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GEOM - A THERMAL-HYDRAULIC
STRESS CODE

AEC Research and Development Report

Atoms International Division
Rockwell International

P.O. Box 309
Canoga Park, California 91304

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E. MOODY

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Atomics International Division
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CONTENTS

	Page
Abstract	7
I. Introduction	9
II. Program Development History	11
III. Calculational Methods	15
A. Hydraulics	15
B. Core Heat Transfer	19
C. Element Geometry	24
D. Mixing	26
E. Core Periphery Heat Transfer	28
F. Cladding Temperature Variation	28
G. Force Balance	32
H. Calculational Interfacing	36
IV. Programming Techniques	41
A. 30-Degree Sector Symmetry	41
B. Built-In Data	41
C. Area and Gap Multipliers	41
D. Iterative Techniques	42
E. Table Look Up	43
F. Simultaneous Equation Solution	44
G. Program Structure	44
V. Program Use	47
A. Input Data Requirements	47
B. Program Options	54
C. Job Submittal	57
VI. Sample Problem	61
VII. References	88

TABLES

	Page
1. Nomenclature	89
2. List of Subroutines	38
3. /DATIN/ Labeled Common Description	48
4. /DATOUT/ Labeled Common Description	52
5. /FRCBAL/ Labeled Common Description	53
6. /SHRT/ Labeled Common Description	53
7. Typical Input Data Sheet	64
8. Typical Comments Sheet	65
9. Typical Random Vector Sheet	66
10. Typical Random Clad Sheet	67
11. Typical Random Asymmetry Sheet	68
12. Typical Bow Summary Sheet	69
13. Typical Core Average Sheet	70
14. Typical Coolant Temperature Sheet	71
15. Typical Channel Area Sheet	72
16. Typical Coolant Flow Sheet	73
17. Typical Mixing Factor Sheet	74
18. Typical Film Coefficient Sheet	75
19. Typical Element Temperature Sheet	76
20. Typical Temperature Summary Sheet	77
21. Typical Edge Heat Loss Sheet	78
22. Typical Internal Reflector Core Side Sheet	79
23. Typical Internal Reflector Shell Side Sheet	80
24. Typical Pressure Vessel Sheet	81
25. Typical Area Summary Sheet	82
26. Typical 6θ Ripple Sheet	83
27. Typical Equivalent ΔT Sheet	84
28. Typical Force Balance Sheet	85
29. Typical Stress Detail Sheet	86
30. Typical Interference Check Sheet	87

FIGURES

	Page
1. GEOM2 30-Degree Model.	10
2. GEOM3 60-Degree Model.	12
3. GEOM85 360-Degree Model	14
4. Friction Factor Test Data Correlation.	17
5. y Factor Approximation	18
6. Fuel Element Thermal Model.	20
7. Nusselt Number vs P/d	23
8. Fuel Element Dimensional Model	25
9. Mixing Model.	27
10. Core Edge Model	29
11. Typical Clad Temperature Profile.	31
12. Cladding Deflections	33
13. Element Force and Deflection Model	35
14. Program Flow Diagram.	37
15. 30-Degree Repeating Sector	40
16. Cluster and Asymmetry Models	42
17. Program Overlay Structure	45
18. Basic Deck Setup	58

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ABSTRACT

This report documents the GEOM computer code (IBM/360) as it existed at the SNAP program close out. The code performs thermal, hydraulic and stress analysis on a liquid metal ZrH reactor core. The theory and empirical data used are described in detail. Instructions for using the code are given with a sample problem for illustration.

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I. INTRODUCTION

It is necessary to know the thermal environment in which a fuel element operates in order to determine fuel swelling, hydrogen leakage, and cladding stresses. The thermal environment is controlled by element deflections (which govern flow channel area), power distribution through the core, and the position of the fuel rod in the cladding (fuel asymmetry).

A three-dimensional model of a reactor core has been developed to compute the thermal and hydraulic analyses required. A force balance subroutine system has been developed to permit calculation of element bow shape (as well as element loads) thereby determining channel area variation to enable calculation of the flow distribution.

This document describes the theory and empirical data used in the code. The programming techniques are delineated and instructions are given for program use. A sample problem is included for illustrative purposes.

Figure 1. GEOM2 30-Degree Model

II. PROGRAM DEVELOPMENT HISTORY

The initial purpose of developing the GEOM code was to account for the fact that the triangular array fuel element arrangement results in unique thermal-hydraulic characteristics for each element in the core. Prior to the advent of the first GEOM code, analysis had been conducted for an average element in each ring. This necessitated that the element be completely symmetric and straight.

The first version of GEOM considered a 30-degree sector of the core (Figure 1). The total core then consisted of 12 of these segments arranged as if the segment were rotated around one side 12 times to make a full circle. This code (GEOM2) was documented in March 1970.⁽¹⁾ It was capable of handling any size core to a maximum of 511 elements. Over a 1-year period, GEOM2 was continually revised to increase the program capability in a series of 11 bulletins. Major improvements included the capability of considering bowed clad and asymmetric fuel, improved heat transfer and fluid mixing calculations, and output suitable for input to stress analysis codes.

It became apparent that the boundary limits imposed by the 30-degree segment resulted in severely limiting the ability to properly analyze the effects of design improvements being developed during that period, primarily the right-left-neutral (RLN) fin arrangement to promote cross flow. Therefore, in April 1971, the program was revised to consider a 60-degree core segment (Figure 2) and renamed GEOM3.⁽²⁾ This revision reduced the number of elements which could be handled to 331 to keep the program within reasonable core storage requirements. This version of the code was also revised periodically to stay abreast of current design developments and test data, primarily in the area of hydraulics.

GEOM2 and GEOM3 were also affected by the then-current core designs. GEOM2 was in the era of the 295-element, 600-kwt core and GEOM3 was during the 199-element, 300-kwt phase. When the reactor design shifted to 85 elements at 100 kwt, it became apparent that a full 360-degree model of this core could be handled within computer limitations. Further, stress analysis efforts had

Figure 2. GEOM3 60-Degree Model

progressed to the code development stage so that it appeared feasible to incorporate a force balance and stress routines to permit a complete rod bundle analysis in a single step.

This effort (GEOM85) was initiated in early 1972 using an 85-element model (Figure 3), also capable of analyzing 55-, 37-, 19-, and 7-element configurations. The initial documentation was released in April 1972⁽³⁾ and the force balance became operable in July 1972. Efforts were made during the GEOM85 development to upgrade GEOM3 accordingly for use in parametric studies because it was recognized that GEOM85 would be more costly to run. The attempt was only partially successful, however, and GEOM3 is no longer used.

GEOM85 incorporates all the features developed in GEOM2 and GEOM3 except the CRT output built in to GEOM2 as this option was rarely used. The documentation contained in this report refers in all cases to GEOM85.

Figure 3. GEOM85 360-Degree Model

III. CALCULATIONAL METHODS

To obtain the required three-dimensional model, the program has been set up to handle a nodal network, both axially and radially. Because the heat transfer element deflections and hydraulics are interdependent, the program uses iterative techniques for solution of the various equation sets treated. There are six major areas of computation in the code. This section describes the equations and methods used for this solution and the methods used to obtain the total solution. Table 1 gives nomenclature used.*

A. HYDRAULICS

Flow through a close-packed rod bundle is highly dependent on the geometry. The principal factors are the element-to-element spacing and the geometry of fins if used. The code considers the right-left-neutral (RLN) fin configuration adopted by Atomics International (AI) as a SNAP reactor standard feature, since test results have shown this configuration to give maximum cross-channel coolant flow. A test series run at $Re \approx 100,000$ ⁽⁴⁾ developed an expression which modified the standard Blasius smooth-tube friction factor:

$$f_f = \frac{0.316}{Re^{0.25}} yz \quad \dots (1)$$

$$z = \frac{4.76}{(L_f/d)^{0.47}} \quad \dots (2)$$

(z = 1 for smooth tubes)

The spacing parameter y was a compendium of tests run by experimenters in Russia, Germany and the U.S. The fin parameter z considered a single wire wrap. This averages out to 1/2 fin in the channel. In addition, the wire wrap was tight against the adjacent rod or vessel wall, whereas tolerances on actual core bundles can cause gaps. Therefore, z was modified to:

$$z = \frac{4.76}{\left(\frac{L_f}{d} \frac{N}{0.5} \frac{S}{h_f} \right)^{0.5}} \quad \dots (3)$$

*For reader convenience, this table is placed at the end of the report as a foldout page.

Early mixing tests run at AI covered the range of $8000 \leq Re \leq 20,000$ and Equation 1 was found satisfactory using the modified z . These tests were run using plastic fins glued to smooth tubes. Later tests were run with hobbled fins and lower Reynolds numbers. Figure 4 shows the results of the two test series. It is apparent that a straight line does not fit the data over the full range of Re . Therefore, the equation was modified to approximate the curvature. The 4.76 constant in z was combined with the smooth-tube constant:

$$f_f = 237 \ y/z (\ln Re)^{-3.72} \quad \dots (4)$$

$$z = \left(\frac{L_f}{d} \frac{N}{0.5} \frac{S}{h_f} \right) \quad \dots (5)$$

($z = 4.76$ for smooth tubes).

The test data was taken over a 19-element bundle and as a result considers an average channel. Channels at the core edge, however, have peculiar geometries and would therefore not be expected to exhibit flow characteristics identical to those of a full tri-cusp channel. The closest data available for similar geometries was that for eccentric annuli,⁽⁵⁾ which indicated a strong friction factor dependency on the diameter ratio of the annulus. Using a fictitious pitch/diameter ratio (P/d) developed from the equation relating tri-cusp area to P/d , it was possible to calculate an equivalent annular diameter ratio. Using the data of Reference 4 for the y factor, modified for edge channels by the data of Reference 5, the y factor approximation shown in Figure 5 was developed. A test series was planned to confirm or modify this approximation at the time of the SNAP program cancellation, thus the data is questionable but currently the best approximation available.

The program assumes no radial pressure gradients in the core, thus equal pressure drop for all channels over a given axial distance:

$$\Delta P = f_f \frac{V^2}{288g} \frac{L}{d_H} \rho = \text{constant} \quad \dots (6)$$

Figure 4. Friction Factor Test Data Correlation

6531-1117

Figure 5. y Factor Approximation

$$\therefore \frac{f_f V^2}{d_H} = \text{constant} \quad \dots (7)$$

Using the relationships:

$$\dot{w} = \frac{V}{25 \rho A} \quad \dots (8)$$

$$d_H = \frac{4A}{P_w} \quad \dots (9)$$

$$R_e = \frac{300 V d_H \rho}{\mu} \quad \dots (10)$$

Equation 7 may be restated as:

$$\dot{w}_1 f_{f1} P_{w1} A_1 = \dot{w}_2 f_{f2} P_{w2} A_2 \quad \dots (11)$$

Solution for the flow may be obtained by an iterative procedure, since conditions in an average channel are simply determined by geometry and total flow rate. The transition from turbulent to laminar flow is considered to follow the intersection of the curves of Figure 4.

B. CORE HEAT TRANSFER

The ZrH fuel rod must provide clearance for swelling which occurs as a result of uranium burnup and hydrogen loss. As a result, there is a gas gap between the fuel rod and cladding. A ceramic barrier is placed on the inside cladding wall to minimize hydrogen loss. Figure 6 shows the thermal model of the fuel element used in the program. Note that this drawing is only one small portion of the total nodal network interconnecting the entire core.

The heat transfer by conduction is calculated by:

$$q = \frac{\Delta T}{R} \quad \dots (12)$$

THERMAL RESISTANCES

R_F = FUEL
 R_G = GAS GAP
 R_B = BARRIER
 R_{cl} = CLAD
 R_{co} = COOLANT
 R_{CH} = CHANNEL

6531-1118

Figure 6. Fuel Element Thermal Model

where:

$$R_{co} = \frac{36}{\pi h_{co} r_{co}} \quad \dots(13)$$

$$R_{cl} = \frac{3 t_{cl}}{\pi k_{cl} r_{cl}} \quad \dots(14)$$

$$R_B = \frac{3 t_B}{\pi k_B r_B} \quad \dots(15)$$

$$R_G = \frac{3 t_c}{\pi k_G r_G} \quad \dots(16)$$

$$R_F = \frac{6}{4\pi k_F} \quad \dots(17)$$

The fuel rod heat flux to each channel (n) is:

$$Q_n = k_n (3412.874 \bar{P} \phi_A \phi_R) \quad \dots(18)$$

where k_n is a factor controlled by coolant channel temperature and fuel asymmetry. The coolant temperature is then computed by:

$$T_{co_{i+1}} = T_{co_i} + \frac{\sum_{n=1}^3 q_i + \sum_{n=1}^3 q_i + 1}{(\dot{w}_i + \dot{w}_{i+1}) c_p} \quad \dots(19)$$

The nodal network is solved iteratively by initially assuming $k_n = 1/6$ and solving for 6 values of fuel temperature to obtain an average value of:

$$\bar{T}_F = \frac{\sum_{n=1}^3 T_F}{6} \quad \dots(20)$$

If the 6 values are not within a tolerance limit:

$$k_n = \frac{\bar{T}_F - T_{con}}{\sum R(3412.874 P \phi_A \phi_R)} \quad \dots (21)$$

and the network is resolved to convergence.

The channel-to-channel heat flow path was added to approximate low-flow, low-power conditions such as a startup transient. Normally, heat transfer is not considered important along this path since mixing results in a mass transfer and the circumferential coolant temperature variation (6θ ripple) around the element precludes conduction. However, when used, the area is the minimum distance between elements times the length of axial segment considered and the thickness is an arbitrary selection by the program user.

While liquid metal does not act like most heat transfer media (such as water) because of its high conductivity, a fictitious film coefficient has been developed and confirmed by test.⁽⁶⁾ This coefficient is dependent on P/d, clad thickness and mixing. The basic film coefficient considers a 10-mil clad thickness. Figure 7 shows the curve of Nu vs P/d. The value of h thus determined is then modified⁽⁷⁾ by the following equations:

$$h_t = h \left[1 + \left(\frac{0.02229}{P/d - 1} \right)^{0.8} \left(0.4394 + \frac{0.004423}{t_{cl}} \right) \right] \quad \dots (22)$$

(clad thickness)

$$h_m = h_t 0.9935 + 0.02875 k_m - 0.2393 (P/d - 1) \quad \dots (23)$$

(mixing rate)

The effect of mixing has not been completely verified by test; primarily because of the questionable accuracy of the thermocouples when after two test series (touching elements and ring spaced) fins were brazed to the test elements and a third test series was run. However, the prime question unresolved was the 6θ ripple effect rather than the film coefficient (Section III.F), and Equation 23 is deemed valid.

6531-1119

Figure 7. Nusselt Number vs P/d

The gas gap contains hydrogen released from the ZrH fuel matrix to attain equilibrium pressure. At low operating power and temperature and during startup, this pressure is very low resulting in free molecular rather than continuum conduction. To decrease this thermal resistance, helium is loaded into the element during manufacture. As a result, the conductivity is that of a mixed gas including the effects of fuel and barrier surface accommodation. Reference 8 gives the method derived for computing gas conductivity based on extensive experimental work conducted at Purdue University. In addition, the heat transfer by radiation from the fuel to the barrier is also considered. The process is necessarily iterative in that the average gap temperature must be solved as it is dependent on the conductivity (which in turn is temperature dependent) as well as the heat flux.

The program considers the average gap width in each of the six segments of the model and also considers the relative thermal expansion of both cladding and fuel.

C. ELEMENT GEOMETRY

To attain the three-dimensional model, the core is divided into 11 planes. Two-dimensional calculations are then conducted at each plane, knowing the inlet temperature and successively working from the cold end of the core to the hot end. The location of these planes is at the discretion of the user other than those at the inlet and outlet. Figure 8 shows the element model. Note that the axial nodes are set over the active fuel length for thermal calculations with two more added at the grid plates for hydraulic and stress calculations.

The program will consider segmented fuel in one to five slugs oriented as desired. The fin height may be varied axially. This has been considered in order to control the location of the contact plane, thereby avoiding secondary element contacts. The allowable element tolerance envelope, Total Indicator Runout (TIR) is used to set location and magnitude for manufacturing bows in the stress calculations.

It should be noted that the axial nodes are used for all calculations, thus careful selection is necessary. In the example shown, the ends of the fuel slugs

Figure 8. Fuel Element Dimensional Model

governed the selection. In the case of a tapered window-type sliding reflector it would be desirable to analyze the effect of the abrupt reflector discontinuities. If variable fin heights are used, the nodes should cover abrupt variations, etc .

D. MIXING

Initially, spacers were considered for positive separation of elements to maintain a relatively constant flow area, thus limiting cross-element temperature gradients. As an extra feature, spiral-type spacers provided cross-channel flow. By using an RLN fin system, a maximum mass transfer is obtained, further reducing cross-element ΔT , thus minimizing element deflections and stresses.

Figure 9 shows the analytical model and equations used to calculate the effects of mixing. Each full channel has one inlet and two outlet or one outlet and two inlet streams as shown. Edge channel flows depend on the type of element involved. Neutral, unfinned elements, do not contribute to the cross flow.

The mixing tests run in a 19-element bundle resulted in the development of the following equation:

$$k_M = \frac{236P_e h_f}{P_f \left(0.433P_e^2 - 0.3927d_e^2 - w_f h_f \right) \left(1 + 0.91e^{-45.2xh_f} \right)} \quad \dots (24)$$

As theoretically expected, mixing is independent of flow but does require a finite axial length to become fully developed. Equations 25 through 28 of Figure 9 are combined to form a total mixing Equation 29. Equations are developed for each core channel and solved simultaneously.

Since flow areas, and therefore flow, may vary axially, the axial flow used for computing cross flow is taken as the average flow around each finned element. While the validity of this assumption has not been proven in the tests performed, there does not appear to be a more logical method of calculation. Since mixing is so effective in reducing cross-element ΔT , it is felt that this method is adequate for the accuracy which is known for flow distribution per se.

NOTE: ONE FIN SHOWN FOR CLARITY, NORMALLY THREE USED

CHANNEL SEGMENT

MASS BALANCE

$$\dot{w}_{A_I} + \dot{w}_{CF_I} + \dot{w}_{A_O} + \dot{w}_{CF_O} \quad \dots(25)$$

ENERGY BALANCE

$$Q_{A_I} + Q_{RODS} + Q_{CF_I} + Q_{A_O} + Q_{CF_O} \quad \dots(26)$$

CROSS FLOW

$$\dot{w}_{CF} = k_M L (\dot{w}_{A_I} + \dot{w}_{A_O})/2 \quad \dots(27)$$

ENERGY LEVEL ($T_O = 0$)

$$Q = \dot{w}_{c_p} T \quad \dots(28)$$

TOTAL MIXING EQUATION

$$T_O = \frac{\dot{w}_{A_I} T_I + Q_{RODS}/c_p + \dot{w}_{CF_I} \bar{T}_{CF_I} - \dot{w}_{CF_O} T_I/2}{\dot{w}_{A_O} + \dot{w}_{CF_O}/2} \quad \dots(29)$$

6531-1121

Figure 9. Mixing Model

E. CORE PERIPHERY HEAT TRANSFER

SNAP-type reactors use a cylindrical pressure vessel to contain the coolant. Use of a triangular fuel element array results in areas at the core edge too small to contain an element and too large to serve as a flow channel. To control flow, these areas are filled with reflective materials to reduce the thickness of the external control reflector. Dependent on the ambient environmental conditions, heat transfer is possible in either direction across the internal reflector and pressure vessel.

Figure 10 shows the physical model and nodal network for solution of this heat transfer. A bypass flow is considered since assembly clearances are necessary, making flow between the internal reflectors and pressure vessel possible. Heat transfer from the pressure vessel to ambient may be conductive or radiative depending on whether the external reflectors are attached firmly to the vessel or there is a clearance. The latter is the normal condition.

