A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

NOTICE

**PORTIONS OF THIS REPORT ARE ILLEGIBLE. It
has been reproduced from the best available
copy to permit the broadest possible avail-
ability.**

ORNL--5951

DE84 016680

Engineering Physics and Mathematics Division

**THR-TH: A HIGH-TEMPERATURE GAS-COOLED NUCLEAR
REACTOR CORE THERMAL HYDRAULICS CODE**

D. R. Vondy

Manuscript Completed: April 1984
Date of Issue: July 1984

This Work Sponsored by
U.S. DOE Office of
Nuclear Power Systems

Prepared by the
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
operated by
Martin Marietta Energy Systems, Inc.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

TABLE OF CONTENTS

	Page
ABSTRACT	v
COMPUTER CODE ABSTRACT	vii
1. INTRODUCTION	1
2. PRISMATIC CORE HYDRAULICS	2
The Effect of Coolant Channel Size Variation	6
The Solution Procedure	7
Regarding Coolant Orificing	10
Coolant Bypass Ignored	11
Coolant Crossflow Ignored	12
3. THE THERMAL CELL	12
The Two-Dimensional Model	12
Absolute Proof Testing	29
More Effective Acceleration	33
The One-Dimensional Cell Model	34
Note About the Cost of Cell Calculations	35
Effects of Thermal Cell Approximations	35
4. CERTAIN APPLICATION SUPPORT INFORMATION	37
Data Handling	37
Solution Reliability	50
Application Considerations	50
Application Experience	52
5. APPLICATION INFORMATION	55
User Control	55
Data Storage	55
Credible Results	57
6. SAMPLE PROBLEM	57
7. PROGRAM CONSIDERATIONS	123
8. GLOSSARY WITH THERMAL HYDRAULIC CODE IMPLICATIONS	126
9. REFERENCES	131

v/vi

ABSTRACT

The ORNL version of PEBBLE, the (RZ) pebble bed thermal hydraulics code, has been extended for application to a prismatic gas cooled reactor core. The supplemental treatment is of one-dimensional coolant flow in up to a three-dimensional core description. Power density data from a neutronics and exposure calculation are used as the basic information for the thermal hydraulics calculation of heat removal. Two-dimensional neutronics results may be expanded for a three-dimensional hydraulics calculation. The geometric description for the hydraulics problem is the same as used by the neutronics code. A two-dimensional thermal cell model is used to predict temperatures in the fuel channel. The capability is available in the local BOLD VENTURE computation system for reactor core analysis with capability to account for the effect of temperature feedback by nuclear cross section correlation. Some enhancements have also been added to the original code to add pebble bed modeling flexibility and to generate useful auxiliary results. For example, an estimate is made of the distribution of fuel temperatures based on average and extreme conditions regularly calculated at a number of locations.

COMPUTER CODE ABSTRACT

1. **Code.** THR-TH Thermal Hydraulics Code Version 1 (1983).¹
2. **Problem.** Steady-state high-temperature gas-cooled reactor core heat removal and fuel temperature calculation: one-dimensional flow in a three-dimensional model for prismatic fuel elements,¹ one- or two-dimensional (RZ) for the pebble bed core,² plus the local thermal cell model of heat transport from the fuel fission source site to the coolant.
3. **Method.** A relatively straightforward accelerated iterative procedure is used to solve the thermal hydraulics problem cast in the stream function form as a mesh-edgepoint finite-difference representation for the pebble bed core.³ For the prismatic core the multiple one-dimensional coolant flow problem is solved with adjustable orifice blocking by iteration. Then the coolant-hole fuel-channel thermal cell problems are cast in a two-dimensional model and the heat transport difference equations are solved by iteration. The reactor core description used by the neutronics code and the power density data generated from the neutronics solution are used directly by this code, minimizing the user input data requirements, and temperature feedback capability is implemented.
4. **Related Material.** This code is used in the local modular code system⁴ for reactor analysis, providing interfacing with the VENTURE diffusion theory neutronics code and associated capability for calculating reactor histories.
5. **Restrictions.** With variably dimensioned data arrays, problem size is limited only by available computer memory, without provision for data transfer during iteration; typically the pebble bed thermal hydraulics problem requires less computer time than the neutronics problem but may require more computer memory for large problems, while the prismatic core problem requires but little computer time. Virtual memory computer operation mode is assumed to be available for large problems. This code is a member of a modular code system and cannot operate in a standalone mode.
6. **Computers.** IBM 360, 370, 303X series.
7. **Running Time.** A 37 x 54 mesh point pebble bed problem required 32K program and 105K data (double precision), 137K short word total, and required 0.81 minutes processor time, 2.6 minutes clock time on an IBM 3033 two-processor multitasking machine. A 7,200 meshpoint two-dimensional triangular grid neutronics problem takes 2.0 minutes IBM-3033 time and an exposure step for 450 depleting zones takes 0.4 minutes; the associated full core hydraulics problem treating 2,700 coolant channels and 12 axial nodes (31,752 coolant locations) required 1.4 min processor time, and the 2,700 thermal cell problems each solved twice took 2.5 min time.
8. **Programming Language.** Fortran 1966 (some service tasks done in assembly language).
9. **Operating System.** IBM OS 303X under HASP II multitasking, compiler OS 370 Fortran H Extended (Enhanced), Version 1.3.0, Optimization Level 3.

10. **Machine Requirements.** Typically 7 disc files are used and 350K short words memory, but the memory requirement depends directly on the problem size (mesh points); the code system operates under a resident driver and managing control module. Codes such as this that are true members of the computation system do not read input data from the stream, but only process interface data files, admitting free ordering and loop structures.
11. **Author.** D. R. Vondy, Engineering Physics and Mathematics Division, Box X, Oak Ridge, Tennessee.
12. **References.**
 1. D. R. Vondy, "THR-TH: A High Temperature Gas Cooled Nuclear Reactor Thermal Hydraulics Code," ORNL-5951 (1984).
 2. D. R. Vondy, "PEBBLE: A Two-Dimensional Steady-State Pebble Bed Reactor Thermal Hydraulics Code," ORNL-5698 (September 1981).
 3. K. R. Stroh, "Thermal-Hydraulic Analysis Techniques for Axisymmetric Pebble Bed Nuclear Reactor Cores," Dissertation, Mech. Eng. CSU (LANSL report in progress, 1978).
 4. D. R. Vondy *et al.*, "A Computation System for Nuclear Reactor Core Analysis," DOE Report, ORNL-5158 (April 1977).
13. **Material Available.** The source program and the documenting reports (refs. 1 and 2) are to be placed in the DOE National Energy Software center with the other codes in this system for distribution. The code consists of about 8,000 source cards.

1. INTRODUCTION

Continuing local evaluation effort on analyses of thermal high-temperature reactors has been deficient because of the lack of a thermal hydraulics analysis capability for a prismatic graphite fuel element core. The route chosen to provide the required capability was enhancement of the local pebble bed thermal hydraulics code already in routine use.¹ Only modest changes had to be made in its computation system interfacing capability, the major one being the extension from one- and two-dimensional (RZ) problem descriptions to allow general use in three dimensions. The original capability was kept, and parallel capability was added for the calculation of one-dimensional coolant flow through holes in a core containing solid fuel elements described in up to three dimensions. Cross and bypass flows are neglected. This report documents the extension and contains basic user information. The earlier report should be referenced for the details of the pebble bed thermal hydraulics treatment.

The calculational procedures that were implemented for the prismatic core are relatively simple. An iterative process is used to solve the problem of one-dimensional flow in parallel channels. Given the coolant flow distribution, the fuel temperatures are estimated with thermal cell calculations. Thus the basic information to support performance evaluation and comparative evaluation is generated. Aspects that are not considered would require further investigation to support design and to qualify analytic effort. The quantitative effect on the fuel temperature distribution of cross flow of the coolant might be anticipated, but the net effect on the results of a comparison of two situations could be less obvious. The intent of this effort was to implement a realistic treatment of the situation, a best estimate, avoiding the distorting effect of one after another assumptions of worst conditions that lead to conservative but often not the most useful data. Routine use is in a fully modular sense in the computation system.²

The author discussed the analysis effort and methods with engineers at GA Technologies, Inc. and is familiar with such implemented capability as the proprietary code POKE.³ A good discussion of the general subject with some detail is presented by A. Shenoy and B. Shamasundar in Ref. 4.

A few modest changes have recently been made to the procedures for the pebble bed reactor analysis capability. These were largely to eliminate some surprises regarding the modeling, effecting what might be more apt to be expected. The accounting for the void fraction was altered due to certain inconsistencies associated with unanticipated and unusual modeling. The void fraction becomes a relatively indirect quantity when there is a mixture of zones and the finer scale subzones. Only when zone and subzone volume fractions that are consistent with an evident void fraction are made available can the data be simply interpreted to allow spacial variation in the void (coolant) fraction.

It is important to observe that this analysis capability has been developed for application to reactor core performance at power at steady state. Although useful application may be made to some other situation, such as overpower or the emergency shutdown state, such analysis would be expected to involve considerations excluded in this development. Therefore the modeling may or may not be adequate and the results must be used carefully.

2. PRISMATIC CORE HYDRAULICS

In a typical application, the heat source distribution is supplied for a three-dimensional mesh point arrangement that was used for the finite difference core neutronics problem. The core inlet and outlet coolant temperatures are specified, thereby establishing the coolant flow rate required for removal of the total amount of heat. A single coolant channel (hole) is associated with each mesh point interval normal to the coolant flow direction, typically on a triangular (hexagonal) arrangement of points. An initial estimate of the coolant flow rates through each of these channels is moved iteratively to an acceptable solution, considering the associated pressure drop and blocked orificing conditions at the inlet or exit. Note that the amount of heat removed by the coolant along each channel is determined from the local power density at the finite-difference level of the neutronics calculation and the coolant hole density. The axial heat source distribution is made available from three-dimensional neutronics calculations, or some two-dimensional situations (RZ), or it may be supplied by the user if only a two-dimensional neutronics problem is treated normal to the coolant flow direction. Note that halving the neutronics mesh spacing causes four times as many flow channels to be treated.

The iteration procedure is rather simple and will not be discussed in detail. A simple objective is defined such as minimizing the peak coolant channel surface temperature in each coolant flow block. The orificing conditions for each coolant flow block are then adjusted, along with the coolant flow rates, by block and in each coolant channel, and this is done each iteration with modest acceleration (or dampening if found by the monitoring procedure to be necessary). Note that minimizing the peak coolant channel surface temperature by coolant flow block causes the peak surface temperatures to all be the same. This result is not the same as that obtained by minimizing the peak exit coolant temperature by block, programmed as an option. The higher the integral heat source along a coolant flow channel, the more the coolant temperature rises, or the higher the coolant flow rate needed to hold down the coolant temperature. Flow rates are, however, determined by the available pressure differential driving force considering the total flow rate and orificing conditions.

Comments are offered about the flow channel referencing. Note that the more cross-sectional mesh points or associated intervals across the core, the more locations at which the coolant flow is calculated. Increasing the number of axial points refines the calculation but does not change the number of flow channels treated. If there is no heat source along any coolant channel, it is dropped from the calculation direct bypass being disallowed. Should there be locations where trivial power density data are supplied [as the consequence of representing an (n,2n) reaction that does not generate significant power, relative to the fission reaction], then the hydraulics calculation will be distorted and likely desired results will not be obtained. Only primary heat removal is considered; there is no mechanism for explicitly treating secondary heat removal as from the reflector or from control rod channels.

Note that in the calculations the pressure is absolute (atm) and the temperature is absolute ($^{\circ}\text{K}$), but primary results are reported in $^{\circ}\text{C}$.

The pressure drop along each coolant channel is the sum of the components: entrance loss, flow loss, change in elevation, exit loss, and associated orificing drop. The entrance and exit losses for an individual channel are calculated from the equations for the entrance

$$\Delta P = -0.4P_g(1.25 - q) \frac{G^2}{2g\rho} , \quad (1)$$

and for the exit

$$\Delta P = -P_g(1 - q)^2 \frac{G^2}{2g\rho} , \quad (2)$$

where G is the coolant mass flow rate in the channel, ρ is the coolant density, g is the gravitational constant, and ΔP is the pressure change associated with the mechanical energy loss. In these equations q is the fractional area of the coolant hole, i.e., the void fraction. Coefficients P with subscript numbers are set to default values listed elsewhere and may be changed by a user. Note that the calculated pressure drop is directly proportional to the coefficient P_g . Core entrance and exit losses and flow loss in inlet piping are not included, nor is the pressure drop through an open orifice.

The coolant flow loss in pressure is calculated from

$$\Delta P = -\frac{G^2}{g} \left[\Delta V + \frac{Bf\Delta Z}{D\rho} \right] + \rho\Delta Z , \quad (3)$$

which is applied to each finite-difference increment ΔZ in height, the last term being the change in elevation (negative if upflow). ΔP is the pressure change, generally negative. ΔV is the change in velocity. G is the mass flow rate, ρ the coolant density, D the hole diameter (or equivalent hydraulic diameter), and B the coefficient that may be altered, called "BFRIC" in the code and set equal to 2.0 as the default.

The friction factor, f , is calculated locally by solving

$$\frac{1}{\sqrt{f}} = 4.0 \log_{10}(R_r\sqrt{f}) - 0.40 \quad (4)$$

iteratively, where Reynold's number is

$$R_r = \frac{DG}{\mu} , \quad (5)$$

where μ is the viscosity. Note that $G = \rho V$, so for fixed G , $V \propto 1/\rho$ and $1/\rho \propto T$ and the temperature change may be used to calculate ΔV . In the range of $2,000 < R_r < 4,000$, the approximation chosen is

$$f = 0.008 + 0.002(R_e - 2000)/2000 , \quad (6)$$

and for $R_e < 2,000$,

$$f = \frac{16}{R_e} . \quad (7)$$

Should a conservative value for the pressure drop be desired, or should a perturbed solution be of interest, the value of B for Eq. (3) may be specified.

The temperature rise of the coolant is calculated from

$$T_{out} = T_{in} + \frac{Q\Delta Z}{GC_p} , \quad (8)$$

where Q is the local heat rate (power density) and C_p is the coolant specific heat at constant pressure. Properties are calculated at effective interval conditions:

Temperature

$$T_e = T_{in} + 0.75(T_{out} - T_{in}) , \quad (9)$$

Pressure

$$P_e = \max(1.5P_{out} - 0.5P_{in}, 0.9P_{out}) , \quad (10)$$

where the referenced "in" and "out" pressures are for the previous interval along the coolant channel, the average pressure for the first interval being the inlet pressure after any orificing. Note that the coefficients have been chosen to arbitrarily weight the endpoint values to play a smaller and smaller role as the size of discrete intervals is decreased.

Correlations of the properties of the helium coolant are taken from a German report⁵ with flexibility provided in the coefficients for user control.

The estimate of the coolant density for the interval is

$$\rho = \frac{P_1 P_e}{T_e \left[1 + P_2 P_e (T_e)^{-P_3} \right]} , \quad (11)$$

and the estimate of the viscosity is

$$\mu = F_c(T_c)^{F_c}, \quad (12)$$

where the coefficients F with subscript letters are assigned default values shown elsewhere and may be changed by a user.

A change in temperature is associated with coolant orificing,

$$T_{out} = T_{in} \left(\frac{P_{out}}{P_{in}} \right)^{F_t}. \quad (13)$$

The equations used for the calculation of the temperature difference across the film at the coolant channel surface are

$$K = \frac{F_c(T_c)^{(F_c + F_t P_c)}}{F_d(1 + F_t P_c)} \quad (14)$$

and

$$H = (C_p K)^{F_h}, \quad (15)$$

C_p being the specific heat and K the thermal conductivity. A contribution to the film heat transfer coefficient is calculated as

$$S = \begin{cases} 0.01 \left(\frac{100}{R_c} \right)^{0.6} & \text{if } R_c < 2,000, \\ P_d(R_c)^{F_d} & \text{if } R_c > 2,000, \end{cases}$$

and for $2,000 < R_c < 10,000$, an adjustment is made,

$$S' = 0.002 + (S - 0.002) \left(\frac{R_c - 2000}{8000} \right)^{0.5}; \quad (16)$$

and finally the temperature elevation of the surface above the local flowing coolant temperature is

$$\Delta T_s = \frac{QD}{4GC_p SH} \quad (17)$$

User control here is primarily in the coefficients for calculating the film coefficient H .

The Effect of Coolant Channel Size Variation

Let us assume that a calculation has been done for the nominal coolant channel size, a cylindrical hole of diameter D . We expect that these channels will vary in size, and we are interested in what effect a modest variation in D has, $D \pm \epsilon$. It is assumed that the pressure drop is set from the calculated conditions, and we ask for the difference in the surface temperature at any location along the channel,

$$T_s = T_c + \Delta T_s ; \quad (18)$$

$$\delta T_s = \delta T_c + \delta(\Delta T_s) . \quad (19)$$

Using the equations

$$T_c = \frac{1}{GC_p} \int Q(z) dz ,$$

$$\delta T_c = \frac{-\delta G}{G} T_c , \quad (20)$$

and

$$\Delta T_s = \frac{43.5 D^{0.2} \mu^{0.47}}{C_p^{1/3} G^{0.8} K^{2/3}} , \quad (21)$$

we find that a perturbation yields

$$\delta(\Delta T_s) = \Delta T_s \left[\frac{\delta(D^{0.2}/G^{0.8})}{D^{0.2}/G^{0.8}} \right] . \quad (22)$$

And further,

$$\frac{dP}{dz} = \text{constant} = \frac{2Gf}{\rho D} \quad (23)$$

The effect of increased D is to increase G , causing the Reynold's number to increase.

Further assuming that

$$f = 0.076 R_e^{-0.25} ,$$

$$G = \left[\frac{6.58 \rho}{\mu^{.25}} \left(\frac{dP}{dz} \right) \right]^{1.33} D^{1.67} \quad (24)$$

and

$$\frac{\delta G}{G} = \frac{\delta D^{1.67}}{D^{1.67}} \quad (25)$$

we obtain

$$\delta(\Delta T_s) = \Delta T_s D^{1.14} \delta D^{-1.14} \quad (26)$$

Thus the coolant flow rate in a coolant channel having a 10% larger diameter than the nominal might be expected to be higher than the nominal rate by 17%, and the associated coolant temperature rise 11% less, while the temperature drop at the surface would be 11% less. The net effect on the surface temperature then depends on the relative magnitudes of the coolant temperature rise and the surface temperature drop. The dominant effect would naturally seem to come from the larger coolant temperature rise so that usually an increase in D decreases the surface temperature, and a decrease in D increases the surface temperature. Note, however, that the axial locations of the dominant effects can be quite different for the nominal peak, the peak for increased D and the peak for decreased D .

The Solution Procedure

The hydraulics equation is solved in difference form for coolant flow through parallel channels. Desired flow and associated pressure and temperature conditions are effected by

an iterative procedure. The iterate estimates of channel flow rates are moved toward the desired solution with attention given to satisfying equal inlet and outlet pressure conditions after orifice provision, while at the same time adjusting the flow to move the target function (peak outlet coolant temperature, for example) toward a preferred distribution over the coolant orifice blocks. This procedure has grown complicated in detail with all of the possible options. The interested developer, as well as the concerned analyst who cannot get desired results, is referred to the full documentation provided by the Fortran source program listing.

The estimated change in flow rate is made on the basis of the pressure drop being approximately proportional to the square of the flow rate. If the pressure drop is too high for a channel, the flow rate is reduced to satisfy the average within a group of channels having a common blocking for orifice control, and the iteration toward a solution proceeds.

Overrelaxation is done in the sense of

$$G_{j,n} = G_{j,n-1} + \alpha_n(G_{j,n}^* - G_{j,n-1}), \quad (27)$$

where G is the flow rate for channel j and iteration n . G^* is the newly calculated value as indicated by pressure drop and possibly desired temperature conditions. Renormalization is then done after the flow rates are adjusted to effect the desired total and associated average coolant temperature rise for the total heat load. Information about the iterative behavior that has been extracted from a problem is shown in Table 1. λ_T and λ_p are error vector eigenvalue estimates from the results for the temperature and pressure (solution vectors). Acceleration is apparently not very important in this case.

Table 1. Data for Acceleration of the Hydraulic Problem Iteration Process

Fixed Acceleration Coefficient	Iterations	λ_T	λ_p	Max T_c
One Situation				
0.8	8	0.675	0.689	989.9
0.9	8	0.641	0.652	989.8
1.0 ^a	7	0.601	0.619	989.9
1.1	7	0.572	0.591	989.8
1.2	7	0.550	0.563	989.8
1.3	6	0.51	0.53	989.8
Another Situation (axial intervals doubled)				
1.4	6	0.489	0.494	989.8
1.5	6	0.445	0.464	989.8
1.6	6	0.402	0.429	989.8

^aNo acceleration, smaller dampens, larger drives.

The iterative behavior is monitored by obtaining the extreme relative changes:

$$\epsilon_{P,n} = \max_j \left| \frac{P_{o,j,n}}{P_{o,j,n-1}} - 1 \right| ; \quad (28)$$

and

$$\epsilon_{T,n} = \max_j \left| \frac{T_{o,j,n}}{T_{o,j,n-1}} - 1 \right| . \quad (29)$$

These are extreme relative changes in the coolant exit conditions over the channels. In addition, the dominant error vector eigenvalues are estimated from L_1 norms:

$$\lambda_{P,n} = \frac{\sum_j |P_{o,j,n} - P_{o,j,n-1}|}{\sum_j |P_{o,j,n-1} - P_{o,j,n-2}|} ; \quad (30)$$

$$\lambda_{T,n} = \frac{\sum_j |T_{o,j,n} - T_{o,j,n-1}|}{\sum_j |T_{o,j,n-1} - T_{o,j,n-2}|} . \quad (31)$$

The procedure for monitoring the iterative process is rather involved. Basically the conditions are either satisfied for identifying a nonconvergent process (the maximum relative change not decreasing), or the conditions are satisfied for a convergent process (the dominant error vector eigenvalue less than unity). If the maximum relative change is decreasing, the process appears to be converging toward a solution, so this behavior is deemed acceptable. On a set delay cycle the accelerating coefficient α is reduced, if nonconvergent. If convergent, as indicated by successive values of the dominant error vector eigenvalue being nearly the same, the coefficient α is increased, also on a set delay cycle.

Also when α is increased, an asymptotic extrapolation is done. Consider a single error vector contribution,

$$X_n - X_\infty = A\lambda^n , \quad (32)$$

X_n being the estimate of the dependent variable for iteration n , X_∞ the unknown solution, and λ the dominant error vector eigenvalue.

$$X_\infty = X_n + \left(\frac{\lambda}{1-\lambda} \right) (X_n - X_{n-1}) \quad (33)$$

Adding this contribution into the overrelaxation scheme for this one iteration after α is increased, the value of α is changed to

$$\alpha_n^1 = \frac{\alpha_{n-1}}{1 - \lambda_{p,n-1}} \quad (34)$$

using data for the pressure behavior, as is found from Eqs. (27) and (33). Note that the above procedure is rather coarse because renormalization is done after applying the acceleration. (An independent assessment of the dominant error vector after renormalization and asymptotic extrapolation with it might prove to be better.)

It is noted that the problems seem to converge rapidly with the programmed procedure. No difficulty has been found in effecting an acceptable degree of convergence. Those problems treating a lower limit on the orifice pressure drop, solved as a perturbation, converge somewhat slower than the others, and this behavior led to the incorporation of asymptotic extrapolation. It is possible that in some applications a solution will be difficult to effect, inviting modification to the procedures that should not be too difficult given information about the iterative behavior. Also, if the scheme of acceleration proves to be ineffective, the user option to override its use should be exercised.

Regarding Coolant Orificing

Generally when a calculation is done for a coolant orificing condition, simple results are obtained for idealized conditions that could not actually be achieved. Practical considerations include (1) the relationship between fuel temperature peaking and what is measured (the latter likely a sampling that approximates the coolant block coolant exit temperatures), (2) the mechanics of the setting of orifice openings as associated with what is measured, (3) perturbations from calculated and measured conditions, and (4) failures in the sense of inaccurate sensing or setting or decision making. Action will be taken based on the available but incomplete and inaccurate information. There is some likelihood that the action simply is the wrong thing to do, and this likelihood is increased in the case of a remote facility. The probability of excessive fuel temperatures is kept acceptably low through an organized and controlled approach of careful design and operation supported by thorough and accurate analysis of anticipated core conditions. A tool such as this code produces key support information. These results are, however, so idealized and the associated modeling of the reactor operation is so simplified, that caution is certainly in order in the use of the results.

The direct consequences of deviation from idealized orificing is an increase in fuel temperature peaking. Hopefully useful information is generated from results for a perturbed condition of altered orifice resistances that has been implemented in this code. Useful information can also be produced by exercising options when solving more than one problem. At some later date special procedures might be added, as to allow the user to specify coolant flow rates by orificing block, or to specify the orifice pressure drops directly, or to perturb the idealized results in some other way for a subsequent calculation. Certainly the code could be altered to produce special information; this approach is likely the most attractive so that additional information is generated routinely from any application.

It is conceivable that fuel temperature peaking could be measured directly and minimized by regular adjustment of orifices. More likely the less severe choice of measuring coolant exit temperature is more practical than measuring temperatures near the fuel. Association of coolant block exit coolant temperature with block peaking temperatures could be made through calculation, but likely won't be. Instead, the measured approximation of the block coolant exit temperatures would likely be used for setting the orifices. Therefore a calculation effecting equal coolant exit temperatures rather than minimizing surface temperature peaking is likely the most realistic. The additional results that are routinely reported for the perturbed condition of an added resistance where there was none in the ideal orificing condition should be interesting.

Note further that the mechanical orificing requirements are not examined in a calculation, so whether or not the pressure drop requirements that are calculated can be met is subject to further assessment. Of primary concern along this line is likely not the maximum pressure drop required but the range required over the fuel element residence history. The suitable positioning of orifices and the association of coolant channels in the fuel assemblies with individual orifices must be effected by the analyst.

Coolant Bypass Ignored

The bypass of coolant through unfueled regions and hence regions not having a primary heat source is ignored. Note that a temperature adjustment should be made for any bypass allowance.

Let

$$\begin{aligned} q &= \text{fraction coolant bypass,} \\ T_{in} &= \text{coolant inlet temperature,} \\ T_{out} &= \text{coolant exit temperatures,} \\ T_a &= \text{exit temperature of non-bypassed coolant.} \end{aligned}$$

Without refinement, a simple approximation neglecting any heating of the bypass coolant yields

$$T_{out} = (T_a - T_{in})(1 - q) + qT_{in}; \quad (35)$$

$$T_a = \left(\frac{1}{1-q} \right) T_{out} + \left(\frac{1-2q}{1-q} \right) T_{in}. \quad (36)$$

Thus an effective outlet temperature for the thermal hydraulics calculation and reduced flow rate is T_e , higher than T_{out} .

Results from a thermal hydraulics calculation should be interpreted as the reported outlet temperature being T_e , and the true coolant outlet temperature would be given by Eq. 35. Note also that the reported coolant flow rate must be multiplied by $1/(1-q)$ to adjust for the fluid that bypasses the core.

Coolant Crossflow Ignored

Ignoring the crossflow of coolant greatly simplifies the thermal hydraulics calculation. Generally the only significant amount of flow goes in the direction of a negative pressure gradient. With inlet orificing, for example, the flow rate is high where a low pressure drop is taken, presumably to remove more heat and reduce temperature peaking. Flow loss then is from the channels where the flow rate is high with inlet orificing. With outlet orificing, the flow is in the direction of equalizing pressures. Perhaps of most concern is the movement of coolant away from where it is most needed to channels of low resistance, generally decreasing the heat removal efficiency. Although mathematical modeling of such phenomena is perhaps possible, the variables such as manufacturing tolerances and degree of fit of the parts seem to force measurements. Design to cause the construction to force rather well defined coolant channels with constraints of crossflow seems essential unless proven unnecessary. Here the crossflow is ignored.

3. THE THERMAL CELL

The Two-Dimensional Model

A core is divided into zones which then may be subdivided into subzones, and a reference thermal cell calculation is done for each of these. Then the calculations are repeated for estimated extreme conditions at each of these same reference coarse locations. Given average fuel temperatures and extreme fuel temperatures, a distribution of fuel temperatures is estimated by assuming a linear function for the available data at reference points and summing results over all locations. Information is presented here about the thermal cell calculation.

It would seem that the prediction of fuel temperatures would be a simple task given power density data and a reasonable sampling of coolant temperatures. The complications include:

1. the cell geometry involving a fuel channel cylinder and a coolant hole cylinder not modeled at all well with a simple coordinate representation,
2. the need to obtain quite a few solutions to generate a representative fuel temperature distribution at a reasonable computation cost, and
3. dependence of the thermal conductivity on the temperature and high energy flux exposure, and the dependence of the radiation and conduction heat transfer rate across the gap at the edge of the fuel channel on the local temperatures.

Following the procedure originally set up for the pebble fuel element analysis and then adopted for the one-dimensional cell modeling, two two-dimensional cell results are needed for each defined zone of material (and for each subdivided subzone).

An illustration of the thermal cell is shown in Fig. 1. Note that a mesh of (I, J) for $I = 3$ and $J = 4$ is shown, coarse for simplicity. The solid material in the fuel channel extends only to $j = 2$ and two meshpoints locate on the coolant hole surface. As indicated, the meshpoints are located on the outer surfaces and inner interfaces, a mesh edge formulation. As coded, the minimum values of the mesh boundaries are $J = 4$ and $I = 3$ for a coarse model. Default values of the mesh limits are recommended; more could be specified if desired for testing or possibly to generate a more accurate solution if deemed desirable, less if the computation cost were to be held down or if coarser results have been found to be adequate.

Fig. 1. The Thermal Cell with a Minimum Meshpoint Arrangement.

As shown in Fig. 2, an original mesh having a regular layout in $(R\theta)$ geometry about the fuel pin has been skewed in the neighborhood of the coolant hole to accurately represent its effect, and also skewed azimuthally. At the time this is written, a simple scheme of relocating the points was used. Note that with more azimuthal points, the coolant hole surface becomes more populated. In both Figures 1 and 2 the full channel hole size is shown somewhat smaller than is expected to be representative of design.

The thermal cell problem is solution of the equation relating the temperatures to the source with account of the thermal conductivity,

$$-k\nabla^2 T = S, \quad (37)$$

Fig. 2. Illustration of a Coarse-Mesh Thermal Cell.

for the cell geometry done in distorted ($R\theta$) coordinates, where S is the total heat source rate. In these calculations, two values of the heat source are used, one for the fuel channel solid material and the other for the outer matrix defaulted to zero. The imposed boundary conditions are

$$\frac{\partial T}{\partial X_n} = 0, \quad (38)$$

where X_n is normal to the surface, except along the coolant channel surface where the heat flow is governed by

$$q = hA(T_s - T_c), \quad (39)$$

h being the film coefficient, A the normal area, T_s the local surface temperature and T_c the coolant temperature, assumed to be constant. As coded, the average coolant surface temperature is required to equal the value obtained in the hydraulics calculation, the film coefficient is assumed to be constant (not varying with the local coolant hole surface temperature variation, the dependence on the average surface temperature being accounted for in the hydraulics calculation).

After a solution to the thermal cell problem has been obtained, the effects of heat source and surface temperature changes can be predicted relatively accurately for the next problem. It is assumed that an adequate prediction can be made to allow average values of the thermal conductivity to be estimated from the temperature and exposure data for the fuel channel and for the outer graphite block matrix. The correlation used to estimate the thermal conductivity values is described in Ref. 1. Thus two values of the thermal conductivity are estimated and then used for each thermal cell problem.

A simple uniform gap containing coolant is assumed to lie between the solid part of the fuel channel and the surface of the hole. Heat transfer is assumed to be by conduction and radiation, the effective conductance term ($q = hA\Delta t$) being

$$h_g = \frac{K_g}{r_f \ln \left(1 + \frac{a}{r_f} \right)} + 2\sigma\epsilon T_g \left(T_{g1}^2 + T_{g2}^2 \right), \quad (40)$$

where T_{g1} and T_{g2} are the gap surface temperatures, K_g is the coolant conductivity calculated at the gap average temperature and the average core coolant pressure,

$$\bar{T}_g = \frac{1}{2} \left(T_{g1}^2 + T_{g2}^2 \right),$$

a is the gap thickness, σ is the Stefan-Boltzman radiation constant, and the emissivity is combined for the surface,

$$\epsilon = \frac{1}{\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1}.$$

For $\epsilon_1 = 0.9$ and $\epsilon_2 = 0.8$, $\epsilon = 0.735$. Note that the value of h at each meshpoint on the coolant hole surface is recalculated each iteration during solution.

In finite difference form, a thermal heat condition heat balance at steady state yields for the mesh edge location and only "nearest neighbor" coupling,

$$C_{i,j,3}T_{i,j} = S_{i,j} + C_{i,j,2}T_{i+1,j} + C_{i-1,j,2}T_{i-1,j} + C_{i,j,1}T_{i,j+1} + C_{i,j-1,1}T_{i,j-1}$$

and

$$C_{i,j,3} = C_{i,j,2} + C_{i-1,j,2} + C_{i,j,1} + C_{i,j-1,1}. \quad (41)$$

Note that requirements at the surfaces to satisfy boundary conditions must be met, generally $C = 0$ for zero temperature derivative, and of course coupling with the coolant temperature along the coolant channel surface is required to account for heat removal. Thus the transport of heat across the surface normal to a line connecting meshpoints i,j and $i,j+1$ is approximated as

$$kA \frac{\partial T}{\partial r} \approx kA \left[\frac{T_{i,j+1} - T_{i,j}}{r_{j+1} - r_j} \right] . \quad (42)$$

A simplification was made regarding the gap in writing the difference equation. Only radial heat flow is considered within the gap and no source is assigned to it. Leaving out the radial conduction in the gap is justified by the low conductivity relative to that in the graphite. This simplifies the accounting for conductivity dependence on temperature, considering that the equation coefficients involve weighting of the properties of materials that abut at a meshpoint location. There is no mixing of different values. Also only one radial mesh interval is associated with the gap independent of the number of radial intervals to allow account of the radiation and conduction across the gap.

In each iteration the first azimuthal row is treated separately as a special case. At $J = 1$, all meshpoints along i are at the same location, so a simple calculation is done,

$$X = \frac{\sum_i \left(S_{i,1} + C_{i,1,1} T_{i,2}^{n-1} \right)}{\sum_i C_{i,1,1}} , \quad (43)$$

where $n - 1$ refers to the previous iteration, and the result is overrelaxed,

$$Y = T_{i,1}^{n-1} + \beta \left(X - T_{i,1}^{n-1} \right) ,$$

$$T_{i,1}^n = Y , \quad (44)$$

for all i .

The heat balance along the last row, reference J , gives

$$T_{i,J} = \left[\frac{1}{C_{i,J,3}} \right] \left[S_{i,J} + C_{i,J,2} T_{i,J}^n + C_{i-1,J,2} T_{i-1,J}^n + T_c C_{i,J,1} \right] . \quad (45)$$

A heat balance is imposed on the coolant hole surface, $i \leq I_1$, requiring a mean temperature

$$X = \frac{Q - T_c \sum_{i \leq I_1} C_{i,J,1}}{\sum_{i \leq I_1} C_{i,J,1} T'_{i,J}} \quad (46)$$

These surface coefficients are the local area times a constant derived from the known average surface and coolant temperatures.

Line relaxation done along azimuthal rows to solve the tri-diagonal matrix problem, obtaining new temperatures simultaneously along each row, was found to be more cost effective than point relaxation. This calculation is done each iteration with σ (even, odd) ordering for $2 \leq j \leq J$. Initialization involves a forward sweep to obtain new coefficients,

$$B_{i,j} = C_{i,j,2} \left\{ \frac{1.0}{C_{i,j,3} - B_{i,j} C_{i-1,j,2}} \right\}, \quad (47)$$

and to eliminate division during iteration,

$$G_{i,j} = 1/C_{i,j,2}. \quad (48)$$

Excluding the first row, during iteration a forward sweep is done,

$$F_i = S_{i,J} + C_{i,J-1,1} T_{i,J-1}^m + C_{i,J,1} T_{i,J+1}^m + B_{i-1,J} F_{i-1}, \quad (49)$$

the superscript m referring to an iteration count reference on the temperatures and F values being recalculated each iteration. A backward sweep then generates new temperatures

$$T'_{i,J} = B_{i,J} \left\{ T_{i+1,J}^m + G_{i,J} F_i \right\}, \quad (50)$$

and these are overrelaxed,

$$T_{i,J}^m = T_{i,J}^{m-1} + \beta (T'_{i,J} - T_{i,J}^{m-1}), \quad (51)$$

n referring to iteration count. With σ_1 ordering, first the odd rows are treated so that m refers to iteration $n - 1$, and then the even rows where m refers to iteration n for only nearest neighbor coupling. Note that the temperature dependent gap coefficients must be recalculated each iteration and the forward sweep Eq. (49) repeated for the two associated azimuthal rows.

The coding was initially done in IBM single precision, but it was not left that way very long because the reason why an acceptable solution to a problem could not be obtained rapidly by iteration could not be readily identified. Originally values of the coolant surface film coefficient were obtained along the coolant hole surface during the solution process as dependent on the local surface temperature. This procedure was discarded, however, when no significant effect was found. So the burden for establishing the average coolant hole surface temperature was left to the hydraulics calculation.

At this time in the development, the newly calculated coolant hole surface temperatures were renormalized each iteration to the desired average. It was found that this scheme effected a more rapid convergence rate than just applying the pointwise equations of iteration. However it seems that often a false convergence was indicated and the rate of solution was unreasonably slow. The unfavorable behavior was corrected only by obtaining the difference between the iterate estimate of the coolant hole average surface temperature and the proper value, and then adjusting (scaling) all of the cell temperatures to eliminate the defect and fully propagate the correction.

A relatively large number of problems were solved with parameter changes during this development stage to produce supporting information. A simple driver program was used to present a series of problems, typically staging the power density and coolant surface temperature up and then back down. This tested the adequacy of the approximation of the thermal hydraulic prediction, for example. Unfortunately the solutions kept changing with development so the testing results were of much significance only to the development. Objectives of eliminating significant dependence of the results on the starting point and producing acceptable results at a modest computation cost were satisfied.

A good temperature distribution is of course desirable as a starting point. The calculations are done specifically for the surface temperature and power density of the first thermal cell problem. Average fuel and matrix temperatures are first estimated from a simple one-dimensional cylindrical conduction equation solution. Given the coefficients, the discretized radial traverse is solved and skewed slightly as the initial starting place. Rather primitive approximations are used to approximate a two-dimensional solution from one-dimensional data. The major deficiency of a one-dimensional model is the lack of flexibility to represent both the volume involved (two-dimensional area) and the limited coolant hole surface area.

Only two values of the thermal conductivity are used, one for the channel containing fuel and the other for the matrix outside of the fuel channel. Provincial references herein will be made to the former as fuel and the latter as matrix. Each time the equation coupling coefficients are reevaluated for new data, the latest conductivity data are saved. When these change for the next thermal cell problems, the coupling coefficients are simply multiplied by the ratio of the new to the old values.

Given the solution from the previous thermal cell case, the new temperature distribution is estimated for the new power density, the new coolant hole surface temperature, the

thermal conductivity data associated with the new temperatures, and the new gap conditions. For the thermal conductivity data, the effects on the average fuel and matrix temperatures are estimated ignoring the changes in the conductivity data. New thermal conductivity values are then obtained for the new temperatures, and then the calculation is repeated. Then the available temperature distribution is simply proportioned such that the new coolant hole surface temperature is satisfied, and the differences between the local temperature and the average coolant hole surface temperature relative to the old differences are proportional to the ratio of the power density divided by the conductivity,

$$T_m - T_{sm} = [T_o - T_{so}] \left[\frac{P_m}{P_o} \right] \left[\frac{c_o}{c_m} \right], \quad (52)$$

where the subscript *s* refers to the coolant hole surface, the subscript *m* to the modified, and the subscript *o* to the old. The actual calculation is a bit more involved to pick up the differences between the fuel and matrix thermal conductivity ratios, and the effect of changes in the temperatures at the gap are estimated. The calculation proceeds from the coolant hole surface temperature to the average temperature of the matrix, to the new gap surface temperature, through the gap, and to the fuel. Of some surprise to the author, Eq. (52) was found to apply directly to the temperatures along the coolant hole; that is, it did not need the conductivity contribution that would change the proportionality.

For the iterative process, the difference equations are solved to obtain the new temperatures simultaneously along an azimuthal row of points at a nominal radius. The ordering is odd,even (σ_1) and overrelaxation is done. Typically an initial 17×25 mesh problem might require 20-25 iterations, while succeeding ones might average 3 to 8 but depend on how large the power density and the thermal conductivity changes are between cases. The amount of calculation depends on the mesh size and the selected convergence level. Increasing the degree of convergence by a factor of 2 requires at least 4 iterations if the dominant error vector exceeds 0.8, more than at low levels of convergence when the error vectors with the large eigenvalues do not contribute significantly then, as may be the case with good initialization.

A measure of the thermal cell computational burden is reported for each problem. This number is

$$\phi = IJ(M + 10), \quad (53)$$

where *I* is the number of azimuthal points, *J* is the number of radial points (*IJ* is the number of temperature values), and *M* is the sum of the number of iterations done, the problem setup burden being set at the equivalent of 10 iterations. Note that if the calculation were done for twice as many locations, the burden would be nearly twice as great, actually somewhat less since an initial problem will require quite a few more iterations than the successive case.

A large number of problems were solved in testing by indexing up the power density and the coolant hole surface temperature, and then scaling these back down so that pairs of problems were solved with initial conditions approached from opposite directions. Typically the average cell power density started at 2 W/cc and was incremented up to 18 W/cc. In what follows immediately, information is shown that was generated prior to the incorporation of the fuel-matrix gap and hence is free from its effects.

Shown in Table 2 is the variation found in the results associated with varying the convergence criterion. For the first in the series of thermal cell problems being solved, a relative absolute error is estimated as

$$T_{\infty} - T_n = \left(\frac{\gamma}{1-\gamma} \right) (T_n - T_{n-1}), \quad (54)$$

Table 2. The Effect of Specified Convergence Criterion on Thermal Cell Results
(13 × 25 mesh)

Maximum Relative Temperature Change	(Average Iterations, 16 Problems)	Absolute Relative Error ^a Level	Calculated Peak Temperature ^b (°K)			
Power Density (W/cc)			2	10	18	10
Surface Temperature (°K)			440	518.564	605.743	518.564
0.001	2.1	0.0067	454.627	579.267	698.725	577.065
0.005	2.4	0.0066	454.625	577.619	697.558	576.735
0.00025	2.7	0.0066	454.625	577.047	697.188	576.622
0.0001	3.4	0.0033	453.126	576.654	696.896	576.532
0.00005	3.9	0.0019	453.079	576.593	696.871	576.532
0.000025	4.8	0.0009	453.035	576.545	696.825	576.535
0.00001	6.6	0.003	453.017	576.552	696.826	576.537
0.000005	7.9	0.0002	453.008	576.552	696.826	576.537
0.0000025	9.6	0.0001	453.006	576.553	696.831	576.539
0.000001	13.2	0.0001	453.004	576.550	696.832	576.539
0.0000005	20.1	0.0001	453.000	576.545	696.828	576.537

^aNote that 0.001 error level on a result of 500° is an uncertainty of 0.5°, and of 1000° is 1.0°.

^bThese results are from a series of problems run for each convergence level; identical results are expected for the second and fourth cases.

where n refers to the terminating iteration count and γ is the dominant error vector eigenvalue. We expect

$$\gamma = \beta - 1 \quad (55)$$

at optimum overrelaxation, where β is the overrelaxation coefficient, although it is estimated from an L_1 norm,

$$\gamma_n = \frac{\sum_i |T_{i,n} - T_{i,n-1}|}{\sum_i |T_{i,n-1} - T_{i,n-2}|}, \quad (56)$$

where index i is over all of the points. When the convergence criterion is satisfied at termination, we expect

$$\epsilon_T = \max \left[\frac{T_{i,n} - T_{i,n-1}}{T_{i,n-1}} \right] . \quad (57)$$

Therefore

$$\epsilon_{T_\infty} = \left[\frac{T_\infty - T_n}{T_\infty} \right] \approx \left[\frac{T_\infty - T_n}{T_n} \right] \approx \left[\frac{\gamma_n}{1 - \gamma_n} \right] \epsilon_T , \quad (58)$$

ϵ_T being less than the specified convergence at an acceptable termination of the iteration process. Note that increasing the number of meshpoints moves λ toward unity and increases the absolute relative error level relative to a fixed criterion.

Results such as displayed in Table 3 led to the selection of 0.00001 as the default convergence criterion, somewhat smaller than might be expected to be necessary to avoid more iteration error than desirable. It should also be noted that any error associated with the solution for the first problem tends to propagate. With very good initialization we might expect less error than indicated by this theoretical measure. Also the procedures are yet being revised so that any specific data obtained during this testing period can be considered to be accurate only in a relative sense. Thus the result of 454.627 obtained for the first problem at a convergence level of 0.001 compares with an earlier result of 452.466, and another exceeding 456 with initialization at different starting points.

A second solution reliability indicator was found to be needed. As the number of meshpoints is increased beyond reasonably sufficient number, the solution wanders off from an accurate representation. An adequate measure of the discrepancy was found to be the calculated heat flow across the gap between the fuel channel and the matrix. The reference mesh keeps the discrepancy in this quantity to below 0.5 percent. The ratio of the calculated value to what it should be is always calculated, and average and extreme values are obtained and reported. The number reported indicates the discrepancy in a heat balance. This discrepancy is associated primarily with the finite-difference representation. It could be influenced by a low level of solution convergence if a large value for the termination criteria were specified. Note that the heat flow is generally overestimated, causing high temperatures to be predicted, the results being conservative in a sense. (A simple correction might be coded into the procedure to improve the solution, but this possibility has not been investigated.)

Table 3. Dependence of Thermal Cell Results on the Mesh^a

Meshpoints	First Problem Iterations	Apparent Absolute Error	Temperatures (see Table 2)			
9 × 9	12	0.0001	452.845	575.879	695.849	575.872
9 × 13	20	0.0002	452.926	576.197	696.326	576.188
9 × 17	27	0.002	452.950	576.317	696.512	576.310
9 × 21	38	0.005	452.973	576.377	696.604	576.367
9 × 25	42	0.0007	452.979	576.417	696.656	576.409
10 × 10	14	0.0001	452.886	576.070	696.122	576.063
13 × 13	20	0.0001	452.947	576.296	696.448	576.279
13 × 25	41	0.007	453.027	576.565	696.837	576.530
17 × 9	11	0.0001	452.871	575.985	695.991	575.977
17 × 17	26	0.0002	453.017	576.528	696.752	576.445
17 × 25	40	0.008	453.077	576.647	696.967	576.675
17 × 33	61	0.0014	453.111	576.719	697.034	576.675
17 × 49	76	0.0003	453.169	576.802	697.135	576.740
21 × 21	32	0.0004	453.082	576.700	696.986	576.660
25 × 25	37	0.007	453.161	576.799	697.135	576.751
33 × 9	12	0.0001	452.902	576.029	696.039	576.014
33 × 17	25	0.0002	453.169	576.728	696.993	576.685
33 × 65	91	0.0004	453.608	577.423	697.377	577.280
50 × 50	115	0.0004	454.233	578.096	698.990	577.977
50 × 100	154	0.0004	454.762	578.755	699.761	578.473
50 × 150	90	0.0004	457.963	580.728	702.138	579.973
65 × 9	13	0.0001	453.183	576.579	696.800	576.547
65 × 17	25	0.0002	453.782	577.654	698.512	577.584
75 × 75	119	0.0004	456.906	581.436	702.864	581.162
75 × 150	98	0.0004	459.990	584.961	707.838	583.476
100 × 100	173	0.0004	461.988	588.443	710.772	587.422
100 × 150	215	0.0004	463.683	591.506	713.842	589.135

^a0.00002 maximum relative temperature change convergence criterion.

A minimum number of iterations is forced in the first problem to support the evaluation of an optimum overrelaxation coefficient. This procedure is somewhat involved and not particularly interesting to the application analyst for whom this report is written. However there may be some interest in how well the coefficient is resolved, as indicated by the results below, starting with a value of 1.3808, the average between unity and the optimum predicted for an idealized uniform mesh problem, 1.7616:

Iterations	Predicted Optimum
	Overrelaxation Coefficient
16	1.6988
35	1.7242
44	1.7258
52	1.7264

Of course we don't want to use this many iterations unless necessary. The estimate obtained for an idealized problem is quite good and might profitably be used initially; indeed a modified value is currently in use. Complexity in the iterative behavior due to error vector deficiency seriously impacts the evaluation as β becomes large (approaches 2 for a many-point problem). So some degree of conservation has been incorporated into the procedures to avoid difficulty for the hard problem. Additional results are reported later. Also a best guess of the optimum coefficient is used initially.

The utility of setting the overrelaxation coefficient to unity at the first iteration was tested. The argument goes to the effect that if there is a poor initial temperature somewhere, it may be best to recalculate it and propagate the effect of the change but not propagate the effect of the overrelaxed change. Succeeding cases were often solved in one iteration this way, whereas otherwise they would have required 4-6 iterations. Satisfying a specified convergence criterion with and without overrelaxation can result in quite different absolute error levels, so an apparent gain is considered to be illusory. Quite generally, for the first of a series of cases, one more iteration was required to satisfy the convergence criteria with no overrelaxation on the first iteration, and no incentive was found to set it to unity for successive cases. So β is not set to unity at the first iteration.

Selected results are reported in Table 3 to show the dependence of the solution on the number of meshpoints. Of some interest is the reported absolute relative error of the solution for the first problem that seems to increase as the number of points along one coordinate increases relative to the number along the other. Such information has gone into the reference meshpoint choice.

Additional results about the dependence of the results on the mesh are shown in Table 4.

To generate computation burden information, several problems were solved to generate statistically meaningful data. The following results were obtained:

IBM-3033 Computer			
Problems Solved	Meshpoints	Processor Time (min)	Local cost (\$)
500	13 x 25	0.23	2.0
750	13 x 25	0.39	3.8
1000	13 x 25	0.50	4.5
2000	26 x 50	1.01	7.8
125	26 x 50	0.34	3.0
250	26 x 50	0.72	5.1
500	26 x 50	1.38	8.5

Table 4. Additional Results to Show the Dependence on the Mesh*

Mesh	Matrix	Fuel	Peak	Interface Slope $\Delta T/\Delta R$
9 × 9	640.466	684.261	695.849	-141.766
13 × 13	640.823	685.571	696.448	-149.142
17 × 17	641.016	686.115	696.752	-153.298
21 × 21	641.125	686.622	696.986	-155.853
25 × 25	641.194	686.622	697.135	-157.588
50 × 50	641.455	687.784	698.990	-164.031
75 × 75	641.735	689.633	702.864	-170.754
100 × 100	642.258	693.193	710.772	-181.458

*18 W/cc, surface temperature of 605.743 °K.

Note that four times as many meshpoints are treated at an increase in cost of roughly a factor of four. Such results have led to the use of more meshpoints and tighter convergence of the iterative process than might otherwise have been selected as defaults.

