepInn
		43	3.40000E-03	! CntrCd ---> Spk1In
		44	2.90000E-03	! CntrCd ---> Spk2In
		45	2.70000E-03	! CntrCd ---> Spk3In
		46	2.60000E-03	! CntrCd ---> Spk4In
		47	3.80000E-03	! CntrCd ---> Spk5In
		48	3.70000E-03	! CntrCd ---> Spk6In
		49	8.69000E-02	! CntrCd ---> Hx1Inn
		50	8.46000E-02	! CntrCd ---> Hx2Inn
		51	8.75000E-02	! CntrCd ---> Hx3Inn
		52	8.60000E-02	! CntrCd ---> Hx4Inn

		53	8.80000E-02	! CntrCd ---> Hx5Inn
		54	8.48000E-02	! CntrCd ---> Hx6Inn
11	19			
		10	6.90000E-02	! OutrCd ---> CntrRd
		11	1.00000E-20	! OutrCd ---> OutrCd
		12	6.62000E-02	! OutrCd ---> AlRod1
		13	3.40000E-03	! OutrCd ---> AlRod2
		15	2.70000E-03	! OutrCd ---> AlRod4
		16	6.62000E-02	! OutrCd ---> AlRod5
		17	1.14000E-01	! OutrCd ---> WbSpk1
		18	1.00000E-03	! OutrCd ---> WbSpk2
		23	3.30000E-03	! OutrCd ---> HexSd1
		27	3.50000E-03	! OutrCd ---> HexSd5
		28	9.71000E-02	! OutrCd ---> HexSd6
		36	4.41800E-01	! OutrCd ---> SepInn
		43	1.15800E-01	! OutrCd ---> Spk1In
		47	1.00000E-04	! OutrCd ---> Spk5In
		48	1.00000E-03	! OutrCd ---> Spk6In
		49	4.60000E-03	! OutrCd ---> Hx1Inn
		50	2.20000E-03	! OutrCd ---> Hx2Inn
		52	2.30000E-03	! OutrCd ---> Hx4Inn
		53	5.80000E-03	! OutrCd ---> Hx5Inn
12	18			
		10	7.14000E-02	! AlRod1 ---> CntrRd
		11	6.62000E-02	! AlRod1 ---> OutrCd
		12	1.00000E-20	! AlRod1 ---> AlRod1
		13	7.30000E-02	! AlRod1 ---> AlRod2
		14	3.00000E-03	! AlRod1 ---> AlRod3
		16	4.00000E-03	! AlRod1 ---> AlRod5
		18	1.06500E-01	! AlRod1 ---> WbSpk2
		19	6.00000E-04	! AlRod1 ---> WbSpk3
		23	9.40000E-02	! AlRod1 ---> HexSd1
		24	3.70000E-03	! AlRod1 ---> HexSd2
		28	3.30000E-03	! AlRod1 ---> HexSd6
		36	4.48700E-01	! AlRod1 ---> SepInn
		43	1.70000E-03	! AlRod1 ---> Spk1In
		44	1.10100E-01	! AlRod1 ---> Spk2In
		50	5.30000E-03	! AlRod1 ---> Hx2Inn
		51	2.20000E-03	! AlRod1 ---> Hx3Inn
		53	1.80000E-03	! AlRod1 ---> Hx5Inn
		54	4.50000E-03	! AlRod1 ---> Hx6Inn
13	18			
		10	6.63066E-02	! AlRod2 ---> CntrRd
		11	4.30043E-03	! AlRod2 ---> OutrCd
		12	6.66067E-02	! AlRod2 ---> AlRod1
		13	1.00000E-20	! AlRod2 ---> AlRod2
		14	6.68067E-02	! AlRod2 ---> AlRod3
		15	2.50025E-03	! AlRod2 ---> AlRod4
		19	1.19412E-01	! AlRod2 ---> WbSpk3
		20	1.10011E-03	! AlRod2 ---> WbSpk4
		23	3.30033E-03	! AlRod2 ---> HexSd1
		24	9.34093E-02	! AlRod2 ---> HexSd2
		25	3.20032E-03	! AlRod2 ---> HexSd3
		36	4.49445E-01	! AlRod2 ---> SepInn

		44	1.30013E-03	! AlRod2 ---> Spk2In
		45	1.08111E-01	! AlRod2 ---> Spk3In
		49	5.20052E-03	! AlRod2 ---> Hx1Inn
		51	4.00040E-03	! AlRod2 ---> Hx3Inn
		52	2.70027E-03	! AlRod2 ---> Hx4Inn
		54	2.30023E-03	! AlRod2 ---> Hx6Inn
14	18			
		10	6.71067E-02	! AlRod3 ---> CntrRd
		12	3.90039E-03	! AlRod3 ---> AlRod1