Using Equation 20 and

$$q = \dot{w}c_p \Delta T, \quad \dots (30)$$

an energy balance equation may be written at each node resulting in a set of simultaneous linear equations which may be solved for the nodal temperatures and heat flows. In the case of radiative heat transfer from the vessel, an iterative procedure is necessary since:

$$R_{VW} = \frac{(T_1 - T_2)}{q} \sigma F_e F_A A (T_1^4 - T_2^4) \quad \dots (31)$$

and q and T_2 are unknowns.

F. CLADDING TEMPERATURE VARIATION

In a close-packed rod bundle, the heat transfer coefficient varies circumferentially, being a maximum at the point of furthest distance to neighboring elements and a minimum at the closest approach. This effect is known as a 6θ ripple in a triangular array and is caused primarily by velocity profiles

NOTE: NUMBERING KEYED TO FIGURE 3

PARTIAL NODAL NETWORK
(FULL NETWORK COVERS 360°)

6531-1122

Figure 10. Core Edge Model

in the tri-cusp channel. Much theoretical and experimental work has been done in the U.S. and other countries on this phenomenon. Reference 6 shows the results obtained from heat transfer tests at AI. For smooth tubes, theory and experimental data show extremely good correlation. As previously indicated, the thermocouple data on the finned test is somewhat questionable. Thus, dependent on the method used to analyze the data, the ripple can be considered to exist or to be completely eradicated. Reference 9 shows that the theoretical effect of mixing is to reduce the magnitude of the ripple and also to move the high and low points approximately 10 degrees in the direction of cross flow. Reference 10 shows good agreement with theory and test data analysis which considers a 120-degree segment of a fuel element rather than a 30-degree segment. The test data analysis also showed an offset of the ripple on the order of 15 degrees.

The thermal model of Figure 6 develops average clad and coolant temperatures at six points around the element. The variation is considered to be a sine wave with the following equations developing the high and low points:

$$T_{cl_MIN} = \bar{T}_{co} + (31.25t_{cl})^{-0.4} (-3.764 + 5.125 \times 10^{-4} h_{co}) PD \quad \dots (31)$$

(note that h_{co} includes mixing effect at this point)

$$T_{cl_MAX} = 2\bar{T}_{cl} - T_{cl_MIN} \quad \dots (32)$$

Since there cannot be thermal discontinuities in the clad, the maximum temperature is taken as the average between those computed for adjacent segments as shown in Figure 11. The data shown is typical for an asymmetric fuel rod where the power density, thus 6θ ripple magnitude, varies circumferentially.

Since the only purpose of computing the temperature distribution is to obtain stress data, a cosine fit is made to the 6θ ripple curve to attain a thermal value which causes bending. Locally, the clad is in compression if the 6θ ripple is above the bending temperature and in tension below. The cosine fit also determines the angle at which the element will bow. Provision is in the code to offset the 6θ ripple (including proper direction governed by fin pitch) if desired.

6531-1123

Figure 11. Typical Clad Temperature Profile

G. FORCE BALANCE

To calculate the core thermal environment it is necessary to know the individual element configurations since this governs channel geometry and finally flow distribution. Conversely, element geometry cannot be calculated without knowledge of the thermal environment which determines element deflections. As a result, an iterative procedure is used wherein a thermal environment is calculated based on straight cladding, deflections are calculated to suit this environment, a new thermal environment is calculated for the deflected cladding, and the process is repeated to convergence.

Three deflections occur which govern the steady-state fuel element shape: thermal, as manufactured, and contact load. Figure 12 illustrates these deflections and Equations 33 through 42 used for calculation. While a manufacturing bow can have any conceivable shape, the assumption is made that the bow occurs in a single plane and follows a sine wave curvature. Locations of peaks are governed by the TIR shown in Figure 8. The thermal bow is not restricted to a single plane and is calculated by a numerical integration procedure as shown in Figure 12. Basically, this is the solution of:

$$T = \int_0^L \frac{M_{t_i} m_i dl}{EI} \quad \dots (43)$$

where

$$M_{t_i} = \frac{\pi}{2} E \alpha T_{tr}^2 \quad \dots (44)$$

and

$$m_i = \frac{x_i}{L} (L - x_i) \quad \dots (45)$$

with a correction added to account for the fact that the incremental length is large since only 13 points are calculated along the element. Reference 11 details the correction method used. Because this analysis is only valid for bending in a single plane, the x-y components of temperature effects are calculated and the resultant of the two is the total thermal deflection.

THERMAL BOW

$$M_{x_i} = \frac{\Delta T_i a}{2r} \sin \phi_i \quad \dots(33)$$

$$M_{y_i} = \frac{\Delta T_i a}{2r} \cos \phi_i \quad \dots(34)$$

$$TD_{i+1} = \frac{(M_i + M_{i+1})}{(TD_1 = 0)} \left(\frac{x_{i+1} - x_i}{2} \right) \quad \dots(35)$$

$$TTD_{i+1} = TDi + TD_{i+1} \quad (TTD_1 = 0) \quad \dots(36)$$

$$TDI_{i+1} = (TTD_i + TTD_{i+1}) \left(\frac{x_{i+1} - x_i}{2} \right) \dots(37)$$

$$\delta_i = -TDI_i + TDI_{i+1} \frac{x_i}{L_E} \quad \dots(38)$$

NOTE: δ_T IS THE RESULTANT VECTOR OF δ_{x_i} AND δ_{y_i}

MANUFACTURING BOW

$$\delta_M = \delta'_M \sin \left(\frac{\pi}{2} \left[\frac{L_E - x}{L_E - L_M} \right] \right) \dots(39)$$

$$\delta_M = \delta'_M \sin \left(\frac{\pi}{2} \frac{x}{L_M} \right) \dots(40)$$

LOAD BOW

$$\delta_P = \left\{ P_R L_P (L_E - x) [2L_E (L_E - L_P) - (L_E - L_P)^2 - (L_E - x)^2] \right\} / 6\pi E_r^3 t L_E + \delta_H x / L_E \quad \dots(41)$$

$$\delta_P = \left\{ P_R x (L_E - L_P) [2L_E (L_E - L_P) - (L_E - L_P)^2 - (L_E - x)^2] \right\} / 6\pi E_r^3 t L_E + \delta_H x / L_E \quad \dots(42)$$

NOTE: DEFLECTIONS GREATLY EXAGGERATED FOR CLARITY

Figure 12. Cladding Deflections

Deflection resulting from load is calculated as a simple beam. The program assumes that contact is limited to a single plane at elevation L_p . Generally speaking, with a three-fin configuration and assuming undercut fins, except in the contact area, contact could occur at either of two planes. However, for the relatively small fin pitch (~ 5 in.) used for SNAP reactors, the deviation from a point halfway between is ± 0.5 in. The effect on deflection and bending stress in an element 15 to 20 in. long is negligible.

Note that the element is pinned at the cold end but can be free to translate within limits at the hot end. This feature was incorporated in the design to minimize loading. As a result, the calculational procedure is complicated by the fact that "load" deflections are possible without loads.

Figure 13 shows the force and combined deflection model used by the code. All calculations are made at the contact plane. The resultant of the thermal and manufacturing bows is calculated for each element. From this, the sector components of the bow are calculated. Because the maximum possible movement of an element is extremely small compared to the element diameter, calculations are based on the assumption that all contact is made on the common centerline of the two elements in contact. The element spring constant is calculated by:

$$k_s = \frac{3 E I L}{L_p^2 (L - L_p)^2} \quad \dots (46)$$

Knowing the clearance between fin and element, S_f :

$$P_i = (\delta_n - \delta_i - S_f) \frac{k_{s_i} k_{s_n}}{k_{s_i} + k_{s_n}} \quad \dots (47)$$

If the force is negative it is set equal to 0. The positive forces are incrementally reduced and summed to attain convergence of the iteration. The resultant of the six summed forces is calculated permitting calculation of the mechanical deflection by Equations 41 or 42. The resultant of free and mechanical bow is then computed to permit the next load calculation. The iteration is continued until the incremental force is negligible (less than 1%).

LEGEND

- INITIAL ELEMENT POSITION
- ... UNRESTRAINED BOW POSITION
- EQUILIBRIUM FORCE POSITION

NOTE: EXAMPLE ASSUMES ADJACENT ELEMENTS IMMOBILE,
DEFLECTIONS EXAGGERATED FOR CLARITY

6531-1125

Figure 13. Element Force and Deflection Model

When the force balance convergence is complete, element stresses are computed at each contact point n as follows:

Bending:

$$\sigma_{B_n} = \frac{P_R L_P (L - L_P) \cos (60n - \varphi_P)}{\pi L r_t^2}$$

6θ :

$$\sigma_{6\theta_n} = -E\alpha(T_{cl_n} - \bar{T}_{cl} - T_B)$$

Total:

$$\sigma_{tot} = \sigma_{B_n} + \sigma_{6\theta_n}$$

Hoop:

$$\sigma_H = Pk_H$$

Axial:

$$\sigma_A = Pk_A$$

Equivalent:

$$\sigma_{EQ_n} = \text{MAX} \left\{ [\sigma_H - \mu(\sigma_A + \sigma_{tot})], (\sigma_{tot} + \sigma_A - \mu\sigma_H) \right\}$$

$$MS = \frac{\sigma_{EQ}}{\sigma_{ALL}} - 1$$

Normally, the allowable stress is governed by the barrier and is the stress at which the onset of gross hydrogen leakage occurs.

H. CALCULATIONAL INTERFACING

Figure 14 is a simplified flow diagram of the GEOM code. Basically there are three nested loops as shown. Each inner loop must converge before the outer loop is entered. Thus the radial loop must converge 11 times for each axial and mechanical loop convergence. The major subroutines used in the

Figure 14. Program Flow Diagram

program are noted by (DRWR). If no notation is given, the calculation is performed by the main program. Table 2 lists the subroutines used by the program by name and function. Details of special routines are given in the next section.

TABLE 2
LIST OF SUBROUTINES

Name	Function
AGMLT	Computes gap and channel area multipliers
ASYMLT	Computes a random array of asymmetry multipliers
BLOCK	Zeroes out and builds data into labeled common
BOWPRT	Prints magnitude and direction of bow and its components
CHNLOC	Computes identification of elements and channels for an input channel number
CORLAY	Computes core dimensions and average hydraulic data
DEFLM	Computes manufacturing bow at nodal points
DEFLT	Computes thermal bow at nodal points
DRVECT	Computes random fuel element dimensional variables
DRWR	Data input read and write
FORCE	Computes core force balance
GAPCND	Computes mixed gas thermal conductivity
GAUSYD	Solves simultaneous linear equations
HEADB	Prints core thermal and hydraulic data
HEADD	Computes and prints equivalent cross element ΔT 's
HEADE	Prints details of core edge heat transfer
HFILM	Computes coolant film coefficient
HYPT	Computes maximum value of an input tabular curve
NLERR	Dumps labeled common on program error

TABLE 2 (Continued)
LIST OF SUBROUTINES

Name	Function
NLEST	Performs method of chords iteration calculations
NLTRP	Tabular data interpolation
PAR	Solves a second-degree polynomial for a three-point input
PINLOC	Computes identification of elements and channels for a given element
POD	Computes an equivalent P/D ratio for edge channels
POLY4	Four-point curve fit (used by NLTRP)
RESULT	Calculates magnitude and direction of resultant of two vectors
REYN	Calculates Reynolds number for laminar/turbulent interface
RIPL6, RIPLR	Computes and prints 6θ ripple data
SHTEDG	Computes core edge geometry
SHORT	Computes core edge heat transfer
SPCHK	Computes element-element clearance at each node
STRSPT	Prints force and stress data for core
THRMBW	Computes element deflection and stresses
TMIX	Computes cross flow and resultant coolant temperatures
XMF	Computes mixing rate
XSET	Sets arrays equal to input single value
YFF	Computes Y factor for hydraulic calculations

6531-1127

Figure 15. 30-Degree Repeating Sector

IV. PROGRAMMING TECHNIQUES

Because of the scope of the program, the amount of data handled is massive. To minimize the effort necessary to run the program, specialized techniques have been used and are described in this section. Internal programming techniques are also described.

A. 30-DEGREE SECTOR SYMMETRY

Many variables are symmetric and as a result are repeated 12 times in the cross-sectional model. Therefore a repeating 30-degree sector (shown in Figure 15) is used in these instances. Data input is then permissible for this sector only when symmetric or for the full 360-degree sector if asymmetric. This technique is also used internally to reduce required data storage by using the 30-degree sector for bookkeeping purposes.

B. BUILT-IN DATA

Many of the input variables used are really quasi-constants in that data changes only as a result of new experimental results, material changes, etc. Therefore, as much data as possible is built into the program to minimize required input and to reduce the possibility of error. In most cases, this built-in data may be overridden simply by entering the desired value in the input string.

C. AREA AND GAP MULTIPLIERS

Channel area and gas gap multipliers are applied to nominal symmetric values to attain the geometric effect of bowed clad and offset fuel. This data may either be input or calculated internally. Figure 16 shows the models used for calculation. In the case of the channel, the area changes resulting from each of the three elements surrounding the channel are summed to determine the total change. The gap multipliers are determined by comparing the area in each sector to that of an equivalent $1/6$ annulus to determine the average gap width for the sector. When using the force balance, area multiplier calculation is automatic. Gap multiplier calculation is always optional.

6531-1128

Figure 16. Cluster and Asymmetry Models

D. ITERATIVE TECHNIQUES

Four major iterative techniques are used:

- 1) Simple substitution of computed value for assumed value (or average of computed and assumed)
- 2) Newton-Rapheson
- 3) Method of chords
- 4) Incremental change of variable.

Method (1) is self-explanatory and method (4) was described for the force balance. Method (2) requires a single equation in terms of x so that the solution is $f(x) = 0$. Assuming a value of x_0 then:

$$F = f(x_0)$$

$$D = f'(x_0)$$

$$x_n = x_0 - F/D$$

If $\left| x_0/x_n - 1 \right| \leq \text{tolerance}$, convergence has been met, otherwise $x_0 = x_n$ and the procedure is repeated.

Method (3) can be used to solve a large set of equations with a common variable x which can result in two solutions y and z . Two initial assumptions are made for x yielding two points $x_1, y_1 - z_1$ and $x_2, y_2 - z_2$, resulting in a straight line equation. x_3 is then calculated as the intersection of this line and $y - z = 0$. A third point is then calculated $x_3, y_3 - z_3$ and the procedure is repeated using the current point $x_i, y_i - z_i$ and the last calculated point $x_{i-1}, y_{i-1} - z_{i-1}$ to obtain the chord. Iteration is continued until $\left| y_i/z_i - 1 \right| \leq \text{tolerance}$.

E. TABLE LOOK UP

The method used for tabular data is based on a routine which fits three mutually tangent polynomials to four points — a second degree between points 1 and 2, a third degree between points 2 and 3, and a second degree between points 3 and 4. The use of this four-point approach rather than the usual three-point parabolic fit permits greater accuracy for skewed curves and also reduces

the number of points required for highly fluctuating curves. The tabular array is searched to locate two points on either side of the input value for solution. Extrapolation is conducted if the point input is at either end of the tabular array. Three-point input curves are treated as parabolas and two-point input as a straight line.

F. SIMULTANEOUS EQUATION SOLUTION

Solution of mixing and edge heat transfer involves a large set of simultaneous equations. If a square matrix were used wherein all values were zero except a few along the diagonal, the cost in required core storage would be prohibitive. Therefore, an iterative Gauss-Seidel method of solution has been used. This is accomplished by setting up a control array of index values to insure proper use of the results. The method is described in Reference 12.

G. PROGRAM STRUCTURE

The code is written in Fortran H for IBM System 360.

To minimize core storage requirements it was necessary to set the program up in an overlay structure as shown in Figure 17. Both decimal and hexadecimal levels of segment origin and end are given. The main program and labeled common, which must reside in the root segment, require $342K_{10}$ storage bytes. The segment lengths are very close to being equal, thus any further reduction could only be accomplished by using more segments and/or relocating routines now in the root segment. However, since computer time is expended in shifting segments for overlay it is desirable to minimize these shifts, thus a balance is necessary to have the lowest total operational cost. The structure used is based on these criteria.

Figure 17. Program Overlay Structure

6531-1129

BLANK

V. PROGRAM USE

While every effort has been made to simplify input to the GEOM code, it is recommended that only personnel very knowledgeable in the workings of a liquid metal ZrH core set up run conditions and analyze the results. While the actual mechanics of using the code are fairly simple, runs are costly because of the extreme complexity of the code.

Tables 3 through 6 describe the four major labeled common blocks used in the program. /DATIN/ is the primary input block, however, certain arrays in /DATOUT/ may be either input or computed. The following sections describe the use of these common blocks.

A. INPUT DATA REQUIREMENTS

The majority of the data in Table 3 is self-explanatory. Those items marked (FLAG) are explained in Section B — Program Options. Those that might not be fully understood are described as follows by location and symbol:

(14) SLOP — This value is a design item wherein elements are allowed some freedom for thermal bow which decreases contact force.

(83-86) EDGM — The edge areas (sans fins) are computed from drawings and ratioed to a full tri-cusp to get these values. The area multipliers are in the order of:

- 1) Two finned elements (16)
- 2) One finned, one neutral element (15, 17)
- 3) One finned element (19)
- 4) One neutral element (18, 20) (See Figure 15)

(111-176) PWIR

(12407-12472) FFP — These data refer to a ring concept for the internal reflector wherein stagnant NaK was contained in a set of steel rings. Some flow was possible, therefore the wetted perimeter was necessary to calculate flow distribution.