Problem solution data are shown in Table 5 for the model before the gap was included, and therefore the fundamental iterative behavior is known theoretically. As the cell problem is made larger in the number of unknowns, it becomes more difficult to solve. It was found that with a reasonable number of meshpoints it was most practical to predict the optimum overrelaxation coefficient initially. Moving toward an optimum from a poor estimate was not found to be easy to do. Results with the fuel-matrix gap included are shown in Table 6 and indicate that the procedures appear to be acceptable. Somewhat improved procedures were adopted to account for the changes from one thermal cell problem to another, as indicated by the reduction in the number of iterations required to solve a succeeding problem, with careful account for the effect of the gap. The gap has temperature-dependent conduction and a small radiation component at this relatively low temperature. Interestingly, the extraction of the largest eigenvalue from a pair (D. Vondy, NS&E 80, 1982) was found to show an advantage without the gap but completely failed when the gap was included.

Evidently an improved estimate of the dominant error vector eigenvalue is needed. Results are shown in Table 7 to indicate some of the testing that was done. Whereas the L_1 norm is the sum of the absolute iterate changes, the L_2 is the square root of the sum of the squares of these changes. It also appeared practical to use both estimates, specifically the square root of their product. Here again primary interest is in solving succeeding problems following the first. (Solution in one iteration is nice, although overrelaxation was not done this first sweep so the results may not be as well converged.) The results shown in Table 8 do not point to an obvious choice. In all of these cases the attempt to extract the larger of a pair of eigenvalues failed, the cause being unknown. Values of the eigenvalue estimates are shown below for the reference mesh (17 × 25) with $\beta = 1.2$:

Table 5. Solution Information for a Small Graphite Thermal Cell Heat Conduction Problem (θR)

Mesh ($\theta \times R$)	Unknowns	Initial Relaxation Coefficient	Was Asymptotic Extrapolation Used*	Iteration First Action Taken	Error Vector Eigenvalue Estimates			Inferred Spectral Radius	New Relaxation Coefficient	Final Relaxation Coefficient	Maximum Relative Temperature Change Last Iteration	Iterations to Solve Problem	Peak Temperature (°K)	Derivative at Fuel Channel Edge (°K/cm)	Iterations to Solve a Next Problem (Power Density Doubled, etc.)
					L_1 Norm	Extracted Largest of a Pair	Associated Eigenvalue Without Acceleration								
8 × 12	96	1.0	Yes	20	0.85660	0.85222	0.85222	0.92316	1.4446	1.4446	4.5-06	22	452.90	-20.24	3
		1.6150 ^a	No							1.7113	1.3-05	13	452.90	-20.24	5
9 × 13	117	1.0	Yes	19	0.89553	0.89568	0.89568	0.94640	1.5117	1.5117	4.6-06	24	452.93	-20.31	3
		1.6461 ^a	No							1.6461	9.3-06	14	452.93	-20.30	4
		1.5897	No							1.5897	8.6-06	12	452.93	-20.32	3
17 × 25	425	1.0	Yes	48	0.96958	0.97038	0.97038	0.98508	1.7063	1.7063	1.8-05	49	453.06	-22.01	5
		1.2	Yes	36	0.95726	0.95810	0.97212	0.98596	1.7138	1.7138	1.1-05	37	453.07	-22.07	4
		1.4	Yes	21	0.93185	0.93595	0.97291	0.98636	1.7173	1.7173	1.7-05	23	453.07	-22.10	4
		1.5	Yes	17	0.91577	0.91815	0.97353	0.98668	1.7201	1.7201	9.6-06	20	453.06	-22.09	4
		1.6	Yes	18	0.88708	0.97359	0.98681	1.7213	1.7213	1.7213	5.9-06	23	453.10	-22.16	5
		1.7	Yes	20	0.77473	0.77654	0.97147	0.98563	1.7110	1.7110	6.7-06	23	453.06	-22.09	4
		1.72	No	End	0.78169	0.89590	0.98517	0.99256		1.7829	3.7-06	23	453.10	-22.16	5
		1.8	No	End						1.7750	2.0-05	24	453.07	-22.12	4
		1.9	No	(24)	1.8550					1.8122	1.8-05	39	453.07	-22.10	6
		1.7973 ^a	No	End						1.8101	2.0-05	22	453.08	-22.15	6
		1.7634	No	End			0.98280	0.99136		1.7683	2.0-05	19	453.07	-22.05	5
							0.96413	0.98190	1.6315	1.8487	1.9-05	101	453.46	-23.72	12
		1.5	No							1.5	2.8-05	61	453.44	-23.58	10
		1.7	Yes	29	0.95467		0.99237	0.99618	1.8393	1.8393	3.8-06	45	453.47	-23.75	12
33 × 49	1,617	1.8	Yes	25	0.93458		0.99364	0.99681	1.8522	1.8522	5.4-06	45	453.47	-23.71	11
		1.85	No							1.85	2.4-06	45	453.48	-23.73	20
		1.9	No	(26)					1.8555	1.8555	8.0-06	45	453.49	-23.74	11
		1.95	No	(23)					1.8574	1.8574	1.9-05	45	453.49	-23.77	12
		1.99	No	(22)						1.8489	1.5-05	71	453.49	-23.67	12
		1.8909 ^a	No	(26)				1.9404		1.8464	1.2-05	39	453.48	-23.68	10
		1.8722	No							1.8722	1.6-05	33	453.51	-23.73	25
		1.0	Yes	19	0.95632	0.96855	0.96855	0.98415	1.6987	1.8942	3.2-07	132	454.46	-25.59	30
		1.5	No							1.5	1.9-05	66	453.91	-25.40	101
49 × 73	3,528	1.9	No	(29)					1.8550	1.8836	4.2-06	66	454.44	-25.56	26
		1.95	No	(20)					1.9025	1.8774	8.9-06	66	454.50	-25.68	33
		1.9254 ^a	No	(28)						1.8791	4.9-06	59	454.49	-25.65	36
		1.9149	Yes	(38)						1.8257	2.0-05	56	454.52	-25.58	31
		1.0	Yes	27	0.97208	0.98067	0.98067	0.99029	1.7559	1.9723	3.6-07	176	455.88	-27.51	58
		1.5	Yes							1.5	1.6-05	74	455.30	-26.72	36
65 × 97	6,305	1.7	Yes	37	0.97247	0.98003	0.99654	0.99827	1.8840	1.9222	1.9-05	89	455.65	-27.23	32
		1.9	No	29	0.94974	0.94995	0.99796	0.99898	1.9135	1.8678	1.7-06	88	455.75	-27.35	45
		1.95	No	(24)						1.8578	1.9-06	88	455.80	-27.46	51
		1.9433 ^a	No	(24)						1.8513	4.1-06	78	455.72	-27.35	38
		1.9334	No	(23)						1.8904	1.0-05	66	455.75	-27.05	35

*Value obtained as optimum for a uniform mesh idealized homogeneous slab problem, and likely this estimate will simply be decreasing somewhat for general use.

Table 6. Solution Information About the Same Cases as Table 5 — But Now with Coolant Gap Treated

Mesh ($\theta \times R$)	Unknowns	Initial Relaxation Coefficient	Was Asymptotic Extrapolation Used?	Iteration First Action Taken	Error Vector Eigenvalue Estimates		Inferred Spectral Radius	New Relaxation Coefficient	Final Relaxation Coefficient	Maximum Relative Temperature Change Last Iteration	Iterations to Solve Problem	Peak Temperature (°K)	Derivative at Fuel Channel Edge (°K/cm)	Iterations to Solve a Next Problem (Power Density Doubled, etc.)		
					L_1 Norm	Extracted Largest of a Pair									Associated Eigenvalue Without Acceleration	
8 × 12	96	1.0	Yes	12	0.86874	0.86874	0.93206	1.4681	1.4681	1.8-05	21	477.254	-39.59	3		
		1.5572	No							1.4-05	13	477.241	-39.58	3		
9 × 13	117	1.0	Yes	12	0.89269	0.89269	0.94482	1.5065	1.5065	8.0-06	22	477.287	-39.60	3		
		1.5897	No							1.1-05	12	477.280	-39.60	4		
17 × 25	425	1.0	Yes	17	0.98191	0.98191	0.99091	1.7629	1.7247	2.7-06	40	477.511	-43.71	5		
		1.2	Yes	15	0.97397	0.98267	0.99129	1.7673	1.7673	1.1-05	31	477.507	-43.67	6		
		1.4	Yes	17	0.94007	0.97463	0.98723	1.7252	1.7252	1.9-05	26	477.549	-43.82	9		
		1.5	Yes	12	0.92347	0.97520	0.98752	1.7279	1.7279	1.8-05	21	477.546	-43.81	9		
		1.6	Yes	15	0.87823	0.97113	0.98567	1.7130	1.7130	1.7-05	23	477.561	-43.84	9		
		1.7	Yes	23	0.81824	0.97411	0.98730	1.7259	1.7259	1.6-05	24	477.531	-43.70	9		
		1.72	No	19				1.8550	1.7241	1.7-05	24	477.557	-43.83	9		
		1.8	No						1.8	1.9-05	24	477.502	-43.65	6		
		1.9	No						1.8122	1.9-05	36	477.496	-43.72	9		
		1.7634	No						1.7634	1.5-05	21	477.517	-43.74	5		
		33 × 49	1,617	1.0	Yes	24	0.95012	0.95013	0.95013	0.97475	1.6349	1.8-05	76	478.440	-46.81	27
				1.5	Yes	28	0.98672		0.99559	0.99779	1.8755	1.8317	1.4-05	49	478.304	-46.39
1.7	Yes			24	0.96574		0.99416	0.99708	1.8580	1.8580	1.8-05	38	478.386	-46.73	23	
1.8	Yes			30	0.92503	0.92504	0.99287	0.99643	1.8443	1.8193	1.8-05	38	478.420	-46.78	27	
1.85	Yes			29	0.87644	0.87751	0.99368	0.99683	1.8527	1.8527	1.8-05	40	478.372	-46.81	22	
1.9	No			27					1.8550	1.8550	1.9-05	38	478.308	-46.301	19	
1.95	No			20					1.9025	1.8574	1.9-05	48	478.320	-46.331	21	
1.99																
1.8722	Yes			31	0.87586	0.87610	0.99534	0.99767	1.8722	1.8722	2.0-05	45	478.355	-46.46	26	
1.0	Yes			23	0.95992		0.95992	0.97976	1.6664	1.9099	3.7-06	112	479.669	-48.55	48	
49 × 73	3,528	1.5	Yes	22	0.94808		0.98301	0.99147	1.7694	1.8899	2.0-05	64	479.783	-48.62	56	
		1.9	No	49					1.8550	1.8550	5.9-06	56	479.686	-48.53	50	
		1.95	No	26					1.9025	1.7849	8.6-06	56	479.622	-48.63	47	
		1.9125	Yes	26	0.92036	0.92039	0.99792	0.99896	1.9128	1.8238	1.9-05	53	479.642	-48.22	41	
		1.0	Yes	26	0.96960	0.96961	0.96961	0.98469	1.7031	1.8513	4.6-05	148	481.568	-50.52	72	
		1.5	Yes	28	0.96693		0.98910	0.99454	1.8109	1.8906	2.0-05	78	481.375	-49.67	57	
		1.7	Yes	29	0.96736		0.99443	0.99721	1.8611	1.8931	9.9-06	74	481.462	-50.18	69	
65 × 97	6,405	1.9	Yes	32	0.92776	0.92777	0.99746	0.99873	1.9040	1.8214	3.5-06	74	481.607	-50.72	85	
		1.95	No	26					1.9025	1.8667	3.5-06	74	481.650	-50.88	80	
		1.9334	No	33					1.8868	1.8441	2.7-06	66	481.612	-50.75	80	

Table 7. Testing Eigenvalue Estimates

Meshpoints	Initial β	Iteration of First Action	Eigenvalue Estimate	μ^2	Apparent Optimum β	Final β	Iterations for Solution	Subsequent Problem	
								Iterations	Final β
(L ₁) Norm Eigenvalue Estimate									
9 × 13	1.0	13	0.89194	0.89194	1.5052	1.5052	22	1	1.5052
17 × 25	1.0	19	0.98362	0.98362	1.7731	1.6977	40	9	1.6977
	1.2	15	0.97400	0.98269	1.7675	1.7675	26	1	1.7675
	1.5	12	0.92303	0.97506	1.7272	1.7272	20	9	1.7272
33 × 49	1.5	31	0.96952	0.98995	1.8177	1.7769	38	28	1.7769
49 × 73	1.5	30	0.97238	0.99088	1.8257	1.8640	56	29	1.8225
(L ₂) Norm Eigenvalue Estimate									
9 × 13	1.0	13	0.89681	0.89681	1.5137	1.5137	22	1	1.5137
17 × 25	1.0	19	0.97971	0.97971	1.7507	1.7131	40	9	1.7131
	1.2	15	0.96831	0.97890	1.7463	1.7463	25	9	1.7463
	1.5	12	0.92211	0.97477	1.7259	1.7259	20	9	1.7259
33 × 49	1.5	28	0.96916	0.98983	1.8168	1.8168	38	22	1.7759
49 × 73	1.5	33	0.97656	0.99225	1.8382	1.7963	56	44	1.8303
(L ₁ , L ₂) Norm Eigenvalue Estimate									
9 × 13	1.0	13	0.89437	0.89437	1.5094	1.5094	22	1	1.5094
17 × 25	1.0	19	0.98167	0.98167	1.7615	1.7234	40	9	1.7234
	1.2	15	0.97115	0.98079	1.7566	1.7566	26	9	1.7566
	1.5	12	0.92257	0.97491	1.7265	1.7265	20	9	1.7265
33 × 44	1.5	31	0.97049	0.99026	1.8204	1.8204	38	28	1.7794
49 × 73	1.5	33	0.97585	0.99202	1.8360	1.7942	56	43	1.8302

Iteration	L_1 Norm	L_2 Norm	L_1, L_2 Norm
10	0.96586	0.95270	0.95926
11	0.96972	0.96176	0.96573
12	0.97284	0.96672	0.96977
13	0.97529	0.96855	0.97191
14	0.97490	0.96938	0.97214
15	0.97400	0.96831	0.97115

In each case the last value was used. Perhaps a better degree of convergence should be effected so that overrelaxation is more nearly optimized.

There is a major difficulty as $\lambda \rightarrow 1$, which occurs as the number of meshpoints in a problem becomes large. The state where successive values are close enough to indicate that resolution is adequate can not be easily established. Apparently tests must be made on $1-\lambda$ to be of significance. It has been found that when the λ_n estimates contain contributions from a pair (λ_1, λ_2) , then $(1-\lambda_n)/(1-\lambda_{n-1})$ tends to remain relatively constant. Use has been made of a test on $(1-\lambda_{n-1})(1-\lambda_{n-2})(1-\lambda_n)^{-2} \approx 1$ and similar techniques with some success.

Table 8. Example Thermal Hydraulics Results

Orificing Block	1	2	3	4
Reference Data				
Relative coolant flow rate	0.98	0.91	1.61	1.93
Coolant exit temperature (°C)	786	738	924	874
Peak surface temperature (°C)	1015	1015	1015	1015
Orifice pressure drop (atm)	0.316	0.334	0.113	0
Perturbed Data (Set Minimum Orifice Pressure Drop)				
Orifice pressure drop (atm)	0.320	0.339	0.114	0.014
Peak surface temperature (°C)	1010	1010	1009	1024
Coolant exit temperature (°C)	784	736	919	881
Relative coolant flow rate	0.99	0.92	1.62	1.91

Results of thermal cell calculations are illustrated by the display in Fig. 3 of the temperatures along a traverse between centers of the fuel channel and the coolant hole. A common coolant hole surface temperature was used in this parametric study showing the dependence of the temperature difference across the gap on the power density without a coolant film effect. Since the heat transfer capability of the gap increases with increase in temperature, the gap contribution tends to be the most significant at low temperature. Of some interest in this area is the requirement for proper account of temperature effects associated with power level changes to predict reactivity response. A usual non-uniform gap would have the effect of skewing the temperature across the fueled channel, but also lowering the peaking somewhat.

Fig. 3. Thermal Cell Results.

A small reactor core was modeled simply with 8 meshpoints (8 coolant channels treated) and 4 zones of different material normal to the direction of coolant flow. With 2 axial zones, thermal cell calculations are performed at 8 reference locations. The average power density was 5.0 W/cc. Results of the hydraulic calculation for a coolant inlet temperature of 350°C and an outlet temperature of 850°C are shown in Table 8. The results with the orificing perturbed are included. The distribution of the fuel temperatures is shown in Table 9 for the reference and perturbed conditions. The perturbation raised the calculated peak fuel temperature from 1144°C to 1152°C. Thus the results for the perturbed state are reported to supplement the reference solution.

Absolute Proof Testing

Lacking a closed solution for even a simple two-dimensional problem, absolute proof testing of these procedures was limited at best. A one-dimensional cylindrical problem that had a uniform source and was homogeneous regarding the thermal conductivity was

Table 9. Fuel Temperature Distribution Results

Reference Temperature (°C)	Fraction Fuel Hotter	
	Reference	Perturbed Orificing
1150		0.0007
1100	0.024	0.024
1050	0.071	0.069
1000	0.127	0.126
950	0.184	0.183
900	0.240	0.239
850	0.297	0.296
800	0.347	0.347
750	0.383	0.384
700	0.415	0.415

approximated. Note that the equations applied are indeed those for a two-dimensional cylinder without the coolant channel. The applicable equations, which are the same equations as used in the initialization procedures with some extension, are as follows:

$$-K\nabla^2 T = q ; \quad (59)$$

$$\frac{1}{r} \frac{dT}{dr} = \frac{-q}{2K} , \text{ constant} . \quad (60)$$

At any radial location

$$T = T_s + \frac{q}{4K} (r_c^2 - r^2) , \quad (61)$$

$$T_{\max} = T_s + \frac{qr_c^2}{4K} , \quad (62)$$

and, obtaining region averages for the fuel and matrix regions and also for the cell,

$$\bar{T}_f = T_s + \frac{q}{qK} \left[2r_c^2 - r_f^2 \right] , \quad (63)$$

$$\bar{T}_m = T_s + \frac{q}{qK} \left[r_c^2 - r_f^2 \right] , \quad (64)$$

$$\bar{T}_c = T_s + \frac{qr_c^2}{qK} . \quad (65)$$

In testing, use is made of the relationship between volume-weighted averages,

$$V_f \bar{T}_f + V_m \bar{T}_m = V_c \bar{T}_c . \quad (66)$$

The slope of the temperature is given by

$$\frac{\partial T}{\partial r} = \frac{-qr}{2K} , \quad (67)$$

checked at the fuel-matrix interface. Note that the slope increases with radius.

Results are displayed in Table 10, along with precise answers. The results are good even with a large number of radial points. The solution rapidly degrades as the number of azimuthal points is increased, the results no longer being acceptable above about 50 points. Apparently the difference representation simply loses accuracy. This discrepancy was later removed by carrying the elemental volumes in higher precision.

Note that the difference error could not be established without an analytic solution. The adequacy of the model for complicated two-dimensional geometry could not be simply established with a very fine meshspacing solution.

The geometric component of the radial coupling coefficient is given by

$$C_r = \frac{\text{Area}}{\text{Distance}} \Big|_r = \left[r + \frac{\Delta r}{2} \right] \frac{\Delta \theta}{\Delta r} = \frac{\pi}{3r_c} \left[\frac{J-1}{I-1} \right] \left[r + \frac{r_c}{2(J-1)} \right] , \quad (68)$$

Table 10. Example Results from a One-Dimensional Simulation
 (A two-dimensional cylindrical sector with uniform azimuthal spacing, fuel channel
 angle $\pi/4$, $T_s = 518.564$, K fixed at 0.18 W/cm 2 -°C-sec, heat source
 12.7324 W/cc, $r_f = 0.25$, $r_s = 1.060660$)

Mesh Azimuthal $\times$ Radial	$\partial T / \partial r$ interface	Temperatures (°K)			
		Peak	Fuel Average	Matrix Average	All Average
Analytic	-8.842	538.458	537.906	527.959	528.511
3 $\times$ 10	-8.683	538.463	537.840	527.900	528.452
3 $\times$ 20	-8.993	538.461	537.895	527.942	528.495
3 $\times$ 40	-8.798	538.422	537.866	527.947	528.500
10 $\times$ 10	-8.784	538.518	537.888	527.909	528.463
10 $\times$ 20	-9.129	538.556	537.963	527.956	528.512
10 $\times$ 40	-9.046	538.650	538.034	527.990	528.548
10 $\times$ 40 ^a	-8.907	538.525	537.935	527.963	528.517
10 $\times$ 80	-8.998	538.533	537.918	527.939	528.493
10 $\times$ 120	-9.029	538.515	537.896	527.948	528.501
20 $\times$ 20	-9.178	538.555	537.972	527.957	528.513
20 $\times$ 40	-9.147	538.629	538.009	527.966	528.524
20 $\times$ 80	-8.913	538.559	537.952	527.979	528.533
20 $\times$ 120	-8.844	538.556	537.943	527.961	528.515
40 $\times$ 40	-10.900	539.442	538.616	528.054	528.641
40 $\times$ 80	-10.065	539.308	538.208	527.962	528.531
40 $\times$ 120	-9.511	539.341	538.092	527.957	528.520
80 $\times$ 40	-29.702	554.513	546.580	529.193	530.159
80 $\times$ 80	-34.476	559.391	547.291	529.128	530.137
80 $\times$ 120	-34.539	561.999	547.387	529.085	530.102
100 $\times$ 100	-32.032	554.286	546.198	529.058	530.010
100 $\times$ 100 ^b	-32.226	554.482	546.373	529.105	530.064

^aSolution approached from different initial conditions.

^bVery tight convergence effected, $E_r = 10^{-7}$ compared to 5×10^{-5} for other cases.

assuming a fuel channel angle of $\pi/3$, where I is the number of azimuthal points and J the number of radial points. Similarly for the azimuthal coefficient,

$$C_\theta = \frac{\text{Area}}{\text{Distance}} \bigg|_\theta = \frac{2\pi r \Delta r}{r \Delta \theta} = 6r_c \left(\frac{I-1}{J-1} \right). \quad (69)$$

Apparently the coefficient C_θ overwhelms C_r for I large and especially for r small near the center of the fuel channel. Note that C_r might tend to overwhelm C_θ for $J \gg I$. For r , near unity we might prefer, at say $r = 1/3$, that $C_r \approx C_\theta$, requiring

$$\left(\frac{J-1}{I-1}\right)^2 \approx 2$$

or

$$J \approx 1 + (I - 1) \sqrt{2} . \quad (70)$$

More Effective Acceleration

As this report is being completed, alternative acceleration schemes are being tested to develop a more effective procedure. Justification for this effort is largely from the need in neutronics applications, inner iteration of the diffusion model of neutron transport and acceleration of the discrete ordinates model. A multigrid procedure⁶ has been coded and is being tested, the details of which will be reported elsewhere. The process involves collapsing the current estimate of the temperature and the coupling coefficients to a coarser mesh for further iteration to reduce the error content. This technique is continued through coarser levels to a very coarse mesh for which a direct solution can be obtained (when needed), and then the calculational procedure passes back down the levels to the original problem. Thus the local inaccuracies are reduced at each grid level, the global discrepancy being reduced at the coarsest level. Of special interest is the insensitivity of the rate of convergence to the acceleration parameters. Solid information about the details of an effective scheme applied to a non-linear problem is scarce, so extensive testing is necessary. An example calculation is illustrated below as extracted for a thermal cell problem:

Level	Mesh ($\theta \times R$)	Iterations	Largest adjusting factors	Maximum temperature change
0	15 × 27	3		2.86-4
1	8 × 13	3	1.00044	
2	4 × 6	3	1.00011	
3*	2 × 3	0	1.00069	
2	4 × 6	3	1.00106	
1	8 × 13	5	1.00189	
2	4 × 6	3	1.00007	
3	2 × 3	0	1.00010	
2	4 × 6	2	1.00018	
1	8 × 13	2	1.00214	
0	15 × 27	3		7.75-5
1	8 × 13	3	1.00015	
2	4 × 6	3	1.00011	
3	2 × 3	0	1.00026	
2	4 × 6	2	1.00042	
1	8 × 13	4	1.00074	
0	15 × 27	3		3.56-5

*At this level the solution is obtained directly.

Significantly different results are being obtained with the multigrid scheme, and this remains to be understood. Also the procedure seems to be ineffective at higher convergence levels, also not understood. As much as half of the computation cost has, however, been found to be eliminated on an initial, very large problem. Of some interest is the rapid rate of suppression of the error vectors that dominate initially by using a much smaller overrelaxation coefficient than would be the optimum for straight overrelaxation. A rather frustrating aspect to the author has been the generally ineffectiveness of modifications intended to improve the procedure.

The One-Dimensional Cell Model

As an option, a simple one-dimensional model is applied with the fuel channel at the center, having the cylindrical coordinate. An effective outer radius, the distance to where the coolant is assumed to be located for heat removal in the simple model, must be specified. Likely this distance lies between the minimum distance to the coolant, $\ell - r_c$, and the characteristic cell dimension ℓ . Equations 59-67 would apply if the thermal conductivity were constant. Of course the heat source is concentrated in the fuel channel, and provision is made for the thermal conductivity to depend on the past exposure and local temperature, so a difference formulation is used to produce the results.

An aspect of some interest is the direct dependence of the temperature on the heat source, Eq. (59). Increasing the local heat source rate increases the fuel temperature. Generally the peak temperature in the fuel occurs where there is both a high power density and a high coolant temperature. The local heat source adds an incremental temperature rise above the local surface temperature which is elevated from the coolant temperature. Concentrating the heat source in a smaller fuel channel at a fixed average power density increases the fuel temperature, since q of Eq. (59) is increased.

Some uncertainty is associated with the thermal conductivity K , leading to uncertainty in the temperature. With high exposure to high energy neutrons comes atomic displacement and degradation in K . Indeed, cracks in an atomic lattice dramatically alter the ability to transport heat, causing local temperature peaking, although the heat removal capability in the aggregate is not entirely lost. Note that the temperature rise is inversely proportional to the conductivity and that a 10% decrease in K causes the temperature difference to rise 11%.

A one-dimensional model tends to underestimate the temperature variation and hence underestimate peaking in the fuel. This is because a cell of the desired size has too large an outer surface for heat removal to the coolant. Perhaps a surface area correction factor should be allowed, but instead the two-dimensional capability is recommended. Also the model was left simple without incorporating the fuel-matrix gap effect. The local conductivity is calculated at each meshpoint rather than use averages as is done for the two-dimensional model.

Note About the Cost of Cell Calculations

Full core calculations have been done that required 5,400 cell problem solutions for one case. These computer calculations cost so much that some scheme is probably needed to make only a few representative cell calculations and parameterize the effects on the results of the primary variables.

Effects of Thermal Cell Approximations

No reasonable way was found to account for such things as variation in the gap between the fueled channel and the matrix. When the gap is narrow, the direct effect of eccentricity is lower temperature in the fuel due to reduced resistance to heat conductivity. Consider a straight gap of arbitrary length with linear variation in the width and fixed temperature on the side of heat extraction.

For the purpose of investigation, assume a linear variation in the thickness of a straight gap and in the temperature along the side from which heat is removed:

$$q = \frac{h}{\Delta} (T_2 - T_1) ,$$

$$h = c [T_2(x) + T_1]^s ,$$

$$\Delta = a + bx ,$$

$$T_2 = e - fx ,$$

$$Q = \int_0^L q dx = \int_0^L \frac{C dx [e - fx + T_1]^s [e - fx - T_1]}{(a + bx)} .$$

Assuming an effective temperature and effective gap width,

$$Q = \frac{h_e}{\Delta_e} (T_e - T_1) = \frac{CL}{\Delta_e} [T_e + T_1]^s [T_e - T_1] .$$

Requiring

$$T_e = \bar{T}_2(x) = e - \frac{fL}{2},$$

$$\Delta_e = \frac{L \left[e - \frac{fL}{2} + T_1 \right]^s \left[e - \frac{fL}{2} - T_1 \right]}{\int_0^L \frac{dx}{(a+bx)} [e - fx + T_1]^s [e - fx - T_1]}.$$

Letting

$$p = \frac{f}{e + T_1}, \quad q = \frac{f}{e - T_1}, \quad s = \frac{b}{a},$$

$$\frac{\Delta_e}{\Delta} = \frac{L \left[1 - \frac{pL}{2} \right]^s \left[1 - \frac{qL}{2} \right]}{\left(1 + \frac{sL}{2} \right) \int_0^L \frac{dx}{(1+sx)} \left[1 - \frac{px}{2} \right]^s [1 - qx]}.$$

Thus a situation can be examined. Since the rate of decrease of the ratio of the numerators to the denominator of the integral grows as x increases (like a cubic with negative coefficients), the effective gap width is somewhat larger than the average. Eccentricity of a cylinder in a cylindrical hole causes even more distortion of this sort in the same direction.

Temperature variation occurs across the fuel assemblies. The power density variation is one cause that may or may not adequately be accounted for, depending on the mesh spacing, on the degree to which variations in the nuclide densities are treated, and on the fine-scale geometric detail, including control rod holes likely not modeled. Decreasing the meshspacing tests for better account of the spacial flux distribution. Perhaps of most concern in this area is an accurate accounting of the peaking near the reflectors, which would require the use of more meshpoints than desired for economic calculations. Reducing the size of the zones of homogeneous material picks up the effects of nuclide changes with exposure. Of course the more accurately the geometry is represented and the better the fuel loading and control and burnable poison are modeled, the more accurate are the results and the less concern there is about uncertainty. Heat conduction occurring across the fuel elements is ignored and has the primary effect of mitigating temperature peaking. Likely this makes up only part of the causes for the modeling to underestimate temperature peaking.

Regarding other approximations, the gross effect is not clear. The assumption that a single representative thermal cell geometry is adequate may or may not be reliable. Certainly there are places where this model is not representative. The use of only two thermal conductivity values over each cell, and these being predicted values, is not precise. Still the calculations should suffice for usual core analysis.

4. CERTAIN APPLICATION SUPPORT INFORMATION

Data Handling

The geometric description including the arrangement of meshpoints for discretization is obtained from the geometry description supplied to the neutronics code, interface data file GEODST. The heat source information is normally obtained from the point power density file PWDINT. If this file is not available, the zone or zone and subzone average values are redistributed using data from file ZNPOWD. Data from this latter file are normally used for the thermal cell calculation when there is the subscale information about subzones. Lacking subzones, these data are generally not available. If file ZNPOWD does not exist, zone average data are collected from the PWDINT file data. If the void fraction is to be varied, then the ZNPOWD file must be supplied and indeed be written by the exposure code where such information is added to the file. The neutronics code can only put zone power density data on this file, not subzone data also. Note that when files are supplied from both the neutronics and the exposure codes, the data may be somewhat inconsistent, being generated by different procedures and associated with somewhat different points in time. Power density peaking and associated fuel temperature extremes tend to occur initially and mitigate with time, but the situation is complicated by partial refueling, control rod positioning, and the zoning of fuel enrichment, along with the use of burnable poison. Exposure data are obtained from the file EXPOHT.

User instructions to this code are obtained from the PBLINS record of the file CONTRL shown in Fig. 4. The input processor can be used to add this information from the user input data stream to an existing file, but in more common practice is the use of the special input processor identified as DUTLIN with a module type 2 access, and often several of these types of computational module control records are supplied at one time. Any change requires another access.

Provision has been made to supply certain special data. This is done with a interface data file named THDATA. The input data processor is used to generate this file one-to-one from data in the user input data stream. The contents of this file are shown in Fig. 5. Perhaps of most interest is the capability to provide special blocking information (5D Record) to associate meshpoint intervals with coolant orificing.

By user instruction the temperature results are put on the file ZNTEMP described in Fig. 6. These data may then be used in the calculation of macroscopic cross sections to apply microscopic cross section correlations at the zone and subzone level for temperature feedback. The user may find that for regions outside of the core proper there is inadequate control over the temperature assignments, requiring processing before use. Such processing may be done with a special code module processor or the data edited and revised by terminal display or even cards.

```

C-----
C
CR      THR-TH THERMAL HYDRAULICS MODULE INSTRUCTIONS, FILE 'CONTRL'
C
CM      (THERMAL PRISMATIC FIXED BED OR PEBBLE BED)
C
CM      DATE OF THESE INSTRUCTIONS --    AUGUST, 1983 -- D VONDY, ORNL
C
CL      PBLINS, (XX(I),I=1,100), (IX(I),I=1,100)
C
CW      101*MULT + 100
C
CM      FOR SLAB (X) AND CYLINDRICAL (RZ) GEOMETRY (FROM THE 'GEODST'
CM      FILE) THIS CODE ASSUMES SPHERICAL PEBBLE FUEL ELEMENTS RANDOMLY
CM      PACKED IN A BED THAT ARE PUSHED OR GRAVITY FLOW THROUGH CAUSING
CM      INCREASING EXPOSURE ALONG THE PATH AND THE CONSEQUENCES THEREOF
CM      UNLESS IX(2) IS NEGATIVE. OTHERWISE THERE ARE PARALLEL
CM      COOLANT CHANNELS (CYLINDRICAL HOLES) EFFECTING 1-D FLOW THROUGH
CM      WHAT IS USUALLY A 3-D PRISMATIC FIXED BED CORE.
C
CM      AS A PROBLEM IS DESCRIBED FOR THE NEUTRONICS CODE, THE COOLANT
CM      FLOW IS LEFT TO FIGHT 1-D, TOP TO BOTTOM 2-D, OR FRONT TO BACK
CM      3-D, DEFAULTED DOWNFLOW. THE FLOW DIRECTION MAY BE REVERSED IN
CM      THE CASE OF THE FIXED BED, BUT NOT FOR THE PEBBLE BED -- SO
CM      TO REVERSE IT IN THIS CASE, THE GEOMETRY DESCRIPTION MUST BE
CM      INVERTED WITH ZONE NUMBERS REASSIGNED TO FOLLOW PEBBLE ROUTES.
C
CM      HYDRAULICS IS DONE ON A ZONE LEVEL, SO SUBZONES CONTAINED IN
CM      ZONES ADMIT A SUBLEVEL TEMPERATURE ANALYSIS (CORRESPONDING TO
CM      A FINE SCALE FUEL ACCOUNTING IGNORED BY THE NEUTRONICS).
C
CM*     * PLACED IN COLUMN 3 INDICATES DATA USUALLY REQUIRED
CNS$    $ IS A FLAG INDICATING NEEDED FIXED BED DATA
CCOX    LINE HEADER SHOWING PEBBLE/FIXED DATA REQUIREMENT BLOCKS/SKIPS
CCOXO   START HERE FOR PEBBLE/FIXED BED DATA
C
CD      PBLINS   THR-TH THERMAL HYDRAULICS DATA IDENTIFIER (6HPBLINS)
C
CD      XX(1)    VOID FRACTION IF TO BE CONSTANT, SEE IX(18) OPTIONS
CD              (DEFAULT VALUE 0.39 LACKING OTHER DATA - THE ZONE
CD              FRACTIONS MAY BE USED AS SOLID FRACTIONS IF .02 < X < .98)
C
CM      NORMALLY THE VOID FRACTION IS CALCULATED DIRECTLY AS THE
CM      REMAINDER FROM THE GEOMETRY DATA ADMITTING SPACIAL VARIATION
CM      OVER THE MESH: 1 MINUS ZONE OR SUM SUBZONE VOLUME FRACTIONS.
C
CM      CARE MUST BE TAKEN IN ASSIGNING NUCLIDE CONCENTRATIONS AND
CM      VOID FRACTIONS TO EFFECT ACCURATE MODELING (THE COOLANT HOLE
CM      DENSITY IS ESTABLISHED BY THE VOID FRACTION IN THE FIXED BED).
CD*     XX(2)    INLET TEMPERATURE OF COOLANT, DEG C (DEFAULT 350.35)
CD*     XX(3)    INLET PRESSURE OF COOLANT, ATM (DEFAULT 40)
CD      XX(4)    COOLANT MASS FLOW RATE FOR CORE PROBLEM (KG/SEC)
CM              CALCULATED FOR HEAT REMOVAL GIVEN TEMPERATURES, LEAVE OUT
CD*     XX(5)    PEBBLE DIAMETER OR COOLANT HOLE DIAMETER, CM
CM              THIS IS THE CHARACTERISTIC COOLANT FLOW DIAMETER
CD      XX(6)    REFERENCE HIGH ENERGY NEUTRON FLUX FLUENCE, N/CM**2
CD              APPLIED ONLY IF IX(3) < 0
C              (CON'T)

```

Fig. 4. User Input Data for Thermal Hydraulics Problem Control CONTRL (Interface Data File Specifications).

```

C
CD XX(7) RECOVERABLE ENERGY FRACTION (DEFAULT 1.0)
C
CN IF NEGATIVE, USED AS A POWER DENSITY PEAKING FACTOR
CN (RELATIVE TO ZONE POWER DENSITY) OVERRIDING USE OF THE
CN POINT OR ZONE PEAK DATA. A VALUE SHOULD BE SUPPLIED WHEN
CN THE DATA IS INADEQUATE TO FURNISH FULL PEAKING INFORMATION
CN (POINT DATA FROM A 1-D CASE IS INADEQUATE, FOR EXAMPLE).
CD XX(8) REACTOR POWER LEVEL DESIRED, W-TH
CN OBTAINED FROM THE HEAT SOURCE (POWER DENSITY) DATA, LEAVE OUT
CN UNLESS SOME CHANGE FROM THE REFERENCE IS DESIRED
CD$ XX(9) CHARACTERISTIC THERMAL CELL DIMENSION, SET = IX(5) IF 0
CD$ CENTER FUEL CHANNEL TO CENTER COOLANT HOLE 2-D (CM)
CD DIAMETER FOR 1-D (CM)
CD* XX(10) RADIUS OF THE ZONE HEAT (FUELED INNER REGION, CM)
CD FOR 1-D FUEL ELEMENT THERMAL CELL PROBLEM
CN RADIUS IS HALF THE DIAMETER!
CD* XX(11) RADIUS OF THE SUBZONE HEAT (FUELED INNER REGION, CM)
CD* XX(12) OUTLET TEMPERATURE OF COOLANT, DEG C (DEFAULT 850.35 IF
CD XX(4)=0), NOT USED IF XX(4) IS NON-ZERO
CD XX(13) RELATIVE FLUENCE, MULTIPLIES SUPPLIED DATA (DEFAULT 1.0)
CD XX(14) RELATIVE PEBBLE GRAPHITE THERMAL CONDUCTIVITY,
CD MULTIPLIER ON THE BUILT-IN OR SUPPLIED DATA (DEFAULT 1.0)
CD XX(15) ITERATION CONVERGENCE CRITERIA, MAXIMUM RELATIVE ITERATE
CD CHANGE FOR TERMINATION (DEFAULT 0.00005)
C
CN THE FIXED BED PRESSURE DROP CONVERGENCE LEVEL IS TEN TIMES THIS
CN WHILE THE FIXED BED THERMAL CELL IS ONE-FIFTH
C
CCOX1 GO TO CCOX4 FOR PEBBLE BED
CCOX2 CONTINUE FOR FIXED BED WITH PARALLEL COOLANT CHANNELS
CD XX(16) AXIAL HEIGHT (CM) FOR EXPANDING 1-D OR 2-D GEOMETRY
C
CN DO NOT SUPPLY IF THE NEUTRONICS CASE IS 3-D OR (FZ)
CD XX(17) AXIAL POWER DISTRIBUTION FACTOR, NO MEANING IF IX(16) = 0
CD AXIAL SINE FUNCTION DISPLACEMENT IF IX(16) = 1
CD AXIAL DISTRIBUTION DATA IF IX(16) = 2
C
CN THE DATA IS ALWAYS NORMALIZED TO UNITY BY THE CODE
CD XX(18) AXIAL SINE FUNCTION SKEW IF IX(16) = 1
CD XX(19-29) RESERVED
C
CCOX3 GO TO CCOX5 FOR FIXED BED
CCOX4 CONTINUE FOR PEBBLE BED
CN APPLY THE FOLLOWING BLOCKED FLOW AREA OPTION WITH CAUTION.
CD XX(16) INSIDE RADIUS OF BLOCKAGE (MUST BE 0 TO BE REALISTIC), CM
CD XX(17) OUTSIDE RADIUS OF BLOCKAGE, CM
CD XX(18) DISTANCE BLOCKAGE STARTS FROM COOLANT INLET, CM
CD XX(19) HEIGHT OF BLOCKAGE, CM
CD XX(20) SOLID BLOCKAGE FRACTION (DEFAULT 0.85 -- USE LARGE VALUES
CD WITH DISCRETION)
C
CN DATA TO DEFINE THE CORE BOUNDARIES FOLLOW -- HOWEVER THIS DATA
CN IS USUALLY NOT INPUT AND THE CODE DETERMINES WHERE THERE IS A
CN SOURCE OF HEAT TO OUTLINE THE CORE.
CD XX(21) INSIDE RADIUS OF CORE, CM (NORMALLY ZERO)
CD XX(22) OUTSIDE RADIUS OF CORE, CM
CD XX(23) DISTANCE FROM BOUNDARY, CM (FROM LEFT 1-D, FROM TOP 2-D)
CD XX(24) HEIGHT OF CORE, CM
CD XX(25) LIMITING PROCESSOR TIME, SECONDS (DEFAULT 120)
C (CONT)

```

Fig. 4. (Continued)

```

C
CN      INITIAL ACCELERATION COEFFICIENTS ARE MADE PROBLEM DEPENDENT
CN      AND MAY BE ALTERED DURING THE PROBLEM SOLUTION IF DEEMED TO BE
CN      DESIRABLE BY THE AUTOMATED MONITORING PROCEDURES.
CN      THE ROUGH ITERATIVE BEHAVIOR EARLY IN HISTORY MAY CAUSE THE
CN      INITIAL COEFFICIENTS TO BE REDUCED, SO SOMEWHAT LARGER VALUES
CN      THAN OPTIMUM ASYMPTOTICALLY MAY BE PREFERABLE INITIALLY.
CD      XX(26)  STREAM FUNCTION OVERRELAXATION COEFFICIENT
CD      XX(27)  BULK TEMPERATURE, DITTO
C
CN      THE RATE OF CONVERGENCE MAY BE VERY DEPENDENT ON THE VALUE OF
CN      THIS COEFFICIENT, SO PROVIDE A TESTED VALUE FOR A SIMILAR CASE
CN      (SMALLER FOR CENTRAL DIFFERENCE THAN UPWIND)
CD      XX(28)  SURFACE TEMPERATURE, DITTO
CN      A VALUE OTHER THAN UNITY LIKELY WILL NOT PROVE EFFECTIVE HERE
CD      XX(29)  PRESSURE, DITTO
C
CCOXS  CONTINUE
CD      XX(30)  SPECIFIC HEAT VALUE (5193.)
C
CN      DATA CHANGES FOR ONE OR TWO SUBSEQUENT CASES DONE IF NONZERO
CD      XX(31)  NEW INLET COOLANT TEMPERATURE, DEG C (DEFAULT XX(2))
CD      XX(32)  NEW OUTLET COOLANT TEMPERATURE, DEG C (DEFAULT XX(12))
CD      XX(33)  RELATIVE POWER LEVEL FOR SUBSEQUENT CALCULATION
CD      THIS MAY BE MADE NEGATIVE (EVEN IF UNITY IS DESIRED) TO
CD      FIX THE ORIFICE RESISTANCES AT RESULTS FOR FIRST CASE
CD      XX(34)  NEW INLET COOLANT TEMPERATURE, DEG C (DEFAULT XX(31))
CD      XX(35)  NEW OUTLET COOLANT TEMPERATURE, DEG C (DEFAULT XX(32))
CD      XX(36)  RELATIVE POWER LEVEL FOR THIRD CASE (DEFAULT XX(33))
CD      (Relative to the Initial Case)
CN      EQUATION COEFFICIENTS AND DATA FOLLOW
CD      XX(37)  MOLECULAR WEIGHT (4.0026)
CD      XX(38)  AZERO (0.0216)
CD      XX(39)  AGAS (0.49849)
CD      XX(40)  B (0.)
CD      XX(41)  C (40.)
CD      XX(42)  RGAS (0.08206)
CD      XX(43)  DZERO (0.014)
CD      XX(44)  PCONA (17.)
CD      XX(45)  PCONB (20.5)
CD      XX(46)  PCONC (-15.37)
CD      XX(47)  BETAK (0.95)
CD      XX(48)  GAMMAK (2./3. SPHERE, PI/4. CYLINDER)
CD      XX(49)  PC (3.674E-07)
CD      XX(50)  PD (0.7)
CD      XX(51)  PE (0.71)
CD      XX(52)  PF (2.682E-03)
CD      XX(53)  PG (0.0011379)
CD      XX(54)  PH (1.4389E-4)
CD      XX(55)  AFRIC (4.1666)  HYDRAULIC EQUATION, FIRST COEFFICIENT
CD      XX(56)  BFRIC (.1754, 2.0 IF XX(13) > 0)
CD      XX(57)  P1 (2.2679E-07, FOR FIXED BED 48.14)
CD      XX(58)  P2 (3.0, FOR FIXED BED 0.4446)
CD      XX(59)  P3 (0.1293, FOR FIXED BED 1.2)
CD      XX(60)  P4 (.3292, FOR FIXED BED 0.022)
CD      XX(61)  P5 (.277, FOR FIXED BED -0.2)
CD      XX(62)  P6 (.2426, FOR FIXED BED -2/3)
CD      XX(63)  P7 (.26, FOR FIXED BED 0.4)
CD      XX(64)  P8 (.476, FOR FIXED BED 1.0)
CD      XX(65)  P9 (.41)
C

```

(CON'T)

Fig. 4. (Continued)

```

C
CD XX(66) PW (1.176E-04)
CD XX(67) P11 (311.)
CD XX(68) FOR ONE-DIMENSIONAL CALCULATIONS, RADIAL PEAKING FACTOR
CD FOR AUXILIARY CALCULATION (DEFAULT 1.2)
CD XX(69) P13 (.005)
CD XX(70) P14 (2., FOR FIXED BED OR IF IX(13) > 0 0.04)
CD XX(71) - XX(83) REFERENCE THERMAL CONDUCTIVITY DATA
CD USED IF XX(71) .NE. 0
C
CN AT NO EXPOSURE, CORRESPONDING TO TEMPERATURES (K) --
CN 300. 350. 400. 500. 600. 700. 800. 900. 1000. 1100. 1200. 1300. 1600.
CN REFERENCE POINT C(2) AT T = 350. IS 1.05 WATTS/CM-DEG DELTA T.
CN TO CONVERT CM-CAL TO WATT-SEC, MULTIPLY BY 4.186
CD XX(84) P15 (0.1905, FOR FIXED BED OR IF IX(13) > 0 0.023)
CD XX(85) P16 (2./3., FOR FIXED BED OR IF IX(13) > 0 0.8)
CD XX(86) EOVR (0.1*DIAMETER OF PEBBLE)
CD XX(87) EOVA (0.5*DIAMETER OF PEBBLE)
CD XX(88) - XX(100) RESERVED
C
CD IX(1) OPTION ON FLUID FLOW GRAVITY TERM
CD -1 NO GRAVITY TERM
CD 0- COOLANT FLOW VERTICALLY DOWNWARD
CD 1- COOLANT FLOW VERTICALLY UPWARD
C
CCOX6 GO TO CCOX9 FOR PEBBLE BED
CCOX7 CONTINUE FOR FIXED BED
CD IX(2) FIXED BED MODEL FORCING OPTION
C
CN MUST BE NEGATIVE TO FORCE THE MODEL OF HOLES IN A SOLID
CN LATTICE FOR (X) SLAB 1-D OR (RZ) 2-D GEOMETRIES
CN (OTHERWISE THE CODE ASSUMES PEBBLE BED)
CD$ IX(3) OPTION ON FLUENCE, <0- DONT READ DATA (SEE XX(6))
CD 0, 1- 'CPHIST' FILE, CONTINUOUS FUELING
CN NOTE THAT THIS FLAG MUST BE SET FOR FIXED FUEL EXPOSURE
CD 2- 'EXPOHT' FILE, FIXED FUEL EXPOSURE
CD IX(4) FLUENCE SELECTION, 0, 1- USE FIRST RANGE IF AVAILABLE
CD 2- USE SECOND RANGE IF AVAILABLE
CD 3- USE TOTAL IF IT IS AVAILABLE
C
CN IF DESIRED DATA IS NOT AVAILABLE, NO DATA IS USED.
CN DATA FOR ONLY THE HIGH ENERGY FLUX MUST NORMALLY BE SUPPLIED
CD IX(5) MEMORY AVAILABLE FOR DATA IN 1000 WORDS
CD (DEFAULT 20000 ADDED TO RECORD 'DRVINS' CONTENT
CD WHICH IS THE NUMBER SUPPLIED TO THE CONTROL MODULE)
CN UNDER VIRTUAL MEMORY, ASSUME FULL CORE CONTAINED
CN AND ALLOCATE SPACE ACCORDINGLY
CD IX(6) REVERSE COOLANT FLOW DIRECTION IF > 0
CD IX(7) DEBUG EDIT LEVEL (0,1,2,3)
CD IX(8) EDIT LEVEL OF RESULTS
CD$ IX(9) OPTIONS ON THE CONTROL OF FLUID FLOW
CD 0- SET TO REMOVE HEAT FOR EACH PATH (IDEAL POINTWISE ORIFICING)
CD 1- SET TO REMOVE HEAT BY BLOCKS OF POINTS (ZONE ORIFICING)
CD 2- PREDEFINED BLOCKING OF POINTS FOR ORIFICING
CD (TO BE IMPLEMENTED, REQUIRES AN ADDITIONAL DATA FILE)
CD 3- ALLOW FLOW FOR THE PRESSURE DROP (NO ORIFICING)
CD 4- SET CONSTANT (IDEALIZED CONDITION)
C (CON'T)

