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CREDIT DOCUMENTATION AND THE MARK 15 SUBROUTINE

INTRODUCTION

Part of the process of preparing the Mark 15 assembly for production operation is the development of thermal-hydraulic limits for the assembly. These limits require, among other items, the development of a Mark 15 assembly subroutine for the CREDIT code. While developing the heat generation data for this assembly subroutine, it was discovered that the low thermal conductivity, thick wall tubes in the Mark 15 had a skewed heat generation profile.

The heat transfer model in CREDIT could not handle the unusual heat generation profile in the Mark 15. As a result, the CREDIT code required modifications to the heat transfer models and the matrix inversion algorithm. While attempting these modifications, small errors were found in one section of the heat

*Only the Introduction and Summary will be sent to these addressees.

transfer theory and another section could not be verified. Because of this, it was decided to rewrite the heat transfer subroutine.

SUMMARY

Documentation for the CREDIT code is presented. Explanations on data input, output, heat transfer theory, hot subchannel factor (HCF) calculations, and the procedure for creating a new assembly subroutine are included. The section on how to generate an assembly subroutine uses the Mark 15 assembly as an example. Summaries of the important subroutines in CREDIT are also given.

Output differences between the old and modified CREDIT codes are presented for a number of parameters. The modified CREDIT code calculates lower HCF's for both Mark 16B and Mark 22 assemblies. For E-D charges, the Mark 16B HCF would be lowered an average of 0.5% from 0% to 45% ^{235}U burnup while for Mark 22 assemblies, the HCF is decreased an average of 0.4% for the same burnup range. The $BOSF_n$ parameter changes are less than 3% while the heat split parameter changes are less than 6%. Changes in the typical heat transfer characteristics are small and are presented.

DISCUSSION

This portion of the report is divided into several sections which discuss

- Output changes in the old and modified CREDIT code
- Heat transfer model in the CREDIT code
- Computer solution of the heat transfer theory
- Explanation of CREDIT output
- HCF calculations in CREDIT
- How to generate an assembly subroutine for CREDIT
- Sample data input

In addition to these sections, three appendices are also provided which

- Discuss how to calculate the flat portion of the HCF curve for Mark 16/16B assemblies (Appendix A)
- Discuss the important subroutines in the CREDIT code (Appendix B)

- Discuss how to calculate heat generation parameters from GLASS computer code data (Appendix C)

Initially, the CREDIT code was to be slightly modified to handle the Mark 15 assembly. The modifications were needed to better model the variation in volumetric heat generation across the low thermal conductivity, thick wall tubes in the Mark 15 assembly. However, as the work progressed, it became apparent that a simple modification to CREDIT would not be adequate for the Mark 15 development. The subroutine for the heat transfer calculations -- subroutine DOTT -- had to be rewritten. The original coding was over 20 years old and could not be verified. During this process, errors in the coefficients of the volumetric heat generation polynomial were found. Also, a new matrix inversion subroutine was added instead of trying to modify the old inversion subroutine. The new inversion subroutine was needed to handle the larger matrices which are used by the Mark 15.

Because of the difficulties encountered in rewriting subroutine DOTT, it was decided to upgrade the CREDIT code with comment cards and documentation on how the code is programmed. Previous documentation[1-5] is not adequate. This report is intended to provide sufficient documentation so that the user can understand the limitations on the parameters calculated by CREDIT. To accomplish this goal, a section on the heat transfer theory was included since References 4 and 5, which previously discussed the theory, give incorrect algebraic expressions. Flow charts for the important subroutines are also included. In explaining how to write an assembly subroutine, the development of the Mark 15 subroutine is presented.

Output Changes

This section will discuss some of the changes in assembly heat transfer characteristics which occur when using the modified CREDIT code. Heat splits, $BOSF_n$ variation, and HCF changes for Mark 16B and Mark 22 assemblies are three items where changes over an entire reactor cycle are presented. Also, tables of general heat transfer characteristics are presented for 0% ^{235}U burnup in Mark 16B and Mark 22 assemblies.

The changes in the computational method between the current and modified CREDIT are not, at first glance, significant. They are:

- The new CREDIT is in double precision whereas the old CREDIT was not.
- The new CREDIT uses a matrix inversion technique from IMSL[6] whereas the old CREDIT uses an individually

written inversion subroutine. The IMSL subroutine is capable of handling matrices larger than third order, which is necessary for Mark 15 work. The Mark 15 assemblies require a fifth order matrix.

- The new CREDIT uses a rewritten subroutine DOTT which performs the heat transfer calculations. The coding in the old DOTT was extremely difficult to follow. Also, there was an error in the coefficients in the volumetric heat generation polynominal.