TABLE 3
/DATIN/ LABELED COMMON DESCRIPTION
(12,500)
(Sheet 1 of 4)

Symbol	Data	Dimension	Location
PCOR	Core Power, kw		1
TIN	Coolant Inlet Temperature, °F		2
WDOT	Coolant Flow Rate, lb/hr		3
CP*	Coolant Specific Heat, Btu/lb (0.21)		4
XMU*	Coolant Viscosity, lb/ft-hr (0.39)		5
RHO	Coolant Density, lb/ft ³ (45)		6
XKO*	Coolant Thermal Conductivity, Btu/hr-ft-°F (14.9)		7
DPEXP*	Friction Factor Re Exponent (-3.273)		8
XKFF	Friction Factor Constant (238)		9
ENFP*	Number of Fins/Element (3)		10
ENP*	Number of Active Elements (85)		11
AGRD1	Inlet Grid Plate Area, in. ²		12
AGRD2	Outlet Grid Plate Area, in. ²		13
SLOP	Allowable Spacing Decrease, in.		14
DPIN	Nominal Cladding Outside Diameter, in.		15
TRPTCH	Triangular Pitch, in.		16
FNWD	Fin Width, in.		17
FNHT	Fin Height, in.		18
XL	Active Fuel Length, ft		19
XLCC	Channel Length, in.		20
TCL	Cladding Thickness, in. (nominal)		21
TGL	Barrier Thickness, in.		22
DFUEL	Fuel Diameter, in. (constant for all elements)		23
XMIX	FLAG - Invokes Mixing Calculations > 0		24
SHTFLG	FLAG - Invokes Short Calculations ≠ 0		25
XKCL*	Cladding Thermal Conductivity, Btu/hr-ft-°F (12.5)		26
XKGL*	Barrier Thermal Conductivity, Btu/hr-ft-°F (1)		27
XKF*	Fuel Thermal Conductivity, Btu/hr-ft-°F (11.5)		28
FLAG	FLAG - Bypasses Spacing Calculation > 0		29
XBP	Bypass Flow Fraction		30
TPV	Pressure Vessel Thickness, in.		31
TBP	Bypass Thickness, in.		32
TLIN	Liner Thickness, in.		33
RLIN*	Liner/Reflector Resistance, Btu/hr-ft ² -°F (1000)		34
HNAKI*	Bypass/Liner Resistance, Btu/hr-ft ² -°F (1000)		35
HNAKO*	Bypass/Vessel Resistance, Btu/hr-ft ² -°F (1000)		36
PTCHAX	Axial Fin Pitch, in.		37
ACTIDL*	Ratio of Actual/Computed Mixing (not used)		38
PWFLG	FLAG - Bypasses Laminar Bypass Calculation > 0		39
AF* }	Fuel Expansion $\alpha_F = a + b\overline{T}_F$ (7.232 x 10 ⁻⁶) (-0.34 x 10 ⁻⁹)		40
BF* }			41
AC* }	Cladding Expansion $\alpha_C = a + b\overline{T}_C$ (7.3525 x 10 ⁻⁶) (1.0375 x 10 ⁻⁹)		42
BC* }			43

TABLE 3
/DATIN/ LABELED COMMON DESCRIPTION
(Sheet 2 of 4)

Symbol	Data	Dimension	Location
SPCFLG	FLAG - Calculates Spacing Only > 0		44
DEBUG	FLAG - Prints Intermediate Calculations > 0		45
ZOLFLG*	FLAG - Uses Input Z/L > 0 (1)		46
DATFLG	FLAG - Reads Comment Cards > 0		47
RIPL*	FLAG - Controls 6θ Ripple Output > 0 (1)		48
PWRFLG*	FLAG - Sets Number of Power Iterations > 0 (3)		49
XMLTFL	FLAG - Sets AM & TGM = 1 > 0		50
CMPMLT	FLAG - Computes AM & TGM > 0		51
BZSET	FLAG - Sets BOWZOL = 1st value > 0		52
ASSET	FLAG - Sets ASYZOL = 1st value > 0		53
DRREST	FLAG - Resets ASYDIR & BOWDIR = 0		54
XKV*	Pressure Vessel Thermal Conductivity, Btu/hr-ft-°F (12.9)		55
XKB*	Bypass Thermal Conductivity, Btu/hr-ft-°F (14.9)		56
XKL*	Liner Thermal Conductivity, Btu/hr-ft-°F (12.9)		57
EPSF*	Equivalent Fuel/Glass Emissivity, $\epsilon = 1/(1/\epsilon_G + 1/\epsilon_F - 1)$ (0.474)		58
PHE*	Helium Loading Pressure, psia (3)		59
XLCND	Conductive Channel-Channel Path Length, in.		60
XWCND	Conductive Channel-Channel Path Width, in.		61
ECLD	Cladding Elastic Modulus, psi (FLAG)		62
ALFCLD	Cladding Instantaneous Expansion, in./in.-°F		63
ACD*	$\eta/m = a(CD) + b$ (not used)		64
BCD*			65
AX*	$h_x = h_{10} \left[1 + \left(\frac{a}{P/D - 1} \right)^b \left(C + \frac{d}{tc} \right) \right] \quad (\text{Eq. 22})$		66
BX*			67
CX			68
DX*			69
ACF	$h_m = h_x \left[a + bx_m + cx_m (P/D - 1) \right] \quad (\text{Eq. 23})$		70
BCF*			71
CCF			72
AR*	$\Delta t_{6\theta} = \left(\frac{tc}{0.032} \right)^a (b + ch)P \quad (\text{Eq. 31})$		73
BR*			74
CR*			75
BOWM			76
ENVI*	Maximum Manufacturing Bow, in.		77
ENVR*	Inlet Grid Velocity Head Coefficient (1)		78
ELI	Outlet Grid Velocity Head Coefficient (0.5)		79
AFC*	Inlet Grid - Fuel Length, in.		80
AGC*	Fuel Accommodation Coefficient (0.9)		81
RMIN	Barrier Accommodation Coefficient (0.3)		82
EDGM (1)*	Liner Inside Radius, in. (output)		83
EDGM (2)*		(0.715)	84
EDGM (3)*	Edge Channel Area Multipliers (Nominal) (0.65)		85
EDGM (4)*		(0.425)	86
		(0.235)	

TABLE 3
/DATIN/ LABELED COMMON DESCRIPTION
(Sheet 3 of 4)

Symbol	Data	Dimension	Location
AFCBR	Average Channel Area, in. ²		87
PWCBR	Average Channel Wetted Perimeter, in.		88
DH	Core Hydraulic, Diameter (in.)		89
VCO2	Average Core Velocity, fps (output)		90
REN	Average Core Reynolds Number		91
YBAR	Average Core Y Factor		92
ZZ	Average Core Z Factor		93
FF	Average Core Friction Factor		94
BWLMT*	Bow Iteration Limit (FLAG) (3)		95
HEL	Radial Hot End Looseness, in.		96
			97
			98
			99
			100
VEC	FLAG - Controls Random Multiplier Calculations		101
CTACT	Distance Cold End to Contact Plane, in.		102
DTOUT	FLAG - Reads In/DATOUT/Data > 0		103
BWOPT	FLAG - Manufacturing Bow Option		104
ELTIR1	Distance Cold End to Lower Manufacturing Bow Limit, in.		105
ELTIR2	Distance Lower End to Upper Manufacturing Bow Limit, in.		106
BWMIN	Minimum Manufacturing Bow Multiplier		107
RIPANG	6 θ Ripple Distortion, deg		108
SPRFLG	FLAG - Prints Stress Details for all Elements > 0		109
ALLOW*	Allowable Cladding Stress, psi (34000)		110
PWIR	Rigid Ring Channel Perimeter, in.	66	111/176
PWIR30	PWIR for 30° Sector	6	177/182
XKRR30*	XKRR for 30° Sector (23)	6	
XKRC30*	XKRC for 30° Sector (23)	6	189/194
FFP30*	FFP for 30° Sector (1)	6	195/200
TPV30*	TPVO for 30° Sector (750)	10,6	201/260
PHI30	PHI for 30° Sector	11,11	261/381
POR	Gap Pressure (H_2) vs r/R_{ψ} , psia	15	382/396
AM*	Area Multipliers (input or computed) (1)	11,204	597/2640
TGM*	Gap Thickness Multipliers (input or computed) (1)	11,85,6	2641/8250
ZOL*	Z/L Ratio (input or computed) (by 1/10)	11	8251/8261
HFINM*	Fin Height Multipliers (vs Z/L) (1)	11	8262/8272
EFFMX*	Mixing Rate Multipliers (vs Z/L) (1)	11	8273/8283
HFTBL*	Nusselt Number vs P/D (See Figure 7)	35	8384/8318
RØDBØW	Maximum Element Bow, in. (input or computed)	85	8319/8403
ASYMRD*	Maximum Fuel Asymmetry, Fraction of Gap (input or computed) (0.9)	85	8404/8488

TABLE 3
/DATIN/ LABELED COMMON DESCRIPTION
(Sheet 4 of 4)

Symbol	Data	Dimension	Location
BØWDIR	Bow Direction Angle, deg (input or computed)	85	8489/8573
ASYDIR	Asymmetry Direction Angle, deg (input or computed)	85	8574/8658
ASYZØL	ASYMRØD Axial Multipliers (for Angle and/or Gap)	11,85	8659/9593
BØWZØL	RØDBØW Axial Multipliers (input or computed)	11,85	9594/10528
TPVØ	Core Ambient Temperatures, °F	10,66	10529/11188
EPS	Effective Pressure Vessel/Ambient Emissivity (0.176)	66	11189/11254
HELMLT	Hot End Looseness Multipliers	85	11255/11339
PHI	Power Factor ($\phi_A \phi_R$) vs Z/L and Element	11,85	11340/12274
XKRR	Internal Reflector Conductivity (Radial), Btu/hr-ft-°F	66	12275/12340
XKRC	Internal Reflector Conductivity (Circumferential) Btu/hr-ft-°F	66	12341/12406
FFP	Internal Reflector Steel Fraction	66	12407/12472
AA	$K_a = a t_{c1} d_{c1} + b$ (Bijlaard Axial Multiplier) (0.38911)		12473
BA	(+0.1576)		12474
PØIR	Poisson's Ratio (Cladding) (0.3)		12475
SPIR	Internal Reflector Spring Constant, lb/in. (10^6)		12476
SCKFLG	FLAG - Suppresses Spacing Check > 0		12477
SEED	Multiplier to Force New Seed for IRNDM		13478
AH	$k_h = a t_{c1} d_{c1} + b$ (Bijlaard Hoop Multiplier) (-114286)		12479
BH*	(4259)		12480
TLID*	Cladding ID Tolerance, in. (0.001)		12481
TLTH	Cladding Thickness Tolerance, in. (Finned Elements) (0.0015)		12482
TLFH	Fin Height Tolerance, in. (0.001)		12483
TLTN	Cladding Thickness Tolerance (Neutral Elements) (0.001)		12484
RNASY	FLAG - > 0 Computes Random ASYZØL		12485
XMASY	FLAG - 1 = ASYZØL on Angle, 2 = on gap, 3 = on both (1)		12486
ENSLG	Number of Fuel Slugs in Element (5 maximum) (5)		12487
ABCDE	FLAG - Each Digit is Number of Z/L Points on Slug (22322)		12488
FNLR	FLAG - Calls NLERR at End of Run		12489
RVRSE	FLAG - Reverses BOWDIR and ASYDIR if > 0		12490
PRTLAM	FLAG - > 0 Prints Laminar/Turbulent Flow Vectors		12491
TØLWAY	FLAG - Controls ± Values of Cladding Tolerance		12492
	Not Used	12493/12500	12493/12500

*Denotes Data Built-In () or see text.

FLAG - Denotes option control, see text, Sec. V. B.

TABLE 4
/DATOUT/ LABELED COMMON DESCRIPTION
(42,500)

Symbol	Data	Dimension	Location
NCHAN*	Array Locating Channel to 30° Sector (Sec.IV.A)	204	1/204
NRØD*	Array Locating Element to 30° Sector (Sec.IV.A)	85	205/289
NP	Element Control Array 0 = in, 1 = out	85	290/374
T	Channel Coolant Temperature, °F	11,204	375/2618
A	Channel Area, in. ²	11,204	2619/4862
W	Channel Flow Rate, lb/hr	11,204	4863/7106
TFC	Fuel Centerline Temperature, °F	11,85	7107/8041
TFS	Fuel Surface Temperature, °F	11,85,6	8042/13651
TGI	Barrier Surface Temperature, °F	11,85,6	13652/19261
TCI	Cladding/Barrier Interface Temperature, °F		19862/24871
TCØ	Coolant/Cladding Interface Temperature, °F	11,85,6	24872/30481
PSEG	Segment Power, kwt/ft	11,85,6	30482/36091
BØWMFG	Manufacturing Bow Direction Angle, deg (input or computed)	85	36092/36176
ELBØWM	Length Cold End to Maximum Manufacturing Bow, in. (input or computed)	85	36177/36261
BWMFML*	Manufacturing Bow Multipliers (input or computed) (1)	85	36262/36346
SPRING	Element Spring Constant, lb/in.	121	36347/36467
ØDCLD	Cladding OD with Tolerance Effects, in.	85	36468/36552
TCLD	Cladding Thickness with Tolerance Effects, in.	85	36553/36637
RFIN	Fin Radius at Contact Point, in.	85	36638/36722
FMIX	Channel Mixing Rate, %/in.	10,204	36772/38811
FILM	Channel Film Coefficient, Btu/hr-ft ² -°F	11,204	38812/41055
ANGP*	30° Sector Element Angle, deg	10	41056/41065
RADP	30° Sector Element Radius, in.	10	41066/41075
ANGC*	30° Sector Channel Angle, deg	20	41075/41095
RADC	30° Sector Channel Radius, in.	20	41096/41115
ARC	30° Sector Channel Area, in. ²	20	41116/41135
ARF	30° Sector Fin Area, in. ²	20	41136/41155
PWC	30° Sector Channel Perimeter, in.	20	41156/41175
PLØAD	Element Contact Force, lb	85	41176/41260
SMARG	Minimum Element Margin of Safety	85	41261/41345
SEQUIV	Element Equivalent Stress, psi	85	41346/41430
SLØAD	Saved Loads for Convergence Check, lb	85	41431/41515
DEFL4	Free Deflection at Contact Plane, in.	85	41516/41600
PHI4	Free Deflection Angle at Contact Plane, deg	85	41601/41685
PHIM	Mechanical Deflection Angle, deg	85	41686/41770
	Not Used	70	41771/41840

*Denotes Data Built-In () or see text

TABLE 5
/FRCBAL/ LABELED COMMON DESCRIPTION
(8330)

Symbol	Data	Dimension	Location
X	Axial Station, in.	13	1-13
BWMF	Manufacturing Bow, in.	13,85	14-1118
DFT	Thermal Bow, in.	13,85	1119/2223
PFT	Mechanical Bow, in.	13,85	2224/3328
SIXS	Six θ Stress, psi	6,85	3329/3838
BEND	Bending Stress, psi	6,85	3839/4348
TOTSTR	Total Stress, psi	6,85	4349/4858
BWDFCN	Contact Plane Manufacturing Bow, in.	85	4859/4943
THDFCN	Contact Plane Thermal Bow, in.	85	4944/5028
THANCN	Contact Plane Thermal Bow Angle, deg	85	5029/5113
PHIR	Contact Plane Resultant Bow, Angle, deg	85	5114/5198
DEFR	Contact Plane Resultant Bow, in.	85	5198/5283
HOOP	Hoop Stress, psi	6,85	5284/5793
AXIAL	Axial Stress, psi	6,85	5794/6303
EQSTR	Equivalent Stress, psi	6,85	6304/6813
P	Contact Load, lb	85,6	6814/7323
PHIBOW	Bow Angle vs Z/L, deg	11,85	7324/8258
PE	Internal Reflector Load, lb	36	8258/8294
PHIE	Internal Reflector Bow Angle, deg	36	8295/8330

TABLE 6
/SHRT/ LABELED COMMON DESCRIPTION
(3433)

Symbol	Data	Dimension	Location
QNØD	Heat Flux Through Pressure Vessel (Btu/hr)	10,66	1/660
TPVAV	Average Pressure Vessel Temperature, °F	10,66	661/1320
TIRI	Core Side Inner Reflector Temperature, °F	10,66	1321/1980
TIRØ	Shell Side Inner Reflector Temperature, °F	10,66	1981/2640
TBP	Bypass Coolant Temperature, °F	11,66	2641/3366
WDB	Bypass Flow, lb/hr	66	3367/3432
N	Number of Segments in Inner Reflector	1	3433

(382-396) POR — This data is needed for gap conductivity computation.

Normally it is obtained from a TEMPRO run.⁽¹³⁾ However, a simple symmetric GEOM run can be made to determine temperatures, using a high He loading and back calculating this table from a ZrH phase diagram. The number of x-y pairs is placed in the first table location, the next two are blank then $x_1 - y_1$, $x_2 - y_2$, etc.

(12478) SEED — The random number generator seed value is set = $WDOT * TIN * PNOM * SEED$. If the first three variables were the same in different runs, the quasi-random numbers would not change, thus this value is needed for control.

B. PROGRAM OPTIONS

The scope of core thermal analysis must encompass many design features and must be capable of a wide variety of parameter manipulation to provide a powerful tool. This section describes the options built into GEOM by number and symbol:

(26) XMIX — If > 0 , cross flow (mixing) is considered

(27) SHRT — Controls method of core edge heat transfer:

0 = none

1 = Pressure vessel temperature fixed

2 = Bypass flow, pressure vessel is adiabatic wall

3 = Radiation to surroundings

(A negative value causes data to be required in /DATOUT/, i.e., EM)

(29) FLAG — This flag skips spacing calculations for consecutive runs where geometry does not vary.

(39) PWFLG — This flag invokes calculation of bypass flow in the core edge if input > 0 . This is used in conjunction with the ring-type reflector described above. Bypass is apportioned strictly by flow area if $PWFLG \leq 0$.

(44) SPCFLG — If greater than 0, the code simply calculates the data of Table 13 (see Section VI for Tables 7 through 30).

- (45) DEBUG — If > 0 , interim calculations are printed to assist the program user in finding errors in either the code or the data.
- (46) ZOLFLG — If > 0 , Z/L is input, otherwise, 11 equal increments are assumed.
- (47) DATFLG — The program reads as many comment cards as the value input (see Table 8) to identify the particular run.
- (48) RIPL — Prior to inclusion of the force balance, GEOM provided punched data cards to an external stress code. This option is still available but no longer used. See Reference 3 for use.
- (49) PWRFLG — Normally, the radial heat transfer loop (Figure 14) converges within three iterations. For difficult cases this can be varied by simple input of the iteration limit.
- (50) XMLTFL — This flag is used to reset TGM and AM at the end of a run to ensure no carryover to the next run.
- (51) CMPMLT — This flag invokes computation of AM and TGM. The use of the force balance automatically sets it for AM.
NOTE: 1 = AM 2 = TGM 3 = AM & TGM for (5) and (51).
- (52) BZSET } — These flags set BØWZØL and ASYZØL(K, N), K = 2, 11)
- (53) ASSET } — to X(1, N) (if input) for ease in input of like values.
- (54) DRREST — This flag resets BØWDIR and ASYDIR to 0 after multiplier calculation to avoid carryover to next run. Value is same as noted for (50) and (51).
- (62) ECLD — Input of this value invokes the force balance. Must be 0 if mechanical loop is excluded.
- (95) BWLMT — Same restraint on mechanical loop as PWRFLG is to radial heat transfer loop.
- (101) VEC — This flag is a five-digit number to control random vector calculations as follows:

A value of 1 causes calculation, 0 bypasses.

(102) DTOUT — This flag permits reading data into /DATOUT/, primarily BØWMFG, ELBØWM and BWMFML.

(103) BWØPT — This flag permits manipulation of the manufacturing bow angle as follows:

- 1 = Bow angle remains as input or computed.
- 2 = Bow angle always coincident with thermal bow.
- 3 = Bow angle always opposing load bow (if load is 0 for a given element, option reverts to 2).
- 4 = Bow angle set at thermal bow angle computed for straight elements.

NOTE: Angles referred to are those at contact plane.

(109) SPRFLG — Stress details are always printed for critical element. This flag permits output for all elements.

(12477) SCKFLG — Fin interference check control.

(12485) RNASY } Fuel slug asymmetry control. Described by
 (12486) XMASY } sample problem, Section VI.

(12488) ABCDE — Value corresponding to Figure 8 would be 22232. Use only as many digits as there are fuel slugs. Not required for a one-piece fuel rod.

(12489) FNLR — Similar to (45) for aid in program debugging. NLERR prints data in all four labeled common blocks.

(12490) RVRSE — This flag is used to gauge the relative effects of manufacturing bow and asymmetry on a particular core when applied at the same angle.

(12491) PRTLAM — GEOM has been used to approximate transient conditions. This flag prints 1 for turbulent and 2 for laminar flow for each of the 204 channels. Output occurs at the bottom of Table 13.

(12492) TOLWAY — This flag controls method of applying tolerances to clad. It is a three-digit number IJK where:

I = thickness

J = inside diameter

K = fin height

The value controls calculation as follows:

0 = random $\pm$

1 = plus only

2 = minus only

These options give the program extreme flexibility and their use singly or in combination make GEOM an extremely powerful analysis tool.

C. JOB SUBMITTAL

At the time of preparing this document, the code resided on a disc pack at the Rockwell International Computing Center. The deck setup was as shown in Figure 18. Should the binary decks be used, the two // control cards shown would need to be replaced with JCL as required by the system used.

The data format is:

I12, 5F12.8, 2A4

A minus sign in Column 2 denotes the end of the data block input. Note that if no data is read into /DATOUT/ the end of data read should be omitted. The title card is always required and reads in an 18A4 format. The title should be centered in the 72-character space for neat printout (see Section VI — Sample Problem). Comment cards also use an 18A4 format and are required as

/DATIN/

IBM 4-500

controlled by DATFLG. Subsequent cases may be run in a single job step by entering only that data which changes. All previous input data remains the same unless changed by the program run calculations.

The program requires 444K bytes of storage. A single run, excluding the mechanical loop, requires approximately 2.5 min of time on the OS 360/85 computer. A three-iteration limit mechanical loop requires approximately 9 min. If the program is loaded from cards, add approximately 1 min for the link edit step.

BLANK

VI. SAMPLE PROBLEM

Tables 7 through 30 show typical output for a typical run. The total output is 210 pages plus the number of pages required to record the input data. For obvious reasons only typical sheets are presented.