```

Fig. 4. (Continued)

```

C
CD IX(10) THERMAL CELL OPTIONS FOR HEAT TRANSPORT IN SOLID
CD 0- TWO-DIMENSIONAL ***** NOT AVAILABLE YET, DEFAULTED TO 1
CD 1- ONE-DIMENSIONAL CYLINDER
CD IX(11) ITERATION COUNT TERMINATION (DEFAULT ESTIMATED BY CODE)
CD -NO ITERATION IF <0
CD$ IX(12) REGARDING ORIFICE LOCATION
CD 0,1- NO ORIFICING CONDITION TO CONSIDER
CD 2- ORIFICE AT THE COOLANT INLET
CD 3- ORIFICE AT THE COOLANT OUTLET
CD$ IX(13) MORE ORIFICING OPTIONS WITH COOLANT BLOCKING
CD 0- SET FOR EQUAL EXIT COOLANT TEMPERATURES BY COOLANT BLOCK
CD 1- SET TO MINIMIZE PEAK SURFACE TEMPERATURE BY BLOCK
CD 2- SET TO MINIMIZE PEAK EXIT COOLANT TEMPERATURE BY BLOCK
C
CN MINIMIZING THE PEAK FORCES THE PEAKS BY BLOCK TO BE EQUAL
CD IX(14) OMIT ENTRANCE/EXIT PRESSURE LOSS IF > C
C
CN OPTIONS TO EXPAND 2-D TO 3-D OR 1-D TO 2-D
CN -----
CD IX(15) NUMBER OF UNIFORM AXIAL INTERVALS
C
CN A DIMENSION IS ADDED IN THE COORDINATE OF THE COOLANT FLOW
CN DIRECTION TO EXPAND THE PROBLEM, AND THE POWER DENSITY DATA
CN NORMAL TO THE FLOW IS THEN EXPANDED (SEE BELOW).
CN USE A REASONABLE NUMBER OF INTERVALS, 20 RATHER THAN 2 OR 60.
CD IX(16) AXIAL POWER SHAPE OPTIONS (DISALLOW ACCELERATION IF <0)
CD <0- (NO ACCELERATION) FOR ITERATION -- FIX INPUT COEFFICIENT)
CD 0- FLAT
CD 1- SINE (SEE XX(17), XX(18))
CD 2- INPUT AXIAL VALUES BY INTERVAL IN XX(17) +
C
CN NOTE THAT IF IX(16) > 0, ARRAY LOCATIONS XX(17+) ARE THEN
CN UNAVAILABLE FOR OTHER DATA USE, TO THE END OF THIS DATA.
CD IX(17) FACTOR BY WHICH THE NUMBER OF ZONES IS EXPANDED
C
CN A 1 HERE MEANS THAT THERE WILL BE ONLY ONE AXIAL ZONE
CN USED FOR FUEL TEMPERATURE CALCULATIONS. IF INPUT 6,
CN CALCULATIONS WILL BE DONE FOR 6 AXIAL ZONES AS CAN BE
CN DISTRIBUTED AS EVENLY AS POSSIBLE EASILY.
CN IF >1, STORAGE REQUIREMENTS INCREASE SOMEWHAT AND THERE
CN IS DIFFICULTY ASSOCIATING TEMPERATURE FEEDBACK.
C
CCOX8 GOTO CCOX10
CCOX9 CONTINUE FOR PEBBLE BED
CD IX(2) OPTION ON PRESSURE DROP AND FILM COEFFICIENT
CD 0- GERMAN
CD 1- US CORRELATIONS (OLD)
CD IX(3) OPTION ON FLUENCE, <0- DON'T READ DATA (SEE XX(6))
CD 0,1- 'CPHIST' FILE, CONTINUOUS FUELING
CN NOTE THAT THIS FLAG SHOULD NORMALLY BE SET IF IX(13) > 0
CD 2- 'EXPOHT' FILE, FIXED FUEL EXPOSURE
CD IX(4) FLUENCE SELECTION, 0,1- USE FIRST RANGE IF AVAILABLE
CD 2- USE SECOND RANGE IF AVAILABLE
CD 3- USE TOTAL IF IT IS AVAILABLE
C
CN IF DESIRED DATA IS NOT AVAILABLE, NO DATA IS USED.
CN DATA FOR ONLY THE HIGH ENERGY FLUX MUST NORMALLY BE SUPPLIED
CN THAT IS SUITABLE FOR ESTIMATING ATOM DISPLACEMENT (DAMAGE).
C (CON'T)

```

Fig. 4. (Continued)


```

C
CD IX(5) MEMORY AVAILABLE FOR DATA IN 1000 WORDS
CD (DEFAULT 20000 ADDED TO RECORD 'DRVINS' ALLOCATION
CD WHICH IS THE NUMBER SUPPLIED TO THE CONTROL MODULE)
CN MEMORY CONTAINED PROBLEMS, MAY NEED VIRTUAL MEMORY
CD IX(6) THERMAL CONDUCTIVITY TREATMENT (FOR GROSS HEAT TRANSFER
CD ACROSS CORE), OPTIONS
CD <0- NO SOLID PHASE HEAT TRANSFER
CD 0- USE ZONE EXPOSURE DATA AND SURFACE TEMPERATURE
CD 1- USE SUBZONE EXPOSURE DATA AND SURFACE TEMPERATURE
CD 2- DITTO, BUT VOLUME FRACTION WEIGHT INSTEAD OF AVERAGE
CD 3- USE BUILT IN AXIAL FUNCTION
CD IX(7) DEBUG EDIT LEVEL (0,1,2,3)
CD IX(8) EDIT LEVEL OF RESULTS (-1,0,1,2)
CD EDIT LEVEL -1 INDEXED UP IF RESULTS SEEM UNUSUAL
CD IX(9) HEAT REMOVAL OPTIONS
CD 0- NORMAL
CD 1- EXCLUDE SOLID CONDUCTION
CD IX(10) FUEL ELEMENT GEOMETRY FOR THERMAL CELL
CD 0- SPHERICAL
CD 1- CYLINDRICAL (INFINITE LENGTH)
CD* IX(11) ITERATION COUNT TERMINATION (DEFAULT ESTIMATED BY CODE)
CD -NO ITERATION IF <0
CD IX(12) OPTION ON RADIAL (CROSS) FLOW, ELIMINATION
CD 0- NORMAL (INCLUDE)
CD 1- EXCLUDE
CD 2- EXCLUDE, AND FIX THE AXIAL FLOW RATE PROPORTIONAL
CD TO THE AXIAL HEAT LOAD (IDEAL ORIFICING)
CD 3- SAME AS 2 BUT ORIFICE AT INLET INSTEAD OF THE OUTLET
C
CN NOTE THAT THE ABOVE NON-ZERO OPTIONS APPLY TO FIXED TRAVERSE
CN COOLANT FLOW INVOLVING ADJUSTMENT OF THE DEFAULT COEFFICIENTS
CD IX(13) CERTAIN OPTIONS OF SMALL INTEREST
CD > 0 FLOW THROUGH COOLANT HOLES (RATHER USELESS)
CD IF 0, THE UPWIND DIFFERENCE IS USED FOR THE BULK
CD TEMPERATURE FLOW COMPONENT, CENTRAL DIFFERENCE IF <0.
CD IX(14) ITERATION PROCEDURE OPTION,
CD -1- DO NOT INCREASE OVERRELAXATION COEFFICIENTS
CD 0- ADJUST OVERRELAXATION COEFFICIENTS DURING ITERATION
CD 1- DO NOT INCREASE NOR DECREASE COEFFICIENTS
CD IX(15) EQUATION SWEEP ORDER,
CD 0- SIGMA-1 (ODD POINTS, THEN EVEN POINTS)
CD 1- NORMAL ORDERED (ONE POINT AFTER THE OTHER, 2 THEN R)
CD IX(16) ASYMPTOTIC EXTRAPOLATION PROCEDURE OPTION,
CD 0- NORMAL (ALLOW)
CD 1- DO NOT ALLOW
CD >1- MINIMUM CYCLE DELAY ITERATION COUNT
CD IX(17) OPTION ON ASYMPTOTIC EXTRAPOLATION, DATA LEVEL
CD 0- STREAM FUNCTION, TEMPERATURES, PRESSURE
CD 1- STREAM FUNCTION, PRESSURE
CD 2- PRESSURE ONLY
CCOX10 CONTINUE
CD IX(18) OPTION ON THE CALCULATION OF THE LOCAL VOID FRACTION
CD (OVERRIDDEN BY XX(1), APPLICABLE ONLY WHEN THERE ARE SUBZONES)
CD 0- SUMS ZONE AND SUBZONE VOLUME FRACTIONS
CD 1- USES ONLY ZONE VOLUME FRACTION
CD 2- SUMS ONLY SUBZONE VOLUME FRACTIONS
C (CON'T)

```

Fig. 4. (Continued)

```

C
CD IX(19)  INITIALIZATION OPTIONS FOR PEBBLE BED HYDRAULICS
CD          -1- ONLY FOR SUBSEQUENT CASE THE SOLUTION IS KEPT
CD          0- AUTOMATED PROCEDURE (AXIAL FLUID HEATING)
CD          1- SOMETHING DIFFERENT FOR HE WHO HAS TRIED EVERYTHING
CD IX(20)  WRITE ZONE TEMPERATURE FILE 'ZNTENP' OPTIONS
CD          -1- NO
CD          0, 1- WRITE OVER EXISTING ONE IF ONE EXISTS
CD                OTHERWISE WRITE NEW ONE
CD          2- WRITE OVER NEXT TO LATEST VERSION IF IT EXISTS,
CD                OTHERWISE WRITE NEW ONE
CD          3- GENERATE NEW FILE
CD IX(21)  SAVE DATA ON AN INTERFACE FILE FOR RECOVERY
CD          -1- SAVE DATA IF CONVERGENCE CRITERIA IS NOT SATISFIED
CD          0- DO NOT SAVE DATA
CD          1- SAVE THE THERMAL HYDRAULICS DATA FOR RECOVERY
CD          2- SAVE ALSO THE THERMAL CONDUCTIVITY DATA
CN          DATA IS SAVED FOR ONLY THE FIRST PROBLEM, NOT SUBSEQUENT CASES
CN          HYDRAULICS DATA SHOULD NEVER BE NEEDED FOR THE FIXED BED
CD IX(22)  RECOVER DATA FROM AN INTERFACE FILE TO CONTINUE ITERATION
CD          OR FOR INITIALIZATION (PROBLEMS MUST BE SIMILAR)
CD          1- RECOVER ALL DATA (NO REPLACEMENT)
CD          2- DO NOT USE VOID FRACTION, POWER DENSITY, NOR
CD                EXPOSURE DATA FROM FILE (USE NEW DATA)
CD IX(23)  OPTION TO RECOVER THE THERMAL CONDUCTIVITY DATA
CD          0- DO NOT RECOVER DATA
CD          1- RECOVER AND USE THE IRRADIATION TEMPERATURE AND
CD                NEUTRON FLUX EXPOSURE FUNCTION DATA (OPTION REQUIRED TO
CD                ACCOUNT FOR THE PAST HISTORY ON PROPERTIES)
CD          2- RECOVER AND USE DIRECTLY THE THERMAL CONDUCTIVITY
C
CN          THERMAL DATA MAY EITHER BE SAVED OR RECOVERED, BUT NOT BOTH.
CN          PERTURBATION FROM SOME REFERENCE STATE MAY REQUIRE THAT THE
CN          DATA BE RECOVERED FOR THE REFERENCE STATE REPRESENTING AN
CN          EXPOSED CONDITION AFFECTING THE THERMAL CONDUCTIVITY, TO BE
CN          REALISTIC. DATA RECOVERY IS GIVEN PREFERENCE OVER SAVING IN
CN          PROCEDURE DEFAULTING, A SINGLE FILE ALLOWING ONLY ONE TASK
CD IX(24)  PEBBLE BED HYDRAULICS OPTION IF > 0, OVERRIDE DEFAULT
CN          THE DEFAULT IS AN ARBITRARY ADJUSTMENT OF THE COOLANT
CN          TEMPERATURES ELIMINATING FINITE DIFFERENCE HEAT BALANCE ERROR.
CD IX(25)  FLUENCE IN THE FUELED REGION OF THE CELL IS MULTIPLIED BY
CD          THIS NUMBER DIVIDED BY 100 IF >0
CD          THIS AFFECTS THE THERMAL CONDUCTIVITY
CD IX(26)  RATIO OF THE HEAT SOURCE IN THE LATTICE TO THAT IN THE
CD          FUEL REGION IS THIS NUMBER DIVIDED BY 10000 (DEFAULT 0),
CD IX(27)  RESERVED
CN$      MORE THERMAL CELL DATA FOLLOWS FOR THE FIXED BED
CCOX11  INPUT FOR THE PEBBLE BED HAS ENDED
CD IX(28)  ANGLE AT THE FUEL CHANNEL OF THE THERMAL CELL IS THIS
CD          NUMBER DIVIDED BY 100 TIMES  $\pi/3$  (DEFAULT 100).
CCOX12  INPUT FOR THE FIXED BED CONTINUES
CD IX(29)  OPTION OF THE GEOMETRIC CELL MODEL
CD          0- MATHEMATICAL TRANSFORM IS USED
CD          1- THE MESH IS DISTORTED DIRECTLY
CD          2- DISTORTION PROCEDURES ARE TESTED WITH A SECTOR
CD          3- A SIMPLE SECTOR OF A CYLINDER IS USED, INACCURATE.
C
          (CON'T)

```

Fig. 4. (Continued)

```

C
CD IX(30) AXINUTHAL MESHPOINTS (DEFAULT 16)
CN THERMAL CELL MESH LIMITED TO A MAX OF 100 X 100
CD IX(31) RADIAL MESHPOINTS (DEFAULT 24).
CD IX(32) ITERATIVE SOLUTION PROCESS OPTION
CD 0- LINE OVERRELAXATION, SIGMA-1 ORDER
CD 1- IMPLICIT LINE RELAXATION, SIGMA-1 ORDERED
CD IX(33) MAXIMUM ITERATIONS, SET BY CODE IF 0
CD IF <0 THERE ARE NO ITERATIONS EXCEPT 1 IS DONE THE FIRST
CD PROBLEM, THIS OPTION USEFUL ONLY FOR TESTING.
CD IX(34) IF >0 THE OVERRELAXATION COEFFICIENT IS SET TO THIS
CD NUMBER DIVIDED BY 100 (DEFAULT CODE CALCULATED).
CD IX(35) IF >0 A SIMPLER PROCEDURE IS USED TO INITIALIZE THE
CD TEMPERATURES FOR THE FIRST CASE (DIFFERENT START)
CD IX(36) IF >0 THE FUEL, MATRIX GAP IS THIS DIVIDED BY 10000
CD DEFAULT GAP THICKNESS 0.0125 CM
CD IX(37) IF >0 THE NET GAP SURFACE EMISSIVITY IS THIS / 1000.
CD DEFAULT VALUE (0.8, 3.9) 0.735
CD IX(38) IF >0 THE FUELED COLUMN THERMAL CONDUCTIVITY IS
CD MULTIPLIED BY THIS /1000., DEFAULT DEGRADING FACTOR 0.50
CD IX(39) MULTIGRID THERMAL CELL ACCELERATION OPTIONS
CD -2 DISALLOW
CD -1 APPLY EACH ITERATION FIRST PROBLEM ONLY
CD 0 AUTOMATED PROCEDURE EXECUTES SPACING
CD 1 APPLY EACH ITERATION EACH PROBLEM
CD >1 START NORMALLY AND THEN SPACE THIS MANY ITERATIONS
CDN NOTE THAT A LARGE NUMBER CAUSES MULTIGRID TO BE DONE ONLY ONCE
CD IX(40) MULTIGRID PROCEDURE OPTIONS AND LEVEL CONSTRAINT
CD -3 GROSS REBALANCE, ALTERNATES COORDINATES
CD -2 GROSS REBALANCE, THETA COORDINATE
CD -1 GROSS REBALANCE, RADIAL COORDINATE
CD 0 MULTIGRID WITHOUT LEVEL CONSTRAINT
CD >0 MULTIGRID WITH THIS LEVEL CONSTRAINT
CD IX(41) OPTIONS ON THE COARSE GRID PROBLEM ACCELERATION SCHEME
CD 0- AUTOMATED PROCEDURE, LINE RELAXATION
CD 1- POINT RELAXATION
CD IX(42) MULTIGRID LEVEL TRAVERSE OPTIONS
CD -1 SOLVE PROBLEMS ONLY IN A DESCENDING TRAVERSE
CD THROUGH THE LEVELS BEGINNING WITH THE COARSEST
CD 0- VARY THE LEVEL AS DEEMED DESIRABLE
CD 1- FIX TO DO THE MAXIMUM LEVEL WITHOUT CHANGE
CD IX(43) MULTIGRID ACCELERATION COEFFICIENT TIMES 100.
CD (OVERRELAXATION HAS BEEN DEIMPLEMENTED)
CD IX(44) MULTIGRID CONVERGENCE LEVEL OPTIONS
CD 0- AUTOMATED
CD 1- FIXED LEVEL
CD 2- INCREASING CONVERGENCE WITH COARSENESS LEVEL
CD IX(45) OVERRIDE ANY AUTOMATED INITIAL GLOBAL 1-D REBALANCE IF >0
CD IX(46) - IX(100) RESERVED
C
C-----

```

Fig. 4. (Continued)

```

C*****
C      REVISED 11-17-93
C
C      THERMA
C
C      THERMAL HYDRAULICS PROBLEM INFORMATION
C
C      PRIMARY USE OF THIS DATA
C      1- ASSIGN A COOLANT REFERENCE TO INTERVALS ALLOWING FLOW CONTROL
C      2- EXTEND TWO-DIMENSIONAL PROBLEMS TO THREE-DIMENSIONAL
C      ADDING AN AXIAL DIMENSION ALONG THE DIRECTION OF FLOW
C
C*****
C-----
C      FILE IDENTIFICATION
C
C      NAME, (HUSE(I), I=1,2), IVERS
C
C      1+3*MULT=NUMBER OF WORDS
C
C      NAME      ROLLER WITH FILE NAME - THERMA - (A6)
C      HUSE(I)    ROLLER WITH USER IDENTIFICATION (A6)
C      IVERS      FILE VERSION NUMBER
C      MULT       DOUBLE PRECISION PARAMETER
C      1- A6 WORD IS SINGLE WORD
C      2- A6 WORD IS DOUBLE PRECISION WORD
C
C-----
C      FILE SPECIFICATIONS      (10 RECORD)
C
C      I0, I1, I2, I3, I4, I5, I6, (I1(J), J=1,13), (DESC(I), I=1,12)
C
C      20 WORDS
C
C      I0      OPTION FOR THERMAL HYDRAULICS DATA
C      I1      NUMBER OF AXIAL INTERVALS
C      I2      NUMBER OF INTERVALS NORMAL TO COOLANT FLOW
C      (NUMBER OF ZONES IF I5 = 2)
C      (TOTAL POINTS WHEN USED WITH OPTION I6)
C      I3      OPTION ON AXIAL INTERVAL DIMENSIONS
C      I4      OPTION ON AXIAL POWER DENSITY DISTRIBUTION
C      I5      OPTION ON COOLANT BLOCKING
C      1- DATA BY INTERVAL ACROSS THE CORE MESH
C      2- DATA BY ZONE, USED ONLY FOR FIRST TRAVERSE)
C      I6      OPTION ON POWER DENSITY ACROSS FUEL ASSEMBLIES
C      I1      RESERVED
C      DESC    DESCRIPTIVE DATA FOR FILE DOCUMENTATION (12A6)
C
C-----
C      THERMAL HYDRAULICS DATA      (20 RECORD)
C
C      PRESENT IF I0.GT.0
C
C      (THDATA(N), N=1,100)
C
C      100*MULT WORDS
C
C      THDATA(N)  THERMAL HYDRAULICS DATA DEFINED IN CODE
C      DOCUMENTATION OF USE
C
C-----
C      (CCW'T)

```

Fig. 5. Thermal Hydraulics Problem Interface Data File Specifications (THDATA).

```

C-----
CF      AXIAL INTERVAL DIMENSIONS          (3D RECORD)
C
CC      PRESENT IF 13.GT.0
C
CL      (ZMESH(I),I=1,I1)
C
CW      I1 WORDS
C
CD      ZMESH(I)          AXIAL INTERVAL THICKNESS, CM
C
C-----
CF      AXIAL POWER DENSITY DISTRIBUTION    (4D RECORD)
C
CC      PRESENT IF 14.GT.0
C
CL      (XKZPD(I),I=1,I1)
C
CW      I1 WORDS
C
CD      XKZPD(I)          RELATIVE POWER DENSITY BY AXIAL INTERVAL
C
CN      THIS DATA ALLOWS A TWO-DIMENSIONAL POWER DENSITY DISTRIBUTION TO
CN      BE EXTENDED TO THREE-DIMENSIONAL (ASSUMING SEPARABILITY)
C
CN      INTERVALS OF ZERO POWER DENSITY INDICATE NON-FUELED ZONES ADDING
CN      PRESSURE DROP AS WILL BE CALCULATED WITH THE HYDRAULICS MODEL
C
C-----
CF      ASSIGNMENT OF INTERVALS NORMAL TO THE COOLANT FLOW TO
CF      COOLANT BLOCKS                      (5D RECORD)
C
CC      PRESENT IF 15.GT.0
C
CL      (IBLK(J),J=1,I2)
C
CW      I2 WORDS (INTEGERS)
C
CD      IBLK(J)          REFERENCE COOLING BLOCKING NUMBER ASSIGNED TO EACH
CD                        INTERVAL NORMAL TO COOLANT FLOW, FROM ONE TO MAX
CD                        (ASSIGNED TO EACH ZONE IF IS=2, DATA USED FOR THE
CD                        FIRST PLANE, ESPECIALLY USEFUL OPTION FOR 2-D)
C
CN      INTERVALS UNDER THE INFLUENCE OF THE SAME ORIFICE WOULD BE
CN      ASSIGNED THE SAME BLOCKING NUMBER
C
CN      THE ARRAY IS NORMALLY TWO-DIMENSIONAL SIMPLY INDEXED SEQUENTIALLY
CN      WITH NORMAL ORDERING ALONG ROWS ONE AFTER THE OTHER
C
C-----
CF      POWER DENSITY DATA, ABSOLUTE        (6D RECORD)
C
CC      PRESENT IF 16.GT.0
C
CL      (PD(K),K=1,I2)
C
CW      I2 WORDS
C
CD      PD(K)            LOCAL POWER DENSITY ON PLANE NORMAL TO COOLANT FLOW
CD                        HEAT SOURCE (#-TH/CC)
C
CN      THIS DATA IS USED PRIMARILY ONLY FOR TESTING
CN      ANY ZERO VALUES WILL REPRESENT BYPASS FLOW WITH NO HEATING
C
C-----
C.....

```

Fig. 5. (Continued)

```

C*****
C          REFERENCE 02/01/79 ORNL-5180
C
CN          ORIGINAL SPECS REVISED TO INCLUDE SUBZONE DATA WHEN NEEDED
C
CF          ZNTEMP
C
CE          ZONE TEMPERATURE DATA
C
C*****
C-----
CR          FILE IDENTIFICATION
C
CL          HNAME,(HUSE(I),I=1,2),IVERS
C
CW          3*MULT + 1
C
CD          HNAME          FILE NAME (A6) 'ZNTEMP'
CD          HUSE           USER IDENTIFICATION (A6)
CD          IVERS          FILE VERSION NUMBER
C
CN          MULT           1 FOR LONG WORD, 2 FOR SHORT WORD MACHINES
C
C-----
C-----
CR          FILE REFERENCE INFORMATION
C
CL          NRZ,NZT,NSZ,(NA(I),I=1,17)
C
CW          20
C
CD          NRZ            NUMBER OF REACTOR ZONES , NOT ZERO
CD          NZT            NUMBER OF TEMPERATURES FOR EACH ZONE .LE. 5
CD          NSZ            NUMBER OF REACTOR SUBZONES
CD          NA             RESERVED
C
CN          OFTEN A SINGLE TEMPERATURE WILL BE CARRIED WHICH SERVES AS A
CN          REFERENCE, AS TO EXPRESS THE EFFECTIVE TEMPERATURE OF THE ZONE-
CN          WHICH MAY BE USED SIMPLY FOR SUCH PURPOSE AS CROSS SECTION
CN          CORRELATION. EVEN IF TWO TEMPERATURES ARE CARRIED TO INCLUDE
CN          THE COOLANT TEMPERATURE, THE FIRST IS INTENDED TO ADMIT SUCH
CN          SIMPLE APPLICATION (LINEAR INTERPOLATION OF CROSS SECTIONS
CN          IS ADMITTED WHICH MAY BE DONE AT THE MACROSCOPIC LEVEL USING
CN          TWO MICROSCOPIC CROSS SECTION SETS).
C
C
C-----

```

Fig. 6. Zone Temperature Interface Data File ZNTEMP Specifications.

```

C-----
CR          ZONE TEMPERATURES                                -
C                                                    -
CC          ALWAYS PRESENT                                    -
C                                                    -
CL          ((ZTEMP(I,M),I=1,NZ      I=1,NRZ)                -
C                                                    -
CW          NZT*NRZ                                           -
C                                                    -
CD          ZTEMP          TEMPERATURE OF REFERENCE I IN ZONE M (DEGREES C) -
CD                                  I      REFERENCE          -
CD                                  -      -----          -
CD                                  1      ACTINIDES (FUEL) --- REFERENCE -
CD                                  2      COOLANT              -
CD                                  3      MODERATOR            -
CD                                  4      STRUCTURAL           -
CD                                  5      SPECIAL              -
C                                                    -
C-----
C-----
CR          SUBZONE TEMPERATURES                              -
C                                                    -
CC          PRESENT IF NSZ .NE. 0                              -
C                                                    -
CL          ((SZTEMP(I,M),I=1,NZT),M=1,NSZ)                    -
C                                                    -
CW          NZT*NSZ                                           -
C                                                    -
CD          SZTEMP          TEMPERATURE OF REFERENCE I IN SUBZONE M (DEGREES C) -
C                                                    -
CN          SEE NOTES ABOUT ZONE TEMPERATURE DATA            -
C                                                    -
C-----
C*****
C                                                    -
CEOF          ZNTEMP                                           -
C                                                    -
C*****

```

Fig. 6. (Continued)

Capability has not yet been added to the Input Processor in the computation system to generate the thermal hydraulics interface data file THERMA. A job for the computer with FORTRAN coding used to make one of these files is shown in Fig. 7. This is not very sophisticated. Requirements were simply satisfied with data statements, and the written file was then read to see that it had been read. Space for the file had previously been allocated on a mass storage device (in a previous computer run using preliminary data). The data array assigning coolant blocking numbers to zones took too many continue statements for the compiler in use, so it was presented in two parts. These data are used to expand the results from a two-dimensional triangular geometry neutronics problem normal to the axis to a three-dimensional thermal hydraulics problem. Thus axial information is given, including an axial power density traverse normalized such that the average is unity. Note that these data could be modified to allow any interface data file to be made; however, the free form format, repeat and other advantages of the computation system Input Processor are not available.

Solution Reliability

The author expects any solution to be reliable if reasonable convergence criteria have been satisfied. If not converged, the iterate result may well not be acceptable. Expect results to be reasonable and if they are not, distrust them. A solution to a mathematical problem may or may not be useful in analysis. Reasonable modeling is required with judicious choices made from the options. Likely the competent analyst will have some understanding of the phenomena under study and the limitations of this code in modeling such. Certainly some consideration must go into such aspects as coolant bypass flow that is ignored before conditions in a core can be considered to be understood.

A unique solution is expected to any problem. Within the degrees of freedom allowed, only one solution should satisfy the mathematical equations. The reason why this is expected is that the pressure drop monotonically increases with the flow rate, and increasing the coolant temperature with an increased heat source reduces its density and increases the pressure drop. Increasing the pressure drop across one orifice reduces the local coolant flow rate and increases it elsewhere under the assumptions. In most situations the power density over a reactor core varies modestly so that extreme conditions of coolant flow and temperature peaking are relatively constrained. This may not, of course, always be the situation.

Application Considerations

Certain aspects of the thermal hydraulics modeling must be understood if the analyst is to use this code reliably. The following introductory discussion should be supplemented by actual test calculations, some of which should no doubt be done for trivial situations at a low cost of calculation and modest investment in the analyst's time.

Consider the array of meshpoints normal to the direction of coolant flow on a plane through the reactor core. Associated with each meshpoint is an elemental volume, typically a three-sided prism. Also associated with this meshpoint or discrete area is coolant flow along a row for heat removal, usually several coolant channels (cylindrical holes) for which the average conditions are to be calculated given the average heat source per channel.


```

//DRVKK JOB (██████, 1003), 'DAVE VONDY 6025', TIME=(0,29).
// MSGLEVEL=(2,0), COND=(5,LT), PASSWORD=YGIRGN
//*JOBPARM LINES=10
//*ROUTE PRINT RBT42
// EXEC PORTHCLG,PARM.FORT='BCD,NODECH,NOLIST,HAP,XREF',
// GOSIZE=540K
//PORT.SYSIN DD *
C DATA FILE GENERATION ROUTINE IN FORTRAN
C
  DIMENSION A(12), L(225), LL(225), C(12), CH(4), IH(8), II(20)
  EQUIVALENCE (CH(1), IH(1))
  REAL *8 CH
C
  DATA IH(7) / 1 /, IH(8) / 0 /
  DATA CH(1) / 6THERMA /, CH(2) / 6H VONDY /, CH(3) / 6HO 1983 /
  DATA A / 52.967, 52.967, 52.967, 52.967, 52.967, 52.967,
  * 52.967, 52.967, 52.967, 52.967, 52.967, 52.967 /
  DATA C / 1.00, 1.02, 1.06, 1.12, 1.18, 1.12, 1.06, 1.00, 0.95, 0.89,
  * 0.83, 0.77 /
  DATA L /
  * 1, 1, 2, 2, 2, 2, 2, 2, 3, 3, 3, 3, 3, 3,
  * 3, 4, 4, 5, 5, 5, 5, 5, 6, 7, 7, 7, 7,
  * 7, 7, 7, 8, 8, 8, 8, 8, 9, 9, 9, 9, 9,
  * 9, 9, 10, 10, 10, 10, 10, 10, 11, 11, 11, 11, 11,
  * 11, 12, 12, 12, 12, 12, 12, 13, 13, 13, 13, 13,
  * 14, 14, 14, 14, 14, 14, 15, 15, 15, 15, 15, 15,
  * 16, 16, 16, 16, 16, 17, 17, 17, 17, 17, 17, 18,
  * 19, 19, 20, 20, 20, 20, 21, 21, 21, 22, 22, 22,
  * 22, 23, 23, 23, 23, 23, 23, 24, 24, 24, 24, 24,
  * 25, 25, 25, 25, 25, 25, 26, 26, 26, 26, 26, 27,
  * 27, 0, 27, 27, 0, 27, 28, 28, 28, 28, 28, 29,
  * 29, 29, 29, 29, 29, 30, 30, 30, 30, 30, 31, 31,
  * 31, 31, 32, 32, 32, 32, 32, 32, 33, 33, 33, 33,
  * 33, 34, 34, 34, 0, 34, 34, 34, 35, 35, 35, 35,
  * 35, 36, 36, 36, 36, 36, 0, 37, 37, 37, 37, 37,
  DATA LL /
  * 38, 38, 38, 38, 21, 21, 21, 0, 39, 40, 40, 41, 41, 41,
  * 41, 41, 41, 42, 42, 42, 42, 42, 42, 43, 43, 43, 43,
  * 43, 43, 44, 44, 45, 45, 45, 45, 45, 46, 46, 46, 46,
  * 46, 46, 46, 47, 47, 47, 47, 47, 47, 48, 48, 48, 48,
  * 48, 48, 49, 49, 49, 49, 49, 49, 50, 50, 50, 50, 50,
  * 50, 51, 51, 51, 51, 51, 51, 52, 52, 52, 52, 52,
  * 53, 53, 54, 54, 54, 54, 54, 54, 55, 55, 55, 55, 55,
  * 55, 56, 56, 56, 56, 56, 56, 56, 57, 57, 0, 0, 65,
  * 58, 58, 58, 58, 58, 59, 59, 59, 59, 59, 59, 60, 60,
  * 61, 61, 61, 61, 61, 61, 62, 62, 62, 62, 62, 62, 63, 63,
  * 63, 63, 63, 63, 63, 64, 64, 65, 65, 65, 65, 65, 66,
  * 66, 66, 66, 66, 66, 67, 67, 67, 67, 67, 67, 68, 68,
  * 68, 68, 68, 68, 69, 69, 70, 70, 70, 70, 70, 70, 71,
  * 71, 71, 71, 71, 72, 72, 72, 72, 72, 72, 73, 73, 74,
  * 74, 74, 74, 74, 74, 75, 75, 75, 75, 75, 75, 75, 0,
  DATA II / 0, 12, 450, 1, 1, 2, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 /
C
  ICUT = 8
  WRITE (IOUT) CH
  WRITE (IOUT) II
  WRITE (IOUT) A
  WRITE (IOUT) C
  WRITE (IOUT) L, LL
  REWIND IOUT
  DO 10 I=1, 5
  READ (IOUT)
10 CONTINUE
  STOP
  END
/*
//LKED.SYSIN DD *
//GO.FT08F001 FT UNIT=2330V, VOLUME=SE5=VBRIAN,
// DCB=(RECFM=VBS, 'RECL=X, BLKSIZE=4000, BUFNO=1),
// DISF=(OLD,KEEP), SPACE=(TRK, (02,2)),
// DSWANE=X.DRV16456.THERMA.HTRG.B
//GO.FTC5F001 DD *
/*
//

```

Fig. 7. Generation of a THERMA Interface Data File of Thermal Hydraulics Data.

Coolant orificing is associated with a block of these meshpoints or area intervals. Typically the blocking is assigned on a zone basis, zones being the division of the geometry into different material assignments for the neutronics problem. A zone is the finest scale on which macroscopic neutronics properties are calculated. Thus zones reflect differences in initial fuel region compositions. Further discretization is done to account for differences that come from exposure and partial refueling. Blocking of the coolant channels for orificing can affect zone assignments. Temperature cell calculations are also done on a zone basis (for average and estimated extreme conditions) and this aspect may influence the assignment of zones. Note that the distribution of fuel temperatures is predicted more precisely the more zone assignments made. Consider these things in preparing the detailed problem definition.

Occasionally there can be some difficulty identifying just where the coolant flows. The objective of the implemented capability is to examine primary heat removal and to ignore low-level heat sources as in moderator or reflector regions. If care is not taken in the data presented, a low-level heat source can be calculated in a reflector as a non-zero power density, and the region would then be treated as if it were a core region containing fuel. (Heat removal from such regions is left as a problem to be addressed with supplemental calculations.) Thus only heavy metal (actinide) nuclides should normally have energy per fission and per capture data assigned. In the event that a core has an odd or irregular shape, heat removal by coolant will be considered only along coolant paths for which the integral of the power density is non-zero.

The finer the meshpoint arrangement, the more detailed is the coolant flow and heat removal calculation. Halving the mesh spacing in two coordinates increases the number of coolant channels treated by a factor of four. Halving the axial mesh spacing doubles the number of locations along each coolant flow channel where discretized calculations are done. Note that increasing the number of meshpoints also has the important effect of producing a more detailed heat source distribution from the power density data generated over the grid by the neutronics code.

In most any study some experience is needed regarding the dependence of the results on the degree of resolution of the spatial power density distribution. Results are shown in Table 11 for a simple situation involving 16 coolant blocks illustrating primary effects.

Another assumption made is that basically the parallel flow channels are all the same length. It is possible that there is no heat source (no fuel) over part of this length for some of the channels, but such modeling would be unusual rather than the norm.

Application Experience

Application of this code and its calculational procedures has been mostly limited to what the author has done. More extensive application will likely prompt revisions. Of some concern is the ability to adequately describe a problem to be solved and the suitability of the results generated. At the time this is written, the fuel management module does not have adequate capability to make the exposure data file consistent with refueling, so these data are inadequate for general use to affect thermal conductivities. So there are known limitations of the computation system for solving global problems. These are not usually easily identified but become identified with careful use of the system.

Table 11. Study of the Dependence of the Hydraulic Results on the Mesh

Core Meshpoints (Planar $\times$ Axial)	Computer Time (cpu min)		Temperatures ($^{\circ}\text{C}$)			
	Neutrons	Hydraulics	Peak Coolant Exit	Peak Surface	Power Weighted Fuel	Peak Fuel
32 $\times$ 8	0.8	6.03	870	1029	501	1049
32 $\times$ 16	1.7	0.05	870	996	504	1016
128 $\times$ 16	6.6	0.08	888	1053	501	1074
512 $\times$ 16	32.0	0.12	897	1031	505	1052

No difficulty has been experienced in solving the hydraulics problems; for example, the iterative process converges rapidly. The following remarks are offered.

1. The results obtained for a thermal hydraulics problem depend on the modeling. There are different types of effects:
 - a. Those that affect the reference conditions as a consequence of the modeling of the physical phenomena, including the basic geometric description and association of materials and the data including the inlet coolant temperature over which there is no qualification imposed.
 - b. Those that additionally affect the conditions due to controllable aspects such as modeling the effect of time.
 - c. Those that directly affect the thermal hydraulics problem such as the power density distribution that is subject to dependence on the discrete mesh.
 - d. Controllable features of the thermal hydraulics calculation such as the orificing, flow rates or exit coolant temperature and modeling options.
 - e. The degree of resolution of the effects of discretization.
2. How well an approximate solution may represent the facts depends on the details. Interest here is in the distribution of the fuel temperatures, for example. There is the extreme, maximum fuel temperature, and then the approximation of it. The analyst must of course be concerned about how well the facts may be represented, i.e., how close is the estimate of the peak fuel temperature. Here we examine only some of the contributions, for example, the dependence of the calculated peak fuel temperature on the controllable modeling variables such as the number of meshpoints. Evidently the accuracy of such a result increases as the calculation is made more detailed. Hopefully reasonable choices have been made from among the alternatives in implementing the calculational procedures to maintain a high accuracy and hold down the discrepancies.
3. A reference core fuel temperature is of considerable interest. For example, this temperature may be used to generate nuclear cross sections appropriate to the situation, and in particular the doppler broadening and resonance shielding depends on the temperature of the materials and the thermal neutron flux spectrum in energy does also.

The effective core fuel temperature is calculated as a volume average and also as the volume average weighted by the local power density, the latter value being preferred by the writer. The effect of change in the temperature as due to a change in power level or coolant conditions may be predicted from the associated two values of the effective fuel temperature. Of course in this computation system the effect of temperature changes may be assessed directly using the temperature correlation of microscopic cross sections. So the effective fuel temperature is of some interest and also the effect on it of controllable variables of the problem.

4. There are modeling options that directly affect the results. For example, without orificing, the coolant flow rate through a channel having a low integral heat source would be much higher than for the average channel, with the net effect of higher temperature peaking where the heat source is high and the coolant flow rate low. The association of the region and coolant channels with an orificed flow affects the results. The coolant flow direction also affects the results, the more so the more axial skewing of the neutron flux and hence of the power density.
5. The effect on the results of the modeling approximations is of interest collectively and individually. Correlations that admit numerical evaluation would be useful. There are, however, so many different aspects that only quantitative assessment may be possible. Where possible, we would like to be able to relate an error to a representation, for example, an error contribution of the form

$$\epsilon_{x,n} = X_{\infty} - X_n = A\lambda^n, \quad (71)$$

where X_{∞} is a precise result, and X_n is the result for n having a finite value (number of meshpoints, for example). A is associated with the level of the error contribution, and λ measures the rate of error reduction with increase in n . We hope for a small value of A (small error) and a small value of λ (rapid error reduction) with increase in n . Finally we hope for a simple situation where this or another formulation is appropriate, adequately representing the facts. Note that

$$\lambda = \frac{X_n - X_{n-1}}{X_{n-2} - X_{n-3}}, \quad (72)$$

requiring results for three values of n ,

$$X_{\infty} = X_n + \left[\frac{\lambda}{1-\lambda} \right] (X_n - X_{n-1}), \quad (73)$$

and

$$A = \left[\frac{\lambda^{1-n}}{1-\lambda} \right] (X_n - X_{n-1}). \quad (74)$$

5. APPLICATION INFORMATION

User Control

Basic user input instructions to this code are shown in Fig. 4. Hopefully the information presented is adequately explained.

Data Storage

It is assumed that the hydraulics problem can be contained in the computer memory. For large problems the virtual memory capability of the local computers may be used efficiently since data transfer from disk is handled nicely by the system.

The data storage requirement is broken down into three parts: initial data plus certain reference storage, data for the hydraulics problem, and data for the thermal cell problem. Reference storage conditions are shown below.

Let J = number of active meshpoints on a plane
normal to the direction of coolant flow.

I = number of active axial points.

N = number of zones.

M = number of subzones.

L = $\max(N, NS)$.

A = number of azimuthal cell problem points.

B = number of radial cell problem points.

Initial Data $2(J+I) + 6JI + 12N + 4M + L$

Hydraulics Problem $8JI + I$

Thermal Cell Problem $5N + 9M + L + (12A + 4)B^a$

If the requirement for the thermal cell problem is less than that for the hydraulics problem, it is overlaid. So the total storage requirement is then only the sum of the first two items above. Information about total memory requirement is given in the section on program considerations.

Refer to the original documentation or the code listing for the pebble bed calculation requirements or details. Information is edited about storage requirements. A prerun can be made to firm requirements and is recommended for a new and unfamiliar problem. Unfortunately the initialization procedures can only report an apparent maximum storage requirement since the power density data must be processed before inactive meshpoints are eliminated from the problem and from the estimate of storage requirements. If there are

^aThe extension to use a multigrid relaxation scheme may increase the last term by 40 to 50 percent.

as many meshpoints in the reflector as in the core, the maximum storage estimate may be nearly twice what is actually needed.

This code is used in a computation system that has data file management. Interface data files are assigned names. The management tables inform a code where a file associated with a specific name is located and where to put a file to be written. Quite generally, when a new file associated with one name is generated it is unique, either being the only one or replacing (written over) an old one of the same name, or it is assigned a version number that is indexed upward. Also quite generally, when data are to be obtained from a file, the one with the highest version number will be read, with certain exceptions where the user exercises control. File proliferation is minimized by having new files written over old ones. Thus if several power density files exist, the one with the highest version number will be read. Certain checks are made to see that it is consistent with the geometric description.

Note that except when a data file is to be supplied or saved, the user is not involved in logical unit assignments. This is handled automatically by the file management system. The actual unit assignments depend on the calculational path and individual tasks carried out. When supplying or saving a file, the user must exercise control over both the logical unit assignment and the physical unit association. Such control is exercised with job control instructions by overriding the catalogued procedure. Special needs are also satisfied with parameters that override default values in the catalogue procedure, as to increase the space on a particular logical unit or to change the blocking.

Reliability is improved by the file management system. Data will not be read from a file and used unless the actual name on the file is correct. This does not mean that action undesired by the user cannot be taken or that an unfriendly user cannot deliberately screw up the system by trying. User understanding comes with use.

Certain auxiliary information is always produced, for example, temperature averages. Some of the features of the calculational procedure adapted for the pebble bed core have been carried over for the prismatic core. For example, it has been found that the best temperature for characterizing the core behavior is a power weighted fuel temperature:

$$T_{f,e} = \frac{\sum_r v_r P_r T_{f,r}}{\sum_r v_r P_r} ,$$

where v is the volume and P is the power density. That is, the temperature where the power density is high is more important than where it is low. Applications include predicting power or temperature coefficients and stability against xenon driven oscillation. So this value is calculated for each case, along with the volumetric average. Cell temperature calculations are always done for reference conditions; then these are requested for the thermal conductivity multiplied by 0.9, and finally they are done for selected estimates of extreme region conditions.

Credible Results

The analyst is urged to carefully study the results for a problem to assure quality. Are the volume and power level reasonable? Are the channel surface area per unit volume and the number of coolant holes per square meter as desired? Is the active meshpoint arrangement correct? Are the power density data reasonable? Are the pressure drop through the core and the individual orifice pressure drop as expected? Are reasonable temperatures of the coolant, surface, and fuel produced? Is the distribution of fuel temperatures as expected? Is there concern regarding excessive error due to discretization or other modeling assumptions?

6. SAMPLE PROBLEM

The results now obtained for the original pebble bed sample problem are slightly different and the printout is revised in comparison with that shown in the original report. Therefore, the new results for this pebble bed problem are reported here to support code validation.

A prismatic core thermal hydraulics problem was added at the end of the original pebble bed problem. A neutronics problem for a fixed core is solved from the input description using the nuclear data of the pebble bed problem. Exposure calculations were not done, so fluence data are not available. Calculations are done for a variety of situations with data recovery options exercised to support code validation. Note that the last case is the same problem as the first, so the differences in the results are due to modeling differences and indicate to some extent the reliability.

Table 12 is a listing of the computer output with many of the pages deleted. The first two pages are a summary of the calculation showing the codes that were used and reporting key results. Note that the first access of DVENTR sets up a description of a pebble bed core while the second one sets up the prismatic core description. At the end of this summary is a list of the active interface data files. The third page shows the job control language with data space allocation and reference to the BOLDVENT system of loaded codes used locally on a production basis. The thermal hydraulics code THR-TH in the code system is overridden in this example with that loaded in data set DRV16456.PBLZDLP that would normally be a development version of indeterminate quality assurance level status any particular day.

Immediately following is a listing of the user input data that includes nuclear data to generate a GRUPXS cross section file with the Input Processor. Data requirements for the special processors are satisfied. The input data listing is followed by the excerpted printout of results. (Note: Text continues on page 122.)