		13	6.81068E-02	! AlRod3 ---> AlRod2
		14	1.00000E-20	! AlRod3 ---> AlRod3
		15	6.39064E-02	! AlRod3 ---> AlRod4
		16	3.50035E-03	! AlRod3 ---> AlRod5
		20	1.13611E-01	! AlRod3 ---> WbSpk4
		21	1.10011E-03	! AlRod3 ---> WbSpk5
		24	3.70037E-03	! AlRod3 ---> HexSd2
		25	9.24092E-02	! AlRod3 ---> HexSd3
		26	3.60036E-03	! AlRod3 ---> HexSd4
		36	4.55045E-01	! AlRod3 ---> SepInn
		45	1.10011E-03	! AlRod3 ---> Spk3In
		46	1.09811E-01	! AlRod3 ---> Spk4In
		49	2.80028E-03	! AlRod3 ---> Hx1Inn
		50	4.40044E-03	! AlRod3 ---> Hx2Inn
		52	3.80038E-03	! AlRod3 ---> Hx4Inn
		53	2.10021E-03	! AlRod3 ---> Hx5Inn
15	18			
		10	6.65000E-02	! AlRod4 ---> CntrRd
		11	3.30000E-03	! AlRod4 ---> OutrCd
		13	4.60000E-03	! AlRod4 ---> AlRod2
		14	6.81000E-02	! AlRod4 ---> AlRod3
		15	1.00000E-04	! AlRod4 ---> AlRod4
		16	6.74000E-02	! AlRod4 ---> AlRod5
		21	1.10600E-01	! AlRod4 ---> WbSpk5
		22	5.00000E-04	! AlRod4 ---> WbSpk6
		25	3.10000E-03	! AlRod4 ---> HexSd3
		26	9.37000E-02	! AlRod4 ---> HexSd4
		27	2.80000E-03	! AlRod4 ---> HexSd5
		36	4.55800E-01	! AlRod4 ---> SepInn
		46	5.00000E-04	! AlRod4 ---> Spk4In
		47	1.09400E-01	! AlRod4 ---> Spk5In
		50	2.00000E-03	! AlRod4 ---> Hx2Inn
		51	4.50000E-03	! AlRod4 ---> Hx3Inn
		53	5.00000E-03	! AlRod4 ---> Hx5Inn
		54	2.10000E-03	! AlRod4 ---> Hx6Inn
16	18			
		10	6.76068E-02	! AlRod5 ---> CntrRd
		11	6.68067E-02	! AlRod5 ---> OutrCd
		12	3.40034E-03	! AlRod5 ---> AlRod1
		14	3.70037E-03	! AlRod5 ---> AlRod3
		15	7.00070E-02	! AlRod5 ---> AlRod4
		16	1.00000E-20	! AlRod5 ---> AlRod5
		17	1.70017E-03	! AlRod5 ---> WbSpk1
		22	1.08011E-01	! AlRod5 ---> WbSpk6
		26	2.50025E-03	! AlRod5 ---> HexSd4

		27	9.29093E-02	! AlRod5 ---> HexSd5
		28	3.50035E-03	! AlRod5 ---> HexSd6
		36	4.51745E-01	! AlRod5 ---> SepInn
		47	1.50015E-03	! AlRod5 ---> Spk5In
		48	1.13111E-01	! AlRod5 ---> Spk6In
		49	2.10021E-03	! AlRod5 ---> Hx1Inn
		51	2.20022E-03	! AlRod5 ---> Hx3Inn
		52	5.20052E-03	! AlRod5 ---> Hx4Inn
		54	4.00040E-03	! AlRod5 ---> Hx6Inn
17	8			
		10	1.88000E-02	! WbSpk1 ---> CntrRd
		11	6.74700E-01	! WbSpk1 ---> OutrCd
		16	6.00000E-03	! WbSpk1 ---> AlRod5
		17	1.00000E-20	! WbSpk1 ---> WbSpk1
		28	3.20000E-02	! WbSpk1 ---> HexSd6
		36	2.61700E-01	! WbSpk1 ---> SepInn
		43	1.40000E-03	! WbSpk1 ---> Spk1In
		53	5.40000E-03	! WbSpk1 ---> Hx5Inn
18	8			
		10	1.91000E-02	! WbSpk2 ---> CntrRd
		11	7.90000E-03	! WbSpk2 ---> OutrCd
		12	6.74500E-01	! WbSpk2 ---> AlRod1
		18	1.00000E-20	! WbSpk2 ---> WbSpk2
		23	3.05000E-02	! WbSpk2 ---> HexSd1
		36	2.62100E-01	! WbSpk2 ---> SepInn
		44	1.50000E-03	! WbSpk2 ---> Spk2In
		54	4.40000E-03	! WbSpk2 ---> Hx6Inn
19	9			
		10	1.69000E-02	! WbSpk3 ---> CntrRd