Figures 1-3 show the differences in HCF, heat split, and $BOSF_n$ for the Mark 16B assembly. Table 1 lists the input parameters which were used to calculate these variables. In Figures 1 and 2, the middle fuel tube results are shown because this tube now has the assembly control surface (outer surface) for online calculations by the reactor control and safety computers. The significance of the differences in heat split values shown in Figure 1 is being evaluated by Reactor and Reactor Materials Technology Department (RRMTD) personnel. In Figure 2, the $BOSF_n$ changes are small; the effect of the different $BOSF_n$ on BOR calculations are also small. The new HCF curve in Figure 3 shows a reduction in the 18% - 40.5% burnup range and a small increase above 40.5% burnup. The net effect is a 0.5% reduction in HCF for an entire E-D fuel cycle. For present reactor operation, this HCF reduction would result in a 0.5% increase in reactor power.

Table 2 tabulates the general heat transfer characteristics for the old and modified CREDIT codes for the conditions in Table 1. The differences between the two code versions are small. When comparing the different channel exit temperatures and HCF curves in Figure 3, the sensitivity of HCF calculations to channel temperature is shown.

Figures 4-6 and Tables 3 and 4 present the same information for the Mark 22 assemblies. As for the Mark 16B assemblies, the differences between the two CREDIT versions are small.

HEAT TRANSFER MODEL

The heat transfer model in CREDIT was first presented in DP-512[4] and later discussed in DP-1392[5]. However, neither reference has a complete explanation of the heat transfer theory. Sign errors and omission of π terms are two problems that were discovered during this review. Because of this problem, the heat transfer model will be presented in this section. There is no change in the basic heat transfer theory described in Reference 4 or 5, the only addition is consistency in sign conventions and surface area calculations.

The DOTT subroutine of CREDIT, where the heat transfer calculations are performed contained very difficult coding. For this reason, the DOTT subroutine was rewritten. At the same time, the necessary modifications for the n^{th} order volumetric heat generation polynomial across the tube core were incorporated in the coding. Sufficient comment statements are also included in the new DOTT subroutine so that the programming is easily understandable.

Some of the variables for the following equations are shown in Figures 7 and 8 while all of the variables are defined in the nomenclature section. Figure 7 correlates the variables with specific points in the tube where the subscript 'j' denotes the j^{th} tube.

When following the heat transfer theory, Figure 8 indicates the major heat transfer modes. The sign convention is heat transfer out of a control volume (CV) is positive while heat transfer into a CV is negative. The q_4 and q_1 terms are convective heat transfer rates and are defined by

$$q_4 = 2\pi R_{4,j} h_{4,j} (T_{4,j} - T_j) \Delta L$$

$$q_1 = 2\pi R_{1,j} h_{1,j} (T_{1,j} - T_{1,j}) \Delta L$$

A distinction is made between q_3 and q_3' and also between q_2 and q_2'. Although they are related by,

$$q_3 = q_3'$$
$$q_2 = q_2'$$

when looking at their definitions

$$q_3 = \pi D_{3,j} \Delta L \left(-k_{f_j} \frac{dt}{dr}\right)$$

$$q_3' = \pi D_{3,j} \Delta L \left(-k_{c_j} \frac{dt}{dr}\right)$$

$$q_2 = \pi D_{2,j} \Delta L \left(-k_{f_j} \frac{dt}{dr}\right)$$

$$q_2' = \pi D_{2,j} \Delta L \left(-k_{c_j} \frac{dt}{dr}\right)$$

a difference in the k dt/dr term appears. When following the theory, one must remember this distinction and also that the derivative term dt/dr does not exist for the cladding material because of the modeling technique used to determine dt/dr for the tube core. This modeling technique required a heat generation term which does not exist for the cladding.

The basic heat transfer equations will be determined by using the steady state integral form of the energy equation

$$\rho\int_\sigma e\bar{V}\cdot\bar{n}d\sigma = -\int_\sigma \bar{q}\cdot\bar{n}d\sigma - P_S + \int_V q''' \, dv - P_T$$

For our problem, this equation reduces to

$$\rho\int_\sigma e\bar{V}\cdot\bar{n}d\sigma + \int_\sigma \bar{q}\cdot\bar{n}d\sigma = \int_V q'''dv \qquad (1)$$

where σ = control volume surface
e = energy per unit mass
$\bar{q}$ = heat transfer vector
q''' = heat generation per unit volume

In CREDIT, the assembly length is normally divided into 150 increments. The various forms of Equation 1 are then used to calculate the assembly heat transfer characteristics at each i^{th} level.