Table 12. Sample Problem Excerpted Output

PCOLD VENTURE VERS-3 RUN ON THE IBM-360/400. CONTROL ROD-CONTROL1, DATE=11-01-83, TIME=22.00.00, JOBNAME=DEVENPH -

INITIALIZATION, REFERENCE - REMAINING I/O= 6.55, CPU RIM= 5.72

RUN TITLE AND COMPILED MODULE DATA
 TWO-TH SAMPLE PROBLEMS, PEBBLE RED THERM HYDRAULICS
 1 2 2 7 13 20 2 20 2 20 2 2 7 20 2 20 2 20
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

INITIAL I/O FILE MANAGEMENT TABLES													
FILE NAME SUPPLIED BY													
FILE NUMBER	SECT	USER-PRST	USER-STACK	VERSION	WRITTEN	USER IDENTIFICATION							
10	CONTROL			1	1	DATE=11-01-83							
MODULES TO BE ACCESSED IN ORDER													
1	2	2	7	13	20	2	20	2	2	7	20	2	20
READ DATA AND ACCESS MODULE 1 - REMAINING I/O= 4.97, CPU RIM= 5.71													
READ DATA FOR A SPECIAL PROCESSOR - REMAINING I/O= 4.77, CPU RIM= 5.42													
ACCESS PROCESSOR 'OUTLIN' - REMAINING I/O= 4.70, CPU RIM= 5.42													
READ DATA FOR A SPECIAL PROCESSOR - REMAINING I/O= 4.73, CPU RIM= 5.41													
ACCESS PROCESSOR 'OUTLIN' - REMAINING I/O= 4.72, CPU RIM= 5.41													
READ INPUT DATA ONLY (LOOK-AHEAD) - REMAINING I/O= 4.70, CPU RIM= 5.41													
ACCESS MODULES 7 13 0 0 0 - REMAINING I/O= 4.49, CPU RIM= 5.41													
ITERATIONS, CONVERGENCE, SEARCH, PEAK POWER DENSITY, K - 0.964406, FISSILE INVENTORY 6.268799E UZ RG, CONVERSION RATIO (PE) 0.58045 PRIMITIVE CONVERSION RATIO, ALSO FOR CRITICAL SYSTEM, FUEL CONSUMPTION (AT-P, WATT-SEC) - 0.57898 0.57105 3.03045E 10 TIME AFTER PERIOD 29967.195 DAYS, ESTIMATED K 0.964406, FISSILE INVENTORY 6.268799E UZ RG, CONVERSION RATIO (PE) 0.58045 EXPOSURE TIME STEP 1100.000 DAYS, TOTAL POWER 1.627773E C9 W(TN) ICRG - PEAK POWER DENSITY 2.16-944E C1 W(TN)/CC, PATH POWER 1.627773E C9 W(TN), FISSILE FUEL RATE 1.277630E CC RG/DAY CURRENT - PEAK POWER DENSITY 0.0 W(TN)/CC, PATH POWER 0.0 W(TN), FISSILE FUEL RATE 0.0 RG/DAY													
ACCESS MODULES 20 0 0 0 0 - REMAINING I/O= 4.23, CPU RIM= 4.52													
MAX TEMPS, PEAK/MEAN BY ZONE, SUZICNE 522.2 918.8 0.0 0.0 POWER WEIGHTED 733.0 0.0 POWER (MWT) 1.6567E 03 MAX TEMPS, PEAK/MEAN BY ZONE, SUZICNE 522.9 919.5 0.0 0.0 POWER WEIGHTED 733.0 0.0 POWER (MWT) 1.6567E 03													
ACCESS PROCESSOR 'OUTLIN' - REMAINING I/O= 4.16, CPU RIM= 3.92													
READ INPUT DATA ONLY (LOOK-AHEAD) - REMAINING I/O= 4.14, CPU RIM= 3.92													
ACCESS MODULES 20 0 0 0 0 - REMAINING I/O= 4.13, CPU RIM= 3.92													
MAX TEMPS, PEAK/MEAN BY ZONE, SUZICNE 522.6 918.2 0.0 0.0 POWER WEIGHTED 732.9 0.0 POWER (MWT) 1.6567E 03													
ACCESS PROCESSOR 'OUTLIN' - REMAINING I/O= 4.10, CPU RIM= 2.13													
READ INPUT DATA ONLY (LOOK-AHEAD) - REMAINING I/O= 4.08, CPU RIM= 2.13													
ACCESS MODULES 20 0 0 0 0 - REMAINING I/O= 4.07, CPU RIM= 2.13													
MAX TEMPS, PEAK/MEAN BY ZONE, SUZICNE 523.1 918.8 0.0 0.0 POWER WEIGHTED 733.0 0.0 POWER (MWT) 1.6567E 03													
ACCESS PROCESSOR 'OUTLIN' - REMAINING I/O= 4.01, CPU RIM= 2.04													
READ DATA FOR A SPECIAL PROCESSOR - REMAINING I/O= 3.96, CPU RIM= 2.04													
ACCESS PROCESSOR 'OUTLIN' - REMAINING I/O= 3.94, CPU RIM= 2.04													
READ INPUT DATA ONLY (LOOK-AHEAD) - REMAINING I/O= 3.93, CPU RIM= 2.03													
ACCESS MODULES 7 20 0 0 0 - REMAINING I/O= 3.73, CPU RIM= 2.03													
ITERATIONS, CONVERGENCE, SEARCH, PEAK POWER DENSITY, K - 31 1.230980-03 0.0 1.05560E 03 1.07241E 5 PRIMITIVE CONVERSION RATIO, ALSO FOR CRITICAL SYSTEM, FUEL CONSUMPTION (AT-P, WATT-SEC) - 0.48934 0.51026 3.06961E 10 MAX TEMPS, PEAK/MEAN BY ZONE, SUZICNE 472.1 865.9 0.0 0.0 POWER WEIGHTED 706.0 0.0 POWER (MWT) 3.0000E 01 MAX TEMPS, PEAK/MEAN BY ZONE, SUZICNE 476.3 869.1 0.0 0.0 POWER WEIGHTED 746.0 0.0 POWER (MWT) 3.0000E 01 MAX TEMPS, PEAK/MEAN BY ZONE, SUZICNE 477.5 870.7 0.0 0.0 POWER WEIGHTED 751.2 0.0 POWER (MWT) 3.0000E 01													
ACCESS PROCESSOR 'OUTLIN' - REMAINING I/O= 3.67, CPU RIM= 1.65													
READ INPUT DATA ONLY (LOOK-AHEAD) - REMAINING I/O= 3.65, CPU RIM= 1.65													
ACCESS MODULES 20 0 0 0 0 - REMAINING I/O= 3.66, CPU RIM= 1.65													
MAX TEMPS, PEAK/MEAN BY ZONE, SUZICNE 477.6 870.8 0.0 0.0 POWER WEIGHTED 751.5 0.0 POWER (MWT) 3.0000E 01 MAX TEMPS, PEAK/MEAN BY ZONE, SUZICNE 479.8 873.0 0.0 0.0 POWER WEIGHTED 751.6 0.0 POWER (MWT) 3.0000E 01													
ACCESS PROCESSOR 'OUTLIN' - REMAINING I/O= 3.61, CPU RIM= 1.12													
ACCESS MODULES 20 0 0 0 0 - REMAINING I/O= 3.59, CPU RIM= 1.17													
MAX TEMPS, PEAK/MEAN BY ZONE, SUZICNE 472.1 865.9 0.0 0.0 POWER WEIGHTED 706.0 0.0 POWER (MWT) 3.0000E 01 MAX TEMPS, PEAK/MEAN BY ZONE, SUZICNE 476.3 869.1 0.0 0.0 POWER WEIGHTED 746.0 0.0 POWER (MWT) 3.0000E 01													

← Pebble Bed Description

← Prismatic Description

WRAP-UP NOW COMPLETE. -- CHIVEN MC SEEN NEW CASE - REMAINING I/C 3.56, CPC DIS 1.29 - TIME 22.34.33

→ THRU code
→ Bold venture codes

PRIMARY MODULE ACCESS AND INPUT DECODE (SCALE DRIVER - 11/24/02 - 16.59)

MOBILE CONTROL WILL BE CALLED TIME OF DAY 22.04.07 DATE 03.105

[illegible]

[illegible]

Table 12. (Continued)[illegible]

Table 12. (Continued)

```

END
          1651-
          1652-
          1653-
          1654-
          1655-
          1656-
          1657-
          1658-
          1659-
          1660-
          1661-
          1662-
          1663-
          1664-
          1665-
          1666-
          1667-
          1668-
          1669-
          1670-
          1671-
          1672-
          1673-
          1674-
          1675-
          1676-
          1677-
          1678-
          1679-
          1680-
          1681-
          1682-
          1683-
          1684-
          1685-
          1686-
          1687-
          1688-
          1689-
          1690-
          1691-
          1692-
          1693-
          1694-
          1695-
          1696-
          1697-
          1698-
          1699-
          1700-
          1701-
          1702-
          1703-
          1704-
          1705-
          1706-
          1707-
          1708-
          1709-
          1710-
          1711-
          1712-
          1713-
          1714-
          1715-
          1716-
          1717-
          1718-
          1719-
          1720-
          1721-
          1722-
          1723-
          1724-
          1725-
          1726-
          1727-
          1728-
          1729-
          1730-
          1731-
          1732-
          1733-
          1734-
          1735-
          1736-
          1737-
          1738-
          1739-
          1740-
          1741-
          1742-
          1743-
          1744-
          1745-
          1746-
          1747-
          1748-
          1749-
          1750-
          1751-
          1752-
          1753-
          1754-
          1755-
          1756-
          1757-
          1758-
          1759-
          1760-
          1761-
          1762-
          1763-
          1764-
          1765-
          1766-
          1767-
          1768-
          1769-
          1770-
          1771-
          1772-
          1773-
          1774-
          1775-
          1776-
          1777-
          1778-
          1779-
          1780-
          1781-
          1782-
          1783-
          1784-
          1785-
          1786-
          1787-
          1788-
          1789-
          1790-
          1791-
          1792-
          1793-
          1794-
          1795-
          1796-
          1797-
          1798-
          1799-
          1800-
          1801-
          1802-
          1803-
          1804-
          1805-
          1806-
          1807-
          1808-
          1809-
          1810-
          1811-
          1812-
          1813-
          1814-
          1815-
          1816-
          1817-
          1818-
          1819-
          1820-
          1821-
          1822-
          1823-
          1824-
          1825-
          1826-
          1827-
          1828-
          1829-
          1830-
          1831-
          1832-
          1833-
          1834-
          1835-
          1836-
          1837-
          1838-
          1839-
          1840-
          1841-
          1842-
          1843-
          1844-
          1845-
          1846-
          1847-
          1848-
          1849-
          1850-
          1851-
          1852-
          1853-
          1854-
          1855-
          1856-
          1857-
          1858-
          1859-
          1860-
          1861-
          1862-
          1863-
          1864-
          1865-
          1866-
          1867-
          1868-
          1869-
          1870-
          1871-
          1872-
          1873-
          1874-
          1875-
          1876-
          1877-
          1878-
          1879-
          1880-
          1881-
          1882-
          1883-
          1884-
          1885-
          1886-
          1887-
          1888-
          1889-
          1890-
          1891-
          1892-
          1893-
          1894-
          1895-
          1896-
          1897-
          1898-
          1899-
          1900-
          1901-
          1902-
          1903-
          1904-
          1905-
          1906-
          1907-
          1908-
          1909-
          1910-
          1911-
          1912-
          1913-
          1914-
          1915-
          1916-
          1917-
          1918-
          1919-
          1920-
          1921-
          1922-
          1923-
          1924-
          1925-
          1926-
          1927-
          1928-
          1929-
          1930-
          1931-
          1932-
          1933-
          1934-
          1935-
          1936-
          1937-
          1938-
          1939-
          1940-
          1941-
          1942-
          1943-
          1944-
          1945-
          1946-
          1947-
          1948-
          1949-
          1950-
          1951-
          1952-
          1953-
          1954-
          1955-
          1956-
          1957-
          1958-
          1959-
          1960-
          1961-
          1962-
          1963-
          1964-
          1965-
          1966-
          1967-
          1968-
          1969-
          1970-
          1971-
          1972-
          1973-
          1974-
          1975-
          1976-
          1977-
          1978-
          1979-
          1980-
          1981-
          1982-
          1983-
          1984-
          1985-
          1986-
          1987-
          1988-
          1989-
          1990-
          1991-
          1992-
          1993-
          1994-
          1995-
          1996-
          1997-
          1998-
          1999-
          2000-
          2001-
          2002-
          2003-
          2004-
          2005-
          2006-
          2007-
          2008-
          2009-
          2010-
          2011-
          2012-
          2013-
          2014-
          2015-
          2016-
          2017-
          2018-
          2019-
          2020-
          2021-
          2022-
          2023-
          2024-
          2025-
          2026-
          2027-
          2028-
          2029-
          2030-
          2031-
          2032-
          2033-
          2034-
          2035-
          2036-
          2037-
          2038-
          2039-
          2040-
          2041-
          2042-
          2043-
          2044-
          2045-
          2046-
          2047-
          2048-
          2049-
          2050-
          2051-
          2052-
          2053-
          2054-
          2055-
          2056-
          2057-
          2058-
          2059-
          2060-
          2061-
          2062-
          2063-
          2064-
          2065-
          2066-
          2067-
          2068-
          2069-
          2070-
          2071-
          2072-
          2073-
          2074-
          2075-
          2076-
          2077-
          2078-
          2079-
          2080-
          2081-
          2082-
          2083-
          2084-
          2085-
          2086-
          2087-
          2088-
          2089-
          2090-
          2091-
          2092-
          2093-
          2094-
          2095-
          2096-
          2097-
          2098-
          2099-
          2100-
          2101-
          2102-
          2103-
          2104-
          2105-
          2106-
          2107-
          2108-
          2109-
          2110-
          2111-
          2112-
          2113-
          2114-
          2115-
          2116-
          2117-
          2118-
          2119-
          2120-
          2121-
          2122-
          2123-
          2124-
          2125-
          2126-
          2127-
          2128-
          2129-
          2130-
          2131-
          2132-
          2133-
          2134-
          2135-
          2136-
          2137-
          2138-
          2139-
          2140-
          2141-
          2142-
          2143-
          2144-
          2145-
          2146-
          2147-
          2148-
          2149-
          2150-
          2151-
          2152-
          2153-
          2154-
          2155-
          2156-
          2157-
          2158-
          2159-
          2160-
          2161-
          2
```

END Input DATA

TOPILE CONTROL IS FINISHED. COMPLETION CODE - SYSTEM 000 USER 0000. CPU TIME USED 265.05 (SECONDS). I/O'S USED 1-00.

Detailed Printout starts

LASTIN - STANDARD DEBT RCDLE APRIL 29, 1981 - QUALITY ASSURANCE LEVEL 0

CASE TITLE - TWO-TH SAMPLE PROBLEM, PURELY 1D WITH PNEUMATIC THERMAL HYDRAULICS

[illegible]

Several
pages
deleted

Table 12. (Continued)

1.400000E-07	7.041720E-07	7.18322E-06	1.90791E-08	1.35321E-09	6.51031E-10	1057.	CARD	1435
2.49305E-07	5.42312E-09	1.10430E-07	5.186220E-04	0.0	1.000000E-05	1058.	CARD	1436
2.18716E-07	2.36162E-04	0.0	3B	2.01720E-05		1059.	CARD	1437
0.0		1.49919E-05	0.0	3B	4.37960E-02	1060.	CARD	1438
0.0	10R	1.36200E-04	0.0	18R	5.18020E-04	1061.	CARD	1439
0.0	1.00000E-09	0.0	2.36162E-04	0.0	3B	1062.	CARD	1440
2.31720E-05	0.0	4R	1.49919E-05	0.0	3B	1063.	CARD	1441
4.37960E-02	0.0	10R	1.36200E-04	0.0	18R	1064.	CARD	1442
5.18020E-04	0.0	1.00000E-09	0.0	2.36162E-04		1065.	CARD	1443
0.0	3B	2.01720E-05	0.0	4R	1.49919E-06	1066.	CARD	1444
0.0	3B	5.37960E-02	0.0	10R	1.36200E-04	1067.	CARD	1445
0.0	18R	5.18020E-04	0.0	1.00000E-09	0.0	1068.	CARD	1446
2.36162E-04	0.0	3B	2.01720E-05	0.0	4R	1069.	CARD	1447
1.49919E-06	0.0	3B	4.37960E-02	0.0	10R	1070.	CARD	1448
1.36200E-04	0.0	18R	5.18020E-04	0.0	1.00000E-09	1071.	CARD	1449
0.0	2.36162E-04	0.0	3B	2.01720E-05		1072.	CARD	1450
0.0	4R	1.49919E-06	0.0	3B	4.37960E-02	1073.	CARD	1451
0.0	10R	1.36200E-04	0.0	18R	5.18020E-04	1074.	CARD	1452
0.0	1.00000E-09	0.0	2.36162E-04	0.0	3B	1075.	CARD	1453
2.31720E-05	0.0	3B	1.49919E-06	0.0	3B	1076.	CARD	1454
4.37960E-02	0.0	10R	1.36200E-04	0.0	18R	1077.	CARD	1455
5.18020E-04	0.0	1.00000E-09	0.0	2.36162E-04		1078.	CARD	1456
0.0	3B	2.01720E-05	0.0	4R	1.49919E-06	1079.	CARD	1457
0.0	3B	4.37960E-02	0.0	10R	1.36200E-04	1080.	CARD	1458
0.0	18R	5.18020E-04	0.0	1.00000E-09	0.0	1081.	CARD	1459
2.36162E-04	0.0	3B	2.01720E-05	0.0	4R	1082.	CARD	1460
1.49919E-06	0.0	3B	4.37960E-02	0.0	10R	1083.	CARD	1461
1.36200E-04	0.0	18R	5.18020E-04	0.0	1.00000E-09	1084.	CARD	1462
0.0	18R	1.50600E-02	0.0	30R	1.26000E-03	1085.	CARD	1463
0.0	15R	8.03700E-02	0.0	46R	7.02600E-02	1086.	CARD	1464
0.0	33R					1087.	CARD	1465
STOP						1088.	CARD	1466

SUMMARY OF FILMS PROCESSED

FILE NAME	LOGICAL UNIT	VERSION
CMRPG2	11	1
CMRPG2	12	1
CMRPG4	13	1

DATA FILE MANAGEMENT TABLES

LOGICAL UNIT	FILE NAME	VERSION	INC	REF DATA
9		0	1	1
10	CONTROL	1	1	1
11	GROUPS	1	1	1
12	EXPOSE	1	1	1
13	ZBATCH	1	1	1
99		0	1	1

TOTAL CPU TIME USED	0.094 MINUTES	TOTAL CLOCK TIME USED	0.723 MINUTES	TOTAL I/O USED	151
---------------------	---------------	-----------------------	---------------	----------------	-----

NORMAL END OF STANDARD INPUT MODULE

DVENTR - SPECIAL INPUT PCFILE - JANUARY 17, 1979 - QUALITY ASSURANCE LEVEL 0

CASE TITLE - THR-TH SAMPLE PROBLEMS, PIPELINE FEE THEN PHYSIC THERMAL HYDRAULICS

PPASNY	140700	0	0	0	0	0	1	0	0	0	0	1
--------	--------	---	---	---	---	---	---	---	---	---	---	---

INPUT SECTION 1

DATE	DESCRIPTION	AMOUNT	CHECK NO.	CHECK TYPE	DEBIT	CREDIT	BALANCE	DATE	DESCRIPTION	AMOUNT	CHECK NO.	CHECK TYPE	DEBIT	CREDIT	BALANCE
12/01/00	OPENING BALANCE	0.00					0.00	12/01/00	DEPOSIT	100.00	100				100.00
12/02/00	PAYROLL	50.00			50.00		50.00	12/02/00	DEPOSIT	50.00	101				100.00
12/03/00	RENT	25.00			25.00		75.00	12/03/00	DEPOSIT	25.00	102				100.00
12/04/00	UTILITIES	10.00			10.00		65.00	12/04/00	DEPOSIT	35.00	103				100.00
12/05/00	SALES	100.00				100.00	165.00	12/05/00	DEPOSIT	100.00	104				265.00
12/06/00	PAYROLL	50.00			50.00		115.00	12/06/00	DEPOSIT	50.00	105				265.00
12/07/00	RENT	25.00			25.00		90.00	12/07/00	DEPOSIT	25.00	106				265.00
12/08/00	UTILITIES	10.00			10.00		80.00	12/08/00	DEPOSIT	10.00	107				265.00
12/09/00	SALES	100.00				100.00	180.00	12/09/00	DEPOSIT	100.00	108				360.00
12/10/00	PAYROLL	50.00			50.00		130.00	12/10/00	DEPOSIT	50.00	109				360.00
12/11/00	RENT	25.00			25.00		105.00	12/11/00	DEPOSIT	25.00	110				360.00
12/12/00	UTILITIES	10.00			10.00		95.00	12/12/00	DEPOSIT	10.00	111				360.00
12/13/00	SALES	100.00				100.00	195.00	12/13/00	DEPOSIT	100.00	112				460.00
12/14/00	PAYROLL	50.00			50.00		145.00	12/14/00	DEPOSIT	50.00	113				460.00
12/15/00	RENT	25.00			25.00		120.00	12/15/00	DEPOSIT	25.00	114				460.00
12/16/00	UTILITIES	10.00			10.00		110.00	12/16/00	DEPOSIT	10.00	115				460.00
12/17/00	SALES	100.00				100.00	210.00	12/17/00	DEPOSIT	100.00	116				560.00
12/18/00	PAYROLL	50.00			50.00		160.00	12/18/00	DEPOSIT	50.00	117				560.00
12/19/00	RENT	25.00			25.00		135.00	12/19/00	DEPOSIT	25.00	118				560.00
12/20/00	UTILITIES	10.00			10.00		125.00	12/20/00	DEPOSIT	10.00	119				560.00
12/21/00	SALES	100.00				100.00	225.00	12/21/00	DEPOSIT	100.00	120				660.00
12/22/00	PAYROLL	50.00			50.00		175.00	12/22/00	DEPOSIT	50.00	121				660.00
12/23/00	RENT	25.00			25.00		150.00	12/23/00	DEPOSIT	25.00	122				660.00
12/24/00	UTILITIES	10.00			10.00		140.00	12/24/00	DEPOSIT	10.00	123				660.00
12/25/00	SALES	100.00				100.00	240.00	12/25/00	DEPOSIT	100.00	124				760.00
12/26/00	PAYROLL	50.00			50.00		190.00	12/26/00	DEPOSIT	50.00	125				760.00
12/27/00	RENT	25.00			25.00		165.00	12/27/00	DEPOSIT	25.00	126		</		

OTNINE RECORD ADDED TO FILE CONTROL

INPUT SECTION 3

7 1 2 2 2 C 0 0 0 0 0 0 0 0 6 C 0 C
JENNER-RT MO. 7 J-D R-Z
PSJ 0.0
IWRN 1
BNC 0.0 4.492070E-01 4.692000E-01 4.642370E-01 5.5999991 29 9.449995E 29
RNDI 4.492000E-01

Table 12. (Continued)

INPUT SECTION 4

```

SHORT REQUIRED 1849
RSHJ/ISMJ 3 1.000000 02 3 4.100000 01 4 5.000000 01 4 6.500000 01 3 3.000000 01 3 3.300000 01
RSHJ/ISMJ 3 3.700000 01 3 3.300000 01 3 3.000000 01 2 1.200000 01 4 8.000000 01
RSHI/ISHI 5 1.600000 02 3 2.800000 01 2 1.200000 01 2 3.055560 01 2 3.055560 01 2 3.055560 01
RSHI/ISHI 2 3.055560 01 2 3.055560 01 2 3.055560 01 2 3.055560 01 2 3.055560 01 2 3.055560 01
RSHI/ISHI 2 3.055560 01 2 3.055560 01 2 3.055560 01 2 1.200000 01 4 8.000000 01
RSHK/ISHK 1 1.000000 00
KRESH 0.0 1.000000 02 1.410000 02 1.990000 02 2.400000 02 2.820000 02 3.150000 02 3.520000 02
KRESH 3.850000 02 4.150000 02 4.270000 02 5.150000 02
KRESH 0.0 1.600000 02 1.800000 02 2.000000 02 2.305556 02 2.611112 02 2.916668 02 3.222224 02
KRESH 3.527780 02 3.833336 02 4.138892 02 4.444448 02 4.750000 02 5.055560 02 5.361116 02 5.666672 02
KRESH 5.972220 02 6.277780 02 6.583340 02 6.888896 02 7.194452 02 7.500008 02 7.800000 02 8.100000 02
KRESH 0.0 1.000000 00

```

```

BOBSEY NO. 7
J/XI 1 0.0 2 57.7350 3 41.4897 4 100.0000 5 115.2982 6 128.7918 7 141.0000 8 157.5131
J/XI 0 172.8548 10 188.7017 11 203.1544 12 217.2128 13 230.8768 14 244.1456 15 257.2910
J/XI 17 269.9284 18 282.0000 19 293.4127 20 304.3970 21 315.0000 22 327.7977 23 340.1182 24 352.0000
J/XI 25 363.3332 26 374.3234 27 385.0600 28 395.2531 29 405.2460 30 415.0000 31 424.0020 32 427.0000
J/XI 33 450.6180 34 473.0507 35 494.4704 36 515.0000 37 534.0000 38 551.0000 39 566.0000 40 580.0000
I/YI 1 0.0 2 32.0000 3 65.6000 4 99.2000 5 131.2000 6 164.0000 7 172.0000 8 188.0000
I/YI 9 188.0000 10 19.0000 11 200.0000 12 215.2770 13 230.5556 14 245.8334 15 261.1112 16 276.3890
I/YI 17 291.6668 18 306.9444 19 322.2220 20 337.5002 21 352.7780 22 368.0556 23 383.3336 24 398.6110
I/YI 25 413.8892 26 429.1670 27 444.4444 28 459.7226 29 475.0000 30 490.2782 31 505.5560 32 520.8330
I/YI 33 536.1116 34 551.3890 35 566.6672 36 581.9440 37 597.2220 38 612.5006 39 627.7784 40 643.0562
I/YI 41 658.3340 42 673.6118 43 688.8896 44 704.1670 45 719.4452 46 734.7230 47 750.0008 48 756.0000
I/YI 49 762.0000 50 784.0000 51 806.0000 52 828.0000
R/XI 1 0.0 2 1.0000
R/XI 1 40.8248 2 70.7107 3 91.2871 4 107.9205 5 122.2313 6 135.0339 7 149.4050 8 165.1545
R/XI 9 179.4603 10 192.7070 11 206.1655 12 216.9715 13 228.1674 14 238.8391 15 250.7336 16 263.6054
R/XI 17 276.0702 18 287.7629 19 298.9577 20 309.7842 21 321.4425 22 333.0127 23 344.1081 24 357.7115
R/XI 25 368.6692 26 379.6992 27 390.1602 28 400.2812 29 410.1524 30 419.8323 31 429.0310 32 438.9658
R/XI 33 447.9486 34 457.8791 35 467.8356 36 477.8000 37 487.8000 38 497.8000 39 507.8000 40 517.8000
I/YI 1 16.4000 2 49.2000 3 82.0000 4 114.0000 5 147.0000 6 168.0000 7 176.0000 8 184.0000
I/YI 9 191.0000 10 197.0000 11 207.6389 12 222.9167 13 238.1945 14 253.4723 15 268.7501 16 284.0279
I/YI 17 299.7057 18 314.9835 19 329.8613 20 344.7391 21 359.6169 22 374.4947 23 389.3725 24 404.2503
I/YI 25 421.5241 26 436.4019 27 451.2807 28 466.1585 29 481.0363 30 495.9141 31 510.7919 32 525.6697
I/YI 33 543.7505 34 558.6283 35 573.5061 36 588.3839 37 603.2617 38 618.1395 39 633.0173 40 647.8951
I/YI 41 665.9729 42 681.2507 43 696.5285 44 711.8063 45 727.0841 46 742.3619 47 757.6397 48 755.0000
R/XI 1 0.0000

```

R. OUT REQUIRED 3956

INPUT SECTION 5

LONG INPUT BY REGION

```

LAYER NUMBER 1
153 153 153 153 153 153 153 153 153 153 154 154
153 153 153 153 153 153 153 153 153 153 154 154
153 153 153 153 153 153 153 153 153 153 154 154
1 1 19 37 55 73 91 109 127 145 154
2 2 20 38 56 74 92 110 128 146 154
3 3 21 39 57 75 93 111 129 147 154
4 4 22 40 58 76 94 112 130 148 154
5 5 23 41 59 77 95 113 131 149 154
6 6 24 42 60 78 96 114 132 150 154
7 7 25 43 61 79 97 115 133 151 154
8 8 26 44 62 80 98 116 134 152 154
9 9 27 45 63 81 99 117 135 153 154
10 10 28 46 64 82 100 118 136 154 154
11 11 29 47 65 83 101 119 137 155 154
12 12 30 48 66 84 102 120 138 156 154
13 13 31 49 67 85 103 121 139 157 154
14 14 32 50 68 86 104 122 140 158 154
15 15 33 51 69 87 105 123 141 159 154
16 16 34 52 70 88 106 124 142 160 154
17 17 35 53 71 89 107 125 143 161 154
18 18 36 54 72 90 108 126 144 162 154
155 155 155 155 155 155 155 155 155 155 154 154
155 155 155 155 155 155 155 155 155 155 154 154

```

INPUT SECTION 12

```

RSE 0
1 104 1 1 6.000000E-01
104 152 1 4 1.000000E 00
153 153 1 2 1.000000E 00
154 154 1 3 1.000000E 00
155 155 1 4 1.000000E 00
0 0 0 0 0.0

```

REGION VOL SUM 7.082851D 08 SOME VOL SUM 7.082846D 08

MEMORY REQUIRED 5245

INTERFACE FILE GHOST HAS BEEN WRITTEN ON UNIT 14

A PLUS - EISENVALDE PEOPLE FOLLOWS
4 INNERS MIN, 4 INNERS MAX - CHERYCHIV PETA ON INNERS

12	997380	13	3.3e5390	13	1.4e2620	13	0.9	9.258e50-01	0.007700-01	9.25650-01	9.995520-01	1.4e03e0-C3	
12	1	1	0	-0.138575-01	0.025167	0.0	1.00000	C.60813	C.60813	0.0	7.67903E	0.9979767	C.5887930
13	1	1	0	7.566237E	0.0	0.0	1.00000	C.66667	C.66667	0.0	7.65513E	0.997351E	
14	1	1	0	2.425130 00	0.0	0.0	1.00000	1.55319	0.0	1.76534E	0.997778E	0.9999902	
15	1	1	0	2.400427E	0.0	1.00000	2.19190	1.00000	0.0	0.36232	7.70096E	0.99701955	
16	1	1	0	2.566630E	0.0	0.70566	2.33436	1.00000	0.0	0.39573	7.60096E	0.99771196	
17	1	1	0	2.007207E	0.0	0.81403	17.67630	1.00000	0.0	0.29432	7.65509E	0.9959247	
18	1	1	1	4.0906160 00	0.66666	0.0	2.24596	1.00000	0.0	1.4973	0.28560E	0.66232E	0.99535013
19	0	1	0	3.47784E	0.0	0.0	7.3	1.00000	0.0	1.59829	7.60501E	0.9980106E	C.597598E
20	1	1	0	2.317525 00	0.0	0.0	0.0	1.00000	C.55039	0.0	7.67703E	0.9972566E	
21	1	0	0	5.596190 00	0.0	0.0	1.00000	C.81861	0.0	0.17002	7.67563E	0.997715E	
22	1	1	0	3.770070 00	1.00000	0.0	2.97032	1.00000	C.61861	0.0	0.17002	7.67535E	0.9973788E
23	1	1	0	2.422970 00	0.83432	1.76537	7.00000	C.81861	C.17002	0.0	7.67672E	0.997666E	
24	1	0	0	3.197695 00	0.73673	3.13113	1.00000	C.81861	0.0	0.17002	7.67673E	0.997626E	
25	1	1	0	7.653250-01	0.70785	0.00731	1.00000	C.81861	0.0	0.17002	7.67673E	0.997500E	
26	1	1	0	0.18160E	C.72735E	3.14076	1.00000	C.81861	0.0	0.17002	7.67673E	0.997606E	
27	2	1	0	1.167955 01	0.0	0.0	1.00000	1.00000	0.0	2.67569	7.67706E	0.997687E	C.597486E
28	1	0	0	3.510770-01	0.0	0.0	1.00000	C.38514	0.0	0.0	7.67744E	0.997766E	
29	1	0	0	-1.876970-01	0.0	0.0	1.00000	0.00545	0.0	C.77955	7.67714E	0.997693E	
30	1	0	0	0.000450-02	0.52738	0.52738	1.00000	0.00588	0.0	C.77995	7.67711E	0.997745E	
31	1	0	0	-0.181325-02	0.97780	3.04479	1.00000	C.00588	0.0	0.07995	7.67714E	0.997741E	
32	1	1	0	-2.718767-02	0.82352	2.81690	1.00000	C.00588	0.0	C.77995	7.67717E	0.997693E	
33	1	1	0	1.734957-02	0.82218	0.68016	0.0	C.00588	0.0	C.77995	7.67719E	0.997744E	
34	2	1	0	-1.457205-02	1.51112	0.53193	1.0	3.66509	2.1235	0.0	7.67723E	0.997765E	
35	0	1	0	2.213447-02	0.0	0.0	1.00000	1.00000	-2.55496	0.0	7.67749E	0.997756E	C.597500E
36	1	1	0	-2.943000-03	0.0	0.0	1.00000	C.67428	0.0	C.67428	0.0	0.0	0.997500E
37	1	1	0	1.57252-03	0.0	0.0	1.00000	C.67428	0.0	0.0	0.0	0.0	0.997500E
38	1	1	0	1.18979E-03	C.76324	3.77032	1.00000	0.0	0.0	0.0	0.0	0.0	0.997500E
39	1	1	0	2.239403-03	C.76324	1.11131	1.00000	C.67428	0.0	0.0	0.0	0.0	0.997500E
40	1	1	0	1.256405-03	0.15126	0.15126	1.00000	C.67428	0.0	0.0	0.0	0.0	0.997500E
41	1	1	0	-1.38137E-03	C.84247	1.35354	1.00000	C.67428	0.0	0.0	0.0	0.0	0.997500E
42	1	0	0	1.28016E-03	0.84152	0.15512	0.0	0.67696	0.0	0.0	0.0	0.0	0.997500E
43	0	0	0	9.27045E-04	1.51617	0.11170	0.0	0.76612	2.66611	0.0	7.67744E	0.997766E	
44	0	1	0	-1.12267E-03	0.0	0.0	1.00000	1.00000	-2.52691	0.0	7.67724E	0.997766E	C.597500E
45	1	0	0	1.12111E-04	0.0	0.0	1.00000	C.53251	0.0	0.0	7.67724E	0.997766E	
46	1	0	0	-8.45117E-05	0.0	0.0	1.00000	C.77303	0.0	0.0	7.67724E	0.997766E	

ESTIMATE TO ABSOLUTE POINT FROM RELATIVE PROPOS 1.26957D-30

2.047612E 13	2.337232E 13	1.917872E 13	1.546472E 13	1.253272E 13	1.013392E 13	8.196170E 12	6.604682E 12	5.086770E 12
9.596292E 13	1.133112E 14	1.047372E 14	9.172592E 13	7.390402E 13	6.906762E 13	5.603602E 13	4.519992E 13	3.639922E 13
2.652122E 13	2.357672E 13	1.992372E 13	1.123502E 13	1.233782E 13	9.956712E 12	8.066152E 12	6.467582E 12	5.208022E 12
9.253232E 13	1.004722E 14	1.071992E 14	9.658092E 13	9.278322E 13	8.625732E 13	7.554992E 13	6.472002E 13	5.597002E 13
8.671002E 13	2.324272E 13	1.471012E 13	1.565432E 13	1.113502E 13	9.781302E 12	1.877362E 12	4.319512E 12	4.844702E 12
9.915122E 13	1.091502E 14	1.027832E 14	8.947052E 13	8.100362E 13	8.732482E 13	5.964212E 13	4.339482E 13	3.527762E 13
2.311122E 13	2.272172E 13	1.621752E 13	1.466772E 13	1.179692E 13	9.486552E 12	1.428282E 12	4.131132E 12	4.630032E 12
9.357632E 13	1.604594E 14	1.504086E 14	9.077492E 13	7.428252E 13	6.802198E 13	5.286922E 13	4.255492E 13	3.614742E 13
2.715402E 13	2.313202E 13	1.756172E 13	1.406662E 13	1.130602E 13	7.072332E 12	7.272052E 12	4.901682E 12	6.767282E 12
9.657292E 13	1.065642E 14	1.003042E 14	8.837272E 13	7.241862E 13	6.016422E 13	4.856252E 13	3.904602E 13	3.155402E 13
2.523292E 13	2.351542E 13	1.511122E 13	1.265172E 13	1.033242E 13	8.260002E 12	6.555092E 12	5.201112E 12	3.777102E 12
6.724362E 13	7.794362E 13	7.646432E 13	7.003162E 13	6.678332E 13	5.015982E 13	4.066482E 13	3.258732E 13	2.603702E 13
2.072552E 13	1.665172E 13	1.317032E 13	1.071692E 13	9.402892E 12	6.705202E 12	5.342252E 12	4.219972E 12	3.373202E 12
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.384602E 13	2.198112E 13							4.963292E 13

THE ELECTRIC POWER DENSITY IS AT PLANE 1, ROW 14, AND COLUMN 1 AND IS 1.686076420 01 WATTS/CC.

THE MAXIMUM NEUTRON DENSITY IS AT PLANE 1, ROW 17, AND COLUMN 1 AND IS 5.675785120 OB NEUTRONS/CC.

THE MAXIMUM POWER DENSITY (WATTS/CC) IN EACH TUBE IS

[illegible]

Table 12. (Continued)

THE RELATIVE POWER DENSITY TRAVERSE LEFT-TO-RIGHT IS

1.010000-00	9.949420-01	9.939850-01	9.905600-01	9.877760-01	9.841080-01	9.843580-01	9.806930-01	9.747770-01
9.647950-01	9.692190-01	9.615020-01	9.515800-01	9.445360-01	9.431720-01	9.296010-01	9.149250-01	9.102520-01
9.920310-01	8.741170-01	8.657560-01	8.388770-01	9.107350-01	7.950420-01	7.687300-01	7.409480-01	7.345930-01
7.276100-01	8.072260-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0

THE RELATIVE POWER DENSITY TRAVERSE TOP-TO-BOTTOM IS

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	8.253330-01	9.639650-01	9.085250-01	1.000000-00	8.843970-01	9.101750-01	7.772780-01	7.623580-01
5.477510-01	7.148010-01	5.239660-01	4.951010-01	4.291020-01	3.941400-01	3.461020-01	3.155340-01	2.792020-01
2.532520-01	2.242050-01	2.037200-01	1.816620-01	1.642920-01	1.470260-01	1.327210-01	1.190130-01	1.073950-01
9.647950-01	8.699160-02	7.917360-02	7.086640-02	6.335420-02	5.712210-02	5.145050-02	4.609480-02	4.308580-02
2.270700-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

POWER DENSITY INTERFACE FILE POINT (VERSION 1) HAS BEEN WRITTEN ON UNIT NUMBER 16 ← **Key Data**
 CORRECT USE OF CONTAINER ARRAYS, CONTROL 11, MAX DATA 83680
 TOTAL CPU MINUTES USED 0.970 TOTAL CLOCK MINUTES USED 7.161 TOTAL I/O USED 356

BURNER - EXPOSURE NOCULE - PRE-RELEASE VERSION 10 - AUGUST 20, 1979 - QUALITY ASSURANCE LEVEL 0

CASE TITLE - TYP-TH SAMPLE PROBLEMS, PEBBLE BED THERM PRISMATIC THERMAL HYDRAULICS

FILE CONTAINED ARRAYS, CONTROL 6 DATA 1

TITLE OF THE LATEST VERSION CROSS SECTION FILE
 EXOP SAME AS EXOS PLUS MP-237, LESS BE-135

METHOD OF SOLUTION - EXPLICIT CHAIN

THE LONGEST EXPLICIT CHAIN IS 16

CONTINUOUS FUELING MODEL

FALSE ZONE NUMBER CONTAINING FUEL MATERIAL COMPOSITION FOR ZONE PATHS	145
NUMBER OF ZONE PATHS THROUGH THE REACTOR	8
NUMBER OF ZONES ALONG EACH ZONE PATH	18
ZONE FUEL OPTION	1 ZONE 145 THROUGH ZONE 152

MAXIMUM ARRAY SIZE USED FOR INITIAL PROCESSING IS 2568

STORAGE REQUIRED FOR BASIC DATA IS 2568

STORAGE SUPPLIED IS	143000
MAXIMUM STORAGE REQUIRED IS	62805
MINIMUM STORAGE REQUIRED IS	12139

MODEL = 0 MODREF = -1

MEMORY ACTUALLY USED WILL BE 62805

NEXT-TO-LATEST VERSION REFLEX NOT AVAILABLE FOR TOWER FLUX APPROXIMATION

EXPOSURE TIME STEP STARTS AT 2.726720E 04 DAYS

EXPOSURE TIME STEP IS 1.100000E 01 DAYS (9.500000E 07 SECONDS) THE NUMBER OF PASSES IS 2

REFERENCE POWER 1.439999E 09 WATTS

AVERAGE POWER	1.631843E 09 WATTS FOR PASS 1
MAXIMUM AVERAGE POWER DENSITY	2.657707E 01 WATTS/CC IN ZONE 2

INITIAL FRACTION RATE WILL BE MULTIPLIED BY 1.003767E 00 FOR NEXT PASS 1.003766E 00

REFERENCE POWER LEVEL HAS BEEN ATTAINED

POWER DENSITIES FOR ZONE PATH 1

TH-232	2.361620E-04	U-235	2.017194E-05	U-238	1.495188E-04	C	8.379596E-02
HE	1.361999E-04	0	5.140191E-04	MOXVEL	5.555925E-10		

FUEL AND DISCHARGE RATES (KILOGRAMS PER DAY) BY ABSOLUTE NUCLEON

NO.	NAME	MOVING ZONES		STATIONARY ZONES	
		FUEL	DISCHARGE	FUEL	DISCHARGE
1	HE	1.468341E-01	1.468341E-01	0.0	0.0
2	C	2.71010E 02	2.71010E 02	4.61563E 02	4.61563E 02
3	MOXVEL	0.0	1.55445E-04	0.0	0.0
4	U-235	0.0	2.08455E-04	0.0	0.0
5	U	1.10910E 00	1.10910E 00	0.0	0.0
6	MOXVEL	0.0	0.0	0.0	0.0
7	CONVARS	0.0	0.0	0.0	0.0
8	U-238	0.0	1.64128E-04	0.0	0.0
9	C-133	0.0	4.95491E-02	0.0	0.0
10	CO-139	0.0	5.40000E-01	0.0	0.0

Table 12. (Continued)

11 CS-135	0.0	6.03523E-03	0.0	0.0
12 PS-147	0.0	5.69152E-03	0.0	0.0
13 PR-149	0.0	1.62370E-05	0.0	0.0
14 PP-144	0.0	6.01665E-04	0.0	0.0
15 SR-109	0.0	2.17610E-05	0.0	0.0
16 SN-151	0.0	2.75981E-04	0.0	0.0
17 RN-153	0.0	3.53250E-03	0.0	0.0
18 T-236	0.0	.87777E-01	0.0	0.0
19 PU-242	0.0	.05479E-03	0.0	0.0
20 AN-243	0.0	2.73460E-04	0.0	0.0
21 PP-2	0.0	1.05429E-00	0.0	0.0
22 PP-1	0.0	2.44652E-01	0.0	0.0
23 TN-232	1.67660E 01	1.36159E 01	0.0	0.0
24 U-233	0.0	3.15810E-01	0.0	0.0
25 U-234	0.0	8.89637E-02	0.0	0.0
26 U-235	1.27763E 00	6.94989E-02	0.0	0.0
27 BP-239	0.0	5.20177E-06	0.0	0.0
28 PR-149	0.0	8.80072E-06	0.0	0.0
29 KN-82	0.0	2.27957E-03	0.0	0.0
30 KN-83	0.0	3.17131E-03	0.0	0.0
31 AN-105	0.0	7.56826E-03	0.0	0.0
32 AN-105	0.0	1.08468E-07	0.0	0.0
33 AT-109	0.0	2.15166E-04	0.0	0.0
34 XE-131	0.0	1.72050E-02	0.0	0.0
35 XE-133	0.0	8.56788E-05	0.0	0.0
36 AN-103	0.0	2.75512E-02	0.0	0.0
37 WD-145	0.0	3.02660E-02	0.0	0.0
38 SN-150	0.0	1.43999E-02	0.0	0.0
39 SN-152	0.0	4.95727E-03	0.0	0.0
40 SN-154	0.0	1.04900E-03	0.0	0.0
41 SN-155	0.0	1.09563E-04	0.0	0.0
42 PA-233	0.0	5.47659E-03	0.0	0.0
43 T-239	9.61460E-02	7.78335E-02	0.0	0.0
44 PH-239	0.0	8.57257E-06	0.0	0.0
45 PT-240	0.0	6.63074E-04	0.0	0.0
46 PT-241	0.0	4.76806E-04	0.0	0.0
47 AP-237	0.0	1.97545E-02	0.0	0.0
FISSILE	1.27763E 00	3.92192E-01	0.0	0.0

POWER (WATTS) FOR EACH ZONE PATH

1) 2.075405E 08 2) 2.030138E 08 3) 2.022753E 08 4) 1.992508E 08 5) 1.970198E 08
 6) 2.281097E 08 7) 2.052765E 08 8) 1.949588E 08

TOTAL POWER (WATTS) FOR ZONE PATHS 1.637777E 09

SUMMARY TABLE FOR ZIRCONIUM FUELING AT TIME 2.036720E 04 DAYS
 FOR CASE THERM SAMPLE FUELLETS, PZBBLE BIC THERM FRICTIONAL THERMAL HYDRAULICS

AVERAGE NEUTRON LOSSES BY NUCLIDE CLASS AND ZONE CLASS - SYSTEM LOSS RATE 1.292059E 10 W/S2C

ZONE CLASS	FISSILE	FERTILE	C. ACTINIDE	FISSION PROD	STRUCTURAL
ID.	1	2	3	4	5
1	0.846110E	7.242423E	0.012224E	0.100572E	0.025707E
2	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.036985E
4	0.0	0.0	0.0	0.0	0.015653E
5	0.0	0.0	0.0	0.0	0.000700E
SUM	0.846110E	0.242423E	0.012224E	0.100572E	0.079051E

ZONE CLASS	ABSORPTION	EFFECTIVE CONVERSION RATIO	POWER (WATTS)
ID.	LOSS	REACTION RATE	
1	0.947118E	0.57940	1.637777E 09
2	0.0	0.0	0.0
3	0.016699E	0.0	0.0
4	0.016693E	0.0	0.0
5	0.000700E	0.0	0.0
OVERALL	0.963142E	0.57940	1.637777E 09
OTHER LOSSES	0.036818E		
TOTAL LOSSES	1.000000E		

EFFECTIVE CONVERSION RATIO FROM MASS BALANCE 0.58045

FISSILE INVENTORY IS 6.288795E 02 KG

FISSILE CONSUMPTION PER UNIT ENERGY GENERATION IS 1.497562E-14 KG/WATT-SEC
 FISSILE CONSUMPTION RATE IS 2.442801E-05 KG/SEC

INTERFACE FILE ZNATHN VERSION 1 (OLD) HAS BEEN WRITTEN ON UNIT 13 WITH DENSITIES AT TIME 2.036720E 04 DAYS.
 DENSITIES WRITTEN = X2 * P(X1) * X2
 WHERE X2 = END OF EXPOSURE DENSITIES, X1 = START OF EXPOSURE DENSITIES, AND P = 0.2200

POWER COMPUTED FROM POWER DENSITY 1.637777E 09

INTERFACE FILE ZNATHN VERSION 1 (NEW) HAS BEEN WRITTEN ON UNIT 19

INTERFACE FILE ZNATHN VERSION 1 (NEW) HAS BEEN WRITTEN ON UNIT 20

0.0333 0.027 0.782 0.793 0.004
0.0611 0.737 0.697 0.702 0.715
0.0809 0.657 0.622 0.627 0.635
0.0967 0.587 0.553 0.557 0.563
0.0988 0.530 0.487 0.458 0.502
0.0722 0.498 0.459 0.454 0.454
1.0000 0.488 0.446 0.437 0.435

GUESS DEL P (ATM) 6.27660-01 AT DENSITY 1.55120 00 VOLUME 2.17580 00, MASS FLOW (KG/SEC) 6.28000 02 POWER (W) 1.65670 09

MAXIMUM INITIALIZED FUEL FLUID AND PIECE TEMPERATURE (C) 931.44 535.96 APPARENT PRESSURE DROP (ATM) 0.6725

INITIALIZATION OF PROBLEM COMPLETE, START ITERATION CONVERGENCE DATA FOLLOWS

PROCESSOR TIME (SEC) AT START OF ITERATION 1.06 ---CORE/ELEMENTS 1.3032 6.7080 1.0000 1.4532 MAX IT 170

ITERATION	VARIABLE	CHANGE (%)	DEL T	DEL P	DEL H	DEL S	DEL E	DEL F	DEL G	DEL I	DEL J	DEL K	DEL L	DEL M	DEL N	DEL O	DEL P	DEL Q	DEL R	DEL S	DEL T	DEL U	DEL V	DEL W	DEL X	DEL Y	DEL Z	DEL A	DEL B	DEL C	DEL D	DEL E	DEL F	DEL G	DEL H	DEL I	DEL J	DEL K	DEL L	DEL M	DEL N	DEL O	DEL P	DEL Q	DEL R	DEL S	DEL T	DEL U	DEL V	DEL W	DEL X	DEL Y	DEL Z	DEL A	DEL B	DEL C	DEL D	DEL E	DEL F	DEL G	DEL H	DEL I	DEL J	DEL K	DEL L	DEL M	DEL N	DEL O	DEL P	DEL Q	DEL R	DEL S	DEL T	DEL U	DEL V	DEL W	DEL X	DEL Y	DEL Z	DEL A	DEL B	DEL C	DEL D	DEL E	DEL F	DEL G	DEL H	DEL I	DEL J	DEL K	DEL L	DEL M	DEL N	DEL O	DEL P	DEL Q	DEL R	DEL S	DEL T	DEL U	DEL V	DEL W	DEL X	DEL Y	DEL Z	DEL A	DEL B	DEL C	DEL D	DEL E	DEL F	DEL G	DEL H	DEL I	DEL J	DEL K	DEL L	DEL M	DEL N	DEL O	DEL P	DEL Q	DEL R	DEL S	DEL T	DEL U	DEL V	DEL W	DEL X	DEL Y	DEL Z	DEL A	DEL B	DEL C	DEL D	DEL E	DEL F	DEL G	DEL H	DEL I	DEL J	DEL K	DEL L	DEL M	DEL N	DEL O	DEL P	DEL Q	DEL R	DEL S	DEL T	DEL U	DEL V	DEL W	DEL X	DEL Y	DEL Z	DEL A	DEL B	DEL C	DEL D	DEL E	DEL F	DEL G	DEL H	DEL I	DEL J	DEL K	DEL L	DEL M	DEL N	DEL O	DEL P	DEL Q	DEL R	DEL S	DEL T	DEL U	DEL V	DEL W	DEL X	DEL Y	DEL Z	DEL A	DEL B	DEL C	DEL D	DEL E	DEL F	DEL G	DEL H	DEL I	DEL J	DEL K	DEL L	DEL M	DEL N	DEL O	DEL P	DEL Q	DEL R	DEL S	DEL T	DEL U	DEL V	DEL W	DEL X	DEL Y	DEL Z	DEL A	DEL B	DEL C	DEL D	DEL E	DEL F	DEL G	DEL H	DEL I	DEL J	DEL K	DEL L	DEL M	DEL N	DEL O	DEL P	DEL Q	DEL R	DEL S	DEL T	DEL U	DEL V	DEL W	DEL X	DEL Y	DEL Z	DEL A	DEL B	DEL C	DEL D	DEL E	DEL F	DEL G	DEL H	DEL I	DEL J	DEL K	DEL L	DEL M	DEL N	DEL O	DEL P	DEL Q	DEL R	DEL S	DEL T	DEL U	DEL V	DEL W	DEL X	DEL Y	DEL Z	DEL A	DEL B	DEL C	DEL D	DEL E	DEL F	DEL G	DEL H	DEL I	DEL J	DEL K	DEL L	DEL M	DEL N	DEL O	DEL P	DEL Q	DEL R	DEL S	DEL T	DEL U	DEL V	DEL W	DEL X	DEL Y	DEL Z	DEL A	DEL B	DEL C	DEL D	DEL E	DEL F	DEL G	DEL H	DEL I	DEL J	DEL K	DEL L	DEL M	DEL N	DEL O	DEL P	DEL Q	DEL R	DEL S	DEL T	DEL U	DEL V	DEL W	DEL X	DEL Y	DEL Z	DEL A	DEL B	DEL C	DEL D	DEL E	DEL F	DEL G	DEL H	DEL I	DEL J	DEL K	DEL L	DEL M	DEL N	DEL O	DEL P	DEL Q	DEL R	DEL S	DEL T	DEL U	DEL V	DEL W	DEL X	DEL Y	DEL Z	DEL A	DEL B	DEL C	DEL D	DEL E	DEL F	DEL G	DEL H	DEL I	DEL J	DEL K	DEL L	DEL M	DEL N	DEL O	DEL P	DEL Q	DEL R	DEL S	DEL T	DEL U	DEL V	DEL W	DEL X	DEL Y	DEL Z	DEL A	DEL B	DEL C	DEL D	DEL E	DEL F	DEL G	DEL H	DEL I	DEL J	DEL K	DEL L	DEL M	DEL N	DEL O	DEL P	DEL Q	DEL R	DEL S	DEL T	DEL U	DEL V	DEL W	DEL X	DEL Y	DEL Z	DEL A	DEL B	DEL C	DEL D	DEL E	DEL F	DEL G	DEL H	DEL I	DEL J	DEL K	DEL L	DEL M	DEL N	DEL O	DEL P	DEL Q	DEL R	DEL S	DEL T	DEL U	DEL V	DEL W	DEL X	DEL Y	DEL Z	DEL A	DEL B	DEL C	DEL D	DEL E	DEL F	DEL G	DEL H	DEL I	DEL J	DEL K	DEL L	DEL M	DEL N	DEL O	DEL P	DEL Q	DEL R	DEL S	DEL T	DEL U	DEL V	DEL W	DEL X	DEL Y	DEL Z	DEL A	DEL B	DEL C	DEL D	DEL E	DEL F</
-----------	----------	------------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	---------

Table 12. (Continued)

1.2722	0.9879	0.9981	0.9962	0.9807	0.9912	0.9951	0.9975	1.0009	1.0058	1.0117	1.0176	1.0232	1.0291
1.2737	0.9826	0.9933	0.9950	0.9795	0.9911	0.9960	0.9978	1.0009	1.0055	1.0110	1.0170	1.0235	1.0296
0.9278	0.9824	0.9937	0.9958	0.9792	0.9910	0.9959	0.9973	1.0009	1.0059	1.0119	1.0177	1.0237	1.0298
0.9555	0.9822	0.9935	0.9955	0.9792	0.9909	0.9958	0.9973	1.0009	1.0060	1.0120	1.0176	1.0237	1.0299
0.9333	0.9823	0.9938	0.9955	0.9791	0.9909	0.9958	0.9972	1.0009	1.0060	1.0121	1.0182	1.0241	1.0301
0.9111	0.9818	0.9932	0.9954	0.9790	0.9907	0.9957	0.9972	1.0009	1.0061	1.0122	1.0183	1.0243	1.0303
0.9198	0.9815	0.9931	0.9953	0.9789	0.9906	0.9957	0.9972	1.0009	1.0062	1.0123	1.0185	1.0245	1.0305
0.9667	0.9815	0.9930	0.9952	0.9788	0.9905	0.9956	0.9972	1.0009	1.0062	1.0123	1.0186	1.0247	1.0306
0.9538	0.9814	0.9929	0.9951	0.9787	0.9905	0.9956	0.9971	1.0009	1.0062	1.0124	1.0187	1.0248	1.0308
1.2722	0.9813	0.9928	0.9950	0.9786	0.9904	0.9955	0.9971	1.0009	1.0063	1.0125	1.0189	1.0250	1.0310
1.2737	0.9812	0.9927	0.9949	0.9785	0.9904	0.9955	0.9971	1.0010	1.0065	1.0126	1.0190	1.0251	1.0310
0.9278	0.9812	0.9927	0.9949	0.9785	0.9904	0.9955	0.9971	1.0010	1.0065	1.0126	1.0190	1.0252	1.0311
0.9555	0.9813	0.9928	0.9948	0.9784	0.9903	0.9955	0.9971	1.0010	1.0065	1.0127	1.0191	1.0253	1.0311
0.9333	0.9813	0.9928	0.9947	0.9784	0.9903	0.9955	0.9971	1.0011	1.0066	1.0128	1.0192	1.0254	1.0312
0.9111	0.9803	0.9923	0.9947	0.9773	0.9902	0.9955	0.9971	1.0011	1.0066	1.0128	1.0192	1.0254	1.0312
0.9198	0.9809	0.9923	0.9946	0.9773	0.9902	0.9954	0.9971	1.0011	1.0067	1.0129	1.0193	1.0255	1.0313
0.9667	0.9807	0.9923	0.9946	0.9772	0.9902	0.9954	0.9971	1.0011	1.0067	1.0129	1.0194	1.0256	1.0313
0.9538	0.9806	0.9922	0.9945	0.9772	0.9902	0.9954	0.9971	1.0011	1.0068	1.0130	1.0194	1.0256	1.0313
0.9272	0.9806	0.9922	0.9945	0.9772	0.9901	0.9954	0.9971	1.0011	1.0068	1.0130	1.0194	1.0256	1.0313
1.2737	0.9805	0.9921	0.9945	0.9771	0.9901	0.9954	0.9971	1.0012	1.0068	1.0130	1.0195	1.0256	1.0313