This particular run randomized all element variables except that the manufacturing bow was always held to the 6-mil maximum. Mixing was included and the core radiated heat to the external reflector. Each element contained five fuel slugs and their orientation was random but always deflected to 90% of the nominal gap. The TIR was between 7 and 13 in. from the cold end.

Table 7 shows the typical input data printout — five pieces of data and the first data location per line. Note that the data from 11340 on is the (11, 85) PHI array. These cards were punched to the proper format by an external nuclear calculation program, indicating another method of minimizing input effort.

Table 8 shows typical comments for a given run. This sheet is important in completely identifying the variables considered in the run. The numbers in parentheses indicate the number of sheets output for the category shown by the table.

Tables 9 and 10 show the random parameters calculated by DRVECT. Table 11 shows the asymmetry multiplier array. In this particular run, these multipliers are only applied to the angle. For angular multiplication a factor of 10 is applied. Thus, for element one having a base angle of 213 degrees, the five slugs would be oriented at 46, 310, 249, 35, and 322 degrees, respectively, from the cold end. Had these multipliers been used on gap as well, for a maximum allowable asymmetry of 6 mils, the slug values would have been 5.2, 0.9, 0.7, 2.1, and 2.9 mils, respectively.

Table 12 shows the element bow deflection data. These data are shown at stations, given in inches from the cold end, which correspond to the fuel rod nodes. The two bows which form the total free deflection are given, as is the resultant bow and its corresponding angle. Note the angle reversal in elements 3, 4, and 7 showing the effect of hot-end looseness. The angle of manufacturing bow was shown in Table 9 and that for thermal bow is shown in Table 27. Loads and their angles are shown in Table 28.

Table 13 shows core average and nominal channel hydraulics and geometry and develops ring average data for a life history type program called TEMPRO.⁽¹³⁾

Tables 14 through 18 show the channel temperatures, areas, flows, mixing rates and film coefficients respectively. The channel areas reflect the tolerance effect on clad diameter as well as the element deflections. These effects also cause mixing rates to fluctuate. Note the buildup of mixing rate axially modeling the actual swirl development in an actual core. The film coefficient reflects the mixing rate variation. At the first node there is no mixing because the fins have not started at this point. The fins are ended prior to the last node, however, the program considers them still there since the momentum of the swirl has not yet dissipated.

Table 19 shows the individual element thermal details. Temperatures read inward from the coolant channel with PSEG denoting the segment power output in kwt/ft. Note the asymmetry effects on PSEG corresponding to the angles given above from Table 11. The peak fuel temperature is also shown as TFC. Table 20 shows the summary thermal printout of peak fuel and channel outlet temperatures.

Tables 21 through 24 show the core edge heat transfer. The second sheet, corresponding to Table 21, summarizes the losses. Typically, radiating to the reflector, these losses are 1 to 2% of core power for a low power density core. As core power density increases, the percentage usually decreases. As this run precluded a bypass flow, no data printed out. If a bypass is included, the data is output.

Table 25 presents a core bundle cross-sectional area breakdown for rough estimates of weight, volume, etc. Table 26 presents the clad temperature variation discussed in Section III.F. The data starts at $\theta = 0$.

Table 27 shows the equivalent cross-element ΔT which provides the basis for calculating thermal bow. While this data is a rough indicator of forces, larger deflections can occur for elements with lower peak ΔT 's than for higher peak ΔT 's since the total deflection is calculated by integrating the ΔT .

Table 28 shows the results of the force balance and stress details for the element exhibiting the lowest margin of safety. Note that elements 16 and 31

are opposing thus exhibit the same force. However, the differences in 6θ temperatures and clad dimensions affecting stresses result in a slightly lower equivalent stress for 31. Table 29 shows the optional stress printout for each element. Table 30 shows the interference check output. This check is made primarily to determine the need for undercutting the fins to avoid secondary contact.

TABLE 7
TYPICAL INPUT DATA SHEET
(VAR)

CARD ORIGIN	LINE 2	LINE 3	LINE 4	LINE 5	LINE 6	CARD ID
1	111.7	1100.	17877.			01000001
12	10.8	10.8	.01	1.005	1.025	01000012
17	.125	.02	1.33333	17.25	.025	01000017
22	.0025	.938	1.	3.		01000022
31	.05	.01	.015			01000031
37	5.		1.			01000037
47	5.				2.	01000047
62	22.3 E+06	9.4 E-06				01000062
76	.006			1.		01000076
86	.2908					01000086
96	.01					01000096
101	11111.	10.583	1.	1.	7.	01000101
106	6.	1.		1.		01000106
382	6.			0.	1.59	01000382
387	.195	1.53	.355	1.42	.525	01000387
392	1.24	.706	1.04	.87	.8	01000392
8252	.1875	.2125	.3875	.4125	.5	01008252
8257	.5875	.6250	.7875	.8125	1.	01008257
8262	1.51	1.51	1.51	1.51	1.51	01008262
8267	1.51	1.51	1.51	1.51	1.51	01008267
8272	1.51					01008272
11340	0.3916E+00	0.1380E+01	0.1462E+01	0.1307E+01	0.1823E+01	00011340
11345	0.1823E+01	0.1739E+01	0.1679E+01	0.1252E+01	0.1164E+01	00011345
11350	0.2462E+00	0.3805E+00	0.1341E+01	0.1421E+01	0.1758E+01	00011350
11355	0.1774E+01	0.1774E+01	0.1691E+01	0.1632E+01	0.1217E+01	00011355
11360	0.1131E+01	0.2386E+00	0.3805E+00	0.1341E+01	0.1421E+01	00011360
11365	0.1758E+01	0.1774E+01	0.1774E+01	0.1691E+01	0.1632E+01	00011365
11370	0.1217E+01	0.1131E+01	0.2386E+00	0.3257E+00	0.1253E+01	00011370
11375	0.1337E+01	0.1719E+01	0.1742E+01	0.1761E+01	0.1684E+01	00011375
11380	0.1622E+01	0.1188E+01	0.1101E+01	0.2296E+00	0.3805E+00	00011380
11385	0.1341E+01	0.1421E+01	0.1758E+01	0.1774E+01	0.1774E+01	00011385
11390	0.1691E+01	0.1632E+01	0.1217E+01	0.1131E+01	0.2386E+00	00011390
11395	0.3805E+00	0.1341E+01	0.1421E+01	0.1758E+01	0.1774E+01	00011395
11400	0.1774E+01	0.1691E+01	0.1632E+01	0.1217E+01	0.1131E+01	00011400
11405	0.2386E+00	0.3257E+00	0.1253E+01	0.1337E+01	0.1719E+01	00011405
11410	0.1742E+01	0.1761E+01	0.1684E+01	0.1622E+01	0.1188E+01	00011410
11415	0.1101E+01	0.2296E+00	0.3603E+00	0.1252E+01	0.1326E+01	00011415
11420	0.1631E+01	0.1644E+01	0.1636E+01	0.1558E+01	0.1504E+01	00011420
11425	0.1125E+01	0.1046E+01	0.2184E+00	0.3707E+00	0.1287E+01	00011425
11430	0.1363E+01	0.1674E+01	0.1688E+01	0.1681E+01	0.1601E+01	00011430

TABLE 8
TYPICAL COMMENTS SHEET
(1)

*** THE CONDITIONS LISTED BELOW APPLY TO THE CASE WHICH FOLLOWS ***

5 KWE RANDOM CORE RUN 1A, 12/1/72

- (1) DESIGN TO POWER & FLOW, BOL POWER DISTRIBUTION
- (2) ALL TOLERANCES RANDOM , 5 FUEL SLUGS
- (3) MANUFACTURING BOW FULL 6 MILS
- (4) ASYMMETRY DIRECTION RANDOM, MAGNITUDE MAXIMUM
- (5) GEOM MODEL CURRENT WITH BULLETIN NUMBER 8

TABLE 9
TYPICAL RANDOM VECTOR SHEET
(1)

5 KWE RANDOM CORE RUN 1A, 12/1/72

RANDOM ASYMMETRY ANGLES

1	213.	16.	138.	320.	252.	204.	114.	187.	97.	7.	122.	123.	110.	211.	144.	99.	58.
18	140.	321.	261.	251.	336.	2.	346.	122.	331.	348.	319.	352.	161.	45.	58.	272.	208.
35	334.	255.	268.	105.	286.	217.	170.	287.	293.	120.	123.	83.	131.	151.	332.	260.	212.
52	157.	37.	306.	265.	138.	54.	163.	144.	166.	216.	298.	221.	64.	26.	110.	298.	316.
69	326.	65.	274.	223.	260.	20.	47.	155.	297.	183.	88.	337.	179.	68.	177.	137.	58.

RANDOM MANUFACTURING BOW ANGLES

1	89.	245.	359.	150.	56.	100.	278.	346.	329.	179.	207.	132.	221.	103.	240.	273.	134.
18	63.	211.	123.	244.	358.	144.	299.	23.	178.	124.	258.	67.	290.	299.	163.	96.	287.
35	295.	171.	332.	110.	213.	48.	125.	82.	314.	168.	322.	183.	122.	317.	3.	353.	185.
52	240.	202.	39.	2.	158.	193.	204.	57.	147.	36.	263.	16.	198.	19.	13.	310.	233.
69	232.	65.	245.	71.	277.	92.	209.	74.	194.	249.	59.	306.	82.	50.	153.	8.	213.

RANDOM MAXIMUM MANUFACTURING BOW LENGTHS

1	8.1	7.1	11.4	10.4	12.5	12.4	9.4	8.9	9.9	8.8	7.2	11.5	9.1	7.9	8.6	8.3	10.7
18	11.8	8.4	11.9	7.2	8.3	9.5	12.6	7.3	9.4	8.5	8.0	10.6	9.0	11.4	11.0	12.4	8.2
35	11.7	11.7	12.9	7.4	10.1	8.5	8.4	12.0	10.0	9.9	11.2	11.1	10.9	10.1	8.8	11.4	8.9
52	7.8	7.1	8.8	12.4	9.9	11.6	8.9	10.9	12.9	8.9	8.5	7.8	11.0	12.9	8.9	11.0	12.1
69	8.5	8.1	10.6	8.6	8.3	12.7	9.9	9.4	7.1	9.9	7.9	9.6	12.7	8.4	10.1	9.1	11.0

RANDOM MANUFACTURING BOW MULTIPLIERS

1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
18	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
35	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
52	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
69	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

TABLE 10
TYPICAL RANDOM CLAD SHEET
(1)

5 KWE RANDOM CORE RUN 1A, 12/1/72

RANDOM CLAD DIAMETERS

1	1.0052	1.0054	1.0076	1.0071	1.0051	1.0054	1.0021	1.0075	1.0062	1.0058	1.0048	1.0053
13	1.0063	1.0058	1.0049	1.0043	1.0052	1.0039	1.0053	1.0072	1.0086	1.0024	1.0030	1.0070
25	1.0051	1.0051	1.0058	1.0032	1.0049	1.0056	1.0083	1.0045	1.0034	1.0038	1.0028	1.0053
37	1.0035	1.0051	1.0046	1.0033	1.0064	1.0055	1.0046	1.0036	1.0027	1.0042	1.0022	1.0041
49	1.0051	1.0030	1.0036	1.0056	1.0051	1.0068	1.0067	1.0070	1.0072	1.0033	1.0062	1.0041
61	1.0062	1.0061	1.0016	1.0067	1.0036	1.0054	1.0077	1.0076	1.0046	1.0054	1.0025	1.0051
73	1.0022	1.0050	1.0051	1.0037	1.0044	1.0071	1.0060	1.0047	1.0067	1.0030	1.0044	1.0050
85	1.0061											

RANDOM FIN RADII

1	0.5128	0.5120	0.5128	0.5129	0.5123	0.5124	0.5131	0.5131	0.5117	0.5115	0.5132	0.5129
13	0.5137	0.5127	0.5121	0.5124	0.5128	0.5134	0.5113	0.5119	0.5127	0.5119	0.5132	0.5130
25	0.5127	0.5128	0.5117	0.5134	0.5134	0.5127	0.5121	0.5130	0.5132	0.5117	0.5118	0.5139
37	0.5127	0.5127	0.5119	0.5119	0.5120	0.5122	0.5116	0.5126	0.5130	0.5131	0.5116	0.5123
49	0.5120	0.5132	0.5128	0.5120	0.5131	0.5129	0.5123	0.5126	0.5123	0.5113	0.5112	0.5127
61	0.5133	0.5115	0.5113	0.5115	0.5126	0.5126	0.5125	0.5121	0.5123	0.5130	0.5115	0.5121
73	0.5118	0.5129	0.5120	0.5133	0.5128	0.5125	0.5122	0.5129	0.5135	0.5116	0.5122	0.5127
85	0.5133											

RANDOM CLAD THICKNESSES

1	0.0253	0.0251	0.0262	0.0258	0.0248	0.0248	0.0239	0.0259	0.0256	0.0254	0.0251	0.0249
13	0.0253	0.0255	0.0250	0.0246	0.0246	0.0240	0.0254	0.0257	0.0265	0.0239	0.0241	0.0260
25	0.0247	0.0246	0.0257	0.0237	0.0247	0.0256	0.0263	0.0243	0.0244	0.0243	0.0243	0.0248
37	0.0243	0.0248	0.0250	0.0245	0.0260	0.0253	0.0252	0.0243	0.0244	0.0249	0.0238	0.0246
49	0.0252	0.0241	0.0239	0.0256	0.0250	0.0259	0.0260	0.0255	0.0263	0.0244	0.0261	0.0245
61	0.0255	0.0260	0.0235	0.0262	0.0243	0.0253	0.0261	0.0261	0.0244	0.0252	0.0240	0.0246
73	0.0241	0.0245	0.0247	0.0239	0.0249	0.0256	0.0250	0.0246	0.0253	0.0245	0.0245	0.0249
85	0.0255											

TABLE 11
TYPICAL RANDOM ASYMMETRY SHEET
(3)

5 KWE RANDOM CORE RUN 1A, 12/1/72

ASYMMETRY MULTIPLIER ARRAY - ASYZOL(11,85)

Z/L =	0.0	0.19	0.21	0.39	0.41	0.50	0.59	0.63	0.79	0.81	1.00
1	0.86681	0.86681	0.14572	0.14572	0.11709	0.11709	0.11709	0.35468	0.35468	0.48927	0.48927
2	0.07197	0.07197	0.88034	0.88034	0.43439	0.43439	0.43439	0.53172	0.53172	0.56612	0.56612
3	0.75220	0.75220	0.47842	0.47842	0.90446	0.90446	0.90446	0.75637	0.75637	0.17103	0.17103
4	0.86084	0.86084	0.48997	0.48997	0.24894	0.24894	0.24894	0.92630	0.92630	0.89076	0.89076
5	0.61945	0.61945	0.13591	0.13591	0.32260	0.32260	0.32260	0.25766	0.25766	0.42440	0.42440
6	0.37801	0.37801	0.21874	0.21874	0.85171	0.85171	0.85171	0.06319	0.06319	0.56242	0.56242
7	0.94176	0.94176	0.95906	0.95906	0.82258	0.82258	0.82258	0.03560	0.03560	0.07605	0.07605
8	0.83221	0.83221	0.09432	0.09432	0.41112	0.41112	0.41112	0.12738	0.12738	0.63522	0.63522
9	0.22672	0.22672	0.45244	0.45244	0.06196	0.06196	0.06196	0.76414	0.76414	0.25118	0.25118
10	0.33071	0.33071	0.72052	0.72052	0.54224	0.54224	0.54224	0.48376	0.48376	0.25766	0.25766
11	0.10737	0.10737	0.29034	0.29034	0.00178	0.00178	0.00178	0.49331	0.49331	0.55444	0.55444
12	0.77216	0.77216	0.99532	0.99532	0.72886	0.72886	0.72886	0.76038	0.76038	0.01456	0.01456
13	0.99383	0.99383	0.84447	0.84447	0.70458	0.70458	0.70458	0.50295	0.50295	0.96768	0.96768
14	0.04206	0.04206	0.43627	0.43627	0.75150	0.75150	0.75150	0.30471	0.30471	0.35318	0.35318
15	0.73855	0.73855	0.24854	0.24854	0.66183	0.66183	0.66183	0.52173	0.52173	0.66750	0.66750
16	0.77679	0.77679	0.69152	0.69152	0.26188	0.26188	0.26188	0.96619	0.96619	0.10877	0.10877
17	0.64345	0.64345	0.89077	0.89077	0.35375	0.35375	0.35375	0.07701	0.07701	0.84102	0.84102
18	0.33643	0.33643	0.68948	0.68948	0.01944	0.01944	0.01944	0.03290	0.03290	0.52051	0.52051
19	0.01186	0.01186	0.59966	0.59966	0.61966	0.61966	0.61966	0.11614	0.11614	0.45262	0.45262
20	0.00228	0.00228	0.75523	0.75523	0.68073	0.68073	0.68073	0.02585	0.02585	0.50320	0.50320
21	0.32358	0.32358	0.16376	0.16376	0.29199	0.29199	0.29199	0.41495	0.41495	0.79018	0.79018
22	0.78964	0.78964	0.89695	0.89695	0.40700	0.40700	0.40700	0.92862	0.92862	0.31547	0.31547
23	0.98614	0.98614	0.20106	0.20106	0.42216	0.42216	0.42216	0.66390	0.66390	0.49357	0.49357
24	0.64139	0.64139	0.34029	0.34029	0.93089	0.93089	0.93089	0.30584	0.30584	0.14014	0.14014
25	0.49029	0.49029	0.76858	0.76858	0.30130	0.30130	0.30130	0.49763	0.49763	0.64380	0.64380
26	0.14307	0.14307	0.26402	0.26402	0.09768	0.09768	0.09768	0.63837	0.63837	0.46722	0.46722
27	0.67292	0.67292	0.47792	0.47792	0.35404	0.35404	0.35404	0.10851	0.10851	0.36581	0.36581
28	0.27509	0.27509	0.56489	0.56489	0.27178	0.27178	0.27178	0.07842	0.07842	0.54538	0.54538

TABLE 12
TYPICAL BOW SUMMARY SHEET
(13)

5 KWE RANDOM CORE RUN 1A, 12/1/72

ELEMENT BOW SUMMARY, MILS

ELEM		1.00	4.00	4.40	7.20	7.60	9.00	10.40	11.00	13.60	14.00	17.00
1	MFG	1.162	4.219	4.538	5.916	5.976	5.922	5.526	5.258	3.504	3.164	0.256
	THR	0.387	1.486	1.625	2.363	2.430	2.586	2.628	2.609	2.084	1.931	0.192
	RES	1.374	4.910	5.277	6.870	6.963	6.967	6.665	6.478	4.702	4.305	0.384
	ANG	75.	73.	73.	70.	70.	68.	67.	67.	66.	66.	64.
2	MFG	1.314	4.636	4.954	5.999	5.983	5.746	5.239	4.945	3.216	2.896	0.233
	THR	0.169	0.729	0.808	1.008	0.981	0.840	0.701	0.657	0.482	0.452	0.050
	RES	1.058	3.632	3.852	4.247	4.157	3.943	3.972	4.113	5.703	6.082	9.658
	ANG	264.	265.	266.	279.	282.	298.	318.	327.	359.	3.	22.
3	MFG	0.826	3.147	3.424	5.029	5.202	5.679	5.945	5.992	4.972	4.584	0.401
	THR	0.858	3.233	3.522	4.985	5.109	5.362	5.332	5.224	3.931	3.609	0.337
	RES	0.969	3.467	3.726	4.670	4.664	4.383	3.746	3.352	0.137	0.980	9.209
	ANG	342.	339.	338.	333.	332.	330.	330.	330.	167.	156.	155.
4	MFG	0.903	3.411	3.703	5.315	5.473	5.868	6.000	5.942	4.452	4.065	0.343
	THR	0.633	2.758	3.073	5.014	5.235	5.761	5.873	5.788	4.399	4.036	0.375
	RES	0.856	3.489	3.824	5.564	5.690	5.758	5.270	4.875	1.646	1.590	9.186
	ANG	139.	138.	138.	137.	137.	138.	141.	144.	199.	232.	299.
5	MFG	0.753	2.895	3.155	4.723	4.903	5.433	5.795	5.896	5.597	5.264	0.494
	THR	0.784	3.169	3.494	5.403	5.608	6.086	6.159	6.058	4.634	4.268	0.408
	RES	1.524	6.045	6.629	10.116	10.501	11.513	11.954	11.954	10.221	9.519	0.898
	ANG	64.	61.	61.	59.	59.	58.	57.	56.	54.	53.	51.
6	MFG	0.760	2.920	3.182	4.754	4.934	5.460	5.814	5.910	5.532	5.189	0.482
	THR	0.701	2.639	2.874	3.993	4.071	4.210	4.157	4.071	3.022	2.759	0.249
	RES	1.155	4.396	4.784	6.855	7.052	7.537	7.795	7.850	7.369	7.208	9.500
	ANG	134.	137.	138.	143.	145.	149.	154.	158.	177.	182.	237.
7	MFG	0.997	3.716	4.023	5.597	5.729	5.986	5.882	5.697	4.006	3.635	0.300
	THR	0.353	1.486	1.648	2.798	2.960	3.366	3.459	3.394	2.584	2.385	0.234
	RES	0.822	3.005	3.230	4.172	4.191	3.899	2.992	2.453	2.529	3.180	9.426
	ANG	288.	286.	286.	284.	284.	284.	290.	297.	42.	50.	64.