The energy balance for coolant channel j, the i^{th} level, is derived from the left hand side of Eq. 1,

$$\rho\int_\sigma e\bar{V}\cdot\bar{n}d\sigma + \int_\sigma \bar{q}\cdot\bar{n}\, d\sigma = 0 \qquad (2)$$

since there is no heat generation in the bulk coolant. Figure 9 shows the control volume for the j^{th} coolant channel. The second term in Eq. 2 is defined by

$$\int_\sigma \bar{q}\cdot\bar{n}d\sigma = \int_\sigma \bar{q}_j\cdot\bar{n}d\sigma_j + \int_\sigma \bar{q}_{j+1}\cdot\bar{n}d\sigma_{j+1}$$

where

$$\int_\sigma \bar{q}_j\cdot\bar{n}d\sigma_j = h_{4,j}(T_{i,j} - T_{4,j})(+1)(\pi D_{4,j}\Delta L)$$

$$\int_\sigma \bar{q}_{j+1}\cdot\bar{n}d\sigma_{j+1} = h_{1,j}(T_{i,j} - T_{1,j+1})(+1)(\pi D_{1,j+1}\Delta L)$$

The +1 term in each of the above expressions is the sign of the dot product $\bar{q}\cdot\bar{n}$. A +1 value occurs when the q and n vectors are pointed in the same direction. When these vectors are pointed in

opposite directions, a -1 value results. The first term in Eq. 2 is defined by

$$\int_\sigma \rho e\bar{V}\cdot\bar{n}d\sigma = \rho e\int_\sigma \bar{V}\cdot\bar{n}d\sigma_{in} + \rho e\int_\sigma \bar{V}\cdot\bar{n}d\sigma_{out}$$

$$= \rho C_p T_{i-1,j}\int_\sigma \bar{V}\cdot\bar{n}d\sigma_{in} + \rho C_p T_{i,j}\int_\sigma \bar{V}\cdot\bar{n}d\sigma_{out}$$

$$= [\rho C_p T_{i-1,j}(-V) + \rho C_p T_{i,j}(V)][\tfrac{\pi}{4}(D_{4,j}^2 - D_{1,j+1}^2)]$$

Now by defining the mass flow M_j, lbm/hr, as

$$M_j = \rho V[\tfrac{\pi}{4}(D_{4,j}^2 - D_{1,j+1}^2)]$$

the first term in Eq. 2 is defined as

$$\int_\sigma \rho e\bar{V}\cdot\bar{n}d\sigma = M_j C_p(T_{i,j} - T_{i-1,j})$$

The expression for Eq. 2 is now

$$M_j C_p(T_{i,j} - T_{i-1,j}) = \pi\Delta L[D_{4,j}h_{4,j}(T_{4,j} - T_{i,j}) + \quad (3)$$

$$D_{1,j+1}h_{1,j+1}(T_{1,j+1} - T_{i,j})]$$

Equation 3 agrees with the equivalent expressions in References 4 and 5.

The energy balance for tube j is determined by dropping the first term from Eq. 1, since $\bar{V} = 0$, to get

$$\int_\sigma \bar{q}\cdot\bar{n}d\sigma = \int_v q'''dv$$

In this equation the control volume in Figure 10 is the i^{th} level of the entire j^{th} tube. The term on the right is simply.

$$\int_v q'''dv = Q\phi \quad (4)$$

where Q = heat generation for the total tube, pcu/hr
ϕ = parameter which determines the fraction of assembly heat in the i^{th} level

The ϕ parameter is the APHI(I,J) variable in the CREDIT code. It is determined in the DITTY subroutine once an axial flux shape is determined. The term to the left of the equal sign in Eq. 4 is defined as

$$\int_{\sigma} \bar{q}\cdot\bar{n}d\sigma = \int_{\sigma} \bar{q}_1\cdot\bar{n}d\sigma_1 + \int_{\sigma} \bar{q}_4\cdot\bar{n}d\sigma_4$$

where q_1 and q_4 are shown in Figure 10. The integral expressions for q_1 and q_4 are

$$\int_{\sigma_1} \bar{q}\cdot\bar{n}d\sigma_1 = h_{1,j}(T_{1,j} - T_{j-1})(+1)(\pi D_{1,j}\Delta L)$$
$$\int_{\sigma_4} \bar{q}\cdot\bar{n}d\sigma_4 = h_{4,j}(T_{4,j} - T_j)(+1)(\pi D_{4,j}\Delta L)$$

where the +1 term is the sign of the $\bar{q}\cdot\bar{n}$ dot product. The resulting expression for Equation 4 is

$$Q\phi = \pi\Delta L[D_{1,j}h_{1,j}(T_{1,j} - T_{j-1}) + D_{4,j}h_{4,j}(T_{4,j} - T_j)] \quad (5)$$

The equivalent equation in DP-1392 was correct. However, the DP-512 expression had omitted the π term.