RELATIVE MASS FLOW RATE, G

PADJAL	0.9277	0.9524	0.9765	1.0000
0.0100	1.0180	1.0175	1.0149	1.0133
0.0200	1.0184	1.0175	1.0149	1.0153
0.0500	1.0196	1.0166	1.0152	1.0131
0.0700	1.0212	1.0200	1.0160	1.0135
0.1000	1.0224	1.0217	1.0172	1.0144
0.1300	1.0244	1.0236	1.0187	1.0158
0.1600	1.0258	1.0249	1.0203	1.0173
0.1800	1.0271	1.0246	1.0219	1.0189
0.2200	1.0281	1.0240	1.0225	1.0205
0.2500	1.0281	1.0239	1.0250	1.0221
0.2700	1.0302	1.0305	1.0264	1.0236
0.3000	1.0313	1.0315	1.0277	1.0251
0.3200	1.0317	1.0326	1.0286	1.0264
0.3600	1.0323	1.0327	1.0310	1.0276
0.3800	1.0324	1.0330	1.0310	1.0280
0.4000	1.0333	1.0350	1.0340	1.0285
0.4500	1.0352	1.0364	1.0358	1.0340
0.5000	1.0372	1.0382	1.0372	1.0375
1.0000	1.0401	1.0405	1.0400	1.0405

PEOPLE AVERAGE SURFACE TEMPERATURE, TS (K)

RADIAL	0.0	0.1391	0.1967	0.2810	0.3778	0.4103	0.3398	0.3756	0.4156	0.4687	0.4795	0.5088	0.5365
0.0000	719.3	712.1	714.8	719.1	717.6	717.1	716.7	716.1	715.3	714.4	713.1	712.9	711.9
0.0074	759.4	750.1	753.5	757.8	757.2	756.5	755.8	755.1	754.5	753.8	753.1	752.6	749.2
0.0156	800.1	800.7	802.8	802.0	801.2	800.4	799.7	799.0	798.2	797.4	796.7	796.4	791.7
0.0237	840.8	846.3	845.4	844.5	843.5	842.6	842.0	841.1	839.4	837.7	836.5	835.2	833.1
0.0311	881.5	885.9	884.9	883.8	882.8	881.7	881.3	880.4	878.5	876.5	874.1	871.7	
0.0389	921.8	923.4	919.1	918.5	917.4	916.3	915.9	915.0	913.0	910.9	909.8	908.5	905.9
0.0467	962.3	957.3	950.1	948.9	947.7	946.5	946.3	945.4	943.3	941.1	940.0	938.7	935.0
0.0546	993.8	977.7	978.4	975.2	973.9	972.7	972.5	971.7	969.5	967.2	964.9	962.0	
0.0622	1001.6	1000.4	986.4	989.1	986.8	985.6	985.5	984.7	982.4	980.1	978.9	976.8	984.8
0.0700	1021.9	1021.1	1019.7	1018.4	1017.0	1015.8	1015.7	1014.9	1012.6	1010.2	1009.2	1007.9	1004.9
0.0778	1039.9	1039.1	1037.6	1036.3	1034.9	1033.7	1033.6	1032.8	1030.5	1028.0	1027.0	1025.7	1022.5
0.0856	1056.0	1055.2	1053.7	1052.3	1050.9	1049.7	1049.6	1048.8	1046.4	1043.9	1042.9	1041.6	1038.4
0.0934	1070.4	1069.5	1068.0	1066.6	1065.2	1064.0	1063.9	1063.0	1060.6	1058.1	1057.1	1055.6	1052.5
0.1011	1087.1	1086.1	1084.5	1083.0	1081.5	1079.9	1079.7	1078.7	1076.3	1073.8	1072.8	1071.4	1068.1
0.1089	1102.6	1101.4	1100.5	1099.0	1097.5	1095.8	1095.6	1094.6	1092.2	1089.7	1088.7	1087.3	1084.1
0.1167	1116.4	1114.9	1113.7	1112.0	1110.4	1108.8	1108.6	1107.5	1105.1	1102.6	1101.6	1100.2	1097.0
0.1245	1128.4	1126.4	1124.8	1123.0	1121.4	1119.8	1119.6	1118.4	1116.0	1113.5	1112.5	1111.1	1107.9
0.1323	1138.0	1135.9	1134.3	1132.3	1130.7	1129.1	1128.9	1127.6	1125.2	1122.7	1121.7	1120.3	1117.1
0.1401	1146.2	1143.9	1142.3	1139.9	1138.3	1136.7	1136.5	1135.2	1132.8	1130.3	1129.3	1127.9	1124.7
0.1479	1153.0	1150.4	1148.7	1146.5	1144.7	1143.0	1142.8	1141.5	1139.1	1136.6	1135.6	1134.2	1131.0
0.1557	1158.0	1155.3	1153.5	1151.6	1149.7	1147.9	1147.7	1146.3	1143.9	1141.4	1140.4	1139.0	1135.8
0.1635	1161.6	1158.8	1156.9	1155.2	1153.3	1151.5	1151.3	1150.0	1147.6	1145.1	1144.1	1142.7	1139.5
0.1713	1164.0	1161.1	1159.1	1157.6	1155.6	1153.7	1153.5	1152.2	1149.8	1147.3	1146.3	1144.9	1141.7
0.1791	1165.0	1162.0	1160.0	1158.5	1156.5	1154.6	1154.4	1153.1	1150.7	1148.2	1147.2	1145.8	1142.6
0.1869	1164.6	1161.6	1159.6	1158.1	1156.1	1154.2	1154.0	1152.7	1150.3	1147.8	1146.8	1145.4	1142.2
0.1947	1162.7	1159.7	1157.7	1156.2	1154.2	1152.3	1152.1	1150.8	1148.4	1145.9	1144.9	1143.5	1140.3
0.2025	1160.0	1157.0	1155.0	1153.5	1151.5	1149.6	1149.4	1148.1	1145.7	1143.2	1142.2	1140.8	1137.6
0.2103	1156.4	1153.4	1151.4	1149.9	1147.9	1146.0	1145.8	1144.5	1142.1	1139.6	1138.6	1137.2	1134.0
0.2181	1151.9	1148.9	1146.9	1145.4	1143.4	1141.5	1141.3	1140.0	1137.6	1135.1	1134.1	1132.7	1129.5
0.2259	1146.4	1143.4	1141.4	1139.9	1137.9	1136.0	1135.8	1134.5	1132.1	1129.6	1128.6	1127.2	1124.0
0.2337	1139.9	1136.9	1134.9	1133.4	1131.4	1129.5	1129.3	1128.0	1125.6	1123.1	1122.1	1120.7	1117.5
0.2415	1132.4	1129.4	1127.4	1125.9	1123.9	1122.0	1121.8	1120.5	1118.1	1115.6	1114.6	1113.2	1110.0
0.2493	1123.9	1120.9	1118.9	1117.4	1115.4	1113.5	1113.3	1112.0	1109.6	1107.1	1106.1	1104.7	1101.5
0.2571	1114.4	1111.4	1109.4	1107.9	1105.9	1104.0	1103.8	1102.5	1100.1	1097.6	1096.6	1095.2	1092.0
 
0.5691	315.4	312.4	310.4	308.9	306.9	305.0	304.8	303.5	301.1	298.6	297.6	296.2	293.0
0.5769	293.9	290.9	288.9	287.4	285.4	283.5	283.3	282.0	279.6	277.1	276.1	274.7	271.5
0.5847	272.4	269.4	267.4	265.9	263.9	262.0	261.8	260.5	258.1	255.6	254.6	253.2	250.0
0.5925	250.9	247.9	245.9	244.4	242.4	240.5	240.3	239.0	236.6	234.1	233.1	231.7	228.5
0.6003	229.4	226.4	224.4	222.9	220.9	219.0	218.8	217.5	215.1	212.6	211.6	210.2	207.0
0.6081	207.9	204.9	202.9	201.4	199.4	197.5	197.3	196.0	193.6	191.1	190.1	188.7	185.5
0.6159	186.4	183.4	181.4	179.9	177.9	176.0	175.8	174.5	172.1	169.6	168.6	167.2	164.0
0.6237	164.9	161.9	159.9	158.4	156.4	154.5	154.3	153.0	150.6	148.1	147.1	145.7	142.5
0.6315	143.4	140.4	138.4	136.9	134.9	133.0	132.8						

PEOPLE AVERAGE SURFACE TEMPERATURE, TS (K)

PERIOD	0.7029	0.7040	0.7050	0.7060	0.7070	0.7080	0.7090	0.7100	0.7110	0.7120	0.7130	0.7140	0.7150	0.7160	0.7170	0.7180	0.7190	0.7200	0.7210	0.7220	0.7230	0.7240	0.7250	0.7260	0.7270	0.7280	0.7290	0.7300
1973-1	713.1	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1973-2	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1973-3	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1973-4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1973-5	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1973-6	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1973-7	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1973-8	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1973-9	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1973-10	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1973-11	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1973-12	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1974-1	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1974-2	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1974-3	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1974-4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1974-5	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1974-6	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1974-7	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1974-8	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1974-9	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1974-10	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1974-11	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1974-12	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1975-1	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1975-2	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1975-3	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
1975-4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4	704.4
 																

Table 12. (Continued)

2-2222	141.5	177.9	177.1	171.8	168.2	158.2	157.5	152.5	146.3	138.0	128.2	120.9	112.3
1-2539	107.6	158.9	157.0	151.5	147.8	133.7	124.8	112.0	101.2	95.8	90.2	84.5	78.9
0-2778	108.2	171.5	167.5	160.9	155.2	140.0	130.0	118.5	108.5	101.2	94.0	87.0	80.0
0-3174	105.1	171.3	157.1	152.5	142.5	130.0	120.9	108.9	100.9	95.5	90.0	84.7	78.7
2-3333	108.1	167.2	164.0	158.3	154.3	142.5	132.0	120.9	110.9	103.9	97.5	91.8	85.7
0-3611	105.1	165.8	156.5	150.7	146.5	134.7	124.0	112.0	102.0	95.5	89.0	83.0	77.0
2-3990	107.1	171.0	167.5	161.8	157.5	145.5	135.2	123.0	113.3	105.3	98.9	92.6	86.6
0-4167	101.2	151.2	157.5	151.8	147.3	136.2	125.9	114.9	104.6	97.5	91.3	85.0	78.0
0-4338	102.5	159.0	156.5	150.0	146.1	135.0	124.5	113.5	103.5	96.5	90.5	84.5	78.5
0-4722	110.7	168.4	158.5	150.8	146.1	134.7	124.0	112.0	102.0	95.5	89.0	83.0	77.0
0-5227	108.1	165.7	157.0	150.0	145.2	134.5	124.0	112.0	102.0	95.5	89.0	83.0	77.0
0-5278	113.4	171.3	164.3	158.5	153.6	141.9	131.5	119.5	109.5	102.5	96.5	90.5	84.5
0-5556	112.8	171.2	161.1	154.4	149.3	137.5	127.0	115.0	105.0	98.0	92.0	86.0	80.0
0-5873	112.1	171.4	161.9	155.7	150.4	138.6	128.0	116.0	106.0	99.0	93.0	87.0	81.0
0-6111	111.2	171.4	162.1	156.4	151.1	139.3	128.7	116.7	106.7	99.7	93.7	87.7	81.7
0-6499	113.5	171.7	162.4	156.7	151.4	139.6	129.0	117.0	107.0	100.0	94.0	88.0	82.0
0-6767	113.5	171.6	162.2	156.5	151.2	139.4	128.8	116.8	106.8	99.8	93.8	87.8	81.8
0-6848	113.1	171.0	161.7	156.0	150.7	138.9	128.3	116.3	106.3	99.3	93.3	87.3	81.3
2-7222	114.3	171.3	162.0	156.3	151.0	139.2	128.6	116.6	106.6	99.6	93.6	87.6	81.6
0-7700	114.9	171.6	162.3	156.6	151.3	139.5	128.9	116.9	106.9	99.9	93.9	87.9	81.9
0-7778	115.1	171.9	162.6	156.9	151.6	139.8	129.2	117.2	107.2	100.2	94.2	88.2	82.2
2-8456	115.1	171.1	161.8	156.1	150.8	139.0	128.4	116.4	106.4	99.4	93.4	87.4	81.4
0-9333	115.5	171.3	162.0	156.3	151.0	139.2	128.6	116.6	106.6	99.6	93.6	87.6	81.6
2-9611	115.5	171.3	162.0	156.3	151.0	139.2	128.6	116.6	106.6	99.6	93.6	87.6	81.6
2-9889	116.0	171.6	162.3	156.6	151.3	139.5	128.9	117.2	107.2	100.2	94.2	88.2	82.2
0-9917	116.1	171.6	162.3	156.6	151.3	139.5	128.9	117.2	107.2	100.2	94.2	88.2	82.2
0-9934	116.1	171.6	162.3	156.6	151.3	139.5	128.9	117.2	107.2	100.2	94.2	88.2	82.2
2-9922	116.0	171.5	162.2	156.5	151.2	139.4	128.8	117.1	107.1	100.1	94.1	88.1	82.1
1-0000	116.1	171.6	162.3	156.6	151.3	139.5	128.9	117.2	107.2	100.2	94.2	88.2	82.2

PEBBLE AVERAGE SURFACE TEMPERATURE, TS (K)

PERIOD	0.9277	0.9528	0.9765	1.0000
0.0000	652.4	652.4	652.4	701.6
0.0001	721.3	722.6	724.6	733.1
0.0002	752.1	753.4	754.5	767.2
0.0003	793.1	794.6	795.6	800.1
0.0004	833.1	834.1	835.5	840.9
0.0005	873.3	874.3	875.5	885.1
0.0006	912.6	914.6	915.6	924.3
0.0007	952.9	953.1	954.0	961.0
0.0008	992.6	993.6	994.0	990.8
0.0009	931.1	931.6	932.6	936.3
0.0010	971.7	971.7	972.3	976.7
0.0011	914.5	914.5	915.4	916.6
0.0012	953.1	953.5	954.1	957.9
0.0013	973.5	973.5	974.6	971.0
0.0014	979.7	979.5	981.0	989.1
0.0015	982.0	982.0	983.6	986.3
0.0016	985.2	985.2	987.3	1002.6
0.0017	1000.1	999.8	1001.3	1008.3
0.0018	1014.1	1014.3	1016.7	1013.3
0.0019	1013.6	1013.6	1013.6	1017.8
0.0020	1018.5	1018.4	1017.9	1021.9
0.0021	1022.3	1023.8	1021.9	1025.5
0.0022	1027.3	1022.8	1025.4	1028.7
0.0023	1033.6	1026.4	1024.6	1031.6
0.0024	1034.3	1029.7	1031.5	1034.2
0.0025	1037.3	1032.5	1034.1	1036.5
0.0026	1039.4	1035.2	1034.5	1038.7
0.0027	1042.3	1037.8	1034.7	1040.6
0.0028	1044.5	1043.0	1039.4	1042.3
0.0029	1046.6	1042.1	1042.4	1043.8
0.0030	1046.6	1043.9	1044.0	1045.2
0.0031	1050.2	1045.6	1045.4	1046.5
0.0032	1051.4	1047.1	1046.8	1047.6
0.0033	1051.2	1046.6	1047.9	1048.6
0.0034	1052.6	1047.4	1048.0	1049.6
0.0035	1055.9	1051.1	1050.1	1050.4
0.0036	1057.1	1052.2	1051.0	1051.2

REMARKS: [illegible]

THE-TH SAYING PROBLEMS, PEOPLE RED THEN PRIVATELY THERMAL HYDRAULICS

ZONES 155 SUPRONS 0 INTERVALS, AXIAL, RADIAL 37 20

ZONE AND SUBZONE TEMPERATURES (DEGREES C) FOR PASS FLUX RATE (KG/SEC) 6.380E 02 BURNED DOWN (MW-TN) 1.6545E 03

ZONE	CONDUCTIVITY AND RESISTIVITY, FLUID				SHELL	HEAT CENTER TEMPERATURES, JET/IN (DEG/CM)			
1	0.0963	0.25560E-21	347.7	485.9	494.7	555.5	605.0	-67.1	
2	0.1193	0.59319E-22	405.4	731.7	591.0	630.2	754.1	-107.4	
3	0.2962	0.5643E-22	503.6	666.0	667.4	744.0	744.0	-114.0	
4	0.2038	0.1473E-22	513.7	701.4	722.2	800.0	844.6	-136.4	
5	0.2404	0.55491E-22	632.6	764.4	762.3	830.5	879.1	-99.1	
6	0.2754	0.57349E-22	720.7	773.0	793.1	844.1	844.6	-72.2	
7	0.2424	0.67557E-22	779.4	806.3	817.0	861.1	900.4	-57.1	
8	0.2822	0.85616E-22	751.0	824.3	837.1	871.4	906.5	-45.1	
9	0.3477	0.87773E-22	816.1	845.2	851.2	880.4	906.5	-36.0	
10	0.2870	0.69210E-22	856.4	867.7	865.1	884.4	910.6	-26.1	
11	0.2691	0.73573E-22	861.1	872.7	877.0	894.7	914.1	-21.0	
12	0.2231	0.71670E-22	857.7	882.3	885.1	900.0	914.6	-16.5	
13	0.2479	0.75120E-22	877.6	897.2	891.1	906.5	914.1	-14.1	

Table 12. (Continued)

10	0.2906	0.7322912	22
15	0.2917	0.7301152	22
16	0.2916	0.7027692	22
17	0.2920	0.7064052	22
18	0.2920	0.7093535	21
19	0.2920	0.7093535	21
20	0.2967	0.7091532	21
21	0.2967	0.7005052	21
22	0.2936	0.7279112	22
23	0.2799	0.5105052	22
24	0.2791	0.5571295	22
25	0.2816	0.5209002	22
26	0.2833	0.6103902	22
27	0.2840	0.6309362	22
28	0.2861	0.6510772	22
29	0.2871	0.6670932	22
30	0.2880	0.6755302	22
31	0.2880	0.6802002	22
32	0.2890	0.6791202	22
33	0.2900	0.6960722	22
34	0.2900	0.7754352	22
35	0.2900	0.7754352	22
36	0.2907	0.7023012	22
37	0.2900	0.7754352	22
38	0.2900	0.7754352	22
39	0.2913	0.1921672	22
40	0.2913	0.1921672	22
41	0.2935	0.3129702	22
42	0.2792	0.4757562	22
43	0.2703	0.5102332	22
44	0.2606	0.5055072	22
45	0.2622	0.5709102	22
46	0.2636	0.5913002	22
47	0.2650	0.6070002	22
48	0.2650	0.6070002	22
49	0.2665	0.6263002	22
50	0.2665	0.1271002	22
51	0.2677	0.1270372	22
52	0.2682	0.1280902	22
53	0.2685	0.1292052	22
54	0.2680	0.1290002	22
55	0.2680	0.1290002	22
56	0.2690	0.1300002	22
57	0.2690	0.1300002	22
58	0.2690	0.1300002	22
59	0.2690	0.1300002	22
60	0.2690	0.1300002	22
61	0.2690	0.1300002	22
62	0.2690	0.1300002	22
63	0.2690	0.1300002	22
64	0.2690	0.1300002	22
65	0.2690	0.1300002	22
66	0.2690	0.1300002	22
67	0.2690	0.1300002	22
68	0.2690	0.1300002	22
69	0.2690	0.1300002	22
70	0.2690	0.1300002	22
71	0.2690	0.1300002	22
72	0.2690	0.1300002	22
73	0.2690	0.1300002	22
74	0.2690	0.1300002	22
75	0.2690	0.1300002	22
76	0.2690	0.1300002	22
77	0.2690	0.1300002	22
78	0.2690	0.1300002	22
79	0.2690	0.1300002	22
80	0.2690	0.1300002	22
81	0.2690	0.1300002	22
82	0.2690	0.1300002	22
83	0.2690	0.1300002	22
84	0.2690	0.1300002	22
85	0.2690	0.1300002	22
86	0.2690	0.1300002	22
87	0.2690	0.1300002	22
88	0.2690	0.1300002	22
89	0.2690	0.1300002	22
90	0.2690	0.1300002	22
91	0.2690	0.1300002	22
92	0.2690	0.1300002	22
93	0.2690	0.1300002	22
94	0.2690	0.1300002	22
95	0.2690	0.1300002	22
96	0.2690	0.1300002	22
97	0.2690	0.1300002	22
98	0.2690	0.1300002	22
99	0.2690	0.1300002	22
100	0.2690	0.1300002	22

Table 12. (Continued)

119	0.2697	0.679238E 22	769.5	765.5	769.5	765.5	0.01.5	-20.8
120	0.2697	0.687885E 22	769.3	773.1	776.3	789.0	0.01.8	-16.5
121	0.2701	0.696797E 22	769.1	779.3	781.8	792.0	0.02.2	-11.1
122	0.2706	0.702652E 22	776.3	786.4	786.4	796.5	0.02.7	-10.5
123	0.2705	0.707094E 22	782.1	789.5	796.2	796.6	0.03.1	-8.4
124	0.2709	0.709616E 22	786.8	792.0	793.2	796.0	0.03.6	-6.6
125	0.2711	0.713017E 22	790.6	796.8	795.8	795.9	0.04.1	-5.3
126	0.2714	0.715530E 22	793.8	797.3	798.2	801.4	0.05.2	-4.5
127	0.2699	0.717986E 21	378.1	453.8	462.5	497.9	536.7	-45.7
128	0.3593	0.531753E 21	436.7	516.5	529.9	583.9	638.9	-49.9
129	0.3337	0.101269E 22	495.5	573.1	588.8	651.1	716.0	-61.0
130	0.3055	0.144021E 22	549.1	617.9	633.0	692.0	752.7	-77.8
131	0.2519	0.192069E 22	596.0	652.2	665.3	717.3	769.1	-67.7
132	0.2848	0.227950E 22	632.2	678.6	689.5	732.5	775.3	-56.0
133	0.2807	0.257913E 22	662.5	699.4	709.2	763.3	777.6	-45.3
134	0.2781	0.283205E 22	686.7	715.9	722.8	758.8	778.5	-36.3
135	0.2765	0.308854E 22	706.1	729.1	736.7	756.9	779.1	-28.9
136	0.2754	0.323637E 22	721.6	739.8	746.3	762.0	779.6	-23.0
137	0.2747	0.340185E 22	738.1	760.5	752.1	766.1	780.2	-18.3
138	0.2742	0.356622E 22	760.1	755.6	758.4	765.6	780.8	-16.6
139	0.2738	0.375992E 22	752.3	761.4	763.7	772.6	781.6	-11.6
140	0.2735	0.394922E 22	759.6	766.2	768.0	775.1	782.3	-9.3
141	0.2733	0.399241E 22	764.4	770.2	771.6	777.3	783.0	-7.4
142	0.2732	0.398162E 22	768.0	773.1	776.4	779.1	783.6	-5.9
143	0.2731	0.405909E 22	772.5	775.1	777.0	780.6	784.2	-4.6
144	0.2730	0.413762E 22	775.4	778.4	779.1	782.1	785.8	-3.8
145	0.0	0.0	850.0	850.0	850.0	850.0	850.0	0.0
146	0.0	0.0	850.0	850.0	850.0	850.0	850.0	0.0
147	0.0	0.0	850.0	850.0	850.0	850.0	850.0	0.0
148	0.0	0.0	850.0	850.0	850.0	850.0	850.0	0.0
149	0.0	0.0	850.0	850.0	850.0	850.0	850.0	0.0
150	0.0	0.0	850.0	850.0	850.0	850.0	850.0	0.0
151	0.0	0.0	850.0	850.0	850.0	850.0	850.0	0.0
152	0.0	0.0	850.0	850.0	850.0	850.0	850.0	0.0
153	0.0	0.0	850.0	850.0	850.0	850.0	850.0	0.0
154	0.0	0.0	850.0	850.0	850.0	850.0	850.0	0.0
155	0.0	0.0	850.0	850.0	850.0	850.0	850.0	0.0

DISTRIBUTION FRACTIONS OF 100 HEAT TEMPERATURES IN TWENTY FRACILES OVER THE RANGE (C) 350.0 910.0
0.0 0.0 0.0 0.0 0.02776 0.02083 0.00694 0.01385 0.01385
0.02779 0.02083 0.02778 0.04167 0.10017 0.15278 0.10017 0.13885 0.15278 0.13885
100 TEMPS, PEAK/MEAN BY ZONE, SURFACE 522.2 916.8 0.0 3.0 POWER WEIGHTED 733.0 0.0 POWER (WAT) 1.65452 03

AVG TEMP AND PEAK TEMPERATURE SLOPE AT PEARL PEARL/SHELL INTERFACE (DEG/C/H) -41.5 -119.0

CORRELATION FAILURE COUNT 1051

ZONE AVERAGE TEMP AND TOP2, TREN SURFACE 793.85 798.35 0.0 0.0

FILE -ZTEMP- WRITEN, UNIT AND VERSION 32 1

TEMPERATURES RECALCULATED FOR THE THERMAL CONDUCTIVITY MULTIPLIED BY 0.5

ZONE	(CONDUCTIVITY AND P(ROPOSE))	FLUID	SURFACE	SHELL	HEAT CENTER TEMPERATURES, DT/DB (DEG/C/H)			
1	0.0016	0.259037E 21	307.3	885.9	500.1	558.2	618.5	-78.9
2	3.3057	0.101601E 22	865.6	570.7	593.7	665.6	778.8	-119.3
3	0.2719	0.210753E 22	543.6	644.8	669.9	770.3	970.0	-130.9
4	0.2571	0.185135E 22	613.7	701.8	728.5	815.1	904.0	-118.6
5	0.2542	0.169970E 22	672.6	764.8	786.2	879.7	973.6	-94.7
6	0.2514	0.144929E 22	720.7	779.0	796.6	855.0	915.6	-83.0
7	0.2516	0.120410E 22	759.6	806.3	816.6	867.1	914.9	-63.3
8	0.2569	0.144619E 22	791.0	828.3	838.1	876.6	914.9	-50.2
9	0.2581	0.165405E 22	816.3	846.2	851.9	884.6	915.3	-39.9
10	0.2591	0.181617E 22	846.4	860.7	866.9	891.6	916.0	-31.9
11	0.3722	0.169298E 21	853.0	882.8	889.1	916.0	916.0	-81.6
12	0.3139	0.112850E 22	510.3	598.9	617.1	685.0	761.9	-93.9
13	0.2921	0.101117E 22	570.0	648.3	661.9	721.3	800.3	-90.8
14	0.2826	0.105975E 22	617.5	680.7	696.3	758.0	819.0	-80.8
15	0.2781	0.122735E 22	656.5	709.8	721.6	773.4	824.6	-67.6
16	0.2761	0.137896E 22	688.1	730.0	740.8	783.7	824.9	-55.2
17	0.2740	0.152672E 22	713.4	767.0	775.6	799.7	843.5	-48.5
18	0.2741	0.166682E 22	733.6	780.8	787.3	796.6	841.7	-35.6
19	0.2740	0.182842E 22	769.9	771.2	776.7	786.8	810.1	-28.3
20	0.2737	0.201431E 22	762.8	779.9	784.2	801.5	818.8	-22.5
21	0.2736	0.219315E 22	773.3	786.9	793.1	806.1	818.0	-17.9
22	0.2735	0.230186E 22	781.7	792.6	795.3	806.3	817.4	-16.3
23	0.2738	0.249478E 22	788.5	797.2	799.8	808.2	817.0	-11.6
24	0.2738	0.272060E 22	798.0	803.9	802.7	809.7	816.8	-9.1
25	0.2737	0.277489E 22	798.4	808.8	806.8	812.4	819.3	-8.3
26	0.2738	0.277290E 22	802.0	809.4	810.0	816.4	822.9	-8.3
27	0.2745	0.281008E 22	805.0	811.5	813.1	819.4	825.9	-8.3
28	0.2590	0.151579E 21	390.1	885.2	895.1	915.6	977.7	-52.7
29	0.4025	0.131437E 21	455.5	467.7	562.4	621.5	681.8	-76.5
30	0.1340	0.100639E 22	514.9	594.6	615.0	680.4	766.4	-84.9
31	0.1109	0.116124E 22	567.2	638.8	654.8	716.5	778.6	-80.9
32	0.2272	0.117822E 22	610.8	670.0	681.8	738.4	792.7	-71.1
33	0.2894	0.221840E 22	645.9	693.6	705.2	750.7	796.0	-59.3
34	0.2846	0.246990E 22	673.4	711.8	721.2	759.2	795.0	-48.3
35	0.2826	0.267748E 22	696.0	726.0	731.6	763.3	792.4	-38.6
36	0.2809	0.282462E 22	713.6	737.3	743.3	767.1	790.8	-31.0
37	0.2745	0.299089E 22	718.7	746.3	751.1	770.1	789.0	-24.7
38	0.2784	0.309789E 22	718.7	753.6	757.4	771.5	787.4	-19.7
39	0.2780	0.314741E 22	727.4	759.8	762.5	776.5	786.5	-15.7
40	0.2775	0.316491E 22	750.8	764.2	766.7	778.3	785.9	-12.5
41	0.2771	0.318425E 22	761.2	768.7	770.7	778.3	786.0	-10.0
42	0.2764	0.328987E 22	766.7	773.1	774.7	781.1	787.5	-8.4
43	0.2764	0.359001E 22	771.3	777.6	779.2	784.7	792.1	-8.4
44	0.2768	0.374239E 22	776.0	781.4	783.0	788.5	795.9	-6.8

Table 12. (Continued)

144	0.2762	0.347012	22	774.1	784.6	784.3	752.7	795.1	-8.4
145	0.0	0.0		0.0	350.0	350.0	350.0	350.0	0.0
146	0.0	0.0		0.0	350.0	350.0	350.0	350.0	0.0
147	0.0	0.0		0.0	350.0	350.0	350.0	350.0	0.0
148	0.0	0.0		0.0	350.0	350.0	350.0	350.0	0.0
149	0.0	0.0		0.0	350.0	350.0	350.0	350.0	0.0
150	0.0	0.0		0.0	350.0	350.0	350.0	350.0	0.0
151	0.0	0.0		0.0	350.0	350.0	350.0	350.0	0.0
152	0.0	0.0		0.0	350.0	350.0	350.0	350.0	0.0
153	0.0	0.0		0.0	350.0	350.0	350.0	350.0	0.0
154	0.0	0.0		0.0	350.0	350.0	350.0	350.0	0.0
155	0.0	0.0		0.0	350.0	350.0	350.0	350.0	0.0
MAX TEMP, PEAK/TEMP BY ZONE, SURFACE 533.2 927.2 0.0 0.0 POWER DENSITY 754.0 0.0 POWER (MW) 1.7670E 03									
AVERAGE AND PEAK TEMPERATURE SLOPE AT PEBBLE JET/SHIELD INTERFACE (DEG/C) -80.1 -110.0									
CORRELATION FAILURE COUNT 300 6									
CRYSTALLINE FRACTIONS OF THE FUEL ARC/CL SHEATH TEMPERATURES, DEG C (SEE BASIC DATA POINTS) 14.19, 144									
925	0.00102369	725	0.02163460	525	0.56709802	Temperature distribution table added			
930	0.10754774	700	0.05455553	500	0.57021780				
875	0.25240025	675	0.07719515	475	0.58726861				
450	0.34202035	650	0.09571452	450	0.59524023				
325	0.08477397	625	0.11146520	425	0.59970367				
400	0.54237852	600	0.12571350	400	0.59999970				
775	0.69719407	575	0.14063344	375	0.60000000				
750	0.70007094	550	0.15505740	350	1.00000000				
EAST RECALCULATED WITH NEW COOLANT TEMPERATURES (C) 350.0 850.0 AND POWER 1.6547350 09									
MASS FLOW RATE (KG/SEC) 4.2004E 02 POWER (W) 1.6567E 09									
MAXIMUM INITIALIZED PEAK FLUID AND PEBBLE TEMPERATURES (C) 915.24 919.71 APPARENT PRESSURE DROP (ATM) 0.6700									
INITIALIZATION OF PROBLEM COMPLETE, START ITERATION ----- CONVERGENCE DATA FOLLOWS									
PROCESSOR TIME (SEC) AT START OF ITERATION 54.71 --COEFFICIENTS 1.3020 0.6102 1.0000 1.0709 MAX IT 170									
ITERATION, UNKNOWN CHANGE (PSI, MIN TEMP, SURF TEMP, PRESSURE), DELTA (S), PRESSURE INCP, DEL BEAT BALANCE, SNO (S)									
1	0.000010	-0.000004	-0.000033	-0.000075	1.1514	0.6710	-0.000063	0.0002	0.0001
2	-0.000078	-0.000042	0.000115	-0.000076	1.1514	0.6710	-0.000072	0.0002	0.0001
3	-0.000066	-0.000050	-0.000119	-0.000077	1.3020	0.6711	-0.000074	0.0002	0.0001
4	-0.000065	-0.000083	-0.000085	0.000009	1.3020	0.6712	-0.000067	0.0002	0.0001
5	-0.000076	-0.000111	-0.000185	-0.000006	1.3020	0.6712	-0.000064	0.0002	0.0001
6	-0.000011	-0.000193	-0.000170	-0.000004	1.3020	0.6714	-0.000060	0.0002	0.0001
7	-0.000011	-0.000185	-0.000164	-0.000005	1.3020	0.6714	-0.000061	0.0002	0.0001
8	0.000009	-0.000174	-0.000161	-0.000004	1.3020	0.6715	-0.000060	0.0002	0.0001
9	0.000007	-0.000169	-0.000155	-0.000004	1.3020	0.6715	-0.000060	0.0002	0.0001
10	0.000007	-0.000164	-0.000151	-0.000004	1.3020	0.6716	-0.000060	0.0002	0.0001
11	0.000007	-0.000161	-0.000155	-0.000003	1.3020	0.6716	-0.000060	0.0002	0.0001
12	0.000009	-0.000154	-0.000152	-0.000003	1.3020	0.6716	-0.000060	0.0002	0.0001
13	0.000009	-0.000155	-0.000152	-0.000003	1.3020	0.6717	-0.000060	0.0002	0.0001
14	0.000010	-0.000151	-0.000151	-0.000003	1.3020	0.6717	-0.000060	0.0002	0.0001
15	0.000011	-0.000152	-0.000150	-0.000003	1.3020	0.6717	-0.000060	0.0002	0.0001
16	0.000011	-0.000151	-0.000145	-0.000002	1.3020	0.6717	-0.000060	0.0002	0.0001
EXTRAPOLATION OF SELECTED TEMPERATURE DATA WITH EIGENVALUE 0.95533 FACTORS 17.38 20.62 23.79 LEVEL 0									
17	0.000010	0.000004	0.000004	-0.000004	1.3528	0.6723	-0.011061	1.6225	1.4054
18	0.000012	0.000147	0.000170	-0.000002	1.3528	0.6723	-0.011061	1.6173	0.9438
19	0.000010	0.000170	0.000355	-0.000003	1.3528	0.6723	-0.012293	1.5400	0.8762
20	0.000022	0.000147	0.000316	-0.000003	1.3524	0.6723	-0.012544	0.8516	0.9713
21	0.000022	0.000134	0.000320	-0.000003	1.3528	0.6722	-0.012285	0.8473	0.8693
22	-0.000020	0.000117	0.000310	-0.000003	1.3528	0.6722	-0.012225	0.8305	0.8491
23	-0.000020	0.000303	0.000255	-0.000002	1.3528	0.6722	-0.013565	0.8815	0.9025
24	-0.000021	0.000291	0.000287	-0.000002	1.3528	0.6722	-0.013903	1.0790	0.9000
25	-0.000022	0.000277	0.000272	-0.000002	1.3528	0.6722	-0.014239	1.0250	0.9217
26	-0.000022	0.000272	0.000265	-0.000002	1.3524	0.6722	-0.014570	1.0011	0.9287
27	-0.000021	0.000255	0.000271	-0.000002	1.3524	0.6722	-0.014891	1.0573	0.9334
28	-0.000023	0.000240	0.000250	-0.000002	1.3528	0.6721	-0.015193	0.9939	0.9470
29	-0.000024	0.000241	0.000235	-0.000002	1.3528	0.6721	-0.015465	1.0379	0.9504
30	-0.000020	0.000230	0.000236	-0.000002	1.3528	0.6721	-0.015692	1.0205	0.9713
31	-0.000028	0.000228	0.000227	-0.000005	1.3190	0.6721	-0.015660	0.9604	0.9835
32	-0.000025	0.000224	0.000222	-0.000004	1.3190	0.6721	-0.015957	1.0422	0.9747
33	-0.000027	0.000218	0.000214	-0.000004	1.3190	0.6721	-0.015974	1.0830	1.0054
34	-0.000010	0.000212	0.000211	-0.000004	1.3190	0.6721	-0.015908	1.1429	1.0010
35	-0.000012	0.000208	0.000207	-0.000004	1.3190	0.6721	-0.015743	1.0565	0.9895
36	-0.000011	0.000201	0.000200	-0.000004	1.3190	0.6721	-0.015567	1.0260	0.9747
37	-0.000012	0.000200	0.000194	-0.000004	1.3190	0.6721	-0.015273	0.9776	0.9612
38	-0.000012	0.000193	0.000192	-0.000003	1.2860	0.6721	-0.014957	0.8890	0.9059
39	-0.000017	0.000181	0.000182	-0.000003	1.2860	0.6721	-0.014616	0.8453	0.9071
40	-0.000012	0.000169	0.000165	-0.000003	1.2860	0.6722	-0.014247	0.8262	0.9200
41	-0.000016	0.000159	0.000151	-0.000003	1.2860	0.6722	-0.013947	0.7935	0.9107
42	-0.000012	0.000154	0.000157	-0.000003	1.2860	0.6722	-0.013595	0.7305	0.9010
43	-0.000009	0.000151	0.000151	-0.000003	1.2860	0.6722	-0.013292	0.7000	0.8902
44	-0.000007	0.000140	0.000135	-0.000003	1.2860	0.6722	-0.013020	0.6332	0.8865
45	-0.000004	0.000126	0.000126	-0.000003	1.2860	0.6722	-0.012780	0.7571	0.8880
46	-0.000005	0.000112	0.000112	-0.000002	1.2860	0.6722	-0.012576	0.7133	0.8965
47	-0.000004	0.000097	0.000097	-0.000002	1.2860	0.6723	-0.012399	0.7792	0.8995
48	0.000003	0.000082	0.000082	-0.000002	1.2860	0.6723	-0.012254	0.7560	0.8963
49	0.000003	0.000069	0.000069	-0.000002	1.2440	0.6723	-0.012175	1.1641	0.8969

Table 12. (Continued)

110	0.3732	3.682950E 21	653.0	542.6	558.1	651.0	685.0	-81.6
111	0.3749	3.132950E 22	518.3	599.0	617.2	685.4	761.9	-93.9
112	0.2523	0.291127E 21	577.0	644.4	661.9	731.3	808.3	-90.4
113	0.2826	0.268097E 22	617.5	680.7	696.4	758.0	819.1	-80.4
114	0.2783	0.327700E 27	656.5	700.5	721.6	773.4	824.7	-67.5
115	0.2761	0.379002E 26	688.1	730.1	748.0	783.1	825.0	-55.2
116	0.2750	0.424156E 22	713.4	747.4	755.7	789.8	823.6	-44.5
117	0.2744	0.464091E 22	733.7	760.5	767.0	794.7	821.8	-35.6
118	0.2740	0.501172E 22	749.9	771.3	775.7	798.5	820.1	-28.3
119	0.2737	3.542003E 22	762.9	780.0	784.3	801.6	818.9	-22.5
120	0.2735	0.543973E 22	773.4	787.8	790.4	804.2	818.0	-17.9
121	0.2735	0.611324E 22	781.0	792.7	795.0	804.4	817.5	-14.3
122	0.2734	0.690767E 22	788.6	797.3	799.5	808.2	817.1	-11.4
123	0.2734	0.776908E 22	794.1	801.0	802.0	809.8	816.9	-9.1
124	0.2734	0.788510E 22	795.5	804.9	806.5	812.9	819.4	-8.3
125	0.2734	0.793310E 22	802.1	808.5	810.1	816.5	823.0	-8.3
126	0.2735	0.785452E 22	805.1	811.6	813.1	819.5	826.0	-8.3
127	0.2736	0.751679E 21	394.2	445.2	495.1	535.6	577.7	-52.3
128	0.4025	0.530155E 21	455.6	547.8	562.5	621.5	681.6	-76.5
129	0.3374	0.300602E 22	514.9	596.4	615.0	668.4	706.4	-84.9
130	0.3109	0.144430E 22	547.3	630.8	650.5	716.6	778.7	-80.8
131	0.2472	0.307812E 22	610.8	570.7	643.9	730.8	792.0	-71.1
132	0.2498	0.220971E 22	645.9	693.7	705.2	758.7	794.0	-59.3
133	0.2854	0.267015E 22	673.9	711.9	721.2	758.3	795.1	-48.3
134	0.2426	0.267751E 22	696.1	726.1	733.6	763.4	793.0	-34.8
135	0.2800	0.284505E 22	713.6	737.4	743.8	767.2	790.0	-31.0
136	0.2795	0.299142E 22	727.6	746.4	751.2	776.1	789.0	-24.7
137	0.2795	0.309412E 22	738.8	753.6	757.5	772.4	787.6	-19.7
138	0.2780	0.318830E 22	747.7	759.5	762.6	776.6	786.6	-15.7
139	0.2775	0.324776E 22	754.9	764.3	766.7	776.3	785.9	-12.5
140	0.2771	0.334204E 22	761.3	768.8	770.8	778.0	786.1	-10.0
141	0.2768	0.344590E 22	766.0	773.1	774.8	781.2	787.6	-8.4
142	0.2765	0.349146E 22	771.4	777.7	779.3	785.8	792.2	-8.4
143	0.2764	3.374439E 22	775.1	781.5	783.1	789.6	796.0	-8.4
144	0.2762	0.387644E 22	778.2	784.8	786.4	792.6	799.2	-8.4
145	0.0	0.0	850.0	350.0	304.0	304.0	304.0	0.0
146	0.0	0.0	850.0	350.0	304.0	304.0	304.0	0.0
147	0.0	0.0	850.0	350.0	304.0	304.0	304.0	0.0
148	0.0	0.0	850.0	350.0	304.0	304.0	304.0	0.0
149	0.0	0.0	850.0	350.0	304.0	304.0	304.0	0.0
150	0.0	0.0	850.0	350.0	304.0	304.0	304.0	0.0
151	0.0	0.0	850.0	350.0	304.0	304.0	304.0	0.0
152	0.0	0.0	850.0	350.0	304.0	304.0	304.0	0.0
153	0.0	0.0	850.0	350.0	304.0	304.0	304.0	0.0
154	0.0	0.0	850.0	350.0	304.0	304.0	304.0	0.0
155	0.0	0.0	850.0	350.0	304.0	304.0	304.0	0.0

THE TEMPS, PEAK/NEAR BY ZONE, SURFACE 932.0 926.7 0.0 0.0 POWER HEIGHTED 750.0 0.0 POWER (WAT, 1.7678E 03)

AVERAGE AND PEAK TEMPERATURE SLOPE AT PEBBLE PAST/SHELL INTERFACE (DEG/CM) -44.1 -110.4

CORRELATION FAILURE COUNT 490 0

CUMULATIVE FRACTIONS OF THE FUEL ABOVE DEFERENCE TEMPERATURES, DEG C (SEE BASIC DATA POINTS 103.99, 104)

425	0.00310915	725	0.02387429	525	0.96750098
900	0.10760401	700	0.45841056	500	0.51031923
475	0.25290212	675	0.87728439	475	0.94726946
850	0.38231331	650	0.89572455	450	0.99524128
825	0.44444774	625	0.91146612	425	0.99970388
800	0.54265716	600	0.92591162	400	0.99999999
775	0.69744204	575	0.94003164	375	1.00000000
750	0.78015049	550	0.95504617	350	1.00000000

TOTAL CPU TIME IS 1.492 MINUTES AND TOTAL CLOCK TIME IS 10.286 MINUTES FOR PEBBLE CODE EXECUTION

---THN-TH- GAS COOLED REACTOR THERMAL HYDRAULICS CODE, ORNL VERSION 0.1, FALL 1982 -- QA LEVEL 0

THN-TH SAMPLE PROBLEMS, PEBBLE PEB 1989 PHOSPHATIC THERMAL HYDRAULICS

--- INTEGER CONTROL VARIABLES ---

IDHPL (2-FLUX DCHW, 1-FLUX HP) 0
 CDHPL/HS PRESSURE DCHW AND PHLA CCHW 0
 IFLOW (-1/0, 1/2- FLUENCE 0/ CPHIST/ REPORT) 0
 IFPHR (-1/0, 1/2- TOTAL/FIRST/SPCCE RANGE) 0
 SOROUT AVAILABLE IF .NE. 0 (WORDS) 0
 HEAT CONDUCTION THERMAL CONDUCTIVITY 0
 LENGTH EDIT LEVEL 0
 EDIT LEVEL OPTION 0
 HEAT REMOVAL OPTIONS 0
 FUEL ELEMENT GEOMETRY, 0- SPHERE, 1- CYL 0

0 0 -1 0 1 0 0 0 0 -1

--- FLOATING POINT CONTROL VARIABLES ---

VOID FRACTION 0.0
 INLET TEMPERATURE (C) 0.35000 03
 INLET PRESSURE (ATM) 0.00000 02
 INLET FLOW RATE (G/GS) 0.0
 CHARACTERISTIC HYDRAULIC DIAMETER (CM) 0.60000 01

```

EXPONENT FLOODE
DECOMPOSED TEMPERATURE FUNCTION 0.0
STRUCTURED POWER LEVEL 0.55000 00
STRUCTURED POWER LEVEL 0.0
DISTRIBUTION OF CELL FOR HEAT REMOVAL (CM) 0.0
TOTAL RADIIUS OF CELL 48.0000 (CM) 0.25000 01

TOTAL RADIIUS OF STRUCTURE MATERIAL (CM) 0.25000 01
OUTLET TEMPERATURE (C) 0.55000 03
RADIANCE MULTIPLIER 0.15000 01
THERMAL CONDUCTIVITY MULTIPLIER 0.25000 01
CONVECTANCE COEFFICIENT 0.0
MAXIMUM CPU TIME IN SECONDS 0.15000 03

0.0 0.0 0.0 0.0 0.500000-CI 0.0 7.0 0.0 0.0 1.500000 02

SARINAT REMOBY REQUIREMENT -- 69514 WORDS, REMOBY AVAILABLE -- 160000 WORDS

POWER OF ZUPPOD - 0.16300 TO DOVS BCL MATCH PRINT- 0.16000 10

TIME OF ZUPPOD- 0.20370 05 DOVS BCL MATCH PRINT- 0.0

DATA USEI HORDERS, SECRETARY, EXPOSURE, EXCHG AND PCINT POWER DENSITY 10 30 19 10

EMPOLET YESH (2-D PLANT) 1 29 11 46 0.0 015.00 200.00 750.00

THE ENDS OF THE VARIABLE DIMENSIONED DATA BLOCES 5415 7061 31090 30967 03031

DATA ARRAY STORAGE REQUIREMENT 00031

MINIMAL VOID FRACTION, MAXIMUM AND MINIMUM 0.00000 0.00000 0.00000

VARIABLE POWER DENSITY (W/CC) LOCATION - RADIIUS / BIRTH PROF TOP (M)
-----
16.170 0.000 / 0.050

TWO-TH SHIPLE PROBLEMS, PEOPLE REC THEN PRISAPIC FORMAL HYDRAULICS

TEMPERATURES APPRIARILY ADJUSTED TO ELIMINATE THE HEAT BALANCE ERROR

RED RADIIUS AND HEIGHT (M) 0.15000 5.50000
THERMAL POWER (MW) 1.65000 03
COPIANT MASS FLOW RATE (KG/S) 6.30000 02
INLET AVERAGE VELOCITY (M/S) 21305.
INLET COPIANT TEMPERATURE (C) 350.0
HEAT OUTLET COPIANT TEMPERATURE (C) 950.
PEAK OUTLET COPIANT TEMPERATURE (C) 910.4 AT RADIIAL LOCATION (M) 0.0
MAX AND MIN SPHICAL SURFACE TEMPERATURES (C) 919.1 015.0
INLET PRESSURE (ATM) 00.700
OUTLET PRESSURE (ATM) 39.320
PRESSURE DROP (ATM) 0.67500
ENRAGE IN FLOW AND HEAT BALANCE (PERCENT) 0.0 -0.97
APPROXIMATE AXIAL PRESSURE CHANGE ACROSS CORE AT 0/3 AND 20/3 (ATM), --NO GRAVITY -0.67005 -0.67070

PAKIIAT RADIAL COMPONENT OF THE RELATIVE MASS FLOW RATE (ABSOLUTE) 0.00500

APPARENT EXTREME PRESSURE DROP (ATM) 0.67500

AXIAL COMPONENT OF RELATIVE MASS FLOW RATE, GZ
RADIAL 0.0 0.1391 0.1947 0.2410 0.2774 0.3103 0.3394 0.3756 0.4154 0.4467 0.4795 0.5004 0.5165
AXIAL
0.0000 0.9707 0.9741 0.9794 0.9805 0.9811 0.9814 0.9820 0.9830 0.9850 0.9855 0.9867 0.9891
0.0274 0.9702 0.9700 0.9796 0.9802 0.9808 0.9810 0.9820 0.9829 0.9840 0.9851 0.9862 0.9880
0.0554 0.9701 0.9700 0.9794 0.9800 0.9806 0.9811 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.0833 0.9700 0.9700 0.9794 0.9800 0.9806 0.9811 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.1111 0.9700 0.9701 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.1389 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.1667 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.1944 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.2222 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.2500 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.2774 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.3056 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.3333 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.3611 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.3889 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.4167 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.4444 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.4722 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.5000 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.5274 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.5556 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.5833 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.6111 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.6389 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.6667 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.6944 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.7222 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.7500 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.7774 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.8056 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.8333 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.8611 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.8889 0.9700 0.9700 0.9787 0.9800 0.9806 0.9810 0.9810 0.9820 0.9830 0.9840 0.9850 0.9860
0.9167
```

Table 12. (Continued)

143	0.2466	0.387611E 22	772.4	775.9	776.8	780.8	784.8	-5.2
144	0.2465	0.394635E 22	775.4	778.3	779.1	782.3	785.6	-4.2
145	0.0	0.0	850.0	850.0	877.0	877.0	877.0	0.0
146	0.0	0.0	850.0	850.0	877.0	877.0	877.0	0.0
147	0.0	0.0	850.0	850.0	877.0	877.0	877.0	0.0
148	0.0	0.0	850.0	850.0	877.0	877.0	877.0	0.0
149	0.0	0.0	850.0	850.0	877.0	877.0	877.0	0.0
150	0.0	0.0	850.0	850.0	877.0	877.0	877.0	0.0
151	0.0	0.0	850.0	850.0	877.0	877.0	877.0	0.0
152	0.0	0.0	850.0	850.0	877.0	877.0	877.0	0.0
153	0.0	0.0	850.0	850.0	877.0	877.0	877.0	0.0
154	0.0	0.0	850.0	850.0	877.0	877.0	877.0	0.0
155	0.0	0.0	850.0	850.0	877.0	877.0	877.0	0.0