		11	1.00000E-04	! WbSpk3 ---> OutrCd
		12	6.40000E-03	! WbSpk3 ---> AlRod1
		13	6.74600E-01	! WbSpk3 ---> AlRod2
		19	1.00000E-20	! WbSpk3 ---> WbSpk3
		24	3.49000E-02	! WbSpk3 ---> HexSd2
		36	2.62000E-01	! WbSpk3 ---> SepInn
		45	1.70000E-03	! WbSpk3 ---> Spk3In
		49	3.40000E-03	! WbSpk3 ---> Hx1Inn
20	9			
		10	1.92000E-02	! WbSpk4 ---> CntrRd
		13	6.20000E-03	! WbSpk4 ---> AlRod2
		14	6.74700E-01	! WbSpk4 ---> AlRod3
		20	1.00000E-20	! WbSpk4 ---> WbSpk4
		25	3.20000E-02	! WbSpk4 ---> HexSd3
		36	2.61700E-01	! WbSpk4 ---> SepInn
		45	1.00000E-04	! WbSpk4 ---> Spk3In
		46	1.90000E-03	! WbSpk4 ---> Spk4In
		50	4.20000E-03	! WbSpk4 ---> Hx2Inn
21	9			
		10	2.01000E-02	! WbSpk5 ---> CntrRd
		13	1.00000E-04	! WbSpk5 ---> AlRod2
		14	6.50000E-03	! WbSpk5 ---> AlRod3
		15	6.74500E-01	! WbSpk5 ---> AlRod4
		21	1.00000E-20	! WbSpk5 ---> WbSpk5
		26	2.96000E-02	! WbSpk5 ---> HexSd4

		36	2.62100E-01	! WbSpk5 ---> SepInn
		47	2.40000E-03	! WbSpk5 ---> Spk5In
		51	4.70000E-03	! WbSpk5 ---> Hx3Inn
22	8			
		10	2.00000E-02	! WbSpk6 ---> CntrRd
		15	5.40000E-03	! WbSpk6 ---> AlRod4
		16	6.74600E-01	! WbSpk6 ---> AlRod5
		22	1.00000E-20	! WbSpk6 ---> WbSpk6
		27	3.06000E-02	! WbSpk6 ---> HexSd5
		36	2.62000E-01	! WbSpk6 ---> SepInn
		48	2.10000E-03	! WbSpk6 ---> Spk6In
		52	5.30000E-03	! WbSpk6 ---> Hx4Inn
23	7			
		11	2.59000E-02	! HexSd1 ---> OutrCd
		12	8.11800E-01	! HexSd1 ---> AlRod1
		13	2.53000E-02	! HexSd1 ---> AlRod2
		18	4.15000E-02	! HexSd1 ---> WbSpk2
		23	1.00000E-20	! HexSd1 ---> HexSd1
		36	5.39000E-02	! HexSd1 ---> SepInn
		44	4.16000E-02	! HexSd1 ---> Spk2In
24	7			
		12	2.69000E-02	! HexSd2 ---> AlRod1
		13	8.12000E-01	! HexSd2 ---> AlRod2
		14	2.68000E-02	! HexSd2 ---> AlRod3
		19	4.10000E-02	! HexSd2 ---> WbSpk3
		24	1.00000E-20	! HexSd2 ---> HexSd2
		36	5.44000E-02	! HexSd2 ---> SepInn
		45	3.89000E-02	! HexSd2 ---> Spk3In
25	7			
		13	2.33000E-02	! HexSd3 ---> AlRod2
		14	8.11800E-01	! HexSd3 ---> AlRod3
		15	2.51000E-02	! HexSd3 ---> AlRod4
		20	4.26000E-02	! HexSd3 ---> WbSpk4
		25	1.00000E-20	! HexSd3 ---> HexSd3
		36	5.20000E-02	! HexSd3 ---> SepInn
		46	4.52000E-02	! HexSd3 ---> Spk4In
26	7			
		14	2.63000E-02	! HexSd4 ---> AlRod3
		15	8.11800E-01	! HexSd4 ---> AlRod4
		16	2.47000E-02	! HexSd4 ---> AlRod5
		21	4.36000E-02	! HexSd4 ---> WbSpk5
		26	1.00000E-20	! HexSd4 ---> HexSd4
		36	5.20000E-02	! HexSd4 ---> SepInn
		47	4.16000E-02	! HexSd4 ---> Spk5In
27	7			
		11	2.47000E-02	! HexSd5 ---> OutrCd
		15	2.67000E-02	! HexSd5 ---> AlRod4
		16	8.12000E-01	! HexSd5 ---> AlRod5
		22	4.38000E-02	! HexSd5 ---> WbSpk6
		27	1.00000E-20	! HexSd5 ---> HexSd5
		36	5.08000E-02	! HexSd5 ---> SepInn
		48	4.20000E-02	! HexSd5 ---> Spk6In