It is necessary to model the Q variable in the last equation so that the individual assembly heat generation rates are adequately considered. First, the radial variation in Q can be determined from

$$\frac{1}{r}\frac{d}{dr}\left(r\frac{dt}{dr}\right) = \frac{-q'''}{k} \quad (6)$$

However, in order for this equation to be useful an expression for $q'''(r)$ is needed. The volumetric heat generation q''' varies with changing neutron flux and fissionable material. Since the flux and amount of fissionable material varies with distance r from the moderator, q''' is $q'''(r)$. The old CREDIT code used

$$q''' = a + br + cr^2 \quad (7)$$

for $q'''(r)$. However, this model is not adequate for tubes with thick wall, low thermal conductivity combinations. Since the Mark 15 assembly has thick tubes with low conductivity, Equation 7 is inadequate. As a result, the revised CREDIT code is capable of

assuming

$$q''' = \sum_{i=1}^{M} a_i r^{i-1} \qquad (8)$$

Calculations to be discussed in the assembly subroutine section of this report indicate that M=5 is adequate for Mark 15 assemblies. The new CREDIT is programmed such that M=7 is the maximum order polynominal allowed. If a new assembly is designed with M>3, the DOTT subroutine in the new CREDIT will require additional coding in the form of logical IF statements. The additional coding will be between the DATA and CALL CLEAR statements and would be similar to the coding for the Mark 15 assembly. These statements are needed to branch to the statements which define the matrix coefficients. The remainder of the DOTT coding which requires a value for M is programmed such that no additional coding is required.

The method for determining the a_i coefficients in Equation 8 will be discussed in the next section.

Once q''' is defined, an expression for the temperature profile in the tube core can be determined. With the temperature profile, the conduction heat transfer terms , q_2 and q_3 in Figure 8, can be determined. Knowing q_1, q_2, q_3, and q_4, it is then possible to formulate the equations using the appropriate control volume from which the tube temperatures can be calculated.

Combining Equations 6 and 8 and then integrating gives

$$\frac{dt}{dr} = \frac{B_j}{r} - \frac{1}{k_{f_j}} \sum_{i=1}^{M} \frac{a_i r^{i+1}}{i+1} \qquad (9)$$

where B_j is a constant of integration. To obtain the temperature at any point in the tube core, integrate Equation 9 from $R_{3,j}$ to $R_{m,j}$, where $R_{m,j}$ is the radius corresponding to a point in the core, to obtain

$$T_{m,j} = B_j \ln \frac{R_{m,j}}{R_{3,j}} - \frac{1}{k_{f_j}} \left[\sum_{i=1}^{M} \frac{a_i}{(i+1)^2} \left(R_{m,j}^{i+1} - R_{3,j}^{i+1}\right)\right] + T_{3,j} \qquad (10)$$

In the revised DOTT subroutine, the program divides the tube core into 100 increments and calculates the core temperature using this equation at each step. The highest temperature from these 100 increments is then considered to be the maximum core temperature. An average core temperature is also calculated for each tube by

taking a simple average of the temperature for the 100 increments. The average core temperature is needed for the current physics model that is used to calculate temperature coefficients. The old version of CREDIT divided the core into 1000 increments which is considered too fine a grid.

The B_j term is evaluated by applying Equation 1 to the inner cladding of the j^{th} tube. Figure 11 shows the control volume for this situation. Since the cladding does not generate any power, Equation 1 reduces to

$$\int_{\sigma} \bar{q} \cdot \bar{n} \, d\sigma = 0$$

or

$$\int_{\sigma_4} \bar{q}_4 \cdot \bar{n} \, d\sigma_4 + \int_{\sigma_3} \bar{q}_3 \cdot \bar{n} \, d\sigma_3 = 0 \qquad (11)$$

where

$$\int_{\sigma_4} \bar{q}_4 \cdot \bar{n} \, d\sigma_4 = (+1) h_{4,j} (T_{4,j} - T_j) \, \Delta L \pi D_{4,j} \qquad (12)$$

$$\int_{\sigma_3} \bar{q}_3 \cdot \bar{n} \, d\sigma_3 = \left[-k_f \frac{dt}{dr}_3\right](-1)(-1)\pi \Delta L D_{3,j} = 0 \qquad (13)$$

In the q_4 expression, the +1 term is the sign of the dot product. For the q_3 expression, the -1 terms result from

- o Sign of the $\bar{q}_3 \cdot \bar{n}$ dot product
- o The vector quantity, $-k_f (dt/dr)_{3,j}$, pointed in the negative r direction

Combining Equations 12 and 13 into Equation 11 and solving for the temperature derivative gives

$$\frac{dt}{dr}_{3,j} = \frac{D_{4,j}}{D_{3,j}} \frac{h_{4,j}}{k_f} (T_{4,j} - T_j) \qquad (14)$$

The equivalent equation in DP-1392 has a negative sign on the right hand side while DP-512 appears to be correct. By evaluating Equation 9 at $D_{3,j}$ and then combining with Equation 14, the expression for B_j is found to be

$$B_j = \frac{D_{4,j}}{D_{3,j}} \frac{h_{4,j}}{k_f} (T_{4,j} - T_j) + \frac{1}{k_{f_j}} \sum_{i=1}^{3} \frac{a_i R_{3,j}^{i+1}}{(i+1)} \qquad (15)$$