TABLE 13
TYPICAL CORE AVERAGE SHEET
(1)

5 KWE RANDOM CORE RUN 1A, 12/1/72

HYDRAULIC DATA			CHANNEL DATA					
AVG CHANNEL VELOCITY, FPS	1.664	TYPE NO.	AREA	VELOCITY	RE	FIN AREA	FLOW	
AVG CHANNEL FLOW, LB/HR	87.6	1 138	0.05828	1.495	6883.	0.003775	91.66	
AVG REYNOLDS NUMBER	6936.	2 6	0.05085	1.567	6233.	0.003775	83.01	
AVG HYDRAULIC DIAMETER, IN	0.120	3 24	0.04596	1.840	6848.	0.001887	91.20	
AVG FRICTION FACTOR	0.072	4 12	0.02541	1.933	3841.	0.001887	51.15	
CORE PRESSURE DROP, PSI	0.154	5 24	0.01695	2.704	3872.	0.0	51.56	
GEOMETRIC DATA			TEMPRO DATA					
TOTAL NO. OF CHANNELS	204	RING =	1	2	3	4	5	6
VESSEL I.D., IN	10.46	R/R0	0.0	0.1960	0.3657	0.5413	0.7357	0.8762
TOTAL PERIMETER, IN	317.2	FLOW	0.8337	0.8967	0.9199	0.9082	0.9467	1.1947
AVG CHANNEL PERIMETER, IN	1.555	FILM	3443.1	3514.6	3513.4	3474.7	3393.5	3134.4
TOTAL FLOW AREA, SQ IN	9.55	PHIF	0.3916	0.3622	0.3463	0.3201	0.2792	0.2537
		PHIF	1.3800	1.3117	1.2417	1.1297	0.9694	0.8600
AVG CHANNEL AREA, SQ IN	0.04682	PHIF	1.4620	1.3930	1.3182	1.1982	1.0272	0.9100
		PHIF	1.8070	1.7450	1.6442	1.4848	1.2557	1.0827
		PHIF	1.8230	1.7633	1.6602	1.4967	1.2609	1.0805
		PHIF	1.8230	1.7697	1.6605	1.4881	1.2340	1.0192
		PHIF	1.7390	1.6887	1.5827	1.4144	1.1652	0.9444
		PHIF	1.6780	1.6287	1.5267	1.3648	1.1261	0.9203
		PHIF	1.2520	1.2073	1.1332	1.0161	0.8456	0.7012
		PHIF	1.1640	1.1210	1.0522	0.9432	0.7838	0.6481
		PHIF	0.2462	0.2356	0.2193	0.1928	0.1546	0.1229

TABLE 14
TYPICAL COOLANT TEMPERATURE SHEET
(6)

5 KWE RANDOM CORE RUN 1A, 12/1/72											
COOLANT BULK TEMPERATURE, DEG F											
Z/L =	0.0	0.19	0.21	0.39	0.41	0.50	0.59	0.63	0.79	0.81	1.00
1	1100.0	1120.5	1125.2	1160.7	1165.2	1177.1	1189.7	1197.4	1229.2	1231.6	1238.2
2	1100.0	1117.5	1121.5	1154.2	1159.2	1176.3	1192.8	1199.6	1224.3	1227.1	1237.1
3	1100.0	1118.8	1122.4	1146.3	1151.2	1171.0	1188.9	1194.0	1207.7	1210.5	1226.5
4	1100.0	1115.9	1120.3	1158.4	1163.7	1181.2	1198.8	1205.8	1228.1	1230.6	1239.6
5	1100.0	1117.8	1122.3	1160.5	1166.1	1183.8	1200.7	1207.3	1228.3	1230.7	1240.1
6	1100.0	1118.0	1121.8	1152.4	1157.8	1176.2	1193.0	1200.3	1228.5	1231.7	1242.7
7	1100.0	1117.4	1121.4	1152.7	1156.8	1169.4	1183.2	1190.0	1218.2	1221.7	1235.4
8	1100.0	1117.7	1120.3	1139.9	1143.6	1158.5	1174.4	1180.9	1204.4	1207.9	1226.2
9	1100.0	1112.8	1115.7	1142.2	1147.1	1166.6	1185.4	1191.5	1210.3	1213.4	1228.8
10	1100.0	1113.6	1117.7	1155.8	1161.8	1183.1	1202.4	1208.9	1229.1	1231.8	1241.4
11	1100.0	1112.9	1116.6	1150.8	1155.8	1172.3	1189.5	1197.2	1224.7	1227.6	1237.3
12	1100.0	1116.7	1119.5	1142.4	1146.8	1163.4	1179.7	1186.2	1211.0	1214.8	1232.4
13	1100.0	1121.9	1124.9	1141.3	1145.2	1162.1	1178.3	1183.6	1200.9	1204.3	1224.2
14	1100.0	1118.9	1121.7	1141.0	1144.8	1159.4	1173.1	1178.3	1198.8	1202.5	1222.6
15	1100.0	1113.8	1116.5	1139.6	1143.4	1157.0	1170.9	1177.5	1206.0	1209.8	1227.7
16	1100.0	1113.2	1116.8	1151.7	1156.6	1171.8	1187.9	1195.8	1226.4	1229.4	1240.2
17	1100.0	1115.8	1119.1	1146.4	1151.0	1167.5	1183.6	1190.6	1217.6	1220.9	1233.5
18	1100.0	1116.4	1119.6	1145.8	1150.9	1171.0	1189.1	1194.4	1211.6	1215.2	1233.1
19	1100.0	1117.8	1122.2	1157.2	1162.5	1179.4	1195.1	1200.2	1216.4	1219.2	1232.8
20	1100.0	1117.9	1121.9	1155.4	1159.1	1168.9	1179.6	1185.3	1211.4	1214.5	1227.8
21	1100.0	1118.0	1121.5	1149.3	1153.3	1165.9	1179.5	1186.3	1214.2	1217.3	1230.1
22	1100.0	1116.8	1120.2	1148.2	1153.3	1172.4	1190.5	1197.5	1223.0	1226.6	1241.8
23	1100.0	1116.5	1120.1	1148.3	1153.1	1170.3	1186.6	1193.2	1216.9	1219.5	1229.3
24	1100.0	1115.6	1119.5	1152.9	1157.8	1174.3	1190.6	1198.7	1229.6	1232.2	1237.9
25	1100.0	1115.5	1119.5	1154.3	1159.5	1176.6	1193.2	1200.6	1227.5	1229.8	1234.6
26	1100.0	1112.6	1116.1	1146.2	1151.1	1168.5	1184.1	1189.4	1205.7	1208.0	1218.2
27	1100.0	1116.9	1120.3	1146.2	1150.8	1168.2	1184.3	1190.8	1212.7	1215.1	1224.9
28	1100.0	1117.0	1120.8	1149.5	1153.9	1169.3	1184.5	1191.1	1214.9	1217.3	1225.0
29	1100.0	1115.1	1118.4	1144.4	1148.7	1163.5	1177.6	1183.3	1203.5	1205.8	1214.4
30	1100.0	1115.3	1118.3	1141.9	1146.6	1164.7	1181.2	1187.5	1208.6	1210.6	1217.3
31	1100.0	1115.1	1118.2	1140.8	1146.1	1167.3	1186.3	1193.0	1214.2	1216.7	1224.7
32	1100.0	1114.3	1117.9	1147.6	1152.6	1170.5	1186.9	1193.5	1216.7	1218.8	1223.9
33	1100.0	1115.6	1119.2	1147.4	1151.6	1166.4	1181.3	1187.3	1208.7	1210.7	1215.2
34	1100.0	1115.1	1118.1	1140.8	1145.9	1166.6	1184.1	1190.8	1215.8	1218.0	1222.9

TABLE 15
TYPICAL CHANNEL AREA SHEET
(6)

5 KWE RANDOM CORE RUN 1A, 12/1/72

CHANNEL AREA, SQ. IN.

Z/L =	0.0	0.19	0.21	0.39	0.41	0.50	0.59	0.63	0.79	0.81	1.00
1	0.05149	0.04572	0.04511	0.04243	0.04233	0.04226	0.04268	0.04297	0.04577	0.04645	0.05303
2	0.05284	0.05192	0.05181	0.05130	0.05123	0.05115	0.05127	0.05134	0.05194	0.05208	0.05314
3	0.05409	0.05464	0.05468	0.05467	0.05459	0.05422	0.05375	0.05348	0.05173	0.05146	0.04937
4	0.05385	0.05202	0.05173	0.04976	0.04951	0.04875	0.04819	0.04806	0.04844	0.04880	0.05382
5	0.05439	0.05219	0.05190	0.05011	0.04988	0.04934	0.04913	0.04916	0.05020	0.05056	0.05476
6	0.05410	0.05136	0.05107	0.04971	0.04962	0.04940	0.04925	0.04918	0.04927	0.04932	0.05033
7	0.05269	0.05092	0.05074	0.04994	0.04996	0.04986	0.04983	0.04981	0.05034	0.05057	0.05314
8	0.05466	0.05858	0.05907	0.06169	0.06196	0.06243	0.06233	0.06207	0.05959	0.05903	0.05379
9	0.05530	0.05956	0.06000	0.06192	0.06200	0.06207	0.06183	0.06163	0.05956	0.05904	0.05411
10	0.05370	0.05439	0.05439	0.05414	0.05403	0.05394	0.05411	0.05430	0.05554	0.05576	0.05773
11	0.05323	0.05126	0.05103	0.04985	0.04980	0.04979	0.05004	0.05028	0.05251	0.05300	0.05804
12	0.05431	0.05667	0.05698	0.05853	0.05866	0.05892	0.05881	0.05869	0.05728	0.05690	0.05382
13	0.05430	0.05665	0.05695	0.05865	0.05877	0.05896	0.05874	0.05849	0.05599	0.05538	0.04946
14	0.05416	0.05521	0.05540	0.05693	0.05714	0.05778	0.05827	0.05842	0.05817	0.05791	0.05432
15	0.05531	0.05821	0.05857	0.06064	0.06086	0.06128	0.06124	0.06105	0.05946	0.05902	0.05471
16	0.05491	0.05596	0.05604	0.05628	0.05633	0.05618	0.05583	0.05561	0.05481	0.05470	0.05439
17	0.05545	0.05762	0.05784	0.05864	0.05864	0.05837	0.05775	0.05739	0.05529	0.05481	0.05033
18	0.05502	0.05625	0.05636	0.05667	0.05662	0.05635	0.05590	0.05569	0.05414	0.05375	0.05019
19	0.05386	0.05042	0.05003	0.04805	0.04789	0.04775	0.04827	0.04868	0.05191	0.05262	0.05913
20	0.05514	0.05434	0.05430	0.05447	0.05460	0.05511	0.05580	0.05611	0.05784	0.05811	0.05996
21	0.05520	0.05455	0.05451	0.05440	0.05441	0.05452	0.05465	0.05471	0.05498	0.05503	0.05549
22	0.05465	0.05344	0.05330	0.05243	0.05232	0.05198	0.05167	0.05153	0.05098	0.05089	0.05046
23	0.05378	0.05392	0.05390	0.05355	0.05346	0.05322	0.05297	0.05290	0.05296	0.05301	0.05365
24	0.05328	0.05255	0.05241	0.05101	0.05079	0.04992	0.04906	0.04873	0.04790	0.04789	0.04862
25	0.05150	0.04831	0.04792	0.04562	0.04540	0.04465	0.04427	0.04418	0.04473	0.04496	0.04760
26	0.05311	0.05084	0.05060	0.04942	0.04935	0.04928	0.04955	0.04973	0.05118	0.05144	0.05373
27	0.05535	0.05716	0.05734	0.05827	0.05831	0.05839	0.05824	0.05809	0.05701	0.05679	0.05484
28	0.05565	0.05602	0.05603	0.05611	0.05608	0.05602	0.05582	0.05575	0.05529	0.05526	0.05544
29	0.05375	0.05221	0.05203	0.05107	0.05094	0.05080	0.05084	0.05099	0.05195	0.05214	0.05412
30	0.05331	0.05175	0.05157	0.05017	0.04997	0.04941	0.04913	0.04912	0.04973	0.05000	0.05348
31	0.05247	0.04841	0.04798	0.04581	0.04561	0.04520	0.04516	0.04529	0.04705	0.04756	0.05341
32	0.05261	0.04775	0.04723	0.04487	0.04474	0.04455	0.04481	0.04509	0.04762	0.04820	0.05390
33	0.05409	0.05317	0.05305	0.05203	0.05189	0.05145	0.05117	0.05112	0.05154	0.05172	0.05413
34	0.05381	0.05270	0.05257	0.05155	0.05143	0.05100	0.05084	0.05080	0.05144	0.05169	0.05395

TABLE 16
TYPICAL COOLANT FLOW SHEET
(6)

5 KWE RANDOM CORE RUN 1A, 12/1/72

COOLANT FLOW, LB/HR

Z/L =	0.0	0.19	0.21	0.39	0.41	0.50	0.59	0.63	0.79	0.81	1.00
1	91.66	77.06	75.40	68.44	67.93	67.95	68.11	69.81	76.33	78.00	96.35
2	96.14	92.74	91.29	90.62	90.80	89.13	90.55	90.41	91.81	93.15	96.71
3	95.87	93.46	95.08	91.35	93.54	93.83	95.26	95.35	91.14	90.81	86.37
4	98.45	93.41	91.38	86.96	85.93	83.74	81.66	81.52	82.84	85.19	98.98
5	98.53	92.95	91.92	86.12	87.10	84.34	84.99	84.42	88.16	88.54	95.10
6	97.55	90.25	90.22	84.82	84.99	84.53	85.39	84.48	84.87	86.20	88.49
7	95.64	89.79	89.50	86.23	87.03	85.98	85.58	85.52	87.01	89.58	95.66
8	94.83	109.07	111.40	117.39	118.38	119.94	119.64	119.04	111.79	110.11	97.84
9	100.55	111.31	112.38	118.96	119.29	119.05	117.88	117.52	111.30	110.49	92.40
10	97.25	97.13	92.88	90.00	93.32	90.78	91.06	91.60	96.35	102.98	102.50
11	97.44	90.25	90.08	86.60	86.83	86.42	87.59	87.34	93.69	95.51	102.87
12	95.33	100.31	103.24	109.08	108.51	110.03	109.32	109.62	101.63	105.04	98.63
13	97.23	98.97	104.88	108.76	109.60	109.43	108.71	108.20	97.77	95.06	86.65
14	97.75	100.88	98.37	98.47	101.04	106.88	106.79	107.97	105.21	105.60	96.86
15	99.54	105.01	108.96	114.86	115.31	116.67	116.58	116.25	111.71	111.18	100.21
16	101.31	99.95	100.81	97.02	101.38	96.97	98.41	97.32	96.85	98.37	93.87
17	97.12	100.84	101.79	109.82	108.43	109.25	104.00	105.22	94.59	95.79	88.82
18	96.68	100.55	100.51	99.83	96.26	96.28	97.99	96.34	92.45	95.93	87.70
19	97.46	87.53	88.19	82.11	81.38	80.86	83.22	83.22	91.06	95.30	111.30
20	94.27	99.37	92.90	98.64	96.73	102.60	103.51	95.48	102.47	103.58	114.94
21	96.31	99.36	98.12	93.50	94.50	94.77	96.20	94.16	101.55	91.37	97.13
22	95.49	97.08	96.52	92.27	92.67	92.15	90.51	90.02	89.04	89.60	88.24
23	97.53	96.60	93.18	96.99	94.70	94.50	94.74	95.18	94.13	94.52	97.37
24	96.54	93.12	93.60	89.01	88.05	86.81	84.78	83.01	82.77	81.90	83.92
25	91.69	82.68	82.02	76.68	75.49	73.14	72.88	71.72	74.35	75.22	82.63
26	97.04	90.55	88.06	84.91	85.08	85.43	85.99	85.91	90.34	91.07	98.68
27	100.36	104.25	106.22	107.13	103.56	108.58	104.28	101.19	103.41	97.42	98.56
28	98.40	96.01	105.07	100.30	97.95	99.95	98.36	98.75	97.76	95.96	100.23
29	97.77	94.03	92.36	89.54	90.20	90.01	89.82	89.28	92.86	92.32	95.88
30	96.65	92.19	90.84	87.28	87.05	86.17	85.63	83.96	86.01	87.74	96.81
31	95.94	83.39	81.91	76.96	76.14	74.49	75.03	75.09	80.33	81.19	97.62
32	95.35	81.55	79.87	74.66	73.76	73.42	74.57	73.87	81.88	83.27	98.21
33	97.55	95.83	94.67	91.97	91.93	90.43	89.91	90.38	90.51	91.97	95.92
34	97.27	94.60	94.10	91.43	90.10	88.66	89.82	89.32	91.21	91.22	94.37

TABLE 17
TYPICAL MIXING FACTOR SHEET
(6)