28	7			
		11	8.11800E-01	! HexSd6 ---> OutrCd

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                    12   2.48000E-02   ! HexSd6 ---> AlRod1
                    16   2.50000E-02   ! HexSd6 ---> AlRod5
                    17   4.35000E-02   ! HexSd6 ---> WbSpk1
                    28   1.00000E-20   ! HexSd6 ---> HexSd6
                    36   5.23000E-02   ! HexSd6 ---> SepInn
                    43   4.26000E-02   ! HexSd6 ---> Spk1In
29      02
                    29         1.e-20  ! M22Tg1 ---> M22Tg1
                    37         1.00    ! M22Tg1 ---> M22Hs1
30      02
                    30         1.e-20  ! M22Tg2 ---> M22Tg2
                    38         1.00    ! M22Tg2 ---> M22Hs2
31      02
                    31         1.e-20  ! M22Tg3 ---> M22Tg3
                    39         1.00    ! M22Tg3 ---> M22Hs3
32      02
                    32         1.e-20  ! M22Tg4 ---> M22Tg4
                    40         1.00    ! M22Tg4 ---> M22Hs4
33      02
                    33         1.e-20  ! M22Tg5 ---> M22Tg5
                    41         1.00    ! M22Tg5 ---> M22Hs5
34      02
                    34         1.e-20  ! M22Tg6 ---> M22Tg6
                    42         1.00    ! M22Tg6 ---> M22Hs6
35      10
                     1   1.36099E-02   ! ThmInn ---> SepHsg
                     2   8.23312E-03   ! ThmInn ---> M22Hs1
                     3   1.36259E-02   ! ThmInn ---> M22Hs2
                     4   8.12510E-03   ! ThmInn ---> M22Hs3
                     5   1.33978E-02   ! ThmInn ---> M22Hs4
                     6   7.98109E-03   ! ThmInn ---> M22Hs5
                     7   2.28031E-04   ! ThmInn ---> M22Hs6
                     8   1.29218E-03   ! ThmInn ---> ThmOut
                    09   1.33318E-01   ! ThmInn ---> SafRod
                    35   8.00189E-01   ! ThmInn ---> ThmInn
 36     26
                    10   8.80000E-03   ! SepInn ---> CntrRd
                    11   1.29600E-01   ! SepInn ---> OutrCd
                    12   1.30100E-01   ! SepInn ---> AlRod1
                    13   1.28300E-01   ! SepInn ---> AlRod2
                    14   1.31500E-01   ! SepInn ---> AlRod3
                    15   1.27200E-01   ! SepInn ---> AlRod4
                    16   1.30100E-01   ! SepInn ---> AlRod5
                    17   1.23000E-02   ! SepInn ---> WbSpk1
                    18   1.40000E-02   ! SepInn ---> WbSpk2
                    19   1.32000E-02   ! SepInn ---> WbSpk3
                    20   2.04000E-02   ! SepInn ---> WbSpk4
                    21   1.19000E-02   ! SepInn ---> WbSpk5
                    22   1.16000E-02   ! SepInn ---> WbSpk6