The core-clad interface temperatures, $T_{2,j}$ and $T_{3,j}$, are determined from the control volume in Figures 11 and 12. For Figure 11, Equation 1 reduces to

$$\int_{\sigma} \bar{q} \cdot \bar{n} d\sigma = 0$$

or

$$\int_{\sigma_4} \bar{q}_4 \cdot \bar{n} d\sigma_4 + \int_{\sigma_3} \bar{q}_3' \cdot \bar{n} d\sigma_3 = 0 \qquad (16)$$

where the $\bar{q}_4$ term is defined by Equation 12. Equation 16 is the same expression as Equation 11 since $\bar{q}_3 = \bar{q}_3'$. However, the $\bar{q}_3'$ expression cannot be evaluated with Equation 13 since there is no simple way to determine the temperature derivative across the cladding. If the q''' term in Equation 6 existed for the clad material, it would be possible to use Equation 13 to evaluate q_3'. Since the clad does not have nuclear heat generation, q''' for the aluminum cladding is zero. The $\bar{q}_3$ expression is determined from

$$q_3' = -2\pi r \Delta Lk_c \frac{dt}{dr}$$

Rearranging and integrating gives

$$q_3' \int_{R_{3,j}}^{R_{4,j}} \frac{dr}{r} = -2\pi \Delta Lk_c \int_{T_{3,j}}^{T_{4,j}} dt$$

Solving for q_3' gives

$$q_3' = \frac{-2\pi Lk_c (T_{4,j} - T_{3,j})}{\ln \frac{R_{4,j}}{R_{3,j}}} \qquad (17)$$

The minus sign is missing from this equation in DP-1392 while the equivalent equation in DP-512 is correct. Combining Equations 12 and 16 into Equation 11 gives

$$T_{3,j} = T_{4,j} + R_{4,j} \frac{h_{4,j}}{k_c} (T_{4,j} - T_j) \ln \frac{R_{3,j}}{R_{4,j}} \qquad (18)$$

This expression is correct in DP-512 but the ratio $R_{3,j}/R_{4,j}$ is reversed in DP-1392.

To develop an equivalent expression for $T_{2,j}$, use the CV in Figure 12. Equations similar to Equations 12, 16, and 17 can be derived to give

$$T_{2,j} = T_{1,j} + R_{1,j}\frac{h_{1,j}}{k_c}(T_{1,j} - T_{j-1}) \ln \frac{R_{1,j}}{R_{2,j}} \qquad (19)$$

At this point, Equations 5, 18, and 19 have the four unknown temperatures, $T_{1,j}$, $T_{2,j}$, $T_{3,j}$, and $T_{4,j}$. The fourth equation which is needed to determine these temperatures is a special form of Equation 10. By letting $R_{m,j}$ equal $R_{2,j}$ and $T_{m,j}$ equal $T_{2,j}$, one can get

$$T_{2,j} - T_{3,j} = B_j \ln \frac{R_{2,j}}{R_{3,j}} - \frac{1}{k_{f_j}}\left[\sum_{i=1}^{M} \frac{a_i}{(i+1)^2}\left(R_{2,j}^{i+1} - R_{3,j}^{i+1}\right)\right]$$

$$= B_j \ln \frac{R_{2,j}}{R_{3,j}} - C_j . \qquad (20)$$

where $$C_j = \frac{1}{k_{f_j}}\left[\sum_{i=1}^{M} \frac{a_i}{(i+1)^2}\left(R_{2,j}^{i+1} - R_{3,j}^{i+1}\right)\right]$$

To solve for $T_{1,j}$ and $T_{4,j}$, two equations are needed. Equation 5 is one. The other equation is obtained by substituting Equations 18 and 19 into Equation 20 to get

$$T_{1,j} - T_{4,j} = B_j \ln\frac{R_{2,j}}{R_{3,j}} - C_j - R_{1,j}\frac{h_{1,j}}{k_c}(T_{1,j} - T_{j-1})\ln \frac{R_{1,j}}{R_{2,j}} \qquad (21)$$

$$+ \frac{R_{4,j}h_{4,j}}{k_c}(T_{1,j} - T_{j-1})\ln\frac{R_{3,j}}{R_{4,j}}$$

The convective heat transfer coefficient is calculated from[8]

$$h_c = \left[157.48 + 3.5533\ T_f - 7.4581 \times 10^{-3}\ T_f^2 - 1.1714 \times 10^{-6}\ T_f^3\right] V^{0.8}/D_e^{0.2}$$

where T_f = film temperature, $1/2(t_s + t_b)$, °C

t_s = tube surface temperature, °C

t_b = bulk coolant temperature, °C

V = fluid velocity, ft/sec

D_e = hydraulic diameter, inches

This equation is the Colburn equation where the physical constants have been correlated as a function of film temperature.