5 KWE RANDOM CORE RUN 1A, 12/1/72

MIXING FACTOR, %/IN										
Z/L =	0.0 / 0.19	0.19/0.21	0.21/0.39	0.39/0.41	0.41/0.50	0.50/0.59	0.59/0.63	0.63/0.79	0.79/0.81	0.81/1.00
1	29.624	32.495	34.248	35.731	35.785	35.603	35.077	33.178	31.739	28.643
2	26.856	27.677	28.216	28.407	28.699	28.701	28.547	28.235	27.943	27.319
3	27.125	27.500	28.161	28.548	28.331	28.080	27.979	28.112	28.564	29.065
4	26.913	28.052	29.221	30.057	30.625	31.285	31.653	31.070	30.267	27.703
5	26.556	27.240	27.993	28.329	28.516	28.821	28.663	28.253	28.023	27.790
6	26.532	27.138	27.515	27.725	27.722	27.673	27.533	27.846	28.018	28.383
7	26.954	27.630	28.031	28.122	28.106	28.073	28.111	28.103	27.737	26.958
8	25.345	23.854	23.264	22.597	22.398	22.246	22.209	22.851	23.718	25.153
9	24.393	23.511	23.008	22.362	22.396	22.495	22.519	23.052	23.729	25.779
10	26.097	26.807	28.067	28.113	28.050	28.361	28.282	27.376	25.930	25.242
11	26.741	27.784	28.583	29.099	29.184	29.103	28.993	27.920	26.912	26.017
12	25.656	24.615	23.784	23.193	23.136	23.087	23.165	23.926	24.637	25.342
13	26.174	25.433	24.573	24.172	24.236	24.340	24.499	25.453	26.952	29.340
14	26.170	26.482	27.026	26.771	25.931	25.207	25.003	24.874	24.833	25.373
15	25.412	24.660	23.768	23.205	23.242	23.092	23.062	23.261	23.487	24.302
16	25.656	25.820	26.341	26.191	26.197	26.486	26.389	26.300	26.052	26.540
17	25.804	25.197	24.254	23.326	23.148	23.475	23.934	25.041	26.528	28.169
18	25.899	25.394	25.619	25.963	26.171	25.768	25.768	26.502	26.808	28.319
19	27.487	28.658	29.267	30.016	30.131	29.743	29.175	27.979	26.571	24.702
20	26.470	26.623	26.597	25.835	25.246	24.535	25.263	25.512	24.765	23.845
21	26.193	25.919	26.586	26.847	26.588	26.481	26.408	25.804	26.450	27.642
22	25.874	25.296	25.511	25.458	25.428	25.742	25.906	26.336	26.829	27.879
23	25.557	25.241	25.154	25.262	25.572	25.519	25.424	25.713	26.128	26.336
24	26.160	26.331	26.884	27.349	27.668	28.143	28.776	29.361	29.933	30.477
25	28.486	29.752	30.869	31.937	32.610	33.047	33.303	33.346	33.105	32.241
26	27.254	28.413	29.506	29.865	29.676	29.311	28.963	28.269	27.576	26.753
27	25.787	25.640	25.833	26.177	26.053	25.902	26.547	26.419	26.614	26.928
28	27.141	26.838	26.837	27.819	27.928	27.803	27.673	27.508	27.590	26.900
29	26.983	27.859	28.836	29.200	29.156	29.116	28.999	28.506	27.944	27.313
30	27.406	28.369	29.446	30.105	30.334	30.478	30.625	30.546	29.784	27.855
31	28.342	30.229	31.505	32.749	33.203	33.264	33.001	32.071	30.996	28.330
32	28.389	30.854	32.355	33.596	33.818	33.611	33.461	31.953	30.383	28.266
33	25.968	26.143	26.789	27.115	27.295	27.581	27.549	27.512	27.497	27.302
34	26.278	26.689	27.320	27.774	28.102	28.165	28.142	28.001	27.931	27.722

TABLE 18
TYPICAL FILM COEFFICIENT SHEET
(6)

5 KWE RANDOM CORE RUN 1A, 12/1/72

FILM COEFFICIENT, BTU/HR-SQ FT- DEG F

Z/L =	0.0	0.19	0.21	0.39	0.41	0.50	0.59	0.63	0.79	0.81	1.00
1	2058.0	2626.1	3859.0	3458.1	4207.8	4560.5	3456.5	4274.0	4262.0	3560.4	3149.1
2	2156.2	4008.0	4072.5	3632.4	4017.3	3310.3	3296.5	3290.8	3198.9	3522.3	3706.5
3	2021.4	3437.5	4110.3	4150.3	4184.0	3545.0	3414.8	3606.7	3656.2	3343.9	3037.1
4	2370.3	3792.3	3339.6	3455.3	3947.9	3676.4	3801.7	2940.2	2866.5	3648.7	3611.7
5	1866.9	3482.0	3742.4	3645.8	3697.9	4002.8	3202.6	3403.2	2836.6	3583.0	3596.6
6	2196.0	3586.9	3659.8	2860.8	3497.0	3737.0	3339.9	3969.6	2928.0	3347.6	3432.0
7	2073.7	3820.6	3698.4	3450.0	3643.4	3849.4	3658.7	3470.7	3401.5	3541.2	3541.7
8	2351.2	4195.7	4457.0	4006.8	3818.3	4128.0	3643.1	3664.9	3806.5	3913.2	3365.9
9	2333.9	3666.5	3842.4	4385.4	3963.9	3588.0	3489.8	3382.8	3594.7	3681.3	3401.6
10	2112.7	3668.9	3707.6	2977.8	3986.6	3495.4	4157.2	4293.5	4080.5	3511.7	4286.9
11	2278.4	3280.4	3547.2	3553.5	3787.6	3593.3	3554.6	3516.1	3905.8	3269.7	3355.8
12	2187.7	4323.8	3783.8	4132.6	3945.2	4184.9	3653.1	4076.6	3999.4	3939.8	3719.1
13	2192.5	3314.4	3841.6	3619.5	4276.0	3708.8	4013.8	4468.8	3950.9	3954.6	3159.6
14	2525.3	4130.8	3808.4	4281.0	3937.7	3672.8	3728.7	4271.9	4150.3	4177.6	3873.0
15	2176.3	4078.6	3708.1	4131.3	3942.3	4033.2	3638.6	3524.0	4091.9	3877.2	3332.3
16	2106.2	4224.0	3911.4	3444.0	3900.1	3916.8	3656.7	3676.4	4089.7	3271.1	3826.3
17	2584.2	3758.5	4146.3	3999.6	4084.7	3962.9	4196.0	3531.7	3979.1	3964.1	3952.1
18	2508.0	3751.2	3711.0	3996.7	3404.4	4224.5	3151.9	3647.7	3702.1	3765.5	3575.5
19	2105.1	3375.1	3282.0	3155.7	3673.5	3242.0	3371.4	3938.1	3025.0	3430.0	3599.2
20	1950.3	3618.8	3458.7	3609.7	3385.2	3466.3	3356.6	3842.1	3971.5	3597.8	3654.7
21	2253.4	3747.3	3227.0	3098.7	3801.0	3258.7	3410.1	3399.3	3340.8	3535.8	3378.0
22	2160.1	3645.1	3630.9	3216.7	3046.7	3445.0	3500.8	3713.5	3624.3	4049.5	2988.0
23	2331.1	3413.5	3885.4	3432.8	3941.2	2993.2	3685.6	3688.5	3361.5	3714.0	2985.6
24	2246.5	2892.7	3256.7	3628.4	3683.0	2866.7	3382.4	3256.5	3613.9	4075.3	3353.2
25	1889.0	4196.2	3930.1	3498.6	3351.6	3015.7	2842.0	2865.2	2782.0	3984.3	3909.6
26	1976.1	2987.0	3639.7	3870.7	3491.4	3902.7	3436.7	3593.5	3930.5	3119.9	3188.7
27	2495.2	3966.6	3028.4	4438.0	4010.2	3550.2	4446.3	3905.9	4020.6	3434.0	3492.9
28	2430.0	3631.5	3942.7	3933.1	4160.6	3674.1	4024.9	4026.0	3734.7	3232.6	3684.3
29	2064.6	3407.7	4021.9	4031.0	3878.0	3311.5	3888.7	3087.9	3516.9	3465.2	3213.4
30	2372.0	3067.4	4052.8	3545.8	3807.8	3083.2	3957.9	3549.8	3664.2	3187.1	3941.0
31	2336.5	2931.1	3947.6	3225.0	3316.8	3153.4	4216.1	3127.3	4231.0	3841.3	3130.6
32	1928.1	3511.6	3730.1	3515.2	3327.8	3941.1	4142.1	3795.2	3721.2	2878.7	3641.9
33	2253.3	3084.2	3450.0	3426.8	2913.8	3709.9	3387.0	3391.8	3339.2	2948.4	3218.5
34	1951.2	3476.0	3337.2	3305.8	3343.1	3980.3	3436.0	3821.8	3724.9	3319.2	3577.9

TABLE 19
TYPICAL ELEMENT TEMPERATURE SHEET
(85)

5 KWE RANDOM CORE RUN 1A, 12/1/72

ELEMENT NUMBER 1 THERMAL DATA												
SEG	Z/L	0.0	0.19	0.21	0.39	0.41	0.50	0.59	0.63	0.79	0.81	1.00
1	TCO	1103.33	1125.30	1126.85	1160.60	1162.80	1180.79	1197.94	1208.40	1236.07	1236.17	1243.29
	TCI	1104.58	1129.75	1130.01	1164.61	1165.76	1183.73	1200.73	1213.88	1239.85	1238.71	1243.65
	TGI	1106.18	1135.48	1134.07	1169.75	1169.58	1187.51	1204.33	1220.92	1244.71	1241.98	1244.12
	TFS	1108.19	1142.23	1163.28	1205.49	1221.33	1238.19	1252.20	1226.23	1248.22	1259.39	1246.65
	PSEG	0.09391	0.33486	0.23753	0.30082	0.22307	0.22089	0.21018	0.41139	0.28391	0.19119	0.02734
2	TCO	1103.07	1128.52	1128.62	1165.31	1168.80	1180.70	1194.43	1203.61	1233.36	1234.54	1238.92
	TCI	1104.15	1132.12	1130.87	1168.02	1171.38	1183.51	1197.22	1208.17	1236.42	1236.34	1239.32
	TGI	1105.54	1136.75	1133.76	1171.52	1174.71	1187.13	1209.81	1214.03	1240.35	1238.66	1239.83
	TFS	1109.99	1150.87	1174.24	1218.82	1223.49	1239.58	1252.40	1236.73	1255.45	1267.10	1246.28
	PSEG	0.08124	0.27045	0.16898	0.20419	0.19419	0.21147	0.20974	0.34270	0.23011	0.13577	0.03001
3	TCO	1101.98	1121.31	1124.74	1158.73	1164.26	1182.51	1198.78	1204.88	1228.39	1230.00	1237.75
	TCI	1102.71	1123.92	1126.96	1161.53	1167.73	1186.01	1202.15	1207.83	1230.65	1231.77	1238.14
	TGI	1103.64	1127.27	1129.83	1165.14	1172.21	1190.51	1206.48	1211.64	1233.55	1234.04	1238.65
	TFS	1113.77	1161.90	1173.53	1218.29	1214.17	1232.20	1246.23	1253.08	1265.14	1267.52	1246.35
	PSEG	0.05480	0.19626	0.16741	0.21087	0.26146	0.26301	0.25291	0.22221	0.16978	0.13277	0.02965
4	TCO	1101.70	1122.25	1126.29	1151.79	1159.20	1180.10	1197.81	1198.38	1211.65	1215.10	1228.07
	TCI	1102.29	1124.30	1129.01	1155.65	1164.94	1185.63	1203.04	1201.06	1214.11	1217.74	1228.91
	TGI	1103.05	1126.95	1132.50	1160.61	1172.32	1192.73	1209.76	1204.52	1217.29	1221.15	1229.98
	TFS	1115.33	1167.82	1166.93	1207.81	1191.05	1210.44	1226.27	1255.47	1263.91	1257.40	1241.69
	PSEG	0.04421	0.15449	0.20418	0.29012	0.43141	0.41535	0.39304	0.20197	0.18541	0.19918	0.06262
5	TCO	1101.56	1119.42	1127.66	1166.75	1171.78	1189.90	1206.75	1211.12	1232.23	1235.28	1240.49
	TCI	1102.20	1121.71	1131.86	1171.68	1177.25	1195.37	1211.94	1213.78	1234.24	1238.19	1241.06
	TGI	1103.01	1124.66	1137.27	1178.03	1184.29	1202.39	1218.61	1217.21	1236.82	1241.92	1241.79
	TFS	1114.82	1165.37	1152.08	1194.67	1193.25	1211.12	1226.70	1258.31	1267.81	1255.34	1244.47
	PSEG	0.04765	0.17241	0.31628	0.37094	0.41124	0.41074	0.38985	0.20023	0.15100	0.21841	0.04276
6	TCO	1102.67	1123.01	1129.51	1169.13	1171.88	1189.12	1206.98	1213.55	1234.13	1236.59	1241.21
	TCI	1103.53	1126.09	1134.12	1174.50	1175.55	1192.78	1210.42	1217.21	1236.97	1240.18	1241.88
	TGI	1104.62	1130.06	1140.04	1181.41	1180.26	1197.49	1214.94	1221.92	1240.62	1244.79	1242.74
	TFS	1112.42	1156.98	1147.82	1189.95	1213.45	1230.28	1245.30	1245.80	1259.05	1248.30	1243.41
	PSEG	0.06415	0.23164	0.34655	0.40401	0.27535	0.27526	0.25822	0.27532	0.21373	0.26991	0.05027
	TFC	1121.53	1189.65	1197.01	1247.90	1251.89	1269.40	1281.99	1284.99	1289.07	1286.27	1250.54

TABLE 20
TYPICAL TEMPERATURE SUMMARY SHEET
(1)

5 KWF RANDOM CORE RUN 1A, 12/1/72

FUEL ELEMENT TEMPERATURE SUMMARY

NO	PEAK FUEL	CHAN OUTL	NO	PEAK FUEL	CHAN OUTL	NO	PEAK FUEL	CHAN OUTL	NO	PEAK FUEL	CHAN OUTL	NO	PEAK FUEL	CHAN OUTL
1	1292.1	1237.5	2	1305.7	1237.4	3	1302.1	1234.6	4	1302.5	1233.6	5	1293.6	1230.3
6	1312.3	1236.5	7	1297.7	1235.4	8	1295.6	1228.8	9	1301.3	1229.1	10	1285.7	1222.8
11	1295.2	1229.1	12	1298.7	1225.9	13	1285.3	1222.8	14	1277.6	1221.2	15	1295.8	1229.3
16	1289.7	1226.4	17	1290.2	1226.1	18	1283.8	1222.0	19	1282.4	1226.0	20	1268.1	1214.5
21	1285.8	1222.3	22	1274.4	1215.6	23	1261.9	1205.7	24	1274.1	1213.9	25	1272.6	1213.8
26	1268.9	1206.5	27	1280.3	1215.3	28	1282.8	1216.4	29	1265.6	1207.6	30	1277.4	1216.2
31	1279.7	1219.9	32	1268.9	1206.6	33	1275.6	1213.2	34	1273.5	1213.3	35	1258.3	1203.8
36	1271.4	1210.4	37	1270.9	1216.5	38	1240.8	1192.1	39	1245.0	1199.3	40	1245.6	1199.8
41	1237.4	1194.6	42	1225.5	1184.2	43	1234.3	1193.1	44	1248.0	1198.5	45	1239.6	1195.0
46	1236.7	1189.6	47	1245.6	1196.4	48	1248.3	1200.3	49	1245.2	1199.5	50	1240.4	1190.6
51	1241.8	1196.4	52	1249.6	1201.2	53	1246.3	1193.0	54	1218.8	1180.2	55	1237.7	1191.7
56	1256.3	1199.7	57	1245.4	1196.8	58	1232.5	1185.1	59	1237.8	1192.3	60	1257.4	1200.2
61	1246.2	1201.3	62	1223.5	1178.5	63	1212.8	1181.2	64	1225.7	1182.2	65	1209.4	1178.0
66	1203.6	1174.2	67	1225.6	1184.1	68	1228.0	1188.1	69	1222.3	1179.7	70	1222.7	1176.3
71	1227.8	1179.7	72	1227.5	1182.2	73	1207.9	1173.4	74	1221.5	1180.8	75	1224.6	1186.5
76	1227.5	1183.0	77	1202.0	1171.2	78	1212.7	1177.5	79	1221.7	1183.4	80	1225.7	1181.7
81	1218.7	1177.6	82	1214.5	1173.1	83	1230.1	1185.5	84	1228.1	1188.3	85	1221.0	1178.3

TABLE 21
TYPICAL EDGE HEAT LOSS SHEET
(2)

5 KWE RANDOM CORE RUN 1A, 12/1/72

CORE PERIPHERY HEAT LOSS(-) OR GAIN(+), BTU/HR

Z/L =	0.0 / 0.19	0.19 / 0.21	0.21 / 0.39	0.39 / 0.41	0.41 / 0.50	0.50 / 0.59	0.59 / 0.63	0.63 / 0.79	0.79 / 0.81	0.81 / 1.00
1	-11.5	-1.6	-11.4	-1.7	-6.1	-6.2	-2.7	-12.1	-1.9	-14.6
2	-10.3	-1.4	-10.0	-1.5	-5.2	-5.3	-2.3	-10.1	-1.6	-12.0
3	-12.4	-1.7	-11.9	-1.7	-6.2	-6.3	-2.7	-12.1	-1.9	-14.5
4	-12.4	-1.7	-12.1	-1.8	-6.4	-6.7	-2.9	-13.0	-2.0	-15.6
5	-13.5	-1.8	-13.3	-2.0	-7.1	-7.3	-3.2	-14.2	-2.3	-17.3
6	-12.9	-1.8	-12.8	-1.9	-6.9	-8.3	-3.7	-16.4	-2.3	-17.4
7	-13.5	-1.8	-13.2	-2.0	-7.1	-9.7	-4.4	-19.2	-2.3	-17.8
8	-12.4	-1.7	-12.2	-1.8	-6.4	-8.7	-3.9	-17.0	-2.0	-15.5
9	-12.5	-1.7	-12.1	-1.8	-6.2	-8.4	-3.7	-16.2	-1.9	-14.2
10	-10.3	-1.4	-9.9	-1.4	-5.1	-7.0	-3.1	-13.5	-1.6	-11.9
11	-11.5	-1.6	-11.3	-1.7	-6.1	-8.2	-3.7	-16.3	-2.0	-15.4
12	-11.5	-1.6	-11.5	-1.7	-6.1	-8.3	-3.7	-16.2	-2.0	-14.9
13	-10.4	-1.4	-10.2	-1.5	-5.3	-7.2	-3.2	-13.9	-1.6	-12.4
14	-12.4	-1.7	-11.9	-1.7	-6.1	-8.3	-3.7	-16.1	-1.9	-14.4
15	-12.5	-1.7	-12.2	-1.8	-6.4	-8.6	-3.9	-16.9	-2.0	-15.6
16	-13.5	-1.8	-13.2	-1.9	-6.9	-9.3	-4.2	-18.2	-2.2	-16.7
17	-12.8	-1.7	-12.7	-1.9	-6.7	-9.1	-4.1	-17.7	-2.1	-16.2
18	-13.5	-1.8	-13.1	-1.9	-6.9	-9.4	-4.2	-18.5	-2.2	-17.1
19	-12.5	-1.7	-12.4	-1.8	-6.6	-8.9	-4.0	-17.4	-2.1	-16.1
20	-12.5	-1.7	-12.5	-1.8	-6.6	-8.8	-3.9	-17.1	-2.0	-15.4
21	-10.3	-1.4	-10.0	-1.5	-5.2	-7.0	-3.1	-13.6	-1.6	-12.1
22	-11.4	-1.5	-11.0	-1.5	-5.8	-7.9	-3.6	-15.6	-1.9	-14.3
23	-11.4	-1.5	-11.1	-1.7	-5.9	-8.1	-3.6	-15.8	-1.9	-14.5
24	-10.3	-1.4	-10.2	-1.5	-5.3	-7.1	-3.2	-13.8	-1.6	-12.3
25	-12.5	-1.7	-12.3	-1.8	-6.4	-8.6	-3.8	-16.7	-2.0	-14.9
26	-12.5	-1.7	-12.2	-1.8	-6.4	-8.6	-3.9	-16.9	-2.0	-15.5
27	-13.7	-1.9	-13.5	-2.0	-7.1	-9.5	-4.3	-18.7	-2.3	-17.5
28	-13.0	-1.8	-13.1	-2.0	-7.0	-8.2	-3.7	-16.3	-2.3	-17.2
29	-13.7	-1.9	-13.7	-2.1	-7.3	-7.5	-3.3	-14.8	-2.4	-18.1
30	-12.4	-1.7	-12.3	-1.8	-6.5	-6.8	-3.0	-13.4	-2.1	-16.3
31	-12.5	-1.7	-12.2	-1.8	-6.2	-6.4	-2.8	-12.3	-1.9	-14.8
32	-10.3	-1.4	-10.0	-1.5	-5.2	-5.2	-2.3	-10.1	-1.6	-12.2
33	-11.4	-1.5	-11.3	-1.7	-6.1	-6.4	-2.8	-12.6	-2.0	-15.1
34	-11.4	-1.6	-11.3	-1.7	-6.1	-6.3	-2.8	-12.4	-2.0	-15.0
35	-10.3	-1.4	-9.9	-1.4	-5.1	-5.2	-2.3	-10.1	-1.6	-12.1