MAX TEMPS, PEAK/MEAN BY ZONE, SURFACE 523.7 918.0 0.6 0.0 POWER HEIGHTS 748.1 0.0 POWER (WTS) 1.6505E 03

AVERAGE AND PEAK TEMPERATURE SLOPE AT PROFILE HEAT/SHELL INTERFACE (DEG/CM) -46.5 -130.7

CORRELATION FAILURE COUNT 910 0

TEMPERATURES RECALCULATED FOR THE PEAK ZONE SURFACE TEMPERATURES (ASSUMED WORST CASE, (ISORGB9) INTEGRALS)

ZONE	(CONDUCTIVITY AND VISCOSITY), FLUID	SURFACE	SHELL	HEAT CENTER TEMPERATURES, DT/DS (DEG/CM)
1	0.8918 0.262331E 21	807.3	521.1	535.0
2	0.3481 0.100300E 22	808.2	600.0	621.9
3	0.3027 0.197699E 22	566.0	664.1	607.1
4	0.2844 0.211479E 22	633.4	715.6	734.5
5	0.2846 0.473104E 22	690.0	757.3	775.0
6	0.2835 0.512062E 22	735.6	790.0	804.6
7	0.2857 0.543744E 22	772.3	816.1	827.7
8	0.2871 0.569326E 22	801.9	837.1	846.3
9	0.2883 0.589939E 22	825.8	854.1	861.4
10	0.2893 0.605346E 22	845.0	867.0	871.4
11	0.2902 0.103307E 23	860.6	879.0	883.6
12	0.2900 0.104468E 23	873.2	888.1	891.0
13	0.2907 0.105342E 23	883.5	895.5	898.5
14	0.2913 0.106049E 23	891.9	901.6	904.0
15	0.2918 0.106621E 23	898.7	906.6	908.5
16	0.2922 0.107084E 23	904.3	910.5	912.2
17	0.2925 0.107450E 23	908.8	914.9	916.4
18	0.2931 0.107745E 23	912.8	919.0	920.5
19	0.2949 0.255124E 21	805.7	517.1	530.6
20	0.3459 0.972859E 21	885.0	595.7	616.7
21	0.3027 0.192433E 22	561.6	658.9	601.7
22	0.2886 0.322572E 22	620.7	710.0	730.7
23	0.2841 0.450510E 22	684.4	751.4	769.1
24	0.2826 0.489244E 22	725.7	783.9	798.5
25	0.2850 0.791993E 22	766.1	809.8	821.4
26	0.2848 0.817691E 22	795.5	830.6	839.0
27	0.2851 0.839029E 22	819.1	847.4	854.7
28	0.2872 0.854565E 22	838.2	860.9	866.0
29	0.2881 0.867886E 22	853.6	871.9	876.6
30	0.2889 0.878627E 22	866.1	880.9	884.6
31	0.2896 0.887297E 22	876.2	888.1	891.2
32	0.2901 0.894302E 22	884.4	894.1	896.5
33	0.2906 0.897965E 22	891.1	898.9	900.9
34	0.2909 0.904541E 22	896.5	902.9	904.4
35	0.2912 0.908224E 22	901.0	907.0	909.5
36	0.2918 0.911047E 22	904.8	911.1	912.5
37	0.2931 0.246280E 21	803.9	512.6	525.7
38	0.3483 0.938779E 21	881.2	590.3	610.8
39	0.3034 0.186116E 22	556.4	653.0	675.5
40	0.2887 0.111862E 22	622.8	703.7	724.2
41	0.2837 0.425772E 22	676.0	744.8	762.5
42	0.2822 0.723862E 22	722.9	777.1	791.6
43	0.2820 0.755214E 22	744.1	802.0	814.3
44	0.2836 0.780503E 22	788.2	823.3	832.5
45	0.2849 0.800931E 22	811.7	839.0	847.1
46	0.2859 0.817333E 22	830.5	853.2	859.0
47	0.2868 0.830527E 22	845.8	864.0	868.6
48	0.2875 0.841151E 22	858.1	872.7	876.5
49	0.2882 0.849713E 22	868.0	879.9	882.9
50	0.2897 0.856619E 22	876.1	885.7	888.1
51	0.2891 0.862192E 22	882.6	890.4	892.3
52	0.2895 0.866687E 22	888.0	894.2	895.8
53	0.2897 0.870297E 22	892.3	898.3	899.0
54	0.2903 0.873040E 22	896.0	902.3	903.0
55	0.2900 0.235123E 21	801.5	504.2	518.7
56	0.3455 0.895017E 21	876.1	582.3	602.2
57	0.3045 0.177390E 22	549.4	644.2	666.1
58	0.2946 0.276112E 22	614.3	694.2	714.0
59	0.2830 0.395342E 22	648.6	734.8	752.3
60	0.2812 0.572323E 22	712.8	766.6	781.1
61	0.2808 0.603275E 22	748.5	791.8	803.4
62	0.2823 0.624288E 22	777.2	812.0	821.1
63	0.2834 0.648396E 22	800.2	828.1	835.4
64	0.2843 0.664557E 22	818.8	841.2	847.0
65	0.2851 0.677540E 22	833.1	851.7	856.3
66	0.2857 0.687975E 22	845.7	860.2	861.9
67	0.2863 0.696371E 22	855.5	867.1	870.1
68	0.2869 0.101861E 23	863.3	872.7	875.1
69	0.2867 0.102405E 23	869.7	877.3	879.2
70	0.2870 0.102444E 23	874.9	881.0	882.5
71	0.2873 0.103195E 23	879.1	885.1	886.6
72	0.2880 0.103463E 23	882.6	888.9	890.4
73	0.2882 0.103462E 23	886.9	892.2	894.9
74	0.2885 0.103462E 23	890.4	895.9	897.4
75	0.2889 0.103462E 23	894.9	899.0	899.0
76	0.2889 0.257545E 22	604.1	682.5	702.3

Table 12. (Continued)

77	0.2020	0.2009192	22	657.0	722.3	739.4	807.2	873.0	-30.3	
78	0.2001	0.4022398	22	700.2	753.4	767.7	823.0	879.0	-71.2	
79	0.2790	0.7267772	22	735.1	777.9	789.0	835.0	879.9	-59.5	
80	0.2792	0.7492408	22	763.1	797.4	806.6	842.9	879.1	-87.0	
81	0.2803	0.7689008	22	785.5	813.1	820.3	849.3	878.3	-37.7	
82	0.2812	0.7866798	22	802.6	825.6	831.3	854.5	877.7	-30.0	
83	0.2819	0.7973308	22	818.0	835.7	840.3	858.0	877.4	-20.0	
84	0.2825	0.8074812	22	829.7	843.9	847.6	862.3	877.2	-19.1	
85	0.2830	0.8156338	22	839.1	850.5	853.0	865.2	877.2	-15.3	
86	0.2834	0.8221822	22	846.6	855.0	858.2	867.5	877.3	-12.3	
87	0.2838	0.8274468	22	852.7	860.1	862.0	869.6	877.4	-9.9	
88	0.2841	0.8316738	22	857.7	863.6	865.2	871.3	877.6	-8.0	
89	0.2843	0.8350522	22	861.7	867.7	869.2	875.4	881.7	-8.0	
90	0.2850	0.8376278	22	865.1	871.3	872.9	879.0	885.3	-7.9	
91	0.5220	0.2061201	21	395.0	490.7	501.6	545.0	591.6	-57.1	
92	0.3628	0.7737151	21	463.0	561.7	579.3	645.0	721.5	-91.0	
93	0.3093	0.7519932	22	530.2	620.1	640.2	719.7	799.3	-103.0	
94	0.2900	0.2330308	22	590.6	667.3	686.4	761.4	835.9	-97.9	
95	0.2823	0.3109508	22	641.6	705.0	722.6	788.5	853.6	-86.0	
96	0.2792	0.4002152	22	683.3	735.6	749.6	800.6	850.9	-71.0	
97	0.2778	0.4961372	22	716.9	759.1	770.5	815.2	859.5	-50.5	
98	0.2773	0.6116542	22	743.0	777.6	786.7	822.5	858.2	-46.6	
99	0.2777	0.6300468	22	765.4	792.0	799.6	828.2	856.0	-37.3	
100	0.2778	0.6350508	22	782.6	800.2	809.9	832.7	855.6	-29.0	
101	0.2770	0.9470952	22	796.4	813.7	818.2	836.4	854.7	-23.7	
102	0.2783	0.9575100	22	807.5	821.3	824.9	839.0	854.1	-18.9	
103	0.2707	0.9652658	22	816.0	827.4	830.3	841.9	853.7	-15.1	
104	0.2791	0.9714608	22	823.5	832.4	834.7	844.0	853.4	-12.1	
105	0.2794	0.9760272	22	829.2	836.4	838.2	845.7	853.2	-9.7	
106	0.2796	0.9800852	22	833.0	839.9	841.4	847.7	854.0	-8.1	
107	0.2799	0.9835752	22	837.6	843.6	845.2	851.4	857.0	-8.1	
108	0.2806	0.9879702	22	840.7	847.0	848.6	854.0	861.2	-8.1	
109	0.5361	0.1907000	21	470.1	570.1	590.1	677.4	760.6	-51.0	
110	0.3736	0.6010222	21	453.7	540.2	559.0	622.7	686.6	-81.5	
111	0.3153	0.1320592	22	515.4	590.7	616.0	680.9	761.4	-93.7	
112	0.2925	0.1993068	22	571.3	642.9	660.5	729.0	790.7	-90.3	
113	0.2827	0.2657002	22	610.7	670.9	690.6	756.2	817.2	-80.0	
114	0.2783	0.3206208	22	657.6	706.0	720.0	771.7	823.0	-67.6	
115	0.2761	0.3760372	22	689.0	728.6	739.4	781.7	823.6	-55.2	
116	0.2769	0.4210162	22	710.2	745.9	754.5	788.6	822.4	-44.5	
117	0.2702	0.4536272	22	730.3	759.6	766.4	793.7	820.9	-35.6	
118	0.2730	0.5033352	22	750.4	770.5	776.0	797.7	819.4	-28.3	
119	0.2736	0.5401022	22	763.3	779.3	783.7	801.0	818.3	-22.5	
120	0.2735	0.5680212	22	773.6	786.4	789.9	803.7	817.5	-17.9	
121	0.2730	0.6190122	22	781.9	792.2	796.9	805.9	817.0	-14.3	
122	0.2733	0.7069608	22	780.6	796.9	799.1	807.0	816.7	-11.0	
123	0.2733	0.8155022	22	790.1	800.7	802.7	809.4	816.5	-9.1	
124	0.2732	0.8190312	22	796.5	804.5	806.1	812.5	819.0	-8.3	
125	0.2737	0.8210322	22	802.0	808.1	809.7	816.1	822.6	-8.3	
126	0.2743	0.8239068	22	805.1	811.4	813.0	819.4	825.9	-8.3	
127	0.5507	0.1517608	21	394.5	487.7	497.7	530.2	560.3	-52.3	
128	0.4024	0.5372312	21	456.4	540.8	563.5	622.5	682.0	-76.0	
129	0.3394	0.1801348	22	516.2	597.9	610.3	679.6	745.5	-84.9	
130	0.3111	0.1059022	22	560.6	637.2	652.0	710.9	776.9	-80.7	
131	0.2972	0.1066912	22	612.1	660.3	682.1	736.6	791.0	-71.1	
132	0.2897	0.2198052	22	647.0	692.1	703.6	749.1	794.4	-59.0	
133	0.2853	0.2461908	22	670.8	710.5	719.9	757.0	793.0	-48.3	
134	0.2825	0.2672698	22	696.7	725.0	732.6	762.4	792.0	-30.0	
135	0.2807	0.2862672	22	710.2	736.5	742.5	766.3	790.0	-31.0	
136	0.2794	0.2901462	22	720.0	745.7	750.5	769.4	788.3	-20.7	
137	0.2785	0.3096082	22	739.0	753.0	756.9	772.0	787.0	-19.7	
138	0.2770	0.3191762	22	747.8	757.0	762.0	774.1	784.1	-15.7	
139	0.2770	0.3272222	22	755.0	763.8	766.2	775.0	785.4	-12.5	
140	0.2770	0.3356592	22	761.3	768.4	770.4	778.0	785.7	-10.0	
141	0.2767	0.3450112	22	766.0	772.8	774.4	780.0	787.2	-8.0	
142	0.2764	0.3600492	22	771.3	777.3	778.9	785.3	791.7	-8.0	
143	0.2762	0.3750152	22	775.0	781.0	782.6	789.1	795.5	-8.0	
144	0.2761	0.3893602	22	778.2	780.5	786.2	792.6	799.0	-8.0	
145	0.0	0.0	0	850.0	350.0	304.0	304.0	304.0	0.0	
146	0.0	0.0	0	850.0	350.0	304.0	304.0	304.0	0.0	
147	0.0	0.0	0	850.0	350.0	304.0	304.0	304.0	0.0	
148	0.0	0.0	0	850.0	350.0	304.0	304.0	304.0	0.0	
149	0.0	0.0	0	850.0	350.0	304.0	304.0	304.0	0.0	
150	0.0	0.0	0	850.0	350.0	304.0	304.0	304.0	0.0	
151	0.0	0.0	0	850.0	350.0	304.0	304.0	304.0	0.0	
152	0.0	0.0	0	850.0	350.0	304.0	304.0	304.0	0.0	
153	0.0	0.0	0	850.0	350.0	304.0	304.0	304.0	0.0	
154	0.0	0.0	0	850.0	350.0	304.0	304.0	304.0	0.0	
155	0.0	0.0	0	850.0	350.0	304.0	304.0	304.0	0.0	
MAX TEMPS, PEAK/MEAN BY ZONE, SURFACE				932.6	926.5	0.0	0.0 POWER HEIGHTS	750.6	O.C POWER (NOT)	1.76708 03
AVERAGE AND PEAK TEMPERATURE SLOPE AT PEBBLE FEAT/SHELL INTERFACE (DEG/IN)				-80.1	-110.2					
CORRELATION FAILURE COUNT				493	0					
CUMULATIVE FRACTIONS OF THE FUEL ARC/FEAT DIFFERENCE TEMPERATURES, DEG C (SEE BASIC DATA SCHEM)				143.99,	100)					
925	0.00270953	725	0.02267709	525	0.16060772					
900	0.10470372	700	0.10401040	500	0.97915161					
875	0.24973565	675	0.07723303	475	0.98706025					
850	0.37472225	650	0.09603690	450	0.99540261					
825	0.48100615	625	0.91236700	425	0.99974000					
800	0.57953260	600	0.92710291	400	0.99999976					
775	0.69300500	575	0.94152210	375	1.00000000					
750	0.77400230	550	0.99647903	350	1.00000000					
TOTAL CPU TIME IS				0.002 MINUTES AND TOTAL CLOCK TIME IS	5.103 SECONDS FOR PEBBLE CODE EXECUTION					

Table 12. (Continued)

---THE-TM- GAS COOLED REACTOR THERMAL HYDRAULICS CODE, ORNL VERSION 4.1, FALL 1983 -- QA LEVEL 0

THE-TM SAMPLE PROBLEMS, PEBBLE BED THERMAL HYDRAULICS

---- INTEGER CONTROL VARIABLES ----

INLET (0-FLUX DOWN, 1-FLUX UP) C
 GEOMETRY/US PRESSURE DROP AND FLOW CORRECTION C
 INLET (-1/0, 1/2- FLOW/US CORRECTION/ REPORT) -1
 INLET (-1/0, 1/2- TOTAL/FIRST/SECOND RANGE) 0
 MEMORY AVAILABLE IF .GE. 0 (WORDS) 0
 HEAT CONDUCTION THERMAL CONDUCTIVITY 0
 KENEC EXIT LEVEL 0
 EXIT LEVEL OPTION 0
 HEAT REMOVAL OPTIONS C
 FUEL ELEMENT GEOMETRY, 0- SPHERE, 1- CYL 0

0 0 0 0 0 0 0 0 0 0 1 0 1 1

---- FLOATING POINT CONTROL VARIABLES ----

VOID FRACTION 0.0
 INLET TEMPERATURE (C) 0.15000 03
 INLET PRESSURE (ATM) 0.00000 02
 MASS FLOW RATE (KG/S) 0.0
 CHARACTERISTIC HYDRAULIC DIAMETER (CM) 0.00000 01

REFERENCE FLUX 0.0
 RECOVERABLE ENERGY FRACTION 0.55000 00
 SPECIFIED POWER LEVEL 0
 DIMENSION OF CELL FOR HEAT REMOVAL (CM) 0
 FUEL RADIUS OF ZONE MATERIAL (CM) 0.0 01

FUEL RADIUS OF SUBSTRATE MATERIAL (CM) 0.15000 01
 OUTLET TEMPERATURE (C) 0.25000 03
 FLUX MULTIPLIER 0.10000 01
 THERMAL CONDUCTIVITY MULTIPLIER 0.10000 01
 CONVERGENCE CRITERIA 0.0

MAXIMUM CPU TIME IN SECONDS 0.10000 03

0.0 0.0 0.0 0.0 0.500000-01 0.0 0.0 0.0 0.0 1.200000 02

MAXIMUM MEMORY REQUIREMENT -- 69514 WORDS, MEMORY AVAILABLE -- 160000 WORDS

POWER OF INFLOW - 0.1638E 10 DOES NOT MATCH EXACTLY- 0.16400E 10

TYPE OF INFLOW- 0.2037E 05 DOES NOT MATCH EXACTLY- 0.0

DATA UNIT NUMBERS, GEOMETRY, EXPOSURE, ZONE AND POINT POWER DENSITY 10 0 10 10

PROBLEM TEST (2-D PLANE) 1 29 11 06 0.0 015.00 200.00 750.00

THE ENDS OF THE VARIABLY DIMENSIONED DATA BLOCKS 5819 7061 31090 30967 03031

DATA ARRAY STORAGE REQUIREMENT 03031

INITIAL VOID FRACTION, MAXIMUM AND MINIMUM 0.00000 0.00000 0.00000

MAXIMUM POWER DENSITY (W/CC) LOCATION - RADIUS / DEPTH FROM TOP (M)

16.070 0.071 0.050

110	0.3712	0.602907E 21	853.0	502.0	558.1	611.0	605.0	-01.6
111	0.3109	0.132049E 22	510.3	590.9	617.1	609.3	761.9	-93.9
112	0.2923	0.201115E 22	570.0	600.3	661.9	731.3	800.3	-90.0
113	0.2826	0.254044E 22	617.5	600.7	696.3	750.0	819.0	-00.0
114	0.2701	0.327726E 22	656.5	700.0	721.6	771.4	824.6	-67.6
115	0.2761	0.370905E 22	688.1	730.0	700.7	783.1	824.9	-55.2
116	0.2750	0.420001E 22	713.0	767.0	755.6	789.7	823.5	-44.5
117	0.2763	0.464600E 22	733.6	760.0	767.3	790.6	821.7	-35.6
118	0.2740	0.502790E 22	709.9	771.2	776.7	790.4	820.1	-28.3
119	0.2737	0.541530E 22	762.0	779.9	780.2	801.5	818.0	-22.5
120	0.2736	0.583037E 22	773.3	780.9	790.3	800.1	818.0	-17.9
121	0.2735	0.629901E 22	781.7	792.6	795.3	800.3	817.4	-10.3
122	0.2710	0.680502E 22	780.5	797.2	799.0	800.2	817.0	-11.0
123	0.2730	0.727600E 22	790.0	800.9	802.7	809.7	816.0	-0.1
124	0.2733	0.776009E 22	790.0	800.0	806.0	812.0	819.3	-0.3
125	0.2730	0.779290E 22	802.1	800.5	810.0	816.0	822.9	-0.3
126	0.2705	0.781804E 22	805.0	811.5	813.1	819.5	825.9	-0.3
127	0.5590	0.151677E 21	390.1	405.2	495.1	535.6	577.7	-52.3
128	0.4025	0.538376E 21	455.5	507.7	562.0	621.5	681.0	-76.5
129	0.3390	0.100639E 22	510.9	590.6	615.0	680.0	706.0	-00.9
130	0.3109	0.106027E 22	567.2	630.0	650.0	710.5	770.6	-00.0
131	0.2972	0.107719E 22	610.7	670.0	693.0	730.0	792.7	-71.1
132	0.2890	0.220850E 22	605.9	692.6	705.1	750.7	795.9	-59.3
133	0.2850	0.245909E 22	673.0	711.0	721.2	750.2	795.0	-00.3
134	0.2824	0.267097E 22	696.0	720.0	733.6	763.3	792.9	-30.0
135	0.2800	0.280051E 22	713.6	737.3	743.3	767.1	790.0	-31.0
136	0.2795	0.290070E 22	727.5	740.3	751.1	770.1	789.0	-20.7
137	0.2706	0.309333E 22	730.7	753.6	757.0	772.5	787.5	-19.7
138	0.2700	0.318703E 22	747.6	750.0	762.5	770.5	786.5	-15.7
139	0.2775	0.326673E 22	750.0	760.2	766.6	770.3	785.0	-12.5

TOTAL CPU TIME IS 0.004 MINUTES AND TOTAL CLOCK TIME IS 0.934 MINUTES FOR PEELE CODE EXECUTION

Prismatic cone Description

OVERVIEW - SPECIAL INFANT MCDOLE - JANUARY 17, 1979 - QUALITY ASSURANCE LEVEL 0

CASE TITLE - TWO-TN SAMPLE PROBLEMS, PEOPLE ARE THEN PRISMATIC THERMAL HYDRAULICS

REF ID: A66006

INPUT SECTION 1

INPUT SECTION 2														
XX1	0.0		0.0		0.0		3.000000E 07	1.000000E-01	1.000000E 00					
XX2	0.0		0.0		0.0		0.0	0.0	0.0					
XX3	0.0		0.0		0.0		0.0	0.0	0.0					
XXC	1	0	0	0	0	-1	0	0	0	0	0	0	0	0
XXE	0	0	0	1	0	0	0	0	0	0	0	0	0	0
XXH	0	0	0	0	0	0	0	0	0	0	0	0	0	0
XXI	0	0	0	0	0	0	0	0	0	0	0	0	0	0
XXJ	0	0	0	0	0	0	0	0	0	0	0	0	0	0
XXK	0	0	0	0	0	0	0	0	0	0	0	0	0	0
XXL	0	0	0	0	0	0	0	0	0	0	0	0	0	0
XXM	0	0	0	0	0	0	0	0	0	0	0	0	0	0
XXN	0	0	0	0	0	0	0	0	0	0	0	0	0	0
XXO	0	0	0	0	0	0	0	0	0	0	0	0	0	0
XXP	0.0		0.0		0.0		0.0	0.0	0.0					
XXQ	0.0		0.0		0.0		0.0	0.0	0.0					

OTWIFB RECORD REPLACED ON FILE CONTROL

IMP3; SECTION 1

```

17 2 0 2 1 2 2 C C 0 0 0 0 0 0 0 0
GEOMETRY NO. 17 1-D TRIANGULAR-Z
TRIANGULAR OPTION 0 PARALLELOGRAM - 120 DEGREES
FSQ 0.1
ISRR 1
ENDC 0.692000E-01 0.0 0.692000E-01 0.0 0.692000E-01 0.692000E-01
ENDI 0.692000E-01

```

INPUT SECTION ■

[illegible]

INDUSTRY NO.	17	2	3	4	5	6	7	8
J/IT	1 0.0	2 12.5000	3 25.0000	4 37.5000	5 50.0000	6 62.5000	7 75.0000	8 87.5000
J/IT	1 100.0000	2 112.5000	3 125.0000	4 137.5000	5 150.0000	6 162.5000	7 175.0000	8 187.5000
J/IT	1 0.0	2 25.0000	3 50.0000	4 75.0000	5 100.0000	6 125.0000	7 150.0000	8 175.0000
J/IT	1 0.0	2 10.0000	3 20.0000	4 30.0000	5 40.0000	6 50.0000	7 60.0000	8 70.0000

Table 12. (Continued)

17/22	2 758.3333	10 881.6667	11 525.0000	12 650.0000	13 775.0000	14 793.7500	15 812.5000	16 831.2500
18/22	17 750.0000							
19/22	1 6.2500	2 10.7500	3 31.2500	4 47.7500	5 56.2500	6 68.7500	7 81.2500	8 93.7500
20/22	9 106.2500	10 118.7500	11 121.2500	12 143.7500				
21/22	1 12.5000	2 37.5000	3 42.5000	4 87.5000	5 112.5000	6 137.5000		
22/22	1 9.3750	2 20.1250	3 46.8750	4 65.6250	5 103.3333	6 175.0000	7 241.6667	8 316.6667
23/22	9 405.0000	10 403.3333	11 507.5000	12 712.5000	13 780.3750	14 803.1250	15 821.8750	16 840.6250

REPORT REQUIRED 2377

INPUT SECTION 5

ZONE INPUT BY SECTION

LAYER NUMBER 1
 19 19 19
 19 19 19
 19 19 19

LAYER NUMBER 2
 20 20 20
 20 1 4
 20 1 2

LAYER NUMBER 3
 20 20 20
 20 1 9
 20 5 6

LAYER NUMBER 4
 20 20 20
 20 1 12
 20 3 13

LAYER NUMBER 5
 19 19 19
 19 19 19
 19 19 19

INPUT SECTION 12

19 19 1 1 4.170000E-01
 20 20 1 1 9.510000E-01
 2 1 1 0 0.0

REPORT REQUIRED 2576

REPORT REQUIRED 2576

INTERFAC FILE REPORT HAS BEEN WRITTEN TO UNIT 16

INPUT SECTION 13

13 13 13

REPORT REQUIRED 1700

TITLE FROM CROSS SECTION FILE /X130 SAME AS BCS PLT5 MP-237, LESS RE-134

BDS(1) 3 POP SET 1

TR-232 PA-233 U-234 U-235 U-236 U-237 U-238 U-239 U-240

INPUT SECTION 20

BDS(1) 3 POP SET 1

TR-232	2.100000E-02	PA-233	1.500000E-06	U-233	4.000000E-04	U-234	9.999999E-07
U-235	9.500000E-06	U-236	3.459999E-06	RECVEL	7.799999E-04	U-237	2.100000E-04
	7.999999E-02		0.0		0.0		0.0
TR-232	2.100000E-04	PA-233	1.500000E-06	U-233	4.000000E-04	U-234	9.999999E-07
U-235	4.000000E-06	U-236	3.459999E-06	RECVEL	5.429999E-04	U-237	2.100000E-04
	7.999999E-02		0.0		0.0		0.0
TR-232	2.100000E-04	PA-233	1.500000E-06	U-233	4.000000E-04	U-234	9.999999E-07
U-235	7.500000E-06	U-236	3.459999E-06	RECVEL	5.429999E-04	U-237	2.100000E-04
	7.999999E-02		0.0		0.0		0.0
TR-232	2.100000E-04	PA-233	1.500000E-06	U-233	4.000000E-04	U-234	9.999999E-07
U-235	4.000000E-06	U-236	3.459999E-06	RECVEL	5.429999E-04	U-237	2.100000E-04
	7.999999E-02		0.0		0.0		0.0

Table 12. (Continued)

12	2.100000E-04	1A-233	1.500000E-04	U-233	4.000000E-05	U-234	1.999999E-07
U-235	5.099999E-04	U-236	3.599999E-04	DECELE	5.079999E-05	DE	2.100000E-04
C	7.999998E-02		0.0		0.0		0.0
13	5.90000E-05	HE	1.000000E-05	C	8.399999E-04		0.0
DECELE							
14	5.900001E-05	HE	2.100000E-04	C	8.399999E-02		0.0
DECELE							
15	9.999998E-05	HE	2.100000E-04	C	8.399999E-02		0.0
DECELE							
0							

INTERFACE FILE DECELE HAS BEEN WRITTEN ON UNIT 15

INTERFACE FILE DECELE HAS BEEN WRITTEN ON UNIT 13

TOTAL CPU TIME USED 0.000 MINUTES TOTAL CLOCK TIME USED 0.052 MINUTES TOTAL I/O USED 36

NORMAL END OF SPECIAL INPUT MODULE DECELE

OUTLINE - SPECIAL INPUT MODULE - JANUARY 17, 1979 - QUALITY ASSURANCE LEVEL 0

*** UTILITY INPUT *** ADD OR REPLACE RECORDS IN CONTROL FILE
 RECORD NAME *PBLIN* NO. HOLLERITH 0 NO. SEAL 36 NO. INTEGER(16) 0 NO. INTEGER(13) 48 PRINT OPT. 0
 RECORD NAME * NO. HOLLERITH 0 NO. SEAL 0 NO. INTEGER(16) 0 NO. INTEGER(13) 0 PRINT OPT. 0

THE FOLLOWING RECORDS ARE ON CONTROL

PBLIN
 EXPINS
 PBLIN
 PBLIN
 PBLIN
 PBLIN
 *

TOTAL CPU TIME USED 0.001 MINUTES TOTAL CLOCK TIME USED 0.021 MINUTES TOTAL I/O USED 13

NORMAL END OF SPECIAL INPUT MODULE OUTLINE

Prismatic Core Neutronics

VENTURE - NEUTRONICS MODULE - VERSION 3.2 - FALL, 1967 -- QUALITY ASSURANCE LEVEL 1

BOOK TITLE - TOP-TO-SAMPLE PROBLEMS, PEOPLE ETC THEN PRISMATIC TRIANGULAR HYDRAULICS

STORAGE REQUIRED FOR CROSS SECTION CHECK 152 WORDS

TITLE OF THE LATEST VERSION CROSS SECTION FILE
 FROM SAME AS 1965 PLUS MP-137, LESS SE-135

CROSS SECTION CHECK COMPLETED NORMALLY

SEQUENCE NO. TIME FROM STARTUP INTERFACE FILE = 0.0 DAYS

SOLUTION BY FINITE-DIFFERENCE DIFFUSION THEORY

GEOMETRY NO. 17 3-D TRIANGULAR-2

TRIANGULAR OPTION 0 PARALLELOGRAM - 120 DEGREE

NUMBER OF ENERGY GROUPS 8

NUMBER OF SCATTER GROUPS (HAE) 0

NUMBER OF DOWNSCATTER GROUPS (HAE) 3

NUMBER OF INTERVALS IN DIMENSION 1 (CELLS) 12

NUMBER OF INTERVALS IN DIMENSION 2 (CELLS) 6

NUMBER OF INTERVALS IN DIMENSION 3 (CELLS) 16

NUMBER OF ZONES 20

NUMBER OF REGIONS 05

NUMBER OF BLACK ABSORBER ZONES 0

BOUNDARY INDICATOR- LEFT 2 RIGHT 0

TOP 2 BOTTOM 0

FRONT 2 REAR 2

MEMORY REQUIREMENTS FOR DATA STORAGE

	TOTAL	A	B	C	D
STORAGE AVAILABLE	140000				
MACRO CALCULATION	1731				

Table 12. (Continued)

```

EQUATIONC CONSTA.S CALCULATION
CODE CONTAINED OR SPACE STORED      7871      8007
PLANE STORED                          1546      2402
BOX STORED                            1128      2060
MULTI-LEVEL PLANE STORED             1610      2546
INITIAL FLUX
CODE CONTAINED OR SPACE STORED      2669      3949
OTHER CODES                           565      1645
ITERATIVE PROCESS
CODE CONTAINED                       48189
SPACE STORED                         16295
16 PLANE STORED                      15634
1 PLANE STORED                       2374
6 BOX STORED                         2678
1 BOX STORED                         1650
16 TO 11-LEVEL PLANE STORED         16946
PERTURBATION CALCULATION              832
DATA WILL BE STORED FOR ALL GROUPS, ALL SPACE
RECORD LOCATIONS RESERVED FOR DATA STORAGE--- 140030
RECORD LOCATIONS REQUIRED FOR THIS PUNCH--- 48149
RECORD LOCATIONS NOT USED----- 1111
  
```

SPECIAL SCRATCH DATASET REQUIREMENTS
TRAINING PHYSICAL RECORD IS 7200 WORDS

TYPE CONTAINER ABRATS, CONTROL		3C DATA	51765							
FILE 28	DEFAULTS TO CODE - NO.BRCS.	SEC.LNTH.	TOT.LNTH.	START LCC.	CODE LEFT.	8	2304	9216	1	82549
"IE 27	DEFAULTS TO CODE - NO.BRCS.	SEC.LNTH.	TOT.LNTH.	START LCC.	CODE LEFT.	4	2304	9216	9217	73333
FILE 28	DEFAULTS TO CODE - NO.BRCS.	SEC.LNTH.	TOT.LNTH.	START LCC.	CODE LEFT.	0	2304	9216	18433	64117
FILE 40	DEFAULTS TO CODE - NO.BRCS.	SEC.LNTH.	TOT.LNTH.	START LCC.	CODE LEFT.	4	6123	20480	27689	39637

10 PARAMETERS FOLLOW FOR B1 = 3520 AND B2 = 2304
 #1- 1 #2- 1 #3- 1 #4- 1 #5- 76 #6- 10 #7- 6 #8- 6 #9- 4 #10- 4 #11- 6 #12- 1 #13- 4 #14- 1 #15- 10
 #16- 1 NOTE THAT IF THE FLURES ARE TO BE EXPANDED FROM EXISTING STILUX, #10- 10)

```

REQUIRED DISK STORAGE SPACE FOR PLUX (UNIT 20,22,28) IS      42700 BYTES
PCN CONSTANTS (UNIT 20) IS--      175160 BYTES
PCN CONSTANTS (UNIT 23) IS--      35200 BYTES
REQUIRED TOTAL DISK STORAGE SPACE IS-----      562250 BYTES

```

FOR THE ASSIGNED DATA STORAGE, THE REQUIRED REGION SIZE IS APPROXIMATELY 890K BYTES

MAXIMUM STORAGE USED FOR EACH SCOPIC CROSS SECTION CALCULATION 1730 WORDS

THE MAXIMUM AND MINIMUM DIFFUSION COEFFICIENTS ARE 2.21176E 00 8.72006E-01

PINE NESH DESCRIPTION - POINT IS LOCATED AT THE CENTROID OF THE VOLUME ELEMENT

[illegible]

ENTERING INITIAL PARAMETERS FOR ITERATIVE SUCCESSORS

```

REFERENCE POINT FOR INITIALIZATION WILL BE AT COLLUM = 11 ROW = 5 PLANE = 8 ZONE = 6
INITIAL OUTER ITERATION EIGENVALUE 0.15255 OPTION 0
INITIAL UNDERRELAXATION COEFFICIENTS MAX. 1.277605 MIN. 1.200000 INNER ITERATIONS MAX. 0 MIN. 4 OPTION 0
RESH POINT SWEEP OPTION 1
OUTER ITERATION LIMIT TO BE USED 30 ESTIMATED 15

```

MAXIMUM STORAGE USED FOR CALCULATING INITIAL PARAMETERS WAS 6560

INITIAL FLUX IS $PRK(J,K) * P1(Y) * P2(KB)$

TOTAL CORE REQUIRED FOR DATA STORAGE IS 4818. WORDS
ELAPSED CPU AND CLOCK MINUTES ARE: 0.026 0.258

A FLUX - EIGENVALUE PROBLEM FOLLOWS
 2 INNER5 MIN, 2 INNER5 MAX - CHERBYCHEV BETA CN INNER5

[illegible]

Table 12. (Continued)

17	0	1	0	3.690420-02	0.83256	0.0	1.00000	4.97211	6.79608	5.04184E 16	1.0125909	1.0125890
18	0	1	0	3.227790-02	0.88618	0.0	1.00000	4.57211	1.59220	5.04173E 16	1.0125890	1.0125781
19	0	1	0	2.863370-02	0.89833	0.0	1.00000	11.46904	-2.68896	5.04161E 16	1.0125781	1.0125651
20	3	1	0	2.609910-01	0.89965	0.0	1.00000	10.23572	-0.55375	5.04148E 16	1.0125651	1.0125517
21	0	0	0	5.285520-03	0.0	0.0	1.00000	C.0	C.0	5.04023E 16	1.0124277	1.0124109
22	0	0	0	5.509360-03	1.00000	0.0	1.00000	1.00000	0.01200	5.04015E 16	1.0124109	1.0124095
23	0	0	0	4.264180-03	0.01955	0.0	1.00000	4.55701	0.01200	5.04009E 16	1.0124095	1.0124043
24	0	0	0	3.517320-03	0.06600	0.0	1.00000	4.55701	1.21642	5.04005E 16	1.0124043	1.0124009
25	0	0	0	2.974690-03	0.07505	0.0	1.00000	2.27432	-1.02024	5.04002E 16	1.0124009	1.0123987
26	0	0	0	2.509210-03	0.08531	0.0	1.00000	-30.06232	35.24083	5.04000E 16	1.0123987	1.0123972
27	0	0	0	2.226770-03	0.05604	0.0	1.00000	-185.22597	158.76177	5.03994E 16	1.0123972	1.0123963
28	0	0	0	1.980030-03	0.98665	0.0	1.00000	421.32571	-331.07769	5.03997E 16	1.0123963	1.0123959
29	0	0	0	1.788690-03	0.91663	0.0	1.00000	209.04819	-160.01447	5.03996E 16	1.0123959	1.0123954
30	3	0	0	7.835610-02	0.92570	0.0	1.00000	184.11594	-137.27925	5.03995E 16	1.0123954	1.0123956
31	0	0	0	1.238980-03	0.0	0.0	1.00000	0.0	0.0	5.03981E 16	1.0124200	1.0124185

*****MAXIMUM NUMBER OF SPECIFIED ITERATIONS REACHED*****

*****WARNING - PROBLEM NOT CONVERGED*****

1.0124185

MULTIPLICATION RELIABILITY ESTIMATORS

BY THE SUM OF THE SQUARES OF THE RESIDUES-----

1.0124098

UPPER AND LOWER BOUNDS ESTIMATES BY MAX DEL FLUX CHANGE-----

1.0131641

UPPER AND LOWER BOUNDS ESTIMATES OVER ALL SIGNIFICANT POINTS-----

1.0133117 1.0134134

*****WARNING - TESTS OF CONVERGENCE INDICATE THE RELIABILITY OF RESULTS IS IN QUESTION.

NUMBER OF INNER ITERATIONS, OUTER ITERATION ERROR EIGENVALUE, AND OVERRELAXATION COEFFICIENTS

4 0.0

1.76901 1.15128 1.15434 1.01758

CPU AND CLOCK HOURS REQUIRED FOR THIS EIGENVALUE PROBLEM ARE 0.838 3.851

SOPC FILE CLOSING DATA - UNIT, ARRAYS 28 26 52129

SOPC FILE CLOSING DATA - UNIT, ARRAYS 24 21 52129

LEAKAGE 1.86002E 17 TOTAL LEAKAGE 1.86002E 17 TOTAL REPRODUCTION 2.35210E 16 REACTION POWER DENSITY 1.00000E 01

PRIMITIVE FISSION CONVERSION RATIO IS 0.893860-01, ESTIMATE FOR CRITICAL SYSTEM IS 1.162380-01
FISSION DESTRUCTION PER UNIT ENERGY (MTCBS/UNIT-SEC) IS 3.861810 10

BOUNDARY NEUTRON LEAKAGE		LEFT		RIGHT		TOP		BOTTOM		FRONT		BACK	
1	4.572980	15	2.974730	17	4.505730	15	-2.974730	17	5.81850E	13	1.485900	13	1.485900
2	9.091650	15	2.300550	17	8.967720	15	-2.300550	17	1.400950	14	4.888070	13	4.888070
3	1.388220	16	1.748900	17	1.371120	16	-1.748900	17	2.658870	14	6.431750	13	6.431750
4	1.587780	17	4.513930	17	1.583400	17	-4.513930	17	9.577470	13	3.961630	13	3.961630
SUM	1.96325E	17	1.15381E	18	1.01520E	17	-1.15381E	18	1.00416E	16	4.11129E	15	4.11129E

OVERALL NEUTRON BALANCE

GROUP ABSORPTIONS		GROUP LOSSES		1/V LOSS		SC-SCATTER		IS-SCATTER		PI IS-SCATTER		SOURCE		POWER (WATTS)	
1	9.12880E	15	0.0	0.0	0.0	2.22932E	18	0.0	0.0	0.0	0.0	2.24761E	18	1.10360E	05
2	5.89247E	16	0.0	0.0	0.0	2.22779E	18	2.22932E	18	0.0	0.0	7.56312E	16	3.11739E	05
3	4.24027E	17	0.0	0.0	0.0	1.77582E	18	2.22779E	18	0.0	0.0	2.61180E	11	2.24127E	06
4	1.84516E	18	0.0	0.0	0.0	0.0	0.0	1.77582E	18	0.0	0.0	4.69821E	07	2.79888E	07
SUM	1.93724E	18	0.0	0.0	0.0	6.23293E	18	6.23293E	18	0.0	0.0	2.32324E	18	3.06122E	07

ZCNE VOLUME'S FOLLOW. TOTAL VOLUME 1.45627E 07

8.33013E	05	8.33013E	05	8.33013E	05	8.33013E	05	8.33013E	05	8.33013E	05	8.33013E	05	8.33013E	05
5.41265E	05	5.41265E	05	5.41265E	05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.86141E	06	7.57771E	06												

core volume 6.06217E 6

ZONE AVERAGE FLUX INTERFACE FILE ZEPIC (VERSION 1) HAS BEEN WRITTEN ON UNIT NUMBER 16

Average power density (th)

GROUP FLUX VALUES AT PLANE 7 ROW 6 COLUMN 11 - POINT AT FIRST GROUP MAXIMUM

5.0497 W/cc

MAXIMUM FIRST GROUP FLUXES BY ZCNE

8.73267E	13	5.51340E	13	4.12811E	13	4.88001E	13	3.62868E	13	4.39266E	13	1.26102E	13	3.62800E	13
2.93702E	13	2.16887E	13	2.41737E	13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.15226E	12	9.94491E	12												

THE MAXIMUM POWER DENSITY IS AT PLANE 7, ROW 6, AND COLUMN 12 AND IS 1.035480E 01 WATTS/CC.

THE MAXIMUM NEUTRON DENSITY IS AT PLANE 7, ROW 6, AND COLUMN 12 AND IS 2.631289920 08 NEUTRONS/CC.

THE MAXIMUM POWER DENSITY (WATTS/CC) IN EACH ZONE IS

9.35332E	00	1.03548E	01	7.81469E	00	8.28758E	00	6.75064E	00	8.13653E	00	6.15195E	00	6.75118E	00
5.46526E	00	4.11723E	00	4.52458E	00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

ZONE POWER DENSITY INTERFACE FILE ZNECD (VERSION 1) HAS BEEN WRITTEN ON UNIT NUMBER 19

↑ This file was written to wipe out
the probe bed results (or
the thermal hydrostatic code
would have used them)

Table 12. (Continued)POINT POWER DISTRIBUTION (WATTS/CC)[illegible][illegible][illegible][illegible][illegible][illegible]

Table 12. (Continued)

PLATE NUMBER 7										
1	2	3	4	5	6	7	8	9	10	11
1 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12										
1 0.0										
2 0.0										
3 6.0700 00										
4 7.5000 00										
5 9.0200 00										
6 1.0360 01										
PLATE NUMBER 8										
1	2	3	4	5	6	7	8	9	10	11
1 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12										
1 0.0										
2 0.0										
3 4.9570 00										
4 6.1550 00										
5 7.0150 00										
6 9.1360 00										
PLATE NUMBER 9										
1	2	3	4	5	6	7	8	9	10	11
1 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12										
1 0.0										
2 0.0										
3 4.2240 00										
4 5.2440 00										
5 6.3150 00										
6 6.9290 00										
PLATE NUMBER 10										
1	2	3	4	5	6	7	8	9	10	11
1 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12										
1 0.0										
2 0.0										
3 3.7070 00										
4 4.6550 00										
5 5.6070 00										
6 6.1530 00										
PLATE NUMBER 11										
1	2	3	4	5	6	7	8	9	10	11
1 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12										
1 0.0										
2 0.0										
3 3.2580 00										
4 4.1170 00										
5 4.9760 00										
6 5.0650 00										
PLATE NUMBER 12										
1	2	3	4	5	6	7	8	9	10	11
1 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12										
1 0.0										
2 0.0										
3 1.0510 00										
4 2.3050 00										
5 2.0870 00										
6 3.1190 00										

--PLATE NUMBER 13

Table 12. (Continued)

- 1- GRAVITY OPTIONS (-1/0/1- NONE/ FLOW DOWN/ FLOW UP)
- 2- NEGATIVE FLOW FLOW THROUGH HOLES IN SOLID LATTICE
- 3- FLUXGATE OPTIONS (-1/0,1/2- NONE/CONST/FILE EXPONT)
- 4- FLUXGATE RANGE (-1/0,1/2- TOTAL/INST/SEC(ND)
- 5- RESPONSE AVAILABLE IF .PE. 0 (WGL2)
- 6- OPTION TO REVERSE THE DIRECTION OF COOLANT FLOW
- 7- DEBUG EXIT LEVEL
- 8- EXIT LEVEL OPTION
- 9- FLOW FLOW CONTROL OPTIONS (-0,1,2,3,4- FCH HEAT/ BLOCK DE 1ST PLANE HOLES/ BLOCKING SUPPLIED/ FCH PRESS DROP/ FLX)
- 10- LATTICE CELL GEOMETRY (0/1- 2-D RECTANGULAR /1-D)
- 11- TERMINATION ITERATION COUNT
- 12- ORIGINATING OPTIONS (-0,1/2,3- NONE/INIT/OUTLET)
- 13- ORIGINATING TASK (-0,1/2- EXIT T/ SURFACE T/ PEAK EXIT T)
- 14- EXIT ENHANCE/EXIT PRESS LOSS IF > 0
- 15- NO. AXIAL INTERVALS FOR STEERING 1-8 OR 2-6 TO 3-0

data not made available

0 ← criticing
2 ← objective function
0
0

0 0 0 1 2

---- FLOATING POINT CONTROL VARIABLES ----

VOID FRACTION	0.17000 00
INLET TEMPERATURE (C)	0.35000 03
INLET PRESSURE (ATM)	0.00000 02
MASS FLOW RATE (KG/S)	0.0
CHARACTERISTIC HYDRAULIC DIAMETER (CM)	0.15000 01

REFERENCE FLUENCE	0.10000 23
RECOVERABLE ENERGY FRACTION	0.50000 00
SPECIFIED POWER LEVEL	0.0
DEVIATION OF CELL FOR HEAT REMOVAL (CR)	0.10000 01
FUEL RADIUS OF CORE MATERIAL (C4)	0.00000 00

FUEL RADIUS OF SUBSTANCE MATERIAL (CM)	0.010000 00
CULLET TEMPERATURE (C)	0.000000 03
FLAMELENGTH MULTIPLIER	0.100000 01
THERMAL CONDUCTIVITY MULTIPLIER	0.100000 01
COVERAGELAKE COEFFICIENT	0.0
MAXIMUM CPU TIME IN SECONDS	
P.120000 03	

0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.100000 JJ		0.0

MAXIMUM REPORT REQUIREMENT -- 10226 WORDS, REPORT AVAILABLE -- 16000 WORDS

TIME OF IMPACT- 0.0 DOES NOT MATCH PRINT- 0.0

DATA UNIT NUMBERS, SECURITY, EXPOSURE, ZONE AND POINT POWER DENSITY 14 0 15 16

EMBLER HESH (PLANT-LITAL)	5	12	3	6	5	12	50.000	150.000	50.000	150.000	75.000	775.000
---------------------------	---	----	---	---	---	----	--------	---------	--------	---------	--------	---------

COMPACTED TREN 1 4 6

COORDINATE DIMENSIONS	0.0	1.2500D 01	2.5000D 01	3.7500D 01	5.0000D 01	6.2500D 01	7.5000D 01	8.7500D 01
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								
31								
32								
33								
34								
35								
36								
37								
38								
39								
40								
41								
42								
43								
44								
45								
46								
47								
48								
49								
50								
51								
52								
53								
54								
55								
56								
57								
58								
59								
60								
61								
62								
63								
64								
65								
66								
67								
68								
69								
70								
71								
72								
73								
74								
75								
76								
77								
78								
79								
80								
81								
82								
83								
84								
85								
86								
87								
88								

COORDINATE DIRECTIONS	0.0	2.50000 01	5.00000 01	7.50000 01	1.00000 02
-----------------------	-----	------------	------------	------------	------------

COORDINATE DIMENSIONS	0.0	6.6667D 01	1.3333D 02	2.0000D 02	2.8333D 02	3.6667D 02	4.5000D 02	5.7500D 02
-----------------------	-----	------------	------------	------------	------------	------------	------------	------------

WREN POWER DENSITY DATA

[illegible]

FRESH ZONE INDEXING

PERSON	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113	2114	2115	2116	2117	2118	2119	2120	2121	2122	2123	2124	2125	2126	2127	2128	2129	2130	2131	2132	2133	2134	2135	2136	2137	2138	2139	2140	2141	2142	2143	2144	2145	2146	2147	2148	2149	2150	2151	2152	2153	2154	2155	2156	2157	2158	2159	2160	2161	2162	2163	2164	2165	2166	2167	2168	2169	2170	2171	2172	2173	2174	2175	2176	2177	2178	2179	2180	2181	2182	2183	2184	2185	2186	2187	2188	2189	2190	2191	2192	2193	2194	2195	2196	2197	2198	2199	2200	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214	2215	2216	2217	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239	2240	2241	2242	2243	2244	2245	2246	2247	2248	2249	2250	2251	2252	2253	2254	2255	2256	2257	2258	2259	2260	2261	2262	2263	2264	2265	2266	2267	2268	2269	2270	2271	2272	2273	2274	2275	2276	2277	2278	2279	2280	2281	2282	2283	2284	2285	2286	2287	2288	2289	2290	2291	2292	2293	2294	2295	2296	2297	2298	2299	2300	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350	2351	2352	2353	2354	2355	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413	2414	2415	2416	2417	2418	2419	2420	2421	2422	2423	2424	2425	2426	2427	2428	2429	2430	2431	2432	2433	2434	2435	2436	2437	2438	2439	2440	2441	2442	2443	2444	2445	2446	2447	2448	2449	2450	2451	2452	2453	2454
--------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------

Hydraulics
problem
solved

Table 12. (Continued)

INLET PRESSURE BY BLOCK, THEN OUTLET BY INTERP 1 (PSI)
 39.6905 60.0000 39.6905 39.6915

39.6910	39.6910	39.6910	39.6910	39.6910	39.6910	39.6910	39.6910	39.6910	39.6910	39.6910
39.6910	39.6910	39.6910	39.6910	39.6910	39.6910	39.6910	39.6910	39.6910	39.6910	39.6910
39.6910	39.6910	39.6910	39.6910	39.6910	39.6910	39.6910	39.6910	39.6910	39.6910	39.6910
39.6910	39.6910	39.6910	39.6910	39.6910	39.6910	39.6910	39.6910	39.6910	39.6910	39.6910