Computer Solution of Heat Transfer Model

The DOTT subroutine solves Equations 5, 18, 19, and 21 for the unknown tube temperatures and Equation 3 for the bulk coolant temperatures in each channel. In solving for these unknowns, initial tube surface temperatures -- $T_{1,j}$ and $T_{4,j}$ -- must be specified along with the initial bulk channel temperatures for only the first assembly length increment. The computer code assumes the initial bulk channel temperatures to be equal to the plenum inlet temperature while the initial tube surface temperatures are equal to the plenum inlet plus 60°C.

The CREDIT code divides an assembly into IJ levels where IJ is normally 150. If an assembly length is 12.5 ft., then the assembly is divided into 1 inch length increments. The heat transfer characteristics are then calculated at each length increment. Before these characteristics can be calculated, the tube surface and bulk coolant temperatures for each channel must be available for the previous length increment. This requirement is why the initial tube surface and channel temperatures in the previous paragraph are given . They are needed for the first length increment. For the remaining length increments, the calculated bulk coolant and tube surface temperatures for the $i-1^{th}$ level are used as initial conditions for the i^{th} level calculations.

Once initial temperatures are specified, the convective heat transfer coefficients from each tube surface are calculated. Since these coefficients are calculated as functions of bulk coolant and tube surface temperatures, the initial temperatures must be specified before these coefficients can be calculated. Once the heat transfer coefficients are calculated, Equation 3 is used to calculate the individual bulk channel temperatures. The DOTT subroutine in turn then calculates for each length increment

- $T_{i,j}$ and $T_{4,j}$ using Equations 5 and 21

- $T_{2,j}$ and $T_{3,j}$ using Equations 18 and 19
- Maximum core temperature using Equation 10
- Average core temperature

Once the unknown temperatures are calculated, the code moves to the next length increment. No iterative technique is used to recalculate the convective heat transfer coefficient for the i^{th} level. The one inch length of each increment is small enough that the iteration on heat transfer coefficient would produce very small, if any, changes in the heat transfer characteristics.

The simultaneous solution of Equations 5 and 21 for the surface clad temperature is difficult. In order to follow this solution in the DOTT subroutine, some additional comments are needed. First, Equations 5 and 21 were rewritten as

$$T_{1,j} + \alpha T_{4,j} = \beta$$

$$(\eta+1)T_{1,j} - (1+\omega+\mu)T_{4,j} = \psi$$

where the Greek variables are defined in Table 5. Solving these two equations then gives

$$T_{4,j} = \frac{\beta(\eta+1) - \psi}{1+\omega+\mu+\alpha(\eta+1)}$$

$$T_{1,j} = \beta - \alpha T_{4,j}$$

Before the unknown tube and channel temperatures can be calculated, the a_i coefficients in Equation 8 must be known. Since these coefficients define the variation in heat generation across the tube core, their values are dependent on assembly type. For all but the Mark 15 assemblies, there are three unknown coefficients. The Mark 15 has five unknowns. These volumetric heat generation rates are named RPHI(I,NU) in the CREDIT code and are defined in the assembly subroutine. The RPHI(I,NU) and PF(NU) variables are determined by fitting an n^{th} order polynomial to assembly power data generated by the GLASS[9] computer code. PF(NU) is the normalized power fraction of the NU tube in the assembly. The method for calculating these variables is discussed in the assembly subroutine section.

As discussed in the assembly subroutine section, the RPHI values are specified for each core-clad interface and each core midpoint. The Mark 15 is slightly different and will be discussed in the following paragraphs. By reading in three RPHI values and knowing the tube radius for each RPHI, three equations in three unknowns -- the a_i values -- are generated from Equation 8. Subroutine MAINV then inverts the coefficient matrix to solve for the a_i values.

It must be remembered that the a_i values from the MAINV subroutine are normalized values. As such, they must be scaled to correctly model the tube's volumetric heat generation. At each length increment in the assembly, the total heat generation is known to be $Q\phi$. The volumetric heat generation in Equation 8 is related to $Q\phi$ by

$$Q\phi = \varepsilon \int_{R_{3,j}}^{R_{2,j}} q''' dv$$

$$= \varepsilon \int_{R_{3,j}}^{R_{2,j}} \left(\sum_{i=1}^{M} a_i r^{i-1} \right) 2\pi \Delta L r dr$$

where ε = scaling factor

$dv = 2\pi \Delta L r dr$

Solving for ε gives

$$\varepsilon = \frac{Q\phi}{2\pi \Delta L \sum_{i=1}^{M} a_i \left(\frac{R_{2,j}^{i+1} - R_{3,j}^{i+1}}{i+1} \right)}$$

The DOTT subroutine calculates ε for each length increment and then redefines the a_i values as εa_i. It is necessary to recalculate ε at each length increment because $Q\phi$ changes for each increment. The old CREDIT did not use this method as it appeared to calculate one ε value for the entire tube length.