TABLE 22
TYPICAL INTERNAL REFLECTOR CORE SIDE SHEET
(2)

5 KWE RANDOM CORE RUN 1A, 12/1/72

INNER REFLECTOR CORE SIDE TEMPERATURES, DEG F

Z/L =	0.0 / 0.19	0.19 / 0.21	0.21 / 0.39	0.39 / 0.41	0.41 / 0.50	0.50 / 0.59	0.59 / 0.63	0.63 / 0.79	0.79 / 0.81	0.81 / 1.00
1	1104.9	1111.3	1121.8	1133.7	1138.0	1145.3	1151.3	1156.7	1165.6	1169.5
2	1103.5	1107.7	1114.2	1121.0	1123.8	1128.1	1131.2	1135.7	1139.9	1143.3
3	1102.4	1105.3	1110.2	1115.3	1118.8	1124.3	1128.2	1133.3	1138.1	1143.3
4	1103.4	1107.5	1115.1	1124.3	1130.8	1141.3	1148.1	1154.1	1160.2	1164.2
5	1102.5	1107.5	1116.9	1129.0	1133.8	1142.4	1149.2	1154.7	1165.2	1168.7
6	1105.3	1112.8	1120.7	1132.3	1138.8	1150.4	1159.2	1169.2	1181.8	1186.2
7	1103.9	1109.4	1115.6	1125.9	1134.7	1149.2	1157.8	1164.0	1172.8	1176.9
8	1103.9	1108.0	1117.1	1125.8	1129.9	1136.9	1143.0	1149.9	1159.6	1163.3
9	1104.9	1111.1	1115.1	1110.3	1121.7	1125.3	1127.8	1131.4	1134.8	1138.6
10	1103.5	1107.9	1111.3	1115.1	1119.0	1125.3	1129.2	1132.8	1136.0	1141.4
11	1105.5	1112.1	1119.9	1131.6	1138.0	1149.6	1158.6	1168.2	1182.2	1185.3
12	1106.0	1112.8	1122.5	1132.8	1140.3	1151.8	1159.1	1165.8	1173.5	1175.9
13	1104.8	1110.6	1117.0	1123.8	1128.1	1134.6	1138.8	1143.2	1147.2	1151.4
14	1102.9	1106.5	1110.5	1114.8	1117.4	1121.5	1124.3	1128.6	1132.8	1141.7
15	1104.4	1110.4	1115.8	1124.1	1127.7	1134.8	1141.0	1147.6	1159.6	1164.3
16	1103.4	1108.2	1114.3	1127.1	1125.1	1130.6	1135.4	1143.1	1153.4	1159.9
17	1103.2	1107.8	1118.3	1128.1	1133.8	1141.6	1146.1	1153.4	1158.9	1165.6
18	1103.0	1107.9	1113.4	1123.1	1127.0	1137.0	1143.9	1150.4	1160.7	1165.6
19	1105.2	1112.1	1121.1	1132.3	1137.9	1147.0	1153.4	1160.6	1170.6	1174.0
20	1106.0	1112.7	1121.8	1130.8	1135.9	1143.4	1148.0	1152.5	1156.6	1161.2
21	1103.7	1108.2	1113.2	1118.4	1121.1	1125.4	1128.5	1134.3	1139.7	1144.5
22	1103.5	1107.6	1112.7	1120.0	1125.4	1135.3	1142.7	1151.7	1161.6	1164.9
23	1103.5	1108.3	1115.4	1126.4	1132.5	1143.3	1150.8	1156.4	1165.5	1168.7
24	1104.0	1108.9	1118.2	1127.5	1130.4	1134.3	1137.1	1142.3	1147.2	1150.3
25	1105.0	1111.4	1118.9	1126.7	1129.4	1133.2	1136.0	1142.5	1148.4	1152.1
26	1104.7	1110.8	1116.6	1124.1	1128.8	1136.7	1142.2	1149.1	1157.5	1163.2
27	1106.1	1113.5	1120.2	1129.8	1133.2	1139.7	1145.7	1154.4	1168.0	1171.9
28	1106.3	1114.2	1126.7	1139.0	1142.6	1149.0	1156.4	1166.9	1180.3	1183.0
29	1106.0	1113.5	1125.4	1137.9	1142.0	1148.3	1153.7	1165.1	1177.2	1181.6
30	1104.2	1109.9	1117.9	1128.6	1134.9	1145.3	1152.5	1162.7	1173.0	1177.4
31	1105.1	1111.0	1115.5	1120.0	1122.7	1127.1	1130.6	1138.5	1145.9	1150.3
32	1103.9	1108.4	1113.0	1117.8	1120.7	1125.5	1128.8	1134.1	1139.2	1146.1
33	1103.3	1108.4	1118.0	1131.7	1139.3	1152.0	1160.7	1168.3	1177.6	1180.3
34	1104.2	1109.0	1119.7	1131.1	1137.9	1148.8	1156.7	1164.8	1173.8	1176.7
35	1102.4	1105.4	1110.3	1115.8	1119.6	1125.6	1129.7	1134.7	1139.5	1146.0

TABLE 23

TYPICAL INTERNAL REFLECTOR SHELL SIDE SHEET
(2)

5 KWE RANDOM CORE RUN 1A, 12/1/72

INNER REFLECTOR SHELL SIDE TEMPERATURES, DEG F

Z/L =	0.0	0.19	0.19/0.21	0.21/0.39	0.39/0.41	0.41/0.50	0.50/0.59	0.59/0.63	0.63/0.79	0.79/0.81	0.81/1.00
1	1103.0	1108.9	1120.2	1132.0	1136.7	1144.1	1150.0	1155.8	1164.4	1168.6	
2	1103.1	1107.1	1113.7	1120.2	1123.1	1127.3	1130.1	1134.8	1138.6	1142.2	
3	1102.3	1105.1	1110.0	1115.1	1118.6	1124.1	1127.9	1133.1	1137.8	1143.1	
4	1102.6	1106.5	1114.3	1123.1	1129.9	1140.6	1147.3	1153.5	1159.1	1163.5	
5	1101.8	1106.4	1116.2	1129.0	1133.0	1141.3	1147.9	1153.5	1163.6	1167.5	
6	1104.5	1111.7	1120.1	1131.2	1138.0	1149.4	1157.9	1168.8	1181.2	1186.3	
7	1103.2	1108.3	1114.8	1124.8	1134.0	1148.4	1156.8	1163.1	1171.5	1176.0	
8	1103.1	1107.7	1116.3	1124.7	1128.9	1135.3	1141.2	1148.4	1158.1	1162.2	
9	1104.8	1110.9	1115.0	1119.1	1121.5	1125.1	1127.5	1131.2	1134.5	1138.4	
10	1103.1	1107.1	1110.5	1113.9	1117.7	1123.6	1127.2	1130.7	1133.3	1139.0	
11	1104.1	1110.3	1118.9	1130.9	1137.8	1149.3	1158.4	1169.7	1185.4	1189.1	
12	1104.6	1110.9	1121.5	1131.0	1139.1	1150.1	1156.7	1163.7	1170.2	1173.2	
13	1104.4	1110.0	1116.6	1123.1	1127.4	1133.7	1137.6	1142.2	1146.0	1150.3	
14	1102.8	1106.3	1110.4	1114.5	1117.2	1121.2	1124.0	1128.4	1132.4	1141.4	
15	1103.7	1109.4	1115.2	1123.2	1127.1	1134.0	1140.0	1146.9	1159.1	1164.1	
16	1102.7	1107.2	1113.5	1120.8	1124.0	1129.1	1133.6	1141.7	1151.9	1158.9	
17	1102.2	1106.2	1117.7	1127.0	1133.2	1140.6	1144.7	1152.4	1157.2	1164.6	
18	1102.3	1106.9	1112.4	1121.7	1126.8	1135.7	1142.3	1149.2	1159.4	1164.7	
19	1104.5	1111.1	1120.6	1131.5	1137.3	1146.0	1152.3	1159.7	1169.7	1173.5	
20	1105.9	1112.6	1121.8	1130.7	1135.9	1143.4	1147.9	1152.4	1156.4	1161.1	
21	1103.4	1107.7	1112.8	1117.7	1120.4	1124.3	1127.0	1132.8	1138.0	1143.0	
22	1101.9	1105.3	1110.6	1117.2	1123.2	1132.8	1140.1	1150.5	1160.9	1164.8	
23	1101.9	1106.2	1114.1	1125.3	1131.9	1142.3	1149.4	1155.2	1164.1	1168.0	
24	1103.6	1108.3	1117.9	1127.0	1130.0	1133.5	1136.0	1141.4	1146.1	1149.3	
25	1104.9	1111.2	1118.8	1126.5	1129.2	1133.0	1135.8	1142.3	1148.1	1151.9	
26	1103.8	1109.5	1115.5	1122.7	1127.6	1135.3	1140.6	1147.7	1155.9	1162.1	
27	1105.6	1112.6	1119.5	1128.7	1132.2	1138.5	1144.2	1153.1	1166.8	1171.1	
28	1105.2	1112.7	1126.0	1137.9	1141.8	1147.9	1155.2	1166.1	1179.2	1182.3	
29	1105.5	1112.6	1124.8	1137.0	1141.4	1147.6	1152.8	1164.3	1176.0	1180.9	
30	1103.4	1108.6	1116.8	1127.2	1133.8	1144.4	1151.6	1162.0	1171.8	1176.7	
31	1105.0	1110.9	1115.4	1119.8	1122.6	1126.9	1130.3	1138.4	1145.7	1150.1	
32	1103.6	1107.9	1112.4	1116.6	1119.5	1123.8	1126.8	1132.1	1136.9	1144.2	
33	1101.6	1106.1	1116.7	1130.9	1139.5	1153.3	1162.2	1170.6	1179.6	1182.5	
34	1102.9	1107.1	1118.5	1129.3	1136.3	1147.0	1154.4	1163.4	1171.6	1175.1	
35	1102.0	1104.8	1109.7	1114.8	1118.6	1124.5	1128.3	1133.4	1137.8	1144.7	

TABLE 24
TYPICAL PRESSURE VESSEL SHEET
(2)

5 KWE RANDOM CORE RUN 1A, 12/1/72

AVERAGE PRESSURE VESSEL TEMPERATURES, DEG F

Z/L =	0.0	0.19	0.21	0.39	0.41	0.50	0.59	0.63	0.79	0.81	1.00
1	1104.3	1110.2	1121.0	1132.4	1137.0	1144.2	1149.9	1155.7	1164.1	1168.5	
2	1103.3	1107.4	1114.1	1120.8	1123.7	1128.0	1131.1	1135.7	1139.8	1143.4	
3	1102.3	1105.2	1110.1	1115.2	1118.7	1124.3	1128.1	1133.3	1138.0	1143.3	
4	1103.0	1107.0	1114.7	1123.7	1130.3	1140.7	1147.4	1153.6	1159.5	1163.7	
5	1102.3	1107.1	1116.6	1128.4	1133.5	1142.1	1148.8	1154.5	1164.7	1168.6	
6	1104.9	1112.0	1120.2	1131.5	1138.2	1149.6	1158.1	1168.4	1180.6	1185.4	
7	1103.7	1108.9	1115.4	1125.5	1134.5	1148.8	1157.1	1163.7	1172.2	1176.6	
8	1103.6	1108.3	1116.7	1125.2	1129.5	1136.4	1142.3	1149.4	1159.0	1162.9	
9	1104.9	1110.9	1115.0	1119.1	1121.6	1125.2	1127.7	1131.4	1134.7	1138.6	
10	1103.4	1107.6	1111.2	1115.1	1119.0	1125.3	1129.2	1133.0	1136.2	1141.7	
11	1104.9	1111.0	1119.1	1130.2	1136.8	1148.0	1156.5	1166.5	1179.9	1183.6	
12	1105.4	1111.7	1121.8	1131.6	1139.2	1150.5	1157.5	1164.7	1172.3	1175.2	
13	1104.6	1110.3	1116.9	1123.5	1127.9	1134.4	1138.5	1143.1	1147.1	1151.3	
14	1102.8	1106.4	1110.5	1114.7	1117.3	1121.4	1124.2	1128.6	1132.7	1141.7	
15	1104.1	1109.8	1115.5	1123.5	1127.2	1134.1	1140.0	1146.9	1158.7	1163.8	
16	1103.2	1107.7	1114.1	1121.6	1124.9	1130.3	1134.9	1142.9	1152.9	1159.7	
17	1102.8	1107.0	1117.8	1127.2	1133.1	1140.6	1144.9	1152.6	1157.9	1165.1	
18	1102.8	1107.5	1113.2	1122.7	1127.7	1136.7	1143.3	1150.1	1160.2	1165.4	
19	1104.9	1111.5	1120.7	1131.7	1137.4	1146.3	1152.5	1159.9	1169.7	1173.5	
20	1105.9	1112.6	1121.7	1130.6	1135.8	1143.3	1147.8	1152.3	1156.4	1161.1	
21	1103.6	1107.9	1113.0	1118.1	1121.0	1125.3	1128.3	1134.3	1139.7	1144.6	
22	1102.9	1106.6	1112.1	1119.0	1124.6	1134.1	1141.0	1150.4	1160.0	1163.9	
23	1102.9	1107.2	1114.7	1125.2	1131.4	1141.9	1149.0	1155.2	1164.0	1167.7	
24	1103.8	1108.6	1118.0	1127.2	1130.2	1134.1	1136.8	1142.2	1147.0	1150.2	
25	1105.0	1111.2	1118.9	1126.6	1129.3	1133.1	1135.9	1142.4	1148.3	1152.0	
26	1104.4	1110.2	1116.3	1123.6	1128.4	1136.1	1141.4	1148.5	1156.9	1162.8	
27	1105.9	1113.0	1120.0	1129.4	1132.9	1139.4	1145.1	1154.1	1167.5	1171.7	
28	1105.9	1113.4	1126.2	1138.1	1141.9	1148.2	1155.3	1166.1	1179.2	1182.4	
29	1105.8	1113.1	1125.1	1137.3	1141.7	1147.9	1153.3	1164.8	1176.7	1181.3	
30	1103.9	1109.4	1117.6	1128.1	1134.5	1144.8	1151.8	1162.3	1172.2	1177.0	
31	1105.0	1110.9	1115.5	1119.9	1122.7	1127.0	1130.5	1138.5	1145.8	1150.2	
32	1103.7	1108.1	1112.9	1117.7	1120.8	1125.6	1128.9	1134.3	1139.4	1146.4	
33	1102.7	1107.4	1117.3	1130.3	1138.1	1150.6	1159.0	1166.9	1175.6	1178.9	
34	1103.6	1108.0	1118.9	1130.0	1137.0	1147.9	1155.5	1164.0	1172.4	1175.8	
35	1102.3	1105.1	1110.2	1115.6	1119.5	1125.6	1129.6	1134.8	1139.4	1146.0	

TABLE 25
TYPICAL AREA SUMMARY SHEET
(1)

5 KWE RANDOM CORE RUN 1A, 12/1/72

CORE MATERIAL AREA DISTRIBUTION

	SQ. IN.	PERCENT
TOTAL CORE AREA	85.9160	100.000
FUEL AREA	58.7375	68.366
HYDROGEN GAP AREA	1.5217	1.771
BARRIER AREA	0.6359	0.740
CLAD AREA	7.1512	8.323
COOLANT AREA	9.5443	11.109
EDGE FILLER AREA	8.3255	9.690

NOTE - THE ABOVE INCLUDES AVERAGE FIN AREA WHICH MAY VARY AXIALLY

TABLE 26
TYPICAL 60 RIPPLE SHEET
(29)

5 KWE RANDOM CORE RUN 1A, 12/1/72

SIX THETA RIPPLE TEMPERATURES

ELEMENT NO. 1												
0.0	1106.24	1099.73	1106.66	1099.76	1105.25	1099.84	1103.83	1099.87	1103.40	1099.87	1104.40	1099.80
0.19	1130.98	1117.32	1135.26	1119.79	1131.37	1117.13	1125.79	1118.41	1124.69	1115.54	1126.00	1117.33
0.21	1134.90	1121.30	1132.37	1124.88	1130.30	1121.23	1129.39	1122.05	1133.13	1119.57	1136.58	1121.60
0.39	1174.07	1151.66	1169.95	1160.26	1167.02	1153.77	1160.72	1145.83	1166.83	1157.58	1177.25	1159.66
0.41	1173.24	1157.35	1170.49	1164.87	1171.27	1158.70	1168.90	1150.41	1174.34	1162.89	1179.46	1165.52
0.50	1190.41	1175.74	1185.24	1176.76	1186.96	1175.73	1189.70	1170.10	1194.78	1180.36	1197.22	1183.25
0.59	1208.58	1192.57	1201.46	1189.25	1202.47	1192.74	1206.48	1187.98	1211.57	1198.00	1214.69	1200.11
0.63	1218.85	1199.56	1213.85	1196.78	1210.55	1199.10	1206.91	1193.59	1210.04	1205.32	1218.69	1206.64
0.79	1242.43	1227.82	1241.14	1228.75	1235.44	1223.86	1224.45	1207.32	1226.34	1227.75	1238.62	1227.72
0.81	1242.03	1231.29	1239.42	1231.28	1235.51	1226.78	1226.70	1210.01	1230.29	1230.17	1241.71	1230.15
1.00	1243.19	1242.61	1241.85	1238.11	1239.08	1237.06	1234.13	1226.31	1235.67	1239.48	1241.95	1240.02
ELEMENT NO. 2												
0.0	1106.47	1099.73	1105.55	1099.82	1103.87	1099.87	1103.24	1099.88	1103.48	1099.85	1105.03	1099.76
0.19	1131.59	1115.74	1130.39	1115.01	1125.76	1117.08	1126.27	1120.15	1127.47	1117.65	1128.16	1116.19
0.21	1127.56	1119.70	1130.99	1118.81	1135.88	1120.60	1136.43	1124.75	1132.10	1121.46	1128.12	1119.92
0.39	1158.69	1147.82	1164.73	1152.17	1171.79	1151.64	1174.32	1160.09	1169.04	1151.90	1160.97	1147.75
0.41	1168.19	1152.28	1173.64	1156.94	1173.40	1156.17	1170.92	1164.88	1169.48	1157.43	1166.52	1152.72
0.50	1188.04	1169.33	1195.50	1173.20	1190.36	1168.83	1182.90	1176.79	1184.13	1175.81	1184.14	1171.87
0.59	1202.39	1185.85	1207.16	1189.68	1203.22	1182.66	1197.16	1189.30	1200.00	1192.65	1201.30	1190.04
0.63	1206.97	1192.53	1213.56	1197.76	1211.99	1189.32	1204.67	1197.03	1205.95	1200.03	1206.69	1197.09
0.79	1229.76	1216.34	1236.24	1228.93	1236.19	1217.67	1231.91	1228.92	1234.72	1228.23	1232.52	1222.64
0.81	1230.92	1219.02	1236.49	1231.65	1237.76	1221.21	1234.83	1231.30	1237.25	1231.47	1234.61	1226.30
1.00	1237.91	1229.18	1236.84	1237.75	1239.20	1235.26	1238.60	1238.12	1241.47	1242.64	1243.15	1241.79
ELEMENT NO. 3												
0.0	1106.35	1099.81	1104.02	1099.88	1102.91	1099.89	1103.29	1099.86	1104.87	1099.77	1106.82	1099.71
0.19	1133.97	1116.93	1125.39	1117.40	1121.50	1112.48	1120.53	1113.26	1125.34	1116.97	1134.89	1119.65
0.21	1134.72	1120.94	1128.21	1120.06	1124.20	1115.35	1124.83	1117.26	1131.14	1120.92	1137.02	1124.58
0.39	1171.96	1152.10	1156.76	1139.53	1149.31	1141.81	1159.59	1155.17	1171.04	1153.35	1175.95	1159.87
0.41	1168.76	1156.36	1161.04	1143.04	1161.62	1146.17	1171.68	1161.17	1172.72	1158.76	1170.38	1164.90
0.50	1180.77	1169.01	1174.61	1157.96	1179.58	1165.59	1193.61	1182.38	1193.40	1175.81	1185.54	1176.81
0.59	1195.10	1182.84	1190.14	1173.74	1197.06	1184.42	1210.53	1201.83	1209.35	1192.32	1200.82	1189.33
0.63	1208.82	1189.36	1197.23	1180.43	1195.34	1191.13	1208.04	1208.60	1215.31	1198.92	1214.20	1196.64
0.79	1234.51	1217.70	1220.44	1204.02	1214.44	1210.02	1225.78	1228.86	1235.28	1223.73	1238.01	1228.67
0.81	1232.89	1221.43	1220.83	1207.57	1218.02	1213.00	1232.63	1231.26	1241.01	1226.54	1238.47	1231.26
1.00	1238.13	1235.31	1232.44	1226.15	1229.82	1228.73	1237.07	1241.32	1241.02	1237.02	1239.46	1238.11