AVERAGE INTERNAL MASS COOLANT FLOW RATE BY BLOCK (GCM/SEC PER CHNCH) -- TOTAL (GCM/SEC) 1.20170 0
 1.0000E-03 1.0000E-03 1.2000E-03 1.0000E-03

COOLANT EXIT TEMPERATURES BY BLOCK
 800.0 800.0 800.0 800.0

PEAK SURFACE TEMPERATURES BY COOLANT BLOCK
 930.0 930.0 930.0 930.0

PRESSURE DROP ACROSS CRIPICE BY COOLANT BLOCK
 0.1015 0.0000 0.1001 0.1105

THERMAL HYDRAULIC P.A. ARRAYS SAVED FOR DECRYPT ON UNIT 31

HYDRAULICS CALCULATION DONE, CALCULATE TEMPERATURES

SAVING CELL THERMAL CONDUCTIVITY DATA, UNIT 31

Note the objective satisfied by adjusting the pressure drops across the orifices

TWO-TW SAMPLE MODELS, PEOPLE SEE THEIR PRISATIC THERMAL HYDRAULICS

ZONES 20 SUBZONES 0

TWO-DIMENSIONAL THERMAL CELL MODEL IS USED, RISK 16 20 ← 2-D OR thermal cell model

STAR* TEMPS, CONDUCTIVITIES, ETC. 657.9 912.3 924.5 926.2 0.23306 0.23322 0.12167 1.12205 0.11261

THERMAL CELL INITIALIZATION, OVERRELAXATION EPSI AND ITERATIONS 0.30927 1.70507 1.70507 1.70507 0

INITIAL DATA 16 20 7 12 11 7.6522E-01 5.9261E-01 2.0290E-01 3.6971E-01 0.1570E-01 5.2360E-01 1.1241E-01

OPTIONS 1 0 0 0 0 15 100
 INITIAL ONE-DIMENSIONAL CROSS OVERLAP, STORAGE 279 -1 -1 1 20 1 WORK 0.1075
 INITIAL MULTI-GRID PROCESS, STORAGE, LEVELS, ETC. 1027 3 5 2 10 2 WORK 1.7969
 17 0 2 -2 1.6546E-05 1.0000 00 935.110 0.5970 0.0436 0.0723 0.0030 1.0000 -1.9005E-05 1.1000
 FIRST THERMAL CELL PROBLEM DATA 16 20 7 12 11 0 0 2 50 0.76522 1.00720 0.20290 0.55461
 0.10276 6.20000 30.55922 0.55777 0.00361 0.0 1.2306E-05 -1.9005E-05 1.0000 1.1000 1.1000
 OVERRELAXATION COEFFICIENT DATA 0.30927 0.70507 0.70507 0.70507 0.0 1.0000 1.0000 1.0000
 ESTIMATES OF THE FIRST THERMAL CELL RESIDUE ERROR LEVEL 0.00009 0.00118 ITERATIONS 17 MAX TEMP (K) 935.1

2	0	0	-2	1.5546E-05	1.0000	00	940.074	0.6685	0.0	0.0	0.0042	1.0000	-2.0532E-05	1.1000
2	0	0	-2	1.5662E-05	1.0000	00	908.908	0.8010	0.0	0.0	0.0039	1.0000	-2.0743E-05	1.1000
1	0	0	-2	1.2614E-05	1.0000	00	909.816	0.0	0.0	0.0	0.0035	1.0000	-3.4502E-05	1.1000
2	0	0	-2	1.5030E-05	1.0000	00	101.1617	0.5501	0.0	0.0	0.0031	1.0000	-2.6170E-05	1.1000
1	0	0	-2	1.0981E-05	1.0000	00	1070.241	0.0	0.0	0.0	0.0047	1.0000	-3.6512E-05	1.1000
1	0	0	-2	1.1364E-05	1.0000	00	1052.750	0.0	0.0	0.0	0.0035	1.0000	-2.9430E-05	1.1000
1	0	0	-2	7.0671E-06	1.0000	00	1057.733	0.0	0.0	0.0	0.0039	1.0000	-3.1053E-05	1.1000
1	0	0	-2	1.0708E-05	1.0000	00	1133.454	0.0	0.0	0.0	0.0020	1.0000	-3.0604E-05	1.1000
1	0	0	-2	6.9894E-06	1.0000	00	1105.115	0.0	0.0	0.0	0.0020	1.0000	-3.1000E-05	1.1000
1	0	0	-2	5.5820E-06	1.0000	00	1129.420	0.0	0.0	0.0	0.0018	1.0000	-2.6985E-05	1.1000
1	0	0	-2	3.3245E-06	1.0000	00	1130.106	0.0	0.0	0.0	0.0020	1.0000	-2.0901E-05	1.1000

ZONE AND SUBZONE TEMPERATURES (DEGREES C) FOR MASS FLOW RATE (GCM/SEC) 1.20170 01 EIGHTH POWER (MW-TW) 1.00000 C1

ZONE	CONDUCTIVITY AND P (EXPOSURE), FLUID	SURFACE	SHELL	HEAT CENTER TEMPERATURES, OT/HR (DEG/C)
1	0.1217 0.10000E 23	800.0	577.4	595.2
2	0.1222 0.10000E 23	800.3	571.7	592.7
3	0.1205 0.10000E 23	839.7	563.2	571.0
4	0.1205 0.10000E 23	838.1	560.6	570.5
5	0.1339 0.10000E 23	630.0	731.3	703.3
6	0.1337 0.10000E 23	627.0	732.0	707.4
7	0.1332 0.10000E 23	626.3	726.6	737.7
8	0.1336 0.10000E 23	626.3	727.3	739.3
9	0.1404 0.10000E 23	770.6	820.0	830.0
10	0.1415 0.10000E 23	768.1	830.2	839.0
11	0.1403 0.10000E 23	768.9	826.6	832.0
12	0.1407 0.10000E 23	769.2	828.7	835.5
13	0.0 0.0	575.0	575.0	575.0
14	0.0 0.0	575.0	575.0	575.0
15	0.0 0.0	575.0	575.0	575.0
16	0.0 0.0	575.0	575.0	575.0
17	0.0 0.0	575.0	575.0	575.0
18	0.0 0.0	575.0	575.0	575.0
19	0.0 0.0	575.0	575.0	575.0
20	0.0 0.0	575.0	575.0	575.0

RELATIVE THERMAL CELL GAP HEAT FLOW (ACCURACY CHECK) WORST AND BEST 1.00110 1.00012
 MAX TEMPS, PEAK/MTW BY ZONE, SOURCE 875.1 865.9 0.0 0.0 POWER WEIGHTED 700.0 0.0 POWER (MW) 1.00000 01

of interest (nuclear important)

Table 12. (Continued)

START TEMPS, CONDUCTIVITIES, ETC. 511.4 511.9 924.1 925.0 0.23330 0.23344 0.12164 0.12242 0.11260

THERMAL CELL INITIALIZATION, OVERRELAXATION DATA AND ITERATIONS 0.90927 1.74567 1.74507 1.74507 40

INITIAL DATA 14 24 7 12 11 1.6522E-01 5.9261E-01 2.0290E-01 1.6971E-01 4.1274E-01 5.2340E-01 1.1262E-01

OPTIONS 1 0 C 00 15 140

INITIAL ONE-DIMENSIONAL CROSS BALANCE, STORAGE 279 -1 -1 1 24 1 WORK 0.1475

INITIAL MULTIDIM PROCESS, STORAGE, LEVELS, ETC. 1057 1 5 2 10 2 WORK 1.7969

17 4 2 -2 1.6599E-05 1.6599E 00 934.701 0.5976 0.0037 0.0723 0.0030 1.0000 -1.0000E-05 1.1000

FIRST THERMAL CELL PROBLEM DATA 14 24 7 12 11 0 0 2 50 0.76522 1.00723 0.20290 0.59261

1.10276 1.20000 10.55922 0.55750 0.60369 0.0 1.6599E-05 -1.9400E-05 1.0000 1.1000 1.1000

OVERRELAXATION COEFFICIENT DATA 5.1277 0.0723 0.0 1.1000 1.1000 1.1000

ESTIMATES OF THE FIRST THERMAL CELL ABSOLUTE ERROR LEVEL 0.00009 0.00110 ITERATIONS 17 MAX TEMP (K) 934.7

2	0	0	-2	1.9830E-05	1.17640 00	945.337	0.6606	0.0	0.0	0.0002	1.0000	-2.4539E-05	1.1000
2	0	0	-2	1.1737E-05	1.10250 00	409.530	0.7945	0.0	0.0	0.0039	1.0000	-2.4765E-05	1.1000
1	0	0	-2	1.2621E-05	1.66660 00	509.844	0.0	0.0	0.0	0.0055	1.0000	-3.4533E-05	1.1000
2	0	0	-2	1.5009E-05	1.11100 00	106.043	0.5546	0.0	0.0	0.0031	1.0000	-2.4222E-05	1.1000
1	0	0	-2	1.1171E-05	1.01000 00	1074.415	0.0	0.0	0.0	0.0007	1.0000	-3.4423E-05	1.1000
1	0	0	-2	1.1129E-05	1.23070 00	1052.348	0.0	0.0	0.0	0.0035	1.0000	-2.9570E-05	1.1000
1	0	0	-2	7.0725E-06	1.12710 00	1057.308	0.0	0.0	0.0	0.0039	1.0000	-3.1395E-05	1.1000
1	0	0	-2	1.1094E-05	9.5671E-01	1132.359	0.0	0.0	0.0	0.0020	1.0000	-3.0731E-05	1.1000
1	0	0	-2	7.0830E-06	5.6790E-01	1167.329	0.0	0.0	0.0	0.0024	1.0000	-3.3506E-05	1.1000
1	0	0	-2	5.4507E-06	6.1180E-01	1128.443	0.0	0.0	0.0	0.0018	1.0000	-2.7366E-05	1.1000
1	0	0	-2	3.3277E-06	6.9974E-01	1133.117	0.0	0.0	0.0	0.0020	1.0000	-2.9443E-05	1.1000

ZONE AND SURFACE TEMPERATURES (DEGREES C) FOR MASS FLOW RATE (KG/SEC) 1.20170 07 SURFACE POWER (W-TM) 1.0000E 01

ZONE	CONDUCTIVITY AND F(EMISSIVITY), FLUID	SURFACE	SHELL	HEAT CENTER TEMPERATURES, BT/HR (C/G/C)		
1	0.1217 0.100000E 23	884.6	577.0	594.8	649.5	667.7
2	0.1233 0.100000E 23	880.7	572.7	593.6	650.0	672.3
3	0.1204 0.100000E 23	839.4	562.0	576.0	625.1	635.5
4	0.1205 0.100000E 23	837.9	560.2	574.1	625.5	636.4
5	0.1234 0.100000E 23	833.4	570.6	562.6	779.5	787.9
6	0.1243 0.100000E 23	828.0	733.7	749.1	754.2	800.9
7	0.1231 0.100000E 23	827.7	725.9	737.0	771.3	776.0
8	0.1235 0.100000E 23	825.7	724.3	730.6	775.6	786.0
9	0.1205 0.100000E 21	769.7	827.0	833.0	824.7	855.5
10	0.1217 0.100000E 23	770.1	832.4	841.2	848.1	874.3
11	0.1202 0.100000E 23	764.1	825.6	831.9	851.1	855.5
12	0.1204 0.100000E 23	760.3	827.7	834.5	855.3	860.1
13	0.0 0.0	575.0	575.0	575.0	575.0	575.0
14	0.0 0.0	575.0	575.0	575.0	575.0	575.0
15	0.0 0.0	575.0	575.0	575.0	575.0	575.0
16	0.0 0.0	575.0	575.0	575.0	575.0	575.0
17	0.0 0.0	575.0	575.0	575.0	575.0	575.0
18	0.0 0.0	575.0	575.0	575.0	575.0	575.0
19	0.0 0.0	575.0	575.0	575.0	575.0	575.0
20	0.0 0.0	575.0	575.0	575.0	575.0	575.0

RELATIVE THERMAL CELL GAP HEAT FLOW (ACCURACY CHECK), WORST AND BEST 1.00110 1.00012

MAX TEMPS, PEAK/AVG BY ZONE, SURFACE 130.1 946.1 0.0 0.0 POWER DENSITY 764.0 0.0 POWER (W-TM) 1.0000E 01

AVERAGE AND PEAK TEMPERATURE SLOPE AT POREL PINT/SHELL INTERFACE (DEG/C/M) -56.5 -93.6

ZONE AVERAGE TEMP AND T002, THEN SURFACE 767.69 771.00 0.0 0.0

TEMPERATURE INTERFACE FILE NOT WRITTEN NOW

TEMPERATURES RECALCULATED FOR THE INITIAL CONDUCTIVITY MULTIPLIED BY 0.5

7	0	0	-2	7.3494E-05	1.02140 00	934.757	0.1358	0.0	0.0	-0.0015	1.0000	1.7430E-05	1.1000
2	0	0	-2	4.4435E-04	1.15900 00	451.463	0.6076	0.0	0.0	0.0025	1.0000	-1.4600E-05	1.1000
2	0	0	-2	4.4437E-04	9.5790E-01	913.319	0.6909	0.0	0.0	0.0027	1.0000	-1.4907E-05	1.1000
1	0	0	-2	7.4305E-05	1.21000 00	914.447	0.0	0.0	0.0	0.0035	1.0000	-2.2303E-05	1.1000
2	0	0	-2	1.5094E-05	1.16660 00	1064.720	0.5320	0.0	0.0	0.0020	1.0000	-1.0503E-05	1.1000
1	0	0	-2	1.1490E-05	1.50240 00	1040.816	0.0	0.0	0.0	0.0027	1.0000	-2.1035E-05	1.1000
1	0	0	-2	1.2492E-05	9.4624E-01	1055.429	0.3	0.0	0.0	0.0022	1.0000	-1.7976E-05	1.1000
1	0	0	-2	5.7641E-04	9.1120E-01	1060.472	0.0	0.0	0.0	0.0024	1.0000	-1.9402E-05	1.1000
1	0	0	-2	1.1117E-05	7.7571E-01	1110.676	0.0	0.0	0.0	0.0012	1.0000	-1.9593E-05	1.1000
1	0	0	-2	6.0099E-06	7.6521E-01	1150.177	0.0	0.0	0.0	0.0014	1.0000	-1.4740E-05	1.1000
1	0	0	-2	6.1664E-06	6.5620E-01	1130.523	0.0	0.0	0.0	0.0011	1.0000	-1.5955E-05	1.1000
1	0	0	-2	2.4204E-06	6.1330E-01	1135.151	0.0	0.0	0.0	0.0012	1.0000	-1.7602E-05	1.1000

ZONE	CONDUCTIVITY AND F(EMISSIVITY), FLUID	SURFACE	SHELL	HEAT CENTER TEMPERATURES, BT/HR (C/G/C)		
1	0.1104 0.100000E 21	884.6	577.0	594.8	653.3	665.0
2	0.1114 0.100000E 23	880.7	572.7	594.0	653.0	674.9
3	0.1047 0.100000E 23	839.4	562.0	579.7	620.7	630.3
4	0.1007 0.100000E 23	837.9	560.2	574.0	629.3	641.5
5	0.1207 0.100000E 23	833.4	570.6	563.9	787.4	791.7
6	0.1211 0.100000E 23	828.0	733.7	750.9	800.0	811.0
7	0.1209 0.100000E 23	827.7	725.9	730.3	774.0	782.6
8	0.1204 0.100000E 21	827.7	724.3	739.9	776.5	787.9
9	0.1244 0.100000E 21	769.7	827.0	834.6	854.1	861.7
10	0.1277 0.100000E 23	770.1	832.4	842.2	870.3	877.2
11	0.1241 0.100000E 23	764.1	825.6	832.4	852.4	857.5
12	0.1247 0.100000E 23	760.3	827.7	835.2	857.0	862.4
13	0.0 0.0	575.0	575.0	575.0	575.0	575.0
14	0.0 0.0	575.0	575.0	575.0	575.0	575.0
15	0.0 0.0	575.0	575.0	575.0	575.0	575.0
16	0.0 0.0	575.0	575.0	575.0	575.0	575.0
17	0.0 0.0	575.0	575.0	575.0	575.0	575.0

Table 12. (Continued)

```

18 0.0 0.0 575.0 575.0 575.0 575.0 575.0 575.0
19 0.0 0.0 575.0 575.0 575.0 575.0 575.0 575.0
20 0.0 0.0 575.0 575.0 575.0 575.0 575.0 575.0

RELATIVE THERMAL CELL GAP HEAT FLOW (ACCURACY CHECK), BOREST AND REAR 1.00000 1.00000
VAL TENS, PRES/HEAD BY TEMP, SURFACE 177.2 170.3 0.0 0.0 POWER DENSITY 709.3 0.0 POWER (MW) 3.0000E 01

AVERAGE AND PEAK TEMPERATURE SLOPE AT VERTEX PEARL/SHELL INTERFACE (DEG/CM) -62.5 -100.2

TEMPERATURES RECALCULATED FOR THE PEARL SCHE SURFACE TEMPERATURES (ASSUMED BOREST CASE, EISENHARDT INTEGRALS)
0 0 0 -2 -6.0508E-06 1.3701E 00 1117.031 0.2466 0.0 -0.0025 1.0000 1.3727E-05 1.1000
1 0 0 -2 -1.5026E-05 1.2670E 00 1090.046 0.0 0.0 0.0 0.0020 1.0000 -5.1964E-06 1.1000
1 0 0 -2 1.3330E-05 1.6327E 00 1073.039 0.0 0.0 0.0 0.0019 1.0000 -6.5272E-06 1.1000
1 0 0 -2 7.1929E-06 0.6970E 01 1070.251 0.0 0.0 0.0 0.0023 1.0000 -5.1359E-06 1.1000
2 0 0 -2 1.0033E-05 7.3507E 01 1150.070 0.0 0.0 0.0 0.0010 1.0000 -3.2796E-06 1.1000
1 0 0 -2 -1.3362E-05 6.0173E 01 1176.990 0.0 0.0 0.0 0.0010 1.0000 -5.3925E-06 1.1000
1 0 0 -2 1.0104E-05 6.6020E 01 1100.709 0.0 0.0 0.0 0.0012 1.0000 -6.1037E-06 1.1000
1 0 0 -2 0.6077E-06 6.6570E 01 1190.955 0.0 0.0 0.0 0.0016 1.0000 -5.6090E-06 1.1000
1 0 0 -2 1.0150E-05 7.0507E 01 1200.919 0.0 0.0 0.0 0.0009 1.0000 -6.1700E-06 1.1000
1 0 0 -2 -1.1931E-05 5.5102E 01 1213.607 0.0 0.0 0.0 0.0007 1.0000 -5.1070E-06 1.1000
1 0 0 -2 1.3073E-05 5.5099E 01 1233.151 0.0 0.0 0.0 0.0007 1.0000 -3.5545E-06 1.1000
1 0 0 -2 -1.2101E-05 7.0330E 01 1205.257 0.0 0.0 0.0 0.0009 1.0000 -6.6702E-06 1.1000

DOSE (CONDUCTIVITY AND R (EXPOSURE)), FLUID SURFACE SHELL GRAY (CENTER TEMPERATURES, J/CM) (DEG/CM)
1 0.1303 0.100000E 23 644.1 700.0 705.5 830.2 800.9 -96.2
2 0.1257 0.100000E 23 640.7 702.6 727.0 800.5 877.0 -100.5
3 0.1305 0.100000E 23 639.6 713.4 731.0 787.5 800.0 -82.6
4 0.1309 0.100000E 23 637.9 713.6 733.0 791.9 805.3 -87.3
5 0.1059 0.100000E 23 633.6 856.9 871.6 915.0 925.1 -45.0
6 0.1030 0.100000E 23 628.0 820.3 830.1 891.7 904.0 -80.0
7 0.1000 0.100000E 23 627.7 805.0 850.3 890.6 907.0 -60.6
8 0.1056 0.100000E 23 625.1 853.7 868.2 911.9 922.0 -45.9
9 0.1569 0.100000E 23 769.7 920.7 937.9 965.7 972.0 -41.0
10 0.1000 0.100000E 23 770.1 806.0 897.9 932.4 940.6 -52.0
11 0.1526 0.100000E 23 768.1 910.6 927.1 952.7 950.6 -30.1
12 0.1570 0.100000E 23 766.3 929.1 930.3 966.0 972.3 -41.0
13 0.0 0.0 575.0 575.0 575.0 575.0 575.0 0.0
14 0.0 0.0 575.0 575.0 575.0 575.0 575.0 0.0
15 0.0 0.0 575.0 575.0 575.0 575.0 575.0 0.0
16 0.0 0.0 575.0 575.0 575.0 575.0 575.0 0.0
17 0.0 0.0 575.0 575.0 575.0 575.0 575.0 0.0
18 0.0 0.0 575.0 575.0 575.0 575.0 575.0 0.0
19 0.0 0.0 575.0 575.0 575.0 575.0 575.0 0.0
20 0.0 0.0 575.0 575.0 575.0 575.0 575.0 0.0

RELATIVE THERMAL CELL GAP HEAT FLOW (ACCURACY CHECK), BOREST AND REAR 1.00000 1.00000
VAL TENS, PRES/HEAD BY TEMP, SURFACE 177.3 166.0 0.0 0.0 POWER DENSITY 877.0 0.0 POWER (MW) 3.9024E 01

AVERAGE AND PEAK TEMPERATURE SLOPE AT VERTEX PEARL/SHELL INTERFACE (DEG/CM) -60.3 -100.5

CUMULATIVE FRACTIONS OF THE FUEL ABOVE DEFERENCE TEMPERATURES, DEG C (FOR BASIC DATA POINTS 12.00, 12)
950 0.01900509 750 0.59107010 550 0.51020301
925 0.05551011 725 0.65776271 525 0.50103075
900 0.17600029 700 0.71297030 500 0.96505060
875 0.10111756 675 0.76257051 475 0.90279550
850 0.26151600 650 0.80605600 450 0.90899000
825 0.33910690 625 0.80732105 425 0.99999000
800 0.62363060 600 0.87050070 400 1.00000000
775 0.50879012 575 0.89057607 375 1.00000000

THERMAL CELL CALCULATIONAL BORDER 0.1233E 00 MULTICELL ITERATIVES 93

CALCULATIONS FOR DOSE FOR NEW COOLANT TEMPERATURES 350.00 800.00 RELATIVE POWER LEVEL 1.1000
THIS PROBLEM INVOLVES BLOCKING OF COOLANT CHANNELS FOR COMMON ORSPICE CONTROL
INTERVAL COOLANT BLOCK ITERATION
2 2 2 2 1 1 1 1 2 2 2 2 0 0 0 0 1 1 1 1
2 2 2 2 1 1 1 1 2 2 2 2 0 0 0 0 1 1 1 1

BASE COOLANT FLOW RATES BY INTERVAL (KG/SEC PER CATCH OF CORE JEN)
1.0131E-03 1.0171E-03 1.0052E-03 1.0050E-03 1.5570E-03 1.5703E-03 1.5766E-03 1.6000E-03 1.6061E-03 1.6050E-03
1.6229E-03 1.6310E-03 1.6407E-03 1.6512E-03 1.6607E-03 1.6703E-03 1.6798E-03 1.6894E-03 1.6977E-03 1.7070E-03
1.7130E-03 1.7330E-03 1.7117E-03 1.7339E-03 1.6637E-03 1.6326E-03 1.5069E-03 1.5000E-03 1.9350E-03 1.9721E-03
1.0000E-03 1.0007E-03 1.0000E-03 1.0000E-03 1.0000E-03 1.0000E-03 1.0000E-03 1.0000E-03 1.0000E-03 1.0000E-03

INTERVAL MASS COOLANT FLOW RATES BY RICC (KG/SEC PER CATCH)
1.5912E-03 1.9090E-03 1.4217E-03 1.1210E-03

CORE AREA (SQ CM), VOLUME (CC), COOLANT FLOW RATE (KG/SEC) 0.66025E 03 6.0E+17E 06 1.612150 01

HYDRAULICS CALCULATION PROCEDURE, POWER LEVEL (W) 3.30000 07 BOREH COOLANT DENSITY (KG/M^3) 2.2000E 00

ITERATION DATA BASED ON EXIT PRESSURES AND TEMPERATURES, MAX ITERATIONS 20
1 PRESS, BORE, TEMP CHANGES 0.027E-03 1.293E-04 1.002E-01 1.000E 0000000000 0.0 0.0 NEW P 39.50 CORP 1.512
2 PRESS, BORE, TEMP CHANGES 3.705E-03 1.297E-05 -1.625E-02 1.000E 0000000000 0.2766 0.2075 NEW P 39.603 CORP 1.512
3 PRESS, BORE, TEMP CHANGES -0.653E-04 1.373E-05 2.103E-02 1.000E 0000000000 0.2556 1.2762 NEW P 39.605 CORP 1.512
4 PRESS, BORE, TEMP CHANGES 6.995E-04 0.570E-06 -7.613E-03 1.000E 0000000000
```


Table 12. (Continued)

9 PRESS, DRCP, TEMP CHANGES		1.245E-05	3.815E-07	-1.472E-04	EIGENVALUES		6.3752	0.3795	MIN P	39.633	CGEP	1.512									
9 PRESS, DRCP, TEMP CHANGES		6.710E-06	3.815E-07	-6.162E-05	EIGENVALUES		0.1470	0.3430	MIN P	39.633	CGEP	1.512									
HYDRAULICS PROBLEM SOLVED, NODAL TEMPERATURES											EXCLUDED REAR HOLE ENTRANCE FLOW EXIT LOSS (ATM)		0.0200								
REAR AND TEMPERATURE EXIT PRESSURES, AND CORE INTERNAL PRESSURE DRCE (ATM)											39.6330	39.6333	0.3667								
REAR / PEAK COOLANT EXIT TEMPS (C)		800.0	001.7 PEAK SURFACE TEMP		931.3																
REAR / PEAK REYNOLDS NUMBERS		37637.	50129. AVERAGED FRICTION FACTOR		5.681492E-03																
MASS COOLANT FLOW RATES BY INTERVAL (GMS/SEC PER CM ² OF CORE AREA)																					
1.0577	-03	1.4579E-03	1.4203E-03	1.4192E-03	1.5336E-03	1.5502E-03	1.5930E-03	1.4207E-03	1.4206E-03												
1.370	-03	1.3699E-03	1.4670E-03	1.4800E-03	1.4600E-03	1.5000E-03	1.6266E-03	1.6052E-03	1.5500E-03	1.5261E-03											
2.004E-03		2.0070E-03	1.9900E-03	2.0071E-03	1.6659E-03	1.6233E-03	1.5720E-03	1.5275E-03	2.0009E-03	1.5011E-03											
1.9533E-03		1.9533E-03																			
COOLANT TEMPERATURES BY ZONE (C)																					
800.7		800.3	830.6	830.0	830.0	830.0	830.0	830.0	830.0	830.0	830.0	830.0	830.0								
799.9		799.2	829.0	829.0	829.0	829.0	829.0	829.0	829.0	829.0	829.0	829.0	829.0								
SURFACE TEMPERATURES																					
579.9		579.3	565.5	562.9	733.2	730.1	720.5	729.2	829.1	931.0											
827.7		829.9	575.0	575.0	575.0	575.0	575.0	575.0	575.0	575.0	575.0	575.0	575.0								
PEAK SURFACE TEMPERATURES																					
700.7		700.3	717.3	717.5	859.9	820.0	807.9	856.7	931.0	800.0											
820.8		831.3	575.0	575.0	575.0	575.0	575.0	575.0	575.0	575.0	575.0	575.0	575.0								
INLET PRESSURE BY BLOCK, THERM OUTPUT BY INTERVAL (ATM)																					
10.9792		10.9790	10.9332	10.9330	10.9330	10.9330	10.9330	10.9330	10.9330	10.9330	10.9330	10.9330	10.9330								
10.9330		10.9330	10.9330	10.9330	10.9330	10.9330	10.9330	10.9330	10.9330	10.9330	10.9330	10.9330	10.9330								
10.9330		10.9330	10.9330	10.9330	10.9330	10.9330	10.9330	10.9330	10.9330	10.9330	10.9330	10.9330	10.9330								
2	1.1366	0.100000E 23	700.3	731.1	811.5	829.6	-110.6														
3	0.1355	0.100000E 23	839.6	717.3	737.0	790.3	812.0	-90.2													
4	0.1359	0.100000E 23	830.0	717.5	730.0	803.2	617.7	-95.4													
5	0.1066	0.100000E 23	630.0	859.9	875.0	930.6	930.6	-72.0													
6	0.1066	0.100000E 23	627.5	820.0	839.6	850.4	911.9	-80.1													
7	1.1052	0.100000E 23	620.2	807.9	862.5	906.4	916.7	-66.3													
8	0.1066	0.100000E 23	626.7	856.7	872.6	920.5	931.5	-72.1													
9	0.1590	0.100000E 23	770.7	931.0	901.1	971.5	970.3	-60.7													
10	1.1092	0.100000E 23	760.1	800.0	897.5	935.6	900.4	-57.3													
11	0.1550	0.100000E 23	760.9	920.0	930.1	950.2	960.5	-41.5													
12	1.1595	0.100000E 23	769.2	931.3	901.0	971.0	970.6	-40.7													
13	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0													
14	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0													
15	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0													
16	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0													
17	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0													
18	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0													
19	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0													
20	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0													
RELATIVE THERMAL CELL GAP HEAT FLOW (ACCURACY CHECK), WORST AND REAR 1.00000 1.00001																					
MAX TEMPS, PEAK/REAR BY ZONE, SURFACE		570.6	971.0	0.0	0.0	PCORR WEIGHTED	500.2	0.0	POWER (MW)	0.3006E 01											
AVERAGE AND PEAK TEMPERATURE SLOPE AT PIERCE FEAT/SHLL INTERFACE (DEG/CM)											-73.7	-110.6									
CUMULATIVE FRACTIONS OF THE FUEL ABOVE REFERENCE TEMPERATURES, DEG C (SURF FAS C DATA POINTS											12.00,	12)									
975	0.00247536	775	0.5327065	575	0.90190051																
950	0.02552778	750	0.41300377	550	0.5251002E																
925	0.06911007	725	0.67540010	525	0.50030011																
900	0.13300077	700	0.72900020	500	0.5700000E																
875	0.20510026	675	0.77700000	475	0.5067005E																
850	0.27990070	650	0.82110020	450	0.55999990																
825	0.35300070	625	0.85520097	425	1.00000000																
800	0.40970070	600	0.87000070	400	1.00000000																
THERMAL CELL CALCULATIONAL BURDEN 0.3700E 00 MULTISTEP ITERATIONS 90																					
TOTAL CPU TIME IS 0.107 MINUTES AND TOTAL CLOCK TIME IS 1.750 MINUTES FOR 8-BIT CODE EXECUTION																					

THM-TH- GAS COOLED REACTOR THERMAL HYDRAULICS CODE, ORNL VERSION 0.1, FALL 1983 -- QA LEVEL 0

THM-TH SAMPLE PROBLEMS, PROBLEM RES THEN DISPARATE THERMAL HYDRAULICS

THIS WILL BE A THREE-DIMENSIONAL PROBLEM WITH ONE-DIMENSIONAL COOLANT FLOW

SPECIAL DATA OPTIONS FOR COOLANT HOLES IN A SOLID LATTICE WITH DEFAULTS ARE IN EFFECT

-- ENTER CONTROL VARIABLES FOR FLOW THROUGH HOLES IN A SOLID LATTICE --

1- GRAVITY OPTION (-1/0/1) NONE/ FLOW DOWN/ FLOW UP) 0

2- HOLES FOR FLOW THROUGH HOLES IN SOLID LATTICE 0

Table 12. (Continued)

```

3- FINANCE OPTIONS (-1/0,1/2- HX/CHIST/FILE REPORT) -1
4- FL. TCR RANGE (-1/0,1/2- TOTAL/INST/SEC) 1
5- REMON. AVAILABLE IF .RE. 0 (WORDS) 0
6- OPTION TO REVERSE THE DIRECTION OF COOLANT FLOW 0
7- DETIC EXIT LEVEL 0
8- EXIT LEVEL OPTION 1
9- FLUID FLOW CONTROL OPTIONS (-0,1,2,3,4- FOR HEAT/ BLOCK
  BY 1ST PLANE ZONES/ BLOCKING SUPPLIED/ FOR FRESH DROOP/ FIX) 1
10- LATTICE CELL GEOMETRY (-0/1- 2-D RECOMMENDED /1-D) 0
11- TERMINATION ITERATION COUNT 0
12- ORIFICE OPTIONS (-0,1/2/3- NONE/INLET/OUTLET) 2
13- ORIFICE TASK (-0/1/2- EXIT 1/ SURFACE 1/ PEAK EXIT 1) 0
14- EXIT ENTRANCE/EXIT PRESS LOSS IF > 0 0
15- NO. AXIAL INTERVALS FOR EXTENDING 1-D OR 2-D TO 3-D 0

0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 -2

---- FLOATING POINT CONTROL VARIABLES ----

VOID FRACTION 0.15000 03
INLET TEMPERATURE (C) 0.15000 03
INLET PRESSURE (ATM) 0.00000 02
MASS FLOW RATE (KG/S) 0.0
CHARACTERISTIC HYDRAULIC DIAMETER (CM) 0.15000 01

REFERENCE FLUENCE 0.10000 23
RECOVERABLE ENERGY FRACTION 0.50000 00
SPECIFIED POWER LEVEL 0.15000 06
DIAMETER OF CELL FOR HEAT REMOVAL (CM) 0.10000 01
FUEL RADIUS OF ZONE MATERIAL (CM) 0.05000 00

FUEL RADIUS OF SHEATH MATERIAL (CM) 0.05000 00
OUTLET TEMPERATURE (C) 0.00000 03
FLUENCE MULTIPLIER 0.10000 01
THERMAL CONDUCTIVITY MULTIPLIER 0.10000 01
CONVERGENCE CRITERIA 0.0 MAXIMUM CPU TIME IN SECONDS 0.12000 03

MAXIMUM MEMORY REQUIREMENT -- 10326 WORDS, REPORT AVAILABLE -- 160000 WORDS

TIME OF ZIMOND- 0.0 DOES NOT MATCH PRECISE- 0.0

DATA UNIT NUMBERS, GEOMETRY, EXPOSURE, ZONE AND POINT POWER DENSITY IN G 19 16

PROBLY DESH (PLANE-AXIAL) 5 12 3 6 5 12 50.000 150.000 50.000 150.000 75.000 775.000

COMPACTED DESH 4 4 4

THE TREATMENT OF ONE-DIMENSIONAL FLOW IN A THREE-DIMENSIONAL NUCLEI FOLLOWS

THE-TH SAMPLE PROBLEMS, PROBLE REE THEN PRISMATIC THERMAL HYDRAULICS

AXIAL INTERVALS 66.667 66.667 66.667 83.333 83.333 83.333 125.000 125.000

ELEMENTAL CROSS SECTION AREA (CM**2) 2.70000E 02 CORE VOLUME (CC) ARE REAR VOID FRACTION 6.06217E 06 1.70000E-01
COOLANT CHANNEL SURFACE TO VOLUME (1-1) AND COOLANT HOLES PER CC. R. 9.28212E 01 2.58337E 02
ZONTS, SUBZONES, PLANNAR POINTS, AXIAL POINTS 20 0 11 1
PRIMARY DATA, DIMENSIONS 0 0 0 ACTIVE POWER GENERATING INTERVALS 32 BICCS 0
X Y AND Z COORDINATES 100.000 100.000 700.000 TOTAL POWER (MW, ZONTS) 3.167320 07 3.06121E 07

UNADJUSTED HEAT SOURCE BY INTERVAL
2.70000E 02 3.70000E 02 3.0555E 02 3.1700E 02 3.0165E 02 3.0341E 02 2.7262E 02 3.0007E 02 3.0521E 02
3.0011E 02 3.0005E 02 3.7300E 02 3.5750E 02 3.7300E 02 3.3975E 02 3.1533E 02 3.3100E 02 3.7322E 02 3.9163E 02
4.1535E 02 4.1627E 02 4.1633E 02 4.1622E 02 2.8605E 02 3.1055E 02 3.5602E 02 3.9070E 02 4.1517E 02 4.1597E 02
4.5707E 02 4.5712E 02

THIS PROBLEM INVOLVES BLOCKING OF COOLANT CHANNELS FOR COMMON ORIFICE CONTROL

INTERVAL COOLANT FLOW INDEXING
1 3 4 0 0 3 3 3 0 0 0 0 1 1 1 1
2 2 1 1 1 2 2 2 1 1 1 1 1 1 1 1

MASS COOLANT FLOW RATES BY INTERVAL (KG/SEC PER CM**2 OF CORE AREA)
1.09700E-01 1.09717E-01 1.0656E-01 1.0650E-01 1.5570E-01 1.5703E-01 1.5706E-01 1.0000E-01 1.0661E-01 1.0656E-01
1.2224E-01 1.0219E-01 1.0907E-01 1.5122E-01 1.0907E-01 1.5122E-01 1.0310E-01 1.0100E-01 1.5677E-01 1.5676E-01
1.9707E-01 1.9310E-01 1.9117E-01 1.9330E-01 1.6636E-01 1.6326E-01 1.5069E-01 1.5066E-01 1.9350E-01 1.9121E-01
1.8907E-01 1.8907E-01

INTERVAL MASS COOLANT FLOW RATES BY BICCS (KG/SEC PER CM**2)
1.5912E-01 1.4900E-01 1.0217E-01 1.4210E-01

CORE AREA (SQ CM), VOLUME (CC), COOLANT FLOW RATE (KG/SEC) 0.66025E 03 1.06217E 06 1.41215E 01
HYDRAULICS CALCULATION PROCEEDS, POWER LEVEL (W) 3.30000 07 BOUND COOLANT DENSITY (G/CM**3) 1.2603E 00

```

Table 12. (Continued)

```

ITERATION DATA BASED ON EXIT PRESSURES AND TEMPERATURES, MAX ITERATIONS 20
1 PRESS, DROP, TEMP CHANGES 0.0271E-03 1.0000E-03 1.0000E-03 ERROR INTERVALS 0.0 0.0 MIN P 39.650 CORR 1.400
2 PRESS, DROP, TEMP CHANGES 3.771E-03 0.011E-03 1.500E-02 ERROR INTERVALS 0.3767 0.1064 MIN P 39.644 CORR 1.400
3 PRESS, DROP, TEMP CHANGES -7.095E-04 1.100E-05 1.000E-02 ERROR INTERVALS 0.2353 1.2293 MIN P 39.646 CORR 1.400
4 PRESS, DROP, TEMP CHANGES 6.119E-04 5.301E-06 -7.520E-03 ERROR INTERVALS 0.7055 0.5161 MIN P 39.639 CORR 1.400
5 PRESS, DROP, TEMP CHANGES 2.529E-04 2.209E-06 3.399E-03 ERROR INTERVALS 0.4295 0.3269 MIN P 39.635 CORR 1.400
6 PRESS, DROP, TEMP CHANGES 1.049E-04 1.100E-06 -1.235E-03 ERROR INTERVALS 0.4157 0.4064 MIN P 39.634 CORR 1.400
7 PRESS, DROP, TEMP CHANGES -0.250E-05 7.629E-07 -5.254E-04 ERROR INTERVALS 0.3084 0.4220 MIN P 39.634 CORR 1.400
8 PRESS, DROP, TEMP CHANGES 1.773E-05 3.815E-07 -2.172E-04 ERROR INTERVALS 0.4150 0.4149 MIN P 39.633 CORR 1.400
9 PRESS, DROP, TEMP CHANGES 7.291E-06 3.615E-07 -9.560E-05 ERROR INTERVALS 0.4168 0.4105 MIN P 39.633 CORR 2.375
10 PRESS, DROP, TEMP CHANGES 2.906E-06 7.629E-07 6.923E-05 ERROR INTERVALS 0.3083 0.6747 MIN P 39.633 CORR 1.512

HYDRAULICS PROBLEM SOLVED, NORMAL TERMINATION. INCLUDED HEAT LOSS ENTRANCE PLUS EXIT LOSS (W) 0.0200
HEAT AND MINIMUM EXIT PRESSURES, AND CORE INTERNAL PRESSURE DROP (ATM) 39.6330 35.6333 0.3067
HEAT / PEAK COOLANT EXIT TEMPS (C) 770.0 801.0 PEAK SURFACE TEMP 931.3
HEAT / PEAK RETENOLS (W) 3737. 5431. AVERAGED FRICTION FACTOR 5.601503E-03
MASS COOLANT FLOW RATES BY INTERVAL (KG/SEC PER CM^2 OF CORE AREA)
1.4577E-03 1.4579E-03 1.4202E-03 1.4194E-03 1.5336E-03 1.5549E-03 1.5937E-03 1.4207E-03 1.4205E-03
1.3702E-03 1.3688E-03 1.4600E-03 1.4600E-03 1.4600E-03 1.5047E-03 1.6265E-03 1.6052E-03 1.5504E-03 1.5260E-03
2.0007E-03 2.0071E-03 1.9805E-03 2.0071E-03 1.6659E-03 1.6203E-03 1.5727E-03 1.5275E-03 2.0090E-03 1.9013E-03
1.9533E-03 1.9533E-03
COOLANT TEMPERATURES BY ZONE (C)
800.7 800.3 839.6 836.0 836.0 627.5 620.2 626.2 770.7 760.1
760.9 769.2 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0
SURFACE TEMPERATURES
579.9 578.3 565.5 564.7 733.2 734.0 720.5 729.2 829.1 831.4
827.7 829.8 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0
PEAK SURFACE TEMPERATURES
748.3 704.3 717.3 717.5 859.9 820.0 848.0 856.7 931.0 880.7
920.8 931.3 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0
INLET PRESSURE BY BLOCK, THEN OUTLET BY INTERVAL (ATM)
39.6792 40.0000 39.6332 39.6589
39.6330 39.6330 39.6330 39.6330 39.6330 39.6330 39.6330 39.6330 39.6330 39.6330
39.6330 39.6330 39.6330 39.6330 39.6330 39.6330 39.6330 39.6330 39.6330 39.6330
39.6330 39.6330 39.6330 39.6330 39.6330 39.6330 39.6330 39.6330 39.6330 39.6330
39.6330 39.6330
AVERAGE INTERVAL MASS COOLANT FLOW RATE BY BLOCK (KG/SEC PER CM^2) -- TOTAL (KG/SEC) 1.40950 01
1.5070E-03 1.9875E-03 1.4169E-03 1.5178E-03
COOLANT EXIT TEMPERATURES BY BLOCK
800.0 800.0 800.0 800.0
PEAK SURFACE TEMPERATURES BY COOLANT BLOCK
931.0 800.7 920.8 931.3
PRESSURE DROP ACROSS CRIPICE BY COOLANT BLOCK
0.1208 0.0000 0.1668 0.1011
HYDRAULICS CALCULATION DONE, CALCULATE TEMPERATURES
RECOVERING CELL THERMAL CONDUCTIVITY DATA, UNIT 31 ← note data recovery test
4 0.1349 0.100000E 23 430.0 717.5 739.0 803.5 810.1 -96.5
5 0.1059 0.100000E 23 630.0 859.9 875.0 923.0 930.8 -72.0
6 0.1736 0.100000E 23 627.5 820.0 839.6 898.6 912.1 -88.7
7 0.1440 0.100000E 23 626.2 848.0 862.6 906.7 916.9 -66.7
8 0.1056 0.100000E 23 626.2 856.7 872.7 920.6 931.7 -72.6
9 0.1571 0.100000E 23 770.7 931.0 941.1 971.6 978.5 -85.1
10 0.1476 0.100000E 23 760.1 884.7 897.5 935.7 944.6 -57.9
11 0.1537 0.100000E 23 760.9 920.8 930.2 958.3 964.7 -61.9
12 0.1572 0.100000E 23 769.2 931.3 941.4 971.9 978.0 -45.5
13 0.0 0.0 575.0 575.0 575.0 575.0 575.0 0.0
14 0.0 0.0 575.0 575.0 575.0 575.0 575.0 0.0
15 0.0 0.0 575.0 575.0 575.0 575.0 575.0 0.0
16 0.0 0.0 575.0 575.0 575.0 575.0 575.0 0.0
17 0.0 0.0 575.0 575.0 575.0 575.0 575.0 0.0
18 0.0 0.0 575.0 575.0 575.0 575.0 575.0 0.0
19 0.0 0.0 575.0 575.0 575.0 575.0 575.0 0.0
20 0.0 0.0 575.0 575.0 575.0 575.0 575.0 0.0
RELATIVE THERMAL CELL GAP HEAT FLOW (ACCURACY CHECK), MONST AND HEAT 0.59999 1.00000
MAX TEMPS, PEAK/HEAT BY ZONE, SIZE/ZONE 570.8 571.9 0.0 0.0 PEAK HEIGHT/ 806.5 0.0 POWER (MW) 0.3800
AVERAGE AND PEAK TEMPERATURE SLOPE AT FUEL/HEAT/SHIELD INTERFACE (DEG/C) -75.2 -119.6
CUMULATIVE FRACTIONS OF THE FUEL ABOVE REFERENCE TEMPERATURES, DEG C (SEE BASIC DATA PCHTS) 12.00, 12)
975 0.00250300 775 0.53315175 575 0.90228375
940 0.02571013 750 0.61857400 550 0.92505800
925 0.06850827 725 0.67672030 525 0.94842574
900 0.13751423 700 0.73051694 500 0.97016907
875 0.20509183 675 0.77768296 475 0.98690884
850 0.28013409 650 0.82244283 450 0.99999994
825 0.35902679 625 0.85594183 425 1.00000000
800 0.45006192 600 0.87911280 400 1.00000000
THERMAL CELL CALCULATIONAL BURDEN 4.6460E ON MULTISTEP ITERATIONS 0
DATA SAVE/RECOVERY DISCONTINUED

```

Table 12. (Continued)

A PERMANENT STATE SOLUTION IS NOW OBTAINED, FINISH ORIFICE RESISTANCE SET TO 0.02 TIMES THE AVERAGE

CALCULATION PROCEEDS WITH FIXED RELATIVE ORIFICES

RELATIVE ORIFICE RESISTANCES, ORIGINAL READ, AND SET MAX AND MIN 4.00520E 04 8.304331E 04 9.610576E 02

INTERVAL COOLANT BLOCK INDEXING

3 3 3 3 4 4 4 4 3 3 3 3 4 4 4 4 1 1 1 1
2 2 2 2 1 1 1 1 2 2 2 2 4 4 4 4 1 1 1 1

HESS COOLANT FLOW RATES BY INTERVAL (GCM/SEC PER CM² OF CORE AREA)

1.4970E-03 1.4971E-03 1.4656E-03 1.4656E-03 1.5570E-03 1.5570E-03 1.5746E-03 1.5746E-03 1.6060E-03 1.6060E-03 1.6651E-03 1.6651E-03
1.4220E-03 1.4219E-03 1.4947E-03 1.5122E-03 1.4947E-03 1.5323E-03 1.4310E-03 1.4310E-03 1.6130E-03 1.5679E-03 1.5679E-03 1.5679E-03
1.9340E-03 1.9330E-03 1.9117E-03 1.9330E-03 1.6636E-02 1.6326E-03 1.5869E-03 1.5869E-03 1.5406E-03 1.9350E-03 1.9121E-03
1.9849E-03 1.8807E-03

INTERVAL MASS COOLANT FLOW RATES BY BLOCK (GCM/SEC PER CM²)

1.5912E-03 1.9890E-03 1.4217E-03 1.5214E-03

CORE AREA (SQ CM), VOLUME (CC), COOLANT FLOW RATE (GCM/SEC) 8.66025E 03 6.06217E 06 1.412150 01

HYDRAULICS CALCULATION PROCEEDS, POWER LEVEL (W) 3.30000 07 ROUGH COOLANT DENSITY (GCM/CM³) 2.2003E 00

ITERATION DATA BASED ON EXIT PRESSURE AND TEMPERATURES, MAX ITERATIONS 20

1	PRESS, DBCP, TEMP CHANGES	9.543E-03	9.305E-04	1.012E-01	ERROR EIGENVALUES	0.0	0.0	M. P	39.622	COEF	1.512
2	PRESS, DBCP, TEMP CHANGES	1.944E-04	1.504E-05	-6.983E-03	ERROR EIGENVALUES	0.6004	0.1101	MIN P	39.620	COEF	1.512
3	PL.LS, DBCP, TEMP CHANGES	-1.837E-04	6.866E-06	-5.467E-03	ERROR EIGENVALUES	1.1322	0.6156	MIN P	39.627	COEF	1.512
4	PRESS, DBCP, TEMP CHANGES	-7.064E-05	2.670E-06	-2.160E-03	ERROR EIGENVALUES	0.4060	0.4007	MIN P	39.630	COEF	1.512
5	PRESS, DBCP, TEMP CHANGES	-2.771E-05	1.226E-06	8.574E-04	ERROR EIGENVALUES	6.4308	0.4278	MIN P	39.631	COEF	1.512
6	PRESS, DBCP, TEMP CHANGES	-1.154E-05	7.629E-07	3.749E-04	ERROR EIGENVALUES	6.4303	0.4309	MIN P	39.632	COEF	2.654
7	PRESS, DBCP, TEMP CHANGES	9.107E-06	7.629E-07	2.990E-04	ERROR EIGENVALUES	0.6030	0.7440	MIN P	39.632	COEF	1.633
8	PRESS, DBCP, TEMP CHANGES	-6.722E-07	3.015E-07	2.025E-05	ERROR EIGENVALUES	0.6612	0.0600	MIN P	39.632	COEF	1.633

HYDRAULICS PROBLEM SOLVED, NORMAL TURBULENCE.