The difference between the Mark 15 and other assemblies is the Mark 15 uses M=5 in Equation 8 while all other current assemblies use M=3. The same procedure for determining the a_i values is used for any type assembly. The lone difference is the Mark 15 has a higher order matrix to invert. Since the Mark 15 uses a fourth order expression for q''' in Equation 8, five different RPHI expressions for each tube are needed. One RPHI expression is needed for the inner and one for the outer tube core

regions. Three additional regions in the core interior were also selected for the three remaining RPHI equations. The radii for these five RPHI expressions in CREDIT are determined with the PC variable in the DOTT subroutine. Additional remarks on the Mark 15 assembly are in the assembly subroutine section.

Slight changes in the nomenclature exist between the equations in this report and the new CREDIT code. Figure 13 shows the coding nomenclature for a four tube assembly.

Explanation of CREDIT Output

In Tables 6-11, a sample output for a Mark 42 assembly is given. A shorter printout can be obtained by specifying PRINT equal zero in the input data. The user would only receive the output in Tables 6-8.

The first output page is a listing of the user's input data. This data should be reviewed carefully to verify that all data is correct as specified. It also provides a good summary of the input operating conditions.

The second output page in Table 7 summarizes the important assembly heat transfer characteristics. The first four groupings of data are assembly parameters. The four diameters are the inside and outside diameters of each cladding layer. The RADIAL POWER numbers are the RPHI (volumetric heat generation) variables evaluated at the desired burnup. In Table 7, the surfaces are labeled as being the outer and inner core diameters and the diameter of the core center. For the Mark 15 assembly, only the outer and inner core diameters are numbered. The remaining three RPHI values do not have a surface number. The power fractions are the PF(NU) variables evaluated at the desired burnup. The clad and core conductivities are the thermal conductivities, k, in pcu/hr-ft-°C.

The MAX TEMP results are the maximum temperatures for each surface in the assembly. For example, the maximum temperature for the inner diameter (surface 2) of the outer clad for tube 3 is 105.05°C; this temperature occurs at level 125. The surface 2 identification has a square drawn around it while the level number is within a circle. Note that the level changes from one tube to another. The maximum core temperature does not occur at the core midpont or even the same tube radius along the tube length. Because of this, the surface for the maximum temperature is not listed.

The next variable is the MAX HEAT FLUX in pcu/(hr-ft^2). It gives the maximum convective heat transfer and is listed for the inner and outer tube surfaces. As for the next four output

variables, the level in the tube where the variable value occurs is also listed. The surface with the highest heat flux defines the tube level at which the next four variables on the printout are defined. In Table 7, the maximum heat flux for tube 3 occurs at level 124. As a result, the BOSF MIN-NOM, HEAT FLUX, TSUB, and BULK DT values are also given for level 124.

The minimum nominal $BOSF_n$ for each tube surface is the next variable. It is dimensionless and is programmed such that 900 is the maximum value that can be printed. The number is generally not useful for the universal sleeve housing (USH), inner housings, and target tubes.

HEAT FLUX and TSUB are the next variables in Table 7. The units for HEAT FLUX are $pcu/(hr\text{-}ft^2)$. TSUB is defined as the amount of subcooling for the cooling water. This number gives an indication of how close one approaches boiling at the point of maximum heat flux. The BULK DT is the temperature rise in °C of the coolant from the channel entrance.

The next output variable is the average surface heat split from each tube surface in the assembly. Summing these values for all the assembly tube surfaces gives a total of one. This variable gives an idea of how much of the total assembly power is being dissipated by a single tube surface.

The remainder of Table 7 summarizes channel information. The equivalent diameter has units of inches while the units on inlet pressure are psia. The EFFLUENT TEMP is the channel exit temperature in °C and the EFFLUENT, MIXED-MEAN TEMPERATURE is simply the assembly exit temperature in °C.

The third page of printout in Table 8 gives each channel's HCF, if this assembly's nonideality factors are programmed into the code. An additional variable, HT1, is also printed on this output page. In the various assembly hydraulic manuals, HT1 is the H_t variable. It is printed so that the user can determine whether HCF values for a 0-4 year or a 4-5 year USH are being calculated.

The fourth page of output in Table 9 starts the long print option of CREDIT. This page lists different surface temperatures every 15 levels in an assembly. The level numbers are inside the rectangle of Table 9. At the bottom of Table 9, the average cladding and tube core temperatures are listed. These numbers are currently needed as input to the physics model which calculates temperature coefficients. The average temperatures are simple averages of the ten temperatures listed for each row in the upper part of the table. For example, the average inner clad OD temperature (in the small rectangle) for tube 2 is the average of

the ten numbers in the dashed rectangle. These average temperatures are calculated in subroutine LONG.