                    23   1.60000E-03   ! SepInn ---> HexSd1
                    24   1.90000E-03   ! SepInn ---> HexSd2
                    25   2.40000E-03   ! SepInn ---> HexSd3
                    26   2.10000E-03   ! SepInn ---> HexSd4
                    27   1.30000E-03   ! SepInn ---> HexSd5
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                    28      2.00000E-03   ! SepInn  ---> HexSd6
                    36      4.41000E-02   ! SepInn  ---> SepInn
                    43      1.35000E-02   ! SepInn  ---> Spk1In
                    44      1.27000E-02   ! SepInn  ---> Spk2In
                    45      1.16000E-02   ! SepInn  ---> Spk3In
                    46      1.28000E-02   ! SepInn  ---> Spk4In
                    47      1.10000E-02   ! SepInn  ---> Spk5In
                    48      1.40000E-02   ! SepInn  ---> Spk6In
37        02
                    29          0.92000   ! M22In1 ---> M22Tg1
                    37          0.08000   ! M22In1 ---> M22In1
38        02
                    30          0.92000   ! M22In2 ---> M22Tg2
                    38          0.08000   ! M22In2 ---> M22In2
39        02
                    31          0.92000   ! M22In3 ---> M22Tg3
                    39          0.08000   ! M22In3 ---> M22In3
40        02
                    32          0.92000   ! M22In4 ---> M22Tg4
                    40          0.08000   ! M22In4 ---> M22In4
41        02
                    33          0.92000   ! M22In5 ---> M22Tg5
                    41          0.08000   ! M22In5 ---> M22In5
42        02
                    34          0.92000   ! M22In6 ---> M22Tg6
                    42          0.08000   ! M22In6 ---> M22In6
43         9
                    10      1.93000E-02   ! Spk1In  ---> CntrRd
                    11      6.74500E-01   ! Spk1In  ---> OutrCd
                    12      7.90000E-03   ! Spk1In  ---> AlRod1
                    17      1.30000E-03   ! Spk1In  ---> WbSpk1
                    18      2.00000E-04   ! Spk1In  ---> WbSpk2
                    28      3.02000E-02   ! Spk1In  ---> HexS[illegible]3
                    36      2.62100E-01   ! Spk1In  ---> SepI[illegible]
                    43      1.00000E-20   ! Spk1In  ---> Spk1In
                    49      4.50000E-03   ! Spk1In  ---> Hx1Inn
44         8
                    10      1.92000E-02   ! Spk2In  ---> CntrRd
                    12      6.74700E-01   ! Spk2In  ---> AlRod1
                    13      7.40000E-03   ! Spk2In  ---> AlRod2
                    18      1.50000E-03   ! Spk2In  ---> WbSpk2
                    23      3.12000E-02   ! Spk2In  ---> HexSd1
                    36      2.61700E-01   ! Spk2In  ---> SepInn