INCLUDED HEAD LOSS ENTRANCE PLUS EXIT LOSS (ATM) 0.0240

PEAK AND MINIMUM EXIT PRESSURES, AND CORE INITIAL PRESSURE DATA (ATM) 39.6321 35.6321 0.3679

HEAT / PEAK COOLANT EXIT TEMPS (C) 800.0 400.6 PEAK SURFACE TEMP 930.1
HEAT / PEAK REYNOLDS NUMBERS 376C1 50454. AVERAGED FRICTION FACTOR 5.6010E-03

HESS COOLANT FLOW RATES BY INTERVAL (GCM/SEC PER CM² OF CORE AREA)

1.4607E-03 1.4609E-03 1.4233E-03 1.4225E-03 1.5368E-03 1.5374E-03 1.5502E-03 1.5970E-03 1.4237E-03 1.4235E-03
1.3732E-03 1.3710E-03 1.4636E-03 1.4638E-03 1.4636E-03 1.3800E-03 1.4300E-03 1.6106E-03 1.5530E-03 1.5294E-03
1.9948E-03 1.9972E-03 1.9706E-03 1.9972E-03 1.6693E-03 1.631 E-03 1.5762E-03 1.5309E-03 1.9991E-03 1.9713E-03
1.9435E-03 1.9430E-03

COOLANT TEMPERATURES BY ZONE (C)

848.5 840.7 839.4 837.8 833.4 828.0 827.6 825.7 769.8 770.2
768.0 768.3 574.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0

SURFACE TEMPERATURES

579.5 575.2 565.1 562.5 732.4 715.0 727.1 728.5 828.1 833.7
826.7 828.8 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0

PEAK SURFACE TEMPERATURES

767.6 765.9 716.6 716.6 858.9 822.2 846.9 855.6 929.8 847.4
919.6 930.1 575.0 575.0 575.0 575.0 575.0 575.0 575.0 575.0

INLET PRESSURE BY BLOCK

4	0.1359	0.100000E 23	837.8	716.4	738.2	802.6	817.1	-95.4
5	0.1465	0.100000E 23	633.4	858.9	874.0	922.4	933.6	-72.0
6	0.1486	0.100000E 23	628.0	822.2	841.8	900.6	914.0	-88.1
7	0.1451	0.100000E 23	627.6	846.9	861.6	905.6	915.0	-66.5
8	0.1463	0.100000E 23	625.7	855.6	871.6	919.5	930.5	-72.3
9	0.1501	0.100000E 23	769.8	929.8	939.9	970.3	977.1	-48.0
10	0.1498	0.100000E 23	770.2	887.4	900.1	938.1	946.8	-57.1
11	0.1547	0.100000E 23	768.0	919.6	929.0	957.0	963.4	-41.6
12	0.1582	0.100000E 23	768.3	930.1	940.2	970.6	977.0	-44.8
13	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
14	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
15	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
16	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
17	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
18	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
19	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
20	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0

RELATIVE THERMAL CELL GAP HEAT FLOW (ACCURACY CHECK), ROUGH AND READ 1.00002 1.00000
MAX TEMPS, PEAK/READ BY ZONE, SUBSCE 577.4 570.6 0.0 0.0 POWER WEIGHTED 886.2 0.0 POWER (WAT) 4.3804E 01

AVERAGE AND PEAK TEMPERATURE SLOPE AT PIPE/SHELL INTERFAC (DEG/CM) -74.7 -116.4

CUMULATIVE FRACTIONS OF THE FUEL ABOVE REFERENCE TEMPERATURES, 510 C (SOL BASIC DATA POINTS) 12.00, 12)

975	0.00160969	775	0.53179514	575	0.90217364
950	0.02034755	750	0.41333198	550	0.52537631
925	0.06783855	725	0.47502431	525	0.54957901
900	0.13330644	700	0.73017177	500	0.57006941
875	0.20575327	675	0.77654893	475	0.58684967
850	0.27985424	650	0.82179370	450	0.59999934
825	0.35909241	625	0.85576124	425	1.00000000
800	0.44977707	600	0.87897490	400	1.00000000

THERMAL CELL CALCULATIONAL BURDEN 4.6080E 04 MULTICORE .SUBRATICS 0

TOTAL CPU TIME IS 0.067 MINUTES AND TOTAL CLOCK TIME IS 0.221 MINUTES FOR PROBLEM CODE EXECUTION

Table 12. (Continued)

---TNP-TN- GAS COOLED REACTOR THERMAL HYDRAULICS CODE, ORNL VERSION 4.1, FALL 1983 -- QA LEVEL 0

TNP-TN SAMPLE PROBLEMS, PEBBLE BED TERN PRISMATIC THERMAL HYDRAULICS

New code access

THIS WILL BE A THREE-DIMENSIONAL PROBLEM WITH ONE-DIMENSIONAL COOLANT FLOW

SPECIAL DATA OPTIONS FOR COOLANT HOLES IN A SOLID LATTICE WITH ERRATAS ARE IN EFFECT

-- INTEGER CONTROL VARIABLES FOR FLOW THROUGH HOLES IN A SOLID LATTICE --

1- GRAVITY OPTION (-1/0/1- NONE/ BULK DROPS/ FLOW UP)	0
2- NEGATIVE FLOW THROUGH HOLES IN SOLID LATTICE	0
3- PLUMCE OPTIONS (-1/0,1/2- NO/CRIST/FILE REPORT)	-1
4- PLUMCE RANGE (-1/0,1/2- TOTAL/INLET/SECURE)	1
5- FLOW AVAILABLE IF .NE. 0 (WORDS)	0
6- OPTION TO REVERSE THE DIRECTION OF COOLANT FLOW	0
7- DEBUG: EXIT LEVEL	0
8- EXIT LEVEL OPTION	1
9- FLUID FLOW CONTROL OPTIONS (-0,1,2,3,4- FCB HEAT/ BLOCK BY 1ST PLANE ZONES/ BLOCKING SUPPLIED/ FCB PRESS DROP/ FIX)	1
10- LATTICE CELL GEOMETRY (-0/1- 2-D RECTANGULAR /1-0)	0
11- TERMINATION ITERATION COUNT	0
12- ORIFICE OPTIONS (-0,1/2/3- NONE/INLET/EXIT)	1
13- ORIFICE TASK (-0/1/2- EXIT T/ SURFACE T/ PEAK EXIT T)	0
14- ORIT ENTRANCE/EXIT PRESS LOSS IF > 0	0
15- F7. AXIAL INTERVALS FOR EXTENDING 1-D OR 2-D TO 3-D	0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 15 27

← Normal cell changed

--- FLOATING PCINT CONTROL VARIABLES ---

VOID FRACTION	0.17000 03
INLET TEMPERATURE (C)	0.35000 03
INLET PRESSURE (ATM)	0.90000 02
FASS FLOW RATE (CM/S)	0.0
CHARACTERISTIC HYDRAULIC DIAMETER (CM)	0.15000 01
EXPERIENCE PLUMCE	0.10000 23
RECOVERABLE ENERGY FRACTION	0.50000 00
SPECIFIED POWER LEVEL	0.0
DIVISION OF CELL FOR HEAT REMOVAL (CM)	0.10000 01
FUEL RADIUS OF ZONE MATERIAL (CM)	0.05000 03
STEEL RADIUS OF SHROUDED MATERIAL (CM)	0.05000 03
OUTLET TEMPERATURE (C)	0.00000 03
PLUMCE MULTIPLIER	0.10000 01
THERMAL CONDUCTIVITY MULTIPLIER	0.10000 01
CONVERGENCE CRITERIA	0.0
MAXIMUM CPU TIME IN SECONDS	0.12000 03

MAXIMUM MEMORY REQUIREMENT -- 12000 WORDS, MEMORY AVAILABLE -- 160000 WORDS

TIME OF ZERO- 0.0 DOES NOT MATCH PRINT- 0.0

DATA UNIT NUMBERS, GEOMETRY, EXPOSURE, ZONE AND PCINT POWER DENSITY 14 0 15 16

PROBLEM MESH (PLANE-AXIAL) 5 12 3 6 5 12 50.000 150.000 50.000 150.000 75.000 775.000

COMPACTED MESH 4 4 8

TNP-TN TREATMENT OF ONE-DIMENSIONAL FLOW IN A THREE-DIMENSIONAL MESH FOLLOWS

TNP-TN SAMPLE PROBLEMS, PEBBLE BED TERN PRISMATIC THERMAL HYDRAULICS

AXIAL INTERVALS 66.667 66.667 66.667 83.333 83.333 83.333 125.000 125.000

ELEMENTAL CROSS SECTION AREA (CM**2) 2.70000 02 CORE VOLUME (CC) AND REAR VOID FRACTION 6.06212E 06 1.70000E-01

COOLANT CHANNEL SURFACE TO VOLUME (M-1) AND COOLANT HOLES PER SQ. M. 0.20212E 01 8.50337E 02

ZONES, SUBZONES, PLANAR PCINTS, AXIAL PCINTS 20 0 12 6

PRIMARY DATA, DIMENSIONS 4 4 8 ACTIVE POWER GENERATING INTERVALS 32 BLOCKS 4

X Y AND Z COORDINATES 100.000 100.000 700.000 TOTAL FCBES (REAR, ZONE) 3.06121E 07 3.06121E 07

UNADJUSTED HEAT SOURCE BY INTERVAL

2.70000 03	2.70000 03	3.05500 03	3.17000 03	3.01650 03	3.01030 03	2.72620 03	3.00070 03	3.05210 03
3.00000 03	3.00000 03	3.77000 03	3.57500 03	3.73000 03	3.39750 03	3.15330 03	3.31500 03	3.91650 03
0.15330 03	0.16270 03	0.16270 03	0.16270 03	2.80050 03	3.10570 03	3.50620 03	3.90700 03	4.15170 03
0.57000 03	0.57120 03							

THIS PROBLEM INVOLVES BLOCKING OF COOLANT CHANNELS FOR COMMON ORIFICE CONTROL

Table 12. (Continued)

INTERVAL COOLANT BLOCK INDEXING
 3 3 3 3 4 4 4 4 3 3 3 3 4 4 4 4 1 1 1 1
 2 2 2 2 1 1 1 1 2 2 2 2 1 1 1 1 1 1 1 1

MASS COOLANT FLOW RATES BY INTERVAL (GCM/SEC PER CM² OF CORE AREA)
 1.3699E-03 1.3610E-03 1.3320E-03 1.3322E-03 1.0150E-03 1.0312E-03 1.0310E-03 1.0603E-03 1.3325E-03 1.3325E-03
 1.2935E-03 1.2927E-03 1.3500E-03 1.3747E-03 1.3500E-03 1.3930E-03 1.4030E-03 1.4671E-03 1.4254E-03 1.4065E-03
 1.7500E-03 1.7500E-03 1.7379E-03 1.7501E-03 1.5120E-03 1.4042E-03 1.4020E-03 1.4070E-03 1.7511E-03 1.7303E-03
 1.7171E-03 1.7170E-03

INTERVAL MASS COOLANT FLOW RATES BY PICK (GCM/SEC PER CM² OF CORE AREA)
 1.4464E-03 1.0902E-03 1.2510E-03 1.3031E-03

CORE AREA (SQ CM), TO WARE (CC), COOLANT FLOW RATE (GCM/SEC) 0.66025E C3 6.06217E 06 1.20370D 01

HYDRAULICS CALCULATION PROCEEDS, POWER LEVEL (W) 3.0000D 07 POWER COEFFICIENT DENSITY (GCM/W^{0.5}) 2.2003E 00

ITERATION DATA BASED ON EXIT PRESSURES AND TEMPERATURES, MAX ITERATIONS 20

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	PRESS.	DROP.	TEMP	CHANGES	7.017E-03	1.003E-04	1.002E-01	ERROR	EIGENVALUES	0.0	0.0	MIN	P	39.705	COEF	1.000			
2	PRESS.	DROP.	TEMP	CHANGES	3.160E-03	7.200E-06	-1.490E-02	ERROR	EIGENVALUES	0.3732	0.1060	MIN	P	39.700	COEF	1.000			
3	PRESS.	DROP.	TEMP	CHANGES	-6.600E-04	9.227E-06	1.071E-02	ERROR	EIGENVALUES	0.2306	1.2450	MIN	P	39.702	COEF	1.000			
4	PRESS.	DROP.	TEMP	CHANGES	5.137E-04	6.559E-06	-7.296E-03	ERROR	EIGENVALUES	0.7953	0.4959	MIN	P	39.696	COEF	1.000			
5	PRESS.	DROP.	TEMP	CHANGES	2.130E-04	2.289E-06	3.330E-03	ERROR	EIGENVALUES	0.4200	0.3303	MIN	P	39.693	COEF	1.000			
6	PRESS.	DROP.	TEMP	CHANGES	9.600E-05	1.100E-06	-1.200E-03	ERROR	EIGENVALUES	0.4130	0.1760	MIN	P	39.692	COEF	1.000			
7	PRESS.	DROP.	TEMP	CHANGES	3.591E-05	7.629E-07	-5.131E-04	ERROR	EIGENVALUES	0.3910	0.4100	MIN	P	39.692	COEF	1.000			
8	PRESS.	DROP.	TEMP	CHANGES	1.076E-05	3.015E-07	-2.160E-04	ERROR	EIGENVALUES	0.4155	0.4190	MIN	P	39.692	COEF	2.011			
9	PRESS.	DROP.	TEMP	CHANGES	5.794E-06	7.629E-07	-1.622E-04	ERROR	EIGENVALUES	0.4201	0.6305	MIN	P	39.691	COEF	1.512			
10	PRESS.	DROP.	TEMP	CHANGES	5.230E-06	3.015E-07	-0.013E-05	ERROR	EIGENVALUES	0.6670	0.1671	MIN	P	39.691	COEF	1.512			

HYDRAULICS PROBLEM SOLVED, NORMAL TERMINATION. INCLUDED DRUM HOLE ENTRANCE PICS BEIT LESS (ATM) 0.0190

HEAD AND DRUM HOLE EXIT PRESSURES, AND CORE INTERNAL PRESSURE DRUG (ATM) 39.6910 39.6910 0.3000

HEAD/DRUM COOLANT EXIT PRESSURE (ATM) 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000

THE-TH SAMPLE PROBLEMS, PROBLEM BEG THEN PRELIMINARY THERMAL HYDRAULICS

LOWES 20 SUBZONES 0

TWO-DIMENSIONAL THERMAL CELL MODEL IS USED, BISH 15 27

START TEMPS, CONDUCTIVITIES, ETC. 157.9 912.3 920.5 926.2 0.23346 0.23352 0.12160 0.12245 0.11201

THERMAL CELL INITIALIZATION, OVERRELAXATION DATA AND ITERATIONS 0.90991 1.75177 1.75177 1.75177 54

INITIAL DATA 15 27 6 10 13 7.6522E-01 5.9290E-01 2.0290E-01 3.5040E-01 0.1570E-01 5.2360E-01 1.1201E-01

OPTIONS 1 0 0 50 16 162
 INITIAL ONE-DIMENSIONAL GROSS REBALANCE, STORAGE 310 -1 -1 1 27 1 DCHK 0.2000
 INITIAL MULTIGRID PROCESS, STORAGE, ITERATIONS, ETC. 1307 3 3 2 7 2 DCHK 1.4500
 20 0 1 -2 1.6510E-05 1.1000 00 935.000 0.1095 0.2130 4.5050 0.0003 1.0000 -1.5379E-06 1.0902
 FIRST THERMAL CELL PROBLEM DATA 15 27 6 10 13 0 54 1 52 0.76522 1.04720 0.20290 0.59290
 0.10276 6.27040 30.55922 0.10950 0.11300 0.0 1.6510E-05 -1.5379E-06 1.0000 1.1000 1.0902
 OVERRELAXATION COEFFICIENT DATA 6.2000 0.5050 0.3331 0.0 1.0902 1.1000 1.1000
 ESTIMATES OF THE FIRST THERMAL CELL ABSOLUTE ERROR LEVEL 0.00007 0.00065 ITERATIONS 20 MAX TEMP (K) 935.0

2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2	0	0	-2	1.9002E-05	1.5612E 00	900.012	0.9001	0.0	0.0	6.8056	1.0000	-3.2931E-05	1.0502					
2	0	0	-2	1.2966E-05	1.5390E 00	900.061	0.7820	0.0	0.0	0.0003	1.0000	-2.7173E-05	1.0502					
1	0	0	-2	1.4817E-05	1.0350E 00	909.767	0.0	0.0	0.0	0.0060	1.0000	-3.8042E-05	1.0502					
2	0	0	-2	1.5020E-05	1.4350E 00	1061.500	0.5910	0.0	0.0	6.0030	1.0000	-2.8055E-05	1.0502					
2	0	0	-2	9.0479E-06	1.4730E 00	1078.210	0.7345	0.0	0.0	0.0039	1.0000	-3.0049E-05	1.0502					
1	0	0	-2	1.2360E-05	1.4157E 00	1052.727	0.0	0.0	0.0	0.0039	1.0000	-3.2386E-05	1.0502					
1	0	0	-2	4.2379E-06	1.5516E 00	1057.700	0.0	0.0	0.0	0.0003	1.0000	-3.4030E-05	1.0502					
1	0	0	-2	1.1806E-05	1.0200E 00	1133.435	0.0	0.0	0.0	0.0022	1.0000	-3.1702E-05	1.0502					
1	0	0	-2	6.9794E-06	1.0612E 00	1105.091	0.0	0.0	0.0	0.0027	1.0000	-3.7269E-05	1.0502					
1	0	0	-2	5.5700E-06	7.4170E-01	1129.411	0.0	0.0	0.0	0.0020	1.0000	-2.9399E-05	1.0502					
1	0	0	-2	3.9005E-06	8.1600E-01	1120.000	0.0	0.0	0.0	0.0022	1.0000	-3.2051E-05	1.0502					

ZONE AND SUBZONE TEMPERATURES (DEGREES C) FOR MASS FLOW RATE (G/SEC) 1.2017E 01 SUBBED POWER (MW) 3.0000E 01

ZONE	CONDUCTIVITY AND EXPOSURE	FLUID	SURFACE	SHELL	HEAT CENTER TEMPERATURES, DT/OR (DEG/CM)			
1	0.1217	0.10000E 23	800.0	577.0	595.1	605.0	602.0	-80.5
2	0.1232	0.10000E 23	800.3	577.7	592.6	607.1	671.0	-90.0
3	0.1205	0.10000E 23	839.0	563.2	578.3	625.0	635.9	-69.1
4	0.1205	0.10000E 23	830.1	560.6	576.5	625.0	630.0	-72.0
5	0.1339	0.10000E 23	630.0	731.3	741.3	780.2	788.6	-55.3
6	0.1351	0.10000E 23	627.0	732.0	747.0	790.1	805.2	-70.6
7	0.1332	0.10000E 23	620.3	726.6	737.7	771.9	779.7	-51.0
8	0.1335	0.10000E 23	626.3	727.3	739.3	776.3	780.7	-55.5
9	0.1006	0.10000E 23	770.6	620.0	634.0	855.6	860.0	-31.7
10	0.1015	0.10000E 23	760.1	630.2	639.0	865.9	877.1	-40.9
11	0.1003	0.10000E 23	760.9	626.6	632.0	852.0	856.0	-29.2
12	0.1007	0.10000E 23	769.2	628.7	635.0	856.3	861.1	-31.7
13	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
14	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
15	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
16	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
17	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
18	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
19	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
20	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0

RELATIVE THERMAL CELL GAP HEAT FLOW (ACCURACY CHECK), WEIGHT AND HEAD 1.00000 1.00000
 MAX TEMP, MIN/HEAD BY ZONE, SUBZONE 172.1 864.9 0.0 0.0 POWER WEIGHT 706.0 0.0 POWER (MW) 3.0000E 01

Table 12. (Continued)

2	0.1355	0.100000E 23	440.3	701.1	775.4	799.1	815.6	-109.5
3	0.1346	0.100000E 23	439.0	714.1	732.4	788.1	800.7	-81.3
4	0.1350	0.100000E 23	438.1	714.3	733.7	792.4	805.9	-40.0
5	0.1460	0.100000E 23	434.0	850.0	872.5	916.1	926.1	-60.3
6	0.1437	0.100000E 23	627.4	815.1	835.9	889.7	901.9	-81.2
7	0.1445	0.100000E 23	628.3	846.1	859.3	899.5	908.7	-61.0
8	0.1457	0.100000E 23	626.3	854.7	869.2	912.9	922.9	-66.4
9	0.1572	0.100000E 23	770.5	930.0	939.2	966.9	973.2	-81.2
10	0.1677	0.100000E 23	768.1	883.0	895.3	930.1	938.1	-53.0
11	0.1539	0.100000E 23	768.9	919.0	928.3	953.9	959.7	-33.3
12	0.1573	0.100000E 23	769.2	930.3	939.5	967.2	973.4	-81.2
13	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
14	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
15	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
16	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
17	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
18	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
19	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
20	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0

RELATIVE INTERNAL CELL GAP HEAT FLOW (ACCURACY CHECK), WORST ARE NEAR 1.00000 1.00000
 MAX TEMPS, PEAR/NEAR BY ZONE, SURFACE 573.4 567.2 0.0 0.0 POWER WEIGHTS 877.9 0.0 POWER (WAT) 3.9644E 01

AVERAGE AND PEAK TEMPERATURE SLOPE AT PEEBLE FEAT/SHELL INTERFACE (DEG/C) -68.5 -109.5

CUMULATIVE FRACTIONS OF THE FUEL ABOVE REFERENCE TEMPERATURES, DEG C (FOR BASIC DATA POINTS 12.00, 12)

950	0.02978267	750	0.59235E71	550	0.5101850E
925	0.05560646	725	0.6578C303	525	0.5019036E
900	0.11451727	700	0.7129810E	500	0.96542223
875	0.18792582	675	0.7634435E	475	0.98283267
850	0.26133436	650	0.8089301E	450	0.9908708E
825	0.33912814	625	0.8473251E	425	0.9999998E
800	0.42348301	600	0.8709477E	400	1.0000000E
775	0.50475031	575	0.8945644E	375	1.0000000E

INTERNAL CELL CALCULATIONAL BURDEN 4.7932E ON MULTIGRID ITERATIONS 55

THIR-TH SAMPLE PROBLEMS, PEEBLE BED IDEM PRISMATIC THERMAL HYDRAULICS

ZONES 20 SURFACES 0

TWO-DIMENSIONAL THERMAL CELL MODEL IS USED, NISH 15 27

START TEMPS, CONDUCTIVITIES, ETC. 157.0 511.9 926.1 925.0 0.23338 0.23304 0.12164 0.12242 0.11260

THERMAL CELL INITIALIZATION, OVERRELAXATION DATA AND ITERATIONS 0.98991 1.75177 1.75177 1.75177 50

INITIAL DATA 15 27 16 13 7.6522E-01 5.9294E-01 2.0290E-01 3.5060E-01 4.1578E-01 5.2360E-01 1.1260E-01

OPTIONS 1 0 50 16 162

INITIAL ONE-DIMENSIONAL UNITS RECALCULATE, STORAGE 114 -1 -1 1 27 1 BORE 0.2000

INITIAL MULTIGRID PROCESS, STORAGE, LEVELS, ETC. 1147 3 3 1 7 2 BORE 1.4508

20 0 1 -2 1.6580E-05 1.1532E 00 934.595 0.1093 0.2140 4.5367 0.0003 1.0000 -1.3055E-06 1.0502

FIRST THERMAL CELL PROBLEM DATA 15 27 16 1 0 50 1 52 0.74522 1.04720 0.16290 0.54298

4.10276 6.20040 12.55922 0.16535 0.11401 0.0 0 50 1 52 0.74522 1.04720 0.16290 0.54298

OVERRELAXATION COEFFICIENT DATA 6.2004 0.16535 0.11401 0.3331 1.6540E-05 -1.5055E-06 1.0000 1.1000 1.0902

ESTIMATES OF THE FIRST THERMAL CELL RESOLUTE FROM LEVEL 0.00007 0.00065 ITERATIONS 20 MAX TEMP (K) 934.6

1	0	-2	1.9033E-05	1.5022E 00	595.276	0.9112	0.0	0.0	0.0057	1.0000	-3.2483E-05	1.0504
2	0	-2	1.2951E-05	1.5401E 00	504.491	0.7806	0.0	0.0	0.0043	1.0000	-2.7201E-05	1.0502
1	0	-2	1.4421E-05	2.0330E 00	504.194	0.0	0.0	0.0	0.0040	1.0000	-3.8085E-05	1.0504
2	0	-2	1.5032E-05	1.4146E 00	1060.427	0.5917	0.0	0.0	0.0034	1.0000	-2.8709E-05	1.0504
2	0	-2	9.0167E-06	1.4780E 00	1079.476	0.7311	0.0	0.0	0.0039	1.0000	-3.0308E-05	1.0502
1	0	-2	1.2095E-05	1.4204E 00	1052.017	0.0	0.0	0.0	0.0039	1.0000	-3.1465E-05	1.0502
1	0	-2	4.2422E-06	1.5470E 00	1056.975	0.0	0.0	0.0	0.0143	1.0000	-3.2457E-05	1.0504
1	0	-2	1.1963E-05	1.0193E 00	1132.440	0.0	0.0	0.0	0.0042	1.0000	-3.3741E-05	1.0502
1	0	-2	7.0661E-06	1.0687E 00	1187.305	0.0	0.0	0.0	0.0027	1.0000	-3.7162E-05	1.0502
1	0	-2	5.4575E-06	7.4150E-01	1124.466	0.0	0.0	0.0	0.0030	1.0000	-1.0078E-05	1.0502
1	0	-2	3.2481E-06	4.1096E-01	1133.118	0.0	0.0	0.0	0.0022	1.0000	-3.2044E-05	1.0502

ZONE AND SURFACE TEMPERATURES (DEGREES C) FOR MASS FLOW RATE (KG/SEC) 1.2817E 01 TURNED POWER (MW-TM) 1.0000E 01

ZONE (CONDUCTIVITY AND P(TEMPERATURE)), FLUID	SURFACE	SHELL	HEAT	CISEM	TEMPERATURES, DE/ON (DEG/C)
1 0.1217 0.100000E 23	844.6	577.0	594.7	644.0	661.6 -80.5
2 0.1233 0.100000E 23	810.7	572.7	593.5	656.0	672.3 -94.4
3 0.1204 0.100000E 23	819.6	562.8	577.9	625.0	635.5 -69.1
4 0.1205 0.100000E 23	817.9	560.2	576.1	625.0	633.4 -72.4
5 0.1334 0.100000E 23	613.4	733.6	742.5	779.4	787.4 -55.3
6 0.1353 0.100000E 23	628.8	733.7	749.1	756.2	806.9 -70.1
7 0.1321 0.100000E 23	627.7	725.9	737.0	771.2	774.0 -51.4
8 0.1314 0.100000E 23	627	726.5	738.5	775.6	784.0 -55.5
9 0.1405 0.100000E 23	769.	827.0	831.8	854.6	859.4 -31.7
10 0.1417 0.100000E 23	770.1	832.4	841.2	864.1	874.3 -40.4
11 0.1402 0.100000E 23	768.1	825.6	831.0	851.0	855.5 -47.2
12 0.1404 0.100000E 23	768.1	827.7	834.5	851.3	860.1 -41.7
13 0.0 0.0	575.0	575.0	575.0	575.0	575.0 0.0
14 0.0 0.0	575.0	575.0	575.0	575.0	575.0 0.0
15 0.0 0.0	575.0	575.0	575.0	575.0	575.0 0.0
16 0.0 0.0	575.0	575.0	575.0	575.0	575.0 0.0
17 0.0 0.0	575.0	575.0	575.0	575.0	575.0 0.0
18 0.0 0.0	575.0	575.0	575.0	575.0	575.0 0.0
19 0.0 0.0	575.0	575.0	575.0	575.0	575.0 0.0
20 0.0 0.0	575.0	575.0	575.0	575.0	575.0 0.0

RELATIVE INTERNAL CELL GAP HEAT FLOW (ACCURACY CHECK), WORST ARE NEAR 1.00000 1.00000
 MAX TEMPS, PEAR/NEAR BY ZONE, SURFACE 174.3 168.1 0.0 0.0 POWER WEIGHTS 746.0 0.0 POWER (WAT) 3.0000E 01

Table 12. (Continued)

2	0.1357	0.100000E 23	440.7	702.4	727.0	800.5	817.0	-109.4
3	0.1345	0.100000E 23	439.4	713.4	731.0	787.5	800.0	-43.3
4	0.1349	0.100000E 23	437.9	713.6	733.0	791.9	805.2	-88.0
5	0.1459	0.100000E 23	633.4	455.9	471.4	915.0	925.1	-66.3
6	0.1434	0.100000E 23	620.0	420.3	430.1	851.7	904.0	-81.1
7	0.1434	0.100000E 23	627.7	445.0	450.3	850.4	907.0	-61.1
8	0.1455	0.100000E 23	625.7	451.7	460.2	811.9	921.9	-66.3
9	0.1569	0.100000E 23	749.7	920.7	937.9	965.7	972.0	-41.3
10	0.1494	0.100000E 23	770.1	886.4	897.9	932.4	940.6	-52.8
11	0.1536	0.100000E 23	760.1	910.6	927.1	952.7	950.5	-30.4
12	0.1570	0.100000E 23	760.3	929.1	930.2	966.0	972.3	-41.3
13	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
14	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
15	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
16	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
17	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
18	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
19	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0
20	0.0	0.0	575.0	575.0	575.0	575.0	575.0	0.0

RELATIVE THERMAL CELL GAP HEAT FLOW (ACCURACY CHECK), BOAST AND BEAR 1.00000 1.00001
 MAX TESTS, PEAK/BEAR BY ZONE, SUBCODE 572.3 566.0 0.0 0.0 POWER DENSITY 877.0 0.0 POWER (BWT) 3.9024E 01

AVERAGE AND PEAK TEMPERATURE SLOPE AT PEBBLE HEAT/SHELL INTERFACE (DEG/CM) -48.9 -109.4

CUMULATIVE FRACTIONS OF THE FUEL ABOVE REFERENCE TEMPERATURES, DEG C (504 BASIC DATA POINTS 12.00, 12)

950	0.01903744	750	0.59138240	550	0.91014405
925	0.05509905	725	0.65771210	525	0.54176703
900	0.11066247	700	0.71205796	500	0.96539122
875	0.18007501	675	0.76290495	475	0.50274430
850	0.26140720	650	0.80002270	450	0.59098571
825	0.33911503	625	0.84727529	425	0.55995940
800	0.42355496	600	0.87085600	400	1.00000000
775	0.50872016	575	0.89422444	375	1.00000000

THERMAL CELL CALCULATIONAL BURDEN 0.7932E 04 MULTITASK ITERATIONS 95

TOTAL CPU TIME IS 0.076 MINUTES AND TOTAL CLOCK TIME IS 1.901 MINUTES FOR PEBBLE CODE EXECUTION

*clock time is high relative to cpu time in a
 multitask environment*

Data for the thermal hydraulics calculation originated as follows:

Nuclear data.....User input to Input Processor
 PBLINS record on CONTROL.....User input to DUTLIN
 Geometry description on GEODST.....User input to DVENTR
 Point power density on PWDINT.....VENTURE neutronics
 Zone power density on ZNPOWD.....VENTURE neutronics
 Temperature results on ZNTEMP.....THR-TH thermal hydraulics

The control over the hydraulics calculation included assigning the inlet orifice blocking at the zone level and setting the orifices to cause equal average outlet temperatures. Note that there are four coolant channel blockings and the coolant flow rates per unit area and pressure drops associated with each were calculated as follows for the conditions specified initially:

Block	1	2	3	4
Coolant mass flow rate (kg/s-cm ²)	1.4440-3	1.8071-3	1.2887-3	1.3803-3
Pressure drop (atm)				
Orifice	0.1015	0.0	0.1401	0.1185
Flow loss	0.2071	0.3086	0.1685	0.1901
Sum	0.3086	0.3086	0.3086	0.3086
Peak surface temperature (°C)	930.0	883.8	919.8	930.3

The pressure drop data include only that through the fuel assemblies and exclude loop, vessel entrance and exit and axial reflector losses.

7. PROGRAM CONSIDERATIONS

This code has some double precision type assignments to avoid the inaccuracy of half precision word length made standard by the computer manufacturer. It is reasonable to assume that such special assignments and associated function names would be altered with a simple processor prior to compiling the source deck on a long word machine. An effective processor would eliminate REAL*8 statements and double precision notation of function references.

Memory allocation is made problem dependent by use of special features of the local operating system. Equivalent capability on another type of computer could be effected only with source deck changes.

The source deck is basically standard ANSI-X3.9-1966 Fortran. Major changes would be necessary before it would conform with the -1978 Fortran standard.

Due to the large size of some of the routines and associated compile tables, considerable compiler capability is needed that may not be available. Locally with the Fortran H compiler, 450K bytes (115,200 short word) storage is needed.

Key information about the code is presented in Fig. 8. Included are interface data file usage, the roles played by the subroutines, and the program overlay structure. Overlay is not used for data blocks.

C
 C INFORMATION ABOUT THE ORNL "THR-TH" THERMAL HYDRAULICS CODE
 C
 C -----
 C
 C

C
 C DATE: SEPT, 1983
 C

C
 C INTERFACE DATA FILES
 C
 C -----
 C

FILE	DATA USE
GEODST	GEOMETRY DESCRIPTION, MESHPOINT AND ZONE LOCATIONS
PWDINT	POWER DENSITY DATA BY MESHPOINT
ZNPWD	POWER DENSITY (FOR ZONE, SUCZONE TEMPS, VOL FRACTS)
	THIS POWER DENSITY IS USED IF THERE IS NO "ZNPWD" FILE
CPHIST	NEUTRON FLUX EXPOSURE, CONTINUOUS FUELING, OR
EXPOT	NEUTRON FLUX EXPOSURE, FIXED FUEL
THERHA	SPECIAL DATA FOR CERTAIN FIXED FUEL OPTIONS
ZWTEMP	TEMPERATURE RESULTS FOR SUBSEQUENT USE BY OTHER CODES
TDATAS	SAVE THERMAL HYDRAULICS RESULTS FOR RECOVERY
	—ONLY A SINGLE VERSION IS PERMITTED TO EXIST

C
 C SINCE ONLY ONE VERSION OF THE FILE "TDATAS" IS ADMITTED, DATA CAN
 C NOT BE RECOVERED AND SAVED SIMULTANEOUSLY FOR THE SAME CASE
 C -- FILE NUMBERS AUTOMATICALLY ASSIGNED INDEX UPWARD
 C AND DEPEND ON PAST ASSIGNMENTS AFFECTING SAVE SELECTION
 C

C
 C INFORMATION ABOUT THE INDIVIDUAL SUBROUTINES
 C
 C -----
 C

ROUTINE NAME	PRIMARY ROLE
MAIN	MAIN ROUTINE, DOES SOME INITIAL CHECKING
IMIL	FILE HEADER READING, CHECK INSTRUCTIONS AND DATA
STRT	LINE ROUTINE THAT CONVEYS DATA ARRAY SPACE
GTDA	MANAGE DATA STORAGE AND ACCESS FROM INTERFACE FILES
GEOD	ACCESS DATA FROM GEOMETRY INTERFACE DATA FILE
PDRD	ACCESS POWER DENSITY, EXPOSURE DATA
PBST	SELECTS CALCULATION PATH, OVERRIDE DEFAULT DATA
GRAC	ESTIMATION OF THE THERMAL CONDUCTIVITY
TBAR	MANAGER ROUTINE TO CALCULATE PEBBLE TEMPERATURES
XOUT	WRITES THE TEMPERATURE INTERFACE DATA FILE
HERE BEGIN THE 2-D PEBBLE BED OPTION ROUTINES	
MPBL	DIRECTS THE TWO-DIMENSIONAL CALCULATION
BLOC	DATA PROCESSING, HEAT SOURCE, VOID FRACTIONS, ETC.
INIT	INITIALIZES THE THERMAL HYDRAULICS PROBLEM
TRAC	SPECIAL EDIT FOR CHECKING DETAILS
IDR	SOLUTION PROCEDURE BY ITERATION
MPLU	PRODUCES AUXILIARY INFORMATION DURING ITERATION
POUT	THERMAL HYDRAULICS PRINTOUT, TWO DIMENSIONS
CLTE	MANAGES THE PEBBLE TEMPERATURE CALCULATION

(CON'T)

Fig. 8. Information About the THR-TH Thermal Hydraulics Code.

```

C
C*  HERE BEGIN THE 3-D FIXED FUEL OPTION ROUTINES
C      TRIP      MANAGER FOR THE SOLID CORE, FIXED FUEL MODEL (3-D)
C      BLAA      SOLVES 1-D FLOW IN PARALLEL CHANNELS
C      CTPP      THERMAL CELL CALCULATION MANAGER
C      ZBAR      SOLVES 2-D THERMAL CELL PROBLEMS
C      ZBAX      INITIALIZES 2-D THERMAL CELL PROBLEMS
C      GRID      MULTIGRID RELAXATION SOLUTION MANAGER
C      MXIT      MULTIGRID COLLAPSE ROUTINE
C      FXIT      MULTIGRID SOLUTION ROUTINE
C*  THESE ARE THE 1-D PEBBLE BED OPTION ROUTINES
C      PBL1      FLUID FLOW FOR ONLY THE ONE-DIMENSIONAL MODEL
C      CALT      PEBBLE TEMPERATURE CALCULATION
C*  THESE ARE SYSTEM STANDARD UTILITY ROUTINES NOT SPECIAL HERE
C      SEEK      DATA FILE MANAGEMENT SERVICE ROUTINE
C      RITE      DATA TRANSFER SERVICE ROUTINE, QUALIFIED WRITE
C      REED      QUALIFIED DATA READ, ENTRY POINT IN "RITE" ROUTINE
C      TIMER     ACCESS CP COMPUTER TIME, ETC.
C      GETCOR    MEMORY SPACE ALLOCATION FOR DATA ARRAYS
C      FRECOR    MEMORY SPACE RELEASE
C
C
C      BLOCKING THE PROGRAM INTO OVERLAY LEVELS
C      -----
C
C      OVERLAY LEVEL      ROUTINES
C      -----
C
C          A              INIL
C          A              PBST
C          B              GTDA,GEOD,PDRD
C          B              MPBL,HPLU
C          C              BLOC,INIT,TRAC
C          C              PDEX,IDER
C          C              POUT,CLTE
C          B              TRIP
C          C              BLAA
C          C              CTPP,ZBAR
C          D              ZBAX
C          D              GRID,MXIT,FXIT
C          B              PBL1,CALT
C          (THE ALIAS IN THE SYSTEM IS CONFIDENTIAL)
C
C
C      MEMORY REQUIREMENT (SHORT WORDS)
C      -----
C
C      PROGRAM ..... 27,800 (57,300 WITHOUT OVERLAY)
C      SYSTEM ROUTINES ..... 8,200
C      MINIMUM DATA ARRAYS . 20,000 (164,000 EXAMPLE, VIRTUAL MEMORY)
C
C      TOTAL ..... 56,000 (200,000 NOT UNUSUAL)
C
C      CEOP

```

Fig. 8. (Continued)

8. GLOSSARY WITH THERMAL HYDRAULIC CODE IMPLICATIONS

The following definitions are presented to clarify usage. Specifically, much of the terminology may be said to have come from the reactor core physics analysis area, albeit provincial even there.

Acceleration. The iteration solution process is accelerated by multiplying the calculated change in the iterate value of a dependent variable by an acceleration coefficient β , typically $\beta = 1.40$ for the hydraulics problem and $\beta = 1.75$ for the thermal cell problems. If $\beta < 1$, the procedure is one of dampening possibly needed for stability.

Blunder. That which produced an error, more often having human source than machine (as developers always say, "check the input first!").

BOLD VENTURE. The name of the computation system, both production and working versions being available for application (development versions separate).

Condensed Edit. A summary of information about the modules used and key results appears in the condensed edit for a computer run. The key temperature data for each thermal hydraulics problem solved are in a one line edit. Note that the reference power level is included for checkings and a list of the interface data files that exist on termination is printed.

Convergence. The results of an iteration process are assumed to be acceptable when certain convergence criteria are satisfied. The maximum relative iterate change in a dependent variable (coolant temperature, pressure) over the mesh is arbitrarily tested against this criterion in this code. A relaxed criterion is also used for testing the core pressure drop changes.

Coolant Channel. An axial traverse up or down (or sideways) along the direction of coolant flow, used here in reference to average heat removal conditions in a discretized grid by gas coolant flow in a cylindrical hole.

DEBUG LEVEL EDIT. Generates considerable output of little interest except to the programmer. The negative option can be of interest to display only the iterative data for the thermal cell problem.

Discretization. The basic equations involve derivatives and/or integrals. For solution, values of the dependent variables are calculated at discrete locations and the applicable equations are solved in difference form, for example $d\phi/dx \approx (\phi_n - \phi_{n-1})/(X_n - X_{n-1})$, in the lowest order, linear approximation.

Dominant Error Vector Eigenvalue. The error content of a dependent vector, such as the coolant temperature values for a grid of meshpoints, is expected to take on a simple form asymptotically as the number of iterations increase (with a fixed procedure). When linearly independent, this dominant error vector is characterized by its eigenvalue λ , often estimated with a mathematical norm involving sums of iterate changes. For a convergent process, $\lambda < 1$, so that λ^n tends to zero, n being the iteration count.

DUTLIN. The name of the special user input data processes used to process formatted model control instructions.

EDIT LEVELS. Reference edits are usually adequate except when a solution is to be studied in detail. Specifying a higher edit level generates output of certain data supplied (power densities).

Energy. The basic units of energy in this application are power times time ($P = dE/dt$), watt-sec = joules = 4.186 Gm-cal = 10^7 ergs = 6.242×10^{18} eV. Roughly 3.1×10^{-11} watt-sec of energy is produced upon the fission of a heavy atom.

Entrance and Exit Losses. The coolant channel diameter is assumed to be very small relative to the plenum sizes, so entrance and exit flow losses are calculated with a simple model. Note that losses associated with the manifold and direction changes and entering and exiting the pressure vessel are not included.

Exit Pressure. The coolant is expected to enter the exit plenum at a common pressure. An acceptable solution to a problem would display equal mean and minimum coolant exit pressures.

Fluence. Product of flux and time ($\int \phi dt$), usually involving only the high energy flux and used to predict the consequences of atom lattice damage on heat transport properties.

Fuel Temperature Distributions. The cumulative volume fractions of all of the fuel having temperatures exceeding values of a reference grid are estimated and reported. These data are a simple approximation based on a linear interpolation using the calculated average and peak values for each fueled zone. Evidently the more meshpoints and the more zones used in a problem, the better is this approximation.

GOSIZE. Job control computer memory allocation for a job, approximately $4 \times \text{WORDS} + 300$, where WORDS is in k short words for data storage and 300 allows for the computation system modules, in bytes. Note that an allocation of WORDS for the system is increased by 20 for the thermal hydraulics code since it is a relatively small code in its load module form with program overlay.

Input Processor. The code module in this system that is used to generate interface data files one-to-one from free form format user input data.

Interface Data Files. Codes are controlled regarding task assignments and options with a record in the file CONTRL, record PBLINS for this code. Special data may be supplied in the file THERMA. Data are read from the latest (highest) version of the GEODST, EXPOHT, PWDINT, ZNPOWD files; temperature results may be written on the ZNTEMP file, and data may be saved on or recovered from the TDATAS file. Files are managed in this system so that logical unit numbers are assigned and determined with special programmed procedures.

Mass Coolant Flow Rates. Mass flow rate is reported on a basis of one cm^2 of core area normal to the direction of flow, kg/sec.

Memory. A certain amount of the computer memory is required to store the data for a problem (in addition to that for the code), typically increasing as the problem size is made larger (increase in meshpoints and zones). The thermal hydraulics problem is stored in the computer memory (no data moved in and out from disk during the solution process). For large problems (many meshpoints), the computer may have to operate in the virtual memory mode, whereby disk space is used and data transferred by the operating system as necessary. The thermal hydraulics code can not initially determine the memory requirement for a problem since inactive meshpoints must be deleted.

Multigrid. An acceleration process that involves solving coarser and coarser grids of meshpoints to a size that can be solved directly, then returning through the levels to construct a new distribution of the estimate of the original fine mesh problem solution.

Multiplication Factors. The value of k_{eff} for the reactor indicating the ratio of the neutron generation rate to the total loss rate; this value should be near unity in modeling the core of an operating reactor.

Orificing and Orifice Block. Several of the coolant channels may be assigned the same blocking number to indicate that the flow in them is under the influence of a single orifice. With the orificing option, the pressure drops across the orifices are adjusted to effect flow rates that result in a preferred condition, such as minimum peak coolant channel surface temperatures by block. Note that to be realistic, the coolant channels assigned to an orificing block would have to be neighbors, although such neighbors can wrap around boundaries when rotational or reflecting surface conditions model geometric repetition. Note also that radial power density flattening (enrichment variation), flux suppression in new fuel assemblies (burnable poison), and preferred control rod positioning can significantly reduce coolant block orificing requirements. The summed pressure drop along a coolant flow rate includes the associate orifice pressure drop.

POINTERS TO DATA LOCATIONS. This is information that is edited to support programmer effort in study of the capability or extending it, not of interest to the analyst.

Power Density. The local heat source rate having the neutron fission as the dominant contribution, typically an average for the local discretized region, usually expressed in thermal watts per second.

Power Weighted Fuel Temperature. Solution of the equation $\int PTdv / \int Pdv$, an effective temperature for auxiliary core analysis support calculations.

Print/Microfiche. Local capability exists for selective edit media.

Reversing the Coolant Flow. The ability to reverse the direction of coolant flow (from the reference direction) is offered as a user convenience but is of secondary importance since a core design and mode of operation are for a known flow direction. The geometric description for the neutronics calculations might be reversed, so exercising the option avoids revising the description. The effects of reversing the flow might be of interest, although likely a higher fuel loading toward the coolant inlet is used to hold down temperature peaking.

Reynolds Number. The ratio of inertia forces to viscous forces, GD/μ , where G is the mass flow rate, D the characteristic diameter of the channel and μ the fluid viscosity.

Subzone. A somewhat abstract accounting of nuclide densities seldom applicable to the prismatic fuel element core; a zone contains 0 or more subzones. Consider a point reactor model: if 1/4 of the core is refueled each time, the accounting of materials and exposure effects can be modeled by assigning 4 subzones, each contributing 0.25 fraction (or less) to the zone material and the contents of each representing a different exposure age. Thus such representation may be used in special cases but normally only when the representation is not explicit of all three dimensions. Subzones can be used to represent special materials. For example the zone content could be one fuel composition while the subzone could be another, representing differences within or between fuel channels. Thermal cell calculations are done at the subzone level.

Surface Temperature. Refers to the conditions at the surface of the coolant channel surface.

Temperatures for Coolant Flow. If the coolant inlet and outlet temperatures are specified, the coolant flow rate is set as necessary to remove the heat.

Thermal Cell. Reference to the representative geometry modeling the locality near the fuel channel and the coolant hole for calculation of the temperature distribution required for removal of the heat.

Time, Computer. The primary cost components of computer calculations are the capital investment, the software (development), and operation. Basic charges to users must be allocated, and the primary way to do this is to measure the central processor use time and charge proportionally to it. Often an effective processor use time is determined by adding in auxiliary cost component equivalents, locally the disk-core data transfer assessment being significant. Reported herein is just the measured central processor time used in a task. (Note that such summed over time falls short of total elapsed time.) Of some interest is clock time for a job because the facilities are tied up this long, but shared multi-tasking confuses the issue, as well as impacts the fact that clock time depends on the current job stream and is sensitive to the computer operating details and the time of day and week.

Two-Dimensional to Three-Dimensional. A procedure is implemented to use the power density data from a two-dimensional neutronics problem with extension in a third dimension in the direction of coolant flow. Special user data are supplied for such a calculation. Note that the heat source from the neutronics code is for a plane normal to the direction of coolant flow, so supplemental information is needed to define the axial coolant traverse and to detail the axial power distribution.

Uncertainty Information. The thermal cell problems are solved with the thermal conductivity values multiplied by 0.9 to display the effect on calculated temperatures as a measure of reliability.

VENTURE. The neutronics code used in this system to produce the neutron flux distribution in space and energy and to generate the power density data at the meshpoint level for use by the thermal hydraulics code as the heat source.

Void Fraction. Refers to the volume fraction associated with the coolant channels.

Zone. A region typically three-dimensional in a problem within which the nuclear properties are assumed to be constant and the nuclide concentrations uniform (homogeneous), excepting where subzone nuclide concentrations are involved. Often the data have been somewhat weighted to account for fine-scale heterogeneities such as fuel pins and coordinate direction dependent neutron transport properties. Macroscopic nuclear data are calculated for zones with contributions from subzone contents included when applicable. For exposure calculations in this computation system, the energy-dependent zone-averaged flux values are used, and at any point in time there is one set of nuclide concentrations for each zone (and one for each subzone when subzones are used). Typically the zone volume fraction (of material in) is subtracted from unity to give the local void fraction of the coolant. Thermal cell calculations are done for mean and extreme conditions in each heated zone and subzone.

Zone Temperatures. Since thermal cell calculations are done on a zone basis, zone values of coolant (fluid), surface, peak surface, shell, fuel (west), peak fuel (center) temperatures are edited.

9. REFERENCES

1. D. R. Vondy, "PEBBLE: A Two-Dimensional Steady-State Pebble Bed Reactor Thermal Hydraulic Code," USDOE Report ORNL-5698 (Sept. 1981).
2. D. R. Vondy, T. B. Fowler, G. W. Cunningham, "The BOLD VENTURE Computation System for Nuclear Reactor Core Analysis, Version III," USDOE Report ORNL-5711 (June 1981).
3. W. Pfeiffer, G. Malek and K. Lund, "POKE, A Gas-Cooled Reactor Flow and Thermal Analysis Code," Gulf General Atomic GA-10226 (July 1970).
4. H. Fenech, editor, *Heat Transfer and Fluid Flow in Nuclear Systems*, Pergamon, N.Y. (1981).
5. A. Banerjee, et al., "Thermodynamische Stoffwerte von HELIUM in Bereich von 20 bis 1500°C und 1 bis 100 bar," Auslegung der Reaktorkerne von gasgekühlten, Berichte Nr.1562, Kernforschungsanlage, Jülich GmbH, Bundesrepublik Deutschland (Dec. 1978).
6. A. Brandt, "Multi-Level Adaptive Solutions to Boundary-Value Problems," *Math. Comp.* 31 No. 138, p. 333 (April 1977).

ORNL-5951

Distribution Category UC-77

INTERNAL DISTRIBUTION

1. L. S. Abbott	26. A. Zucker
2. D. E. Bartine	27. P. W. Dickson, Jr. (Consultant)
3. T. J. Burns	28. G. H. Golub (Consultant)
4. J. C. Cleveland	29. H. J. C. Kouts (Consultant)
5. F. J. Homan	30. D. Steiner (Consultant)
6-15. P. R. Kasten	31-32. Central Research Library
16. F. C. Maienschein	33. Y-12 Technical Library
17. D. L. Moses	Document Reference Section
18. A. R. Oisen	34-35. Laboratory Records Department
19. C. O. Slater	36. Laboratory Records ORNL, RC
20-24. D. R. Vondy	37. ORNL Patent Office
25. B. A. Worley	38. EPIC
	39. EPMD Reports Office

EXTERNAL DISTRIBUTION

- 40-41. G. A. Newby, Director, Division of HTR Development, DOE, NE-15, Washington, D.C. 20545
42. Office of Assistant Manager for Energy Research and Development, DOE-ORO, P.O. Box E, Oak Ridge, TN 37830
Attention: S. W. Ahrends
43. Director, Office of Converter Reactor Deployment, DOE, NE-10, Washington, D.C. 20545
44. Manager, SAN-SAN Diego, DOE, 110 West A Street, Suite 460, San Diego, CA 92101
45. Director, Office of Nuclear Power Systems, DOE, Washington, D.C. 20545
- 46-47. Director, High Temperature Reactor Programs, Office of Nuclear Power Systems, DOE, Washington, D.C. 20545
48. Office of Assistant Manager for Energy Research and Development, Oak Ridge Operations Office, DOE, Oak Ridge, TN 37830
Attention: F. E. Dearing
General Atomic Company, P.O. Box 81608, San Diego, CA 92138
- 49-50. E. O. Winkler
51. A. Baxter
52. W. Davidson
General Electric Company
53. C. Cowan, Box 508, Sunnyvale, CA 94086
54. G. R. Flasterer, Box 508, Sunnyvale, CA 94086
55. C. Robertson, FBRD, Cincinnati, OH 45289
56. D. T. Bradshaw, TVA, Chattanooga, TN 37401
- 57-188. For distribution as shown in TID-4500, Distribution Category UC-77 — Gas Cooled Reactor Technology