TABLE 27
TYPICAL EQUIVALENT ΔT SHEET
(3)

5 KWE RANDOM CORE RUN 1A, 12/1/72

EQUIVALENT CROSS ELEMENT OUTER CLAD TEMPERATURE GRADIENTS, DEG F

Z/L =	0.19	0.21	0.39	0.41	0.50	0.59	0.63	0.79	0.81	1.00
1	6.1/ 98	2.6/ 21	9.9/ 23	6.6/ 6	8.2/330	10.7/325	10.6/ 6	16.9/ 52	15.0/ 46	10.2/ 45
2	1.7/340	5.9/207	12.2/208	6.0/196	2.7/ 92	3.7/ 27	2.2/ 53	3.4/231	4.5/238	6.6/291
3	10.5/ 6	10.2/356	22.0/328	15.0/310	18.2/278	20.1/265	20.8/290	23.0/316	22.4/306	11.3/308
4	9.2/310	2.7/329	19.0/117	19.6/106	22.8/101	23.5/101	24.7/106	28.3/122	23.4/119	14.1/130
5	11.7/164	4.5/133	19.7/ 44	18.8/ 65	22.9/ 78	26.6/ 78	24.9/ 54	29.0/ 30	30.2/ 32	17.1/ 28
6	7.9/ 77	8.5/101	19.1/130	10.5/124	11.1/116	11.5/111	19.6/142	19.9/171	15.6/169	7.9/178
7	3.4/ 10	3.8/ 20	7.5/304	14.8/262	18.3/243	22.7/230	14.9/212	15.3/184	17.2/183	14.4/179
8	4.4/177	6.5/214	16.4/202	11.6/174	14.2/174	16.6/169	20.6/200	28.1/207	27.6/196	17.4/192
9	6.1/264	0.7/143	12.5/ 41	14.7/ 44	17.4/ 54	18.3/ 57	19.8/ 44	24.1/ 20	20.3/ 4	15.8/341
10	5.5/ 69	7.8/ 82	9.9/109	9.2/103	7.0/104	4.0/ 77	4.4/ 75	6.8/ 77	7.1/ 65	10.9/ 13
11	6.5/164	1.9/ 26	15.0/336	14.1/337	13.8/349	15.1/351	14.8/319	18.2/309	19.2/320	19.0/336
12	4.9/259	4.1/185	10.1/130	9.9/140	9.3/138	10.3/135	7.6/126	4.2/ 76	11.1/ 64	16.3/ 31
13	9.7/ 45	3.5/ 22	12.2/263	4.9/286	2.0/ 6	3.7/ 61	5.0/217	14.1/194	8.2/168	11.4/ 90
14	6.3/129	5.1/186	20.2/218	20.8/208	19.0/207	18.2/208	13.7/235	6.8/269	1.1/301	7.8/ 84
15	8.3/ 2	8.6/ 5	15.7/ 31	10.2/ 11	11.9/ 2	12.8/ 10	18.4/ 38	17.8/ 61	12.5/ 62	12.5/ 92
16	4.7/ 69	5.1/358	8.4/313	9.9/289	7.5/280	4.7/266	4.8/253	8.2/238	7.0/187	12.0/156
17	3.7/ 28	5.1/181	19.2/162	16.2/177	17.0/196	20.2/217	11.4/202	7.2/153	10.7/173	15.2/192
18	7.8/171	7.4/221	15.9/245	8.1/233	1.4/243	3.5/ 80	3.7/121	8.7/202	8.9/219	12.6/223
19	3.7/ 17	1.7/245	8.4/223	12.7/238	19.2/232	22.3/232	14.6/244	14.6/257	14.9/256	18.2/244
20	4.3/ 10	2.5/230	9.2/228	7.6/287	12.7/285	17.0/281	14.8/265	20.4/255	26.7/259	31.9/262
21	3.9/106	5.1/ 74	9.9/ 6	12.0/354	15.7/343	18.9/341	22.8/333	30.4/333	26.5/326	21.2/330
22	5.6/192	5.6/203	6.0/212	7.7/290	13.4/292	16.7/305	18.6/293	24.8/283	23.5/293	18.5/300
23	7.5/ 28	7.9/ 24	12.6/ 12	13.3/ 8	19.3/355	24.6/351	26.0/349	30.4/348	30.5/347	28.6/340
24	6.4/ 42	4.7/ 68	5.4/ 90	8.3/ 17	16.6/358	20.3/347	22.6/345	26.2/337	22.1/330	18.3/312
25	6.8/304	6.4/300	12.7/323	16.6/355	24.5/ 9	29.0/ 13	28.2/ 5	30.0/ 10	32.0/ 22	24.9/ 38
26	5.2/110	3.3/124	7.0/ 92	11.9/ 39	19.1/ 10	26.9/ 5	28.4/ 6	34.8/ 13	31.1/ 19	24.7/ 14
27	2.6/214	4.0/261	5.8/336	2.1/ 32	4.5/150	8.9/171	5.6/103	18.6/ 69	13.7/ 80	11.6/ 76
28	6.2/208	1.3/318	12.5/ 17	6.0/ 13	6.0/326	6.9/308	12.8/309	9.3/311	9.2/326	6.0/ 12

TABLE 28
TYPICAL FORCE BALANCE SHEET
(1)

5 KWE RANDOM CORE RUN 1A, 12/1/72

FORCE BALANCE & STRESS SUMMARY

ELEM	FORCE	M/S	PHI	FORCE	M/S	PHI	FORCE	M/S	PHI	FORCE	M/S	PHI	FORCE	M/S	PHI
1	0.47	38.47	272.	0.56	47.47	23.	0.59	30.76	155.	0.02	73.05	300.	0.0	66.30	235.
6	0.08	51.67	240.	0.08	49.60	64.	0.10	53.17	355.	0.09	45.07	180.	0.11	57.06	0.
11	0.03	61.24	34.	0.0	54.63	308.	0.0	65.01	39.	0.0	70.90	324.	0.0	61.06	100.
16	2.46	8.24	120.	0.01	60.11	300.	0.00	64.55	240.	0.0	45.54	44.	0.0	63.09	348.
21	0.01	67.99	120.	0.0	87.77	148.	0.0	77.47	237.	0.11	63.48	180.	0.04	55.49	180.
26	0.0	84.41	272.	0.0	78.27	297.	0.35	34.72	90.	0.40	34.62	300.	0.0	65.77	142.
31	0.0	56.67	61.	2.46	8.36	300.	0.10	60.06	180.	0.0	79.68	94.	0.04	57.27	120.
36	0.00	73.51	60.	0.0	83.85	165.	0.0	85.76	244.	0.01	68.53	0.	0.01	62.73	180.
41	0.0	61.97	257.	0.10	73.91	0.	0.0	77.10	143.	0.03	68.46	300.	0.0	85.32	142.
46	0.0	71.34	344.	0.0	45.93	272.	0.20	66.90	180.	0.0	67.82	243.	0.04	81.62	180.
51	0.06	64.00	23.	0.08	54.95	120.	0.0	100.65	11.	0.0	86.25	263.	0.0	77.55	247.
56	0.10	74.98	0.	0.04	79.41	300.	0.0	77.07	21.	0.0	95.64	244.	0.0	67.51	343.
61	0.06	66.29	240.	0.0	93.82	103.	0.0	73.07	157.	0.05	96.42	0.	0.05	76.80	180.
66	0.10	73.18	180.	0.03	94.81	120.	0.0	77.37	63.	0.0	47.54	176.	0.0	82.29	223.
71	0.0	113.02	343.	0.0	104.39	232.	0.0	67.02	247.	0.03	104.10	240.	0.01	88.99	180.
76	0.09	103.49	304.	0.0	63.84	357.	0.0	57.33	53.	0.0	76.57	291.	0.0	108.55	80.
81	0.0	51.32	272.	0.0	90.98	16.	0.0	98.26	353.	0.0	100.61	152.	0.06	71.07	60.

CRITICAL ELEMENT (16) STRESS DETAILS

THETA	6 TH STRESS	BEND STRESS	TOTAL STRESS	CONTACT FORCE	HOOP STRESS	AXIAL STRESS	EQUIV STRESS	M/S
60	-791.	258.	-533.	0.0	0.	0.	160.	211.60
120	-937.	516.	-421.	0.0	0.	0.	126.	268.16
180	-1345.	258.	-1087.	0.0	0.	0.	326.	103.25
240	-1722.	-258.	-1980.	0.0	0.	0.	594.	56.23
300	-1503.	-516.	-2020.	2.462	3529.	1511.	3681.	8.24
360	-980.	-258.	-1239.	0.0	0.	0.	372.	90.50

NOTE - ALL DATA IS AT CONTACT PLANE, 10.6 IN

TABLE 29
TYPICAL STRESS DETAIL SHEET
(21)

5 KWE RANDOM CORE RUN 1A, 12/1/72

ELEMENT STRESS DETAILS

THETA	6 TH STRESS	BEND STRESS	TOTAL STRESS	CONTACT FORCE	HOOP STRESS	AXIAL STRESS	EQUIV STRESS	M/S
ELEMENT NUMBER 1								
60	-1345.	-81.	-1426.	0.255	343.	149.	726.	45.82
120	-1677.	-84.	-1760.	0.284	383.	166.	861.	38.47
180	-928.	-3.	-941.	0.0	0.	0.	282.	119.44
240	-792.	81.	-711.	0.0	0.	0.	213.	158.43
300	-1651.	84.	-1567.	0.0	0.	0.	470.	71.33
360	-1466.	3.	-1463.	0.0	0.	0.	439.	76.49
ELEMENT NUMBER 2								
60	-2162.	92.	-2070.	0.0	0.	0.	621.	53.76
120	-1993.	-14.	-2007.	0.0	0.	0.	602.	55.48
180	-673.	-106.	-780.	0.391	537.	232.	701.	47.47
240	-1012.	-92.	-1104.	0.255	350.	151.	636.	52.45
300	-945.	14.	-931.	0.0	0.	0.	279.	120.70
360	-777.	106.	-671.	0.0	0.	0.	201.	167.99
ELEMENT NUMBER 3								
60	-1325.	-10.	-1335.	0.0	0.	0.	401.	83.88
120	-567.	94.	-473.	0.0	0.	0.	142.	238.80
180	-1197.	104.	-1092.	0.0	0.	0.	328.	102.76
240	-1026.	10.	-1016.	0.0	0.	0.	305.	110.56
300	-1134.	-94.	-1228.	0.284	353.	156.	675.	49.40
360	-2062.	-104.	-2167.	0.391	485.	214.	1071.	30.76
ELEMENT NUMBER 4								
60	-1408.	-2.	-1410.	0.0	0.	0.	423.	79.38
120	-1444.	-4.	-1449.	0.022	28.	12.	459.	73.05
180	-1068.	-2.	-1070.	0.0	0.	0.	321.	104.93
240	-862.	2.	-860.	0.0	0.	0.	258.	130.84
300	-1055.	4.	-1051.	0.0	0.	0.	315.	106.87
360	-1225.	2.	-1222.	0.0	0.	0.	367.	91.71

TABLE 30
TYPICAL INTERFERENCE CHECK SHEET
(11)

5 KWF RANDOM CORE RUN 1A, 12/05/72

ELEMENT INTERFERENCE CHECK AT ELEVATION 1.0 INCHES

1	10.0	10.1	10.5	12.5	11.9	8.9	9.9	9.0	8.6	10.7	9.8	10.8	8.0	9.0
15	8.5	8.2	9.7	9.9	11.2	10.3	8.9	8.0	10.8	11.5	10.2	10.0	11.4	9.6
29	10.2	10.2	9.2	8.6	7.9	12.3	10.1	9.0	9.6	10.2	10.9	9.3	9.2	8.9
43	8.7	8.6	8.4	9.3	8.1	6.6	8.6	8.2	11.4	13.2	8.2	8.7	7.4	10.1
57	9.3	10.6	10.2	7.3	9.0	10.8	9.8	9.0	9.7	8.6	11.1	10.6	10.5	11.8
71	10.0	10.7	8.9	9.7	9.0	8.0	8.8	12.7	10.9	10.2	11.0	12.4	11.4	9.7
85	10.5	8.1	9.8	9.3	10.2	10.1	12.4	11.2	8.4	9.7	9.3	7.2	8.5	9.4
99	7.5	9.5	12.6	10.8	12.7	12.4	11.1	7.7	11.9	11.1	11.2	9.2	9.4	11.5
113	10.8	11.9	7.9	10.7	10.1	10.9	10.9	10.9	8.3	9.1	9.6	8.6	10.7	12.1
127	10.7	7.7	9.8	9.1	9.9	11.4	11.9	13.3	10.1	7.9	11.2	9.9	12.8	9.4
141	10.9	10.9	9.9	10.3	12.9	11.1	10.0	12.8	12.2	8.4	8.3	10.9	10.8	10.1
155	8.1	8.8	12.4	12.3	12.0	11.2	11.0	10.1	7.9	8.1	9.7	9.0	9.6	10.7
169	13.5	11.5	10.2	13.0	12.9	10.9	10.1	9.4	10.6	11.0	11.4	9.1	11.2	10.4
183	8.8	9.8	10.4	12.2	13.4	13.1	9.9	12.5	9.0	10.3	10.5	10.0	10.8	8.8
197	9.1	8.4	10.2	9.2	9.3	8.2	8.1	8.9	10.8	10.6	9.1	10.2	10.4	11.7
211	11.4	12.6	10.8	9.0	9.5	9.4	9.6	13.1	11.0	10.9	10.1	9.4	6.9	8.4
225	9.3	10.1	10.8	12.1	12.2	10.7	9.9	10.0	9.7	9.1	11.9	7.9	3.7	11.1
239	9.5	9.1	10.5	11.9	10.9	10.6	8.6	10.6	9.9	9.1	10.0	10.0	11.7	10.7
253	10.6	11.2	11.8	11.6	9.8	10.0	9.3	10.0	10.5	9.1	10.2	9.3	9.8	10.1
267	10.5	10.3	11.4	12.4	12.0	11.2	9.0	9.1	9.7	10.4	8.6	9.7	9.7	10.2
281	7.5	8.6	10.9	10.5	9.2	8.4	9.3	9.5						

THERE ARE 0 INTERFERENCE POINTS (NEGATIVE VALUE) AT THIS ELEVATION

VII. REFERENCES

1. E. Moody, "Core Sector Thermal-Hydraulic Code GEOM2," TI-696-24-063 (March 26, 1970)*
2. E. Moody, "60° Core Sector Thermal Hydraulic Code GEOM3," TI-759-240-039 (April 15, 1971)*
3. E. Moody, "360° Core Thermal Hydraulic Code GEOM85," TI-653-200-003 (April 19, 1972)*
4. W. A. Sangster, "Calculation of Rod Bundle Pressure Loss," ASME Paper 68-WE/HT-35.
5. D. E. Bourne, et al., "Laminar and Turbulent Flow in Annuli of Unit Eccentricity," CJCE, Vol 46, October 1968
6. A. R. Marchese, "Experimental Study of Heat Transfer to NaK Flowing In-Line Through Tightly Packed Rod Bundles," TR-653-360-001 (October 10, 1971)*
7. L. D. Felten, "Correlation of NaK Film Coefficients and Cladding Temperature Ripple for Input to the GEOM Computer Program," IL (March 1, 1971)*
8. L. D. Felten, "Thermal Conductivity and Temperature Jump for Hydrogen-Helium Mixtures," TI-653-240-021 (February 9, 1972)*
9. L. D. Felten, "NaK Film Coefficients and 60° Temperature Ripple for the ZrH Reference Reactor," TI-759-240-038 (April 1, 1971)*
10. E. Moody to J. Asquith, "Heat Transfer Test 60° Ripple Correlation," IL (March 6, 1972)*
11. R. A. Castle, "Fuel Element Computerized Stress Analysis with Core Force Balance," TI-652-240-008 (August 25, 1972)*
12. E. Moody to A. N. Nichols, "Simultaneous Equation Solution," IL (January 27, 1972)*
13. E. Moody, "TEMPRO2 - Heat Transfer and Reactivity Lifetime Computer Code," TI-696-24-065 (April 1969) (CRD)

*Internal document, not for general distribution.

Symbol	Parameter	Units	Symbol	Parameter	Units
A	Area	in. ²	μ	Viscosity, Poisson's Ratio	lb/ft-hr
c_p	Specific Heat	Btu/lb	ρ	Density	lb/ft ³
d	Diameter	in.	σ	Stress, Stefan-Boltzmann Constant	psi
d_H	Equivalent Diameter	in.	ϕ	Deflection and Force Angles	deg
E	Modulus of Elasticity	psi		Power Ratio	-
f_f	Friction Factor	-	<u>Subscripts</u>		
F_R	Radiation Emissivity Factor	-	A	Axial	
F_A	Radiation Configuration Factor	-	ALL	Allowable	
g	Gravitational Constant	ft/sec ²	B	Bending, Barrier	
h	Height	in.	BC	Bypass Circumferential	
	Heat Transfer Coefficient	Btu/hr-ft ² -°F	BP	Bypass	
I	Moment of Inertia	in. ⁴	BV	Bypass to Vessel	
k	Thermal Conductivity, Constant	Variable	CF	Cross Flow	
L	Length	Btu/ft-nr-°F	cl	Cladding	
M_t	Restrained Moment due to Temperature Gradient	in.-lb	CH	Channel	
M	Virtual Moment	in.	co	Coolant	
M_s	Margin of Safety	-	CR	Coolant to Reflector	
N	Number	-	e,E	Element	
Nu	Nusselt Number	-	EQ	Equivalent	
P	Pressure	psi	f	Fin	
	Force	lb	F	Fuel, Free	
	Power	kwt	G	Gap	
PD	Power Density	kwt/ft	H	Hoop, Hot End	
P_w	Wetted Perimeter	in.	i	Denotes Order in an Array	
Q, q	Heat Flux	Btu/hr	I	In	
r	Radius	in.	M	Manufacturing, Mixing	
R	Thermal Resistance	ft-F-hr/Btu	MAX	Maximum	
Re	Reynolds Number	-	MIN	Minimum	
S	Element to Element Spacing	in.	n	Denotes Numerical Order of Elements	
S_f	Fin to Element Clearance	in.	O	Out	
t	Thickness	in.	P	Load, Contact Plane	
T	Temperature	°F, °R	R	Radial, Resultant, Reflector	
V	Velocity	fp	RB	Reflector to Bypass	
W	Width	in.	RC	Reflector Circumferential	
$\dot{w}$	Flow Rate	lb/hr	S	Spring	
x	Axial Distance from Cold End	in.	T	Temperature	
y	Pitch/Diameter Effect on f_f	-	t	Thickness	
z	Fin Geometry Effect on f_f	-	TOT	Total	
α	Instantaneous Coefficient of Thermal Expansion	in./in.-°F	V	Vessel	
δ	Deflection	in.	VC	Vessel Circumferential	
θ	Circumferential Angle of Temperature	deg	VW	Vessel to Ambient	
			W	Wall	

Table 1. Nomenclature