                    44      1.00000E-20   ! Spk2In  ---> Spk2In
                    50      4.30000E-03   ! Spk2In  ---> Hx2Inn
45         9
                    10      1.81000E-02   ! Spk3In  ---> CntrRd
                    13      6.74600E-01   ! Spk3In  ---> AlRod2
                    14      5.10000E-03   ! Spk3In  ---> AlRod3
                    19      1.90000E-03   ! Spk3In  ---> WbSpk3
                    20      1.00000E-04   ! Spk3In  ---> WbSpk4
                    24      3.40000E-02   ! Spk3In  ---> HexSd2
                    36      2.62000E-01   ! Spk3In  ---> SepInn
                    45      1.00000E-20   ! Spk3In  ---> Spk3In
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		51	4.20000E-03	! Spk3In ---> Hx3Inn
46	9			
		10	1.99000E-02	! Spk4In ---> CntrRd
		14	6.74500E-01	! Spk4In ---> AlRod3
		15	5.50000E-03	! Spk4In ---> AlRod4
		16	1.00000E-04	! Spk4In ---> AlRod5
		20	2.00000E-03	! Spk4In ---> WbSpk4
		25	3.07000E-02	! Spk4In ---> HexSd3
		36	2.62000E-01	! Spk4In ---> SepInn
		46	1.00000E-20	! Spk4In ---> Spk4In
		52	5.20000E-03	! Spk4In ---> Hx4Inn
47	8			
		10	1.92000E-02	! Spk5In ---> CntrRd
		15	6.74700E-01	! Spk5In ---> AlRod4
		16	6.60000E-03	! Spk5In ---> AlRod5
		21	2.10000E-03	! Spk5In ---> WbSpk5
		26	3.17000E-02	! Spk5In ---> HexSd4
		36	2.61700E-01	! Spk5In ---> SepInn
		47	1.00000E-20	! Spk5In ---> Spk5In
		53	4.00000E-03	! Spk5In ---> Hx5Inn
3	9			
		10	2.02000E-02	! Spk6In ---> CntrRd
		11	5.60000E-03	! Spk6In ---> OutrCd
		12	1.00000E-04	! Spk6In ---> AlRod1
		16	6.74600E-01	! Spk6In ---> AlRod5
		22	1.90000E-03	! Spk6In ---> WbSpk6
		27	3.06000E-02	! Spk6In ---> HexSd5
		36	2.62000E-01	! Spk6In ---> SepInn
		48	1.00000E-20	! Spk6In ---> Spk6In
		54	5.00000E-03	! Spk6In ---> Hx6Inn
49	13			
		10	7.40600E-01	! Hx1Inn ---> CntrRd
		11	3.48000E-02	! Hx1Inn ---> OutrCd
		13	3.77000E-02	! Hx1Inn ---> AlRod2
		14	1.84000E-02	! Hx1Inn ---> AlRod3
		16	1.78000E-02	! Hx1Inn ---> AlRod5
		19	6.60000E-03	! Hx1Inn ---> WbSpk3
		36	3.00000E-04	! Hx1Inn ---> SepInn
		43	6.10000E-03	! Hx1Inn ---> Spk1In
		49	1.00000E-20	! Hx1Inn ---> Hx1Inn
		50	5.61000E-02	! Hx1Inn ---> Hx2Inn
		51	1.20000E-02	! Hx1Inn ---> Hx3Inn
		53	1.34000E-02	! Hx1Inn ---> Hx5Inn
		54	5.62000E-02	! Hx1Inn ---> Hx6Inn
50	13			
		10	7.39200E-01	! Hx2Inn ---> CntrRd
		11	1.90000E-02	! Hx2Inn ---> OutrCd
		12	3.75000E-02	! Hx2Inn ---> AlRod1
		14	3.75000E-02	! Hx2Inn ---> AlRod3
		15	1.82000E-02	! Hx2Inn ---> AlRod4
		20	7.70000E-03	! Hx2Inn ---> WbSpk4
		36	6.00000E-04	! Hx2Inn ---> SepInn
		44	8.50000E-03	! Hx2Inn ---> Spk2In
		49	5.35000E-02	! Hx2Inn ---> Hx1Inn

		50	1.00000E-20	! Hx2Inn ---> Hx2Inn
		51	5.46000E-02	! Hx2Inn ---> Hx3Inn
		52	1.21000E-02	! Hx2Inn ---> Hx4Inn
		54	1.16000E-02	! Hx2Inn ---> Hx6Inn
51	13			
		10	7.40600E-01	! Hx3Inn ---> CntrRd
		12	1.75000E-02	! Hx3Inn ---> AlRod1
		13	3.68000E-02	! Hx3Inn ---> AlRod2
		15	3.37000E-02	! Hx3Inn ---> AlRod4
		16	1.82000E-02	! Hx3Inn ---> AlRod5
		21	7.20000E-03	! Hx3Inn ---> WbSpk5
		36	1.00000E-04	! Hx3Inn ---> SepInn
		45	6.80000E-03	! Hx3Inn ---> Spk3In
		49	1.29000E-02	! Hx3Inn ---> Hx1Inn
		50	5.69000E-02	! Hx3Inn ---> Hx2Inn
		51	1.00000E-20	! Hx3Inn ---> Hx3Inn
		52	5.58000E-02	! Hx3Inn ---> Hx4Inn
		53	1.35000E-02	! Hx3Inn ---> Hx5Inn
52	13			
		10	7.40600E-01	! Hx4Inn ---> CntrRd
		11	1.74000E-02	! Hx4Inn ---> OutrCd
		13	1.87000E-02	! Hx4Inn ---> AlRod2
		14	3.55000E-02	! Hx4Inn ---> AlRod3
		16	3.61000E-02	! Hx4Inn ---> AlRod5
		22	7.60000E-03	! Hx4Inn - -> WbSpk6
		36	2.00000E-04	! Hx4Inn ---> SepInn
		46	6.90000E-03	! Hx4Inn ---> Spk4In
		50	1.24000E-02	! Hx4Inn ---> Hx2Inn
		51	5.49000E-02	! Hx4Inn ---> Hx3Inn
		52	1.00000E-20	! Hx4Inn ---> Hx4Inn
		53	5.76000E-02	! Hx4Inn ---> Hx5Inn
		54	1.21000E-02	! Hx4Inn ---> Hx6Inn
53	13			
		10	7.39200E-01	! Hx5Inn ---> CntrRd
		11	3.58000E-02	! Hx5Inn ---> OutrCd
		12	1.83000E-02	! Hx5Inn ---> AlRod1
		14	1.74000E-02	! Hx5Inn ---> AlRod3
		15	3.67000E-02	! Hx5Inn ---> AlRod4
		17	6.80000E-03	! Hx5Inn ---> WbSpk1
		36	3.00000E-04	! Hx5Inn ---> SepInn
		47	7.30000E-03	! Hx5Inn ---> Spk5In
		49	1.21000E-02	! Hx5Inn ---> Hx1Inn
		51	1.32000E-02	! Hx5Inn ---> Hx3Inn
		52	5.57000E-02	! Hx5Inn ---> Hx4Inn
		53	1.00000E-20	! Hx5Inn ---> Hx5Inn
		54	5.72000E-02	! Hx5Inn ---> Hx6Inn
54	13			
		10	7.40600E-01	! Hx6Inn ---> CntrRd
		12	3.40000E-02	! Hx6Inn ---> AlRod1
		13	1.73000E-02	! Hx6Inn ---> AlRod2
		15	1.71000E-02	! Hx6Inn ---> AlRod4
		16	3.73000E-02	! Hx6Inn ---> AlRod5
		18	8.60000E-03	! Hx6Inn ---> WbSpk2
		36	1.00000E-04	! Hx6Inn ---> SepInn

```
                              48      6.70000E-03    ! Hx6Inn  ---> Spk6In
                              49      5.67000E-02    ! Hx6Inn  ---> Hx1Inn
                              50      1.18000E-02    ! Hx6Inn  ---> Hx2Inn
                              52      1.35000E-02    ! Hx6Inn  ---> Hx4Inn
                              53      5.63000E-02    ! Hx6Inn  ---> Hx5Inn
                              54      1.00000E-20    ! Hx6Inn  ---> Hx6Inn
      55          02
                              35          1.00000    ! SafInn  ---> ThmInn
                              55          1.0E-20    ! SafInn  ---> SafInn
```

****

Pages 52 through 91 contain a listing of the GAM_HEAT source code.

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END