The fifth and sixth output pages in Table 10 and 11 are similar to Table 9 in that a listing of important heat transfer characteristics is given for every 15th level in the assembly. In Table 11, the average temperature of the entire coolant channel is given. These numbers are also needed as input to the temperature coefficient model and are calculated using the same procedure that was used for determining the average clad and core temperatures.

HCF Calculation

The DITTY subroutine calculates the HCF values for Mark 16/16B, Mark 42, and Mark 22 assemblies. The subroutine is not programmed to handle other quadrant monitored assemblies. Also it is not programmed to calculate any HCF values for annular monitored assemblies.

The HCF calculation procedure is discussed in Reference 10. In summary, the HCF is calculated from the equation

$$HCF = 1 + \sqrt{(HCF_n - 1)^2 + \Sigma (h_i - 1)^2} \qquad (22)$$

where HCF_n = nominal hot subchannel factor

$$HCF_n = \frac{\Delta T_{assembly}}{\Delta T_{HP}} \quad \frac{\Delta T_{channel}}{\Delta T_{assembly}} \quad \frac{\Delta T_{subchannel}}{\Delta T_{channel}}$$

$$\frac{\Delta T_{channel}}{\Delta T_{assembly}} = \frac{\text{Channel Exit Temperature - Inlet Temperature}}{\text{Assembly Exit Temperature - Inlet Temperature}}$$

$$\frac{T_{assembly}}{\Delta T_{HP}} = 0.98 \text{ for Mark 16/16B assemblies} \qquad (23)$$

$$\frac{\Delta T_{subchannel}}{\Delta T_{channel}} = H_t$$

H_t = nonideality which accounts for variation in coolant temperature within one flow channel. This value is given in the respective assembly hydraulic manuals.

h_i = nonideality factors

ΔT_{HP} = effluent temperature as indicated by the hottest thermocouple (hot pin or HP) minus the assembly inlet temperature.

The H_t and h_i factors are assembly and channel dependent. There are a total of five h_i factors. Table 12 lists the values of these factors for the outer flow channel of a Mark 16B assembly. In the DITTY subroutine coding, the H_t factor for channel 1 is labeled HT1 while successive channels are HT2, HT3, etc. The value of the $\Sigma(h_i - 1)^2$ term is labeled SH1 for channel 1 while successive channels are SH2, SH3, etc. The ratio in Equation 23 is an experimentally determined number.

There is one case where an HCF value cannot be calculated. The problem occurs when the $(HCF_n - 1)$ term in Equation 22 is a negative number. When this happens, the coding sets the HCF value for that channel equal to zero. In Table 8, channels 1 and 2 had a $(HCF_n - 1)$ term less than zero.

To produce an HCF curve for an assembly, it is necessary to use the limiting HCF for each channel at a given burnup. Figure 14 shows the HCF values for the three channels which determine the modified CREDIT results in Figure 3. In Figure 14, the HCF values for each channel are plotted and a curve for each channel is drawn. After the individual channel curves are drawn, the limiting HCF line is a composite of whichever channel lines are limiting.

The only exception to determining HCF values by this technique is when HCF values have been calculated from thermocouple data. Figure 14 shows the cutoff line which was obtained from Mark 16 thermocouple assemblies.[10] A sample calculation of how to determine the horizontal cutoff for a different lithium loading is in Appendix A.

HCF factors for several assemblies are dependent on whether a 0-4 year or a 4-5 year USH is in use. The H_t factor in Table 12 is the factor which takes into account the increased USH rib wear when using an USH with 4-5 years of actual service life. In the CREDIT printout, H_t is printed below the HCF factors to remind the user as to whether the HCF factors are for a 0-4 or 4-5 year USH. For the Mark 16, Mark 16B, and Mark 42 assemblies, the H_t factor in Table 12 is increased by 2.1%[11] for a 4-5 year USH. Reference 12 discusses reasons for increasing rib wear in an USH with increasing life.

GENERATING AN ASSEMBLY SUBROUTINE

An assembly subroutine contains

- Basic assembly parameters
- Experimentally derived equations for pressure losses in flow channels and bottom fitting inserts
- Experimentally derived equations for the assembly flow distribution into the individual channels
- Tube power fractions, PF(NU), and volumetric heat generation, RPHI(I,NU), equations

The contents of the Mark 15 assembly subroutine will be discussed in this section.

The initial section of the subroutine contains basic assembly parameters. The first data statement contains the inner and outer diameters (inches) of the inner and outer cladding. Since this Mark 15 contains four tubes -- USH, outer fuel, inner fuel, inner housing -- a total of sixteen diameter values are given. The USH and inner housing must be given four diameter values, even though they do not have separate clad and core regions. The second DATA statement contains the equivalent diameter (DIAME in inches) for the four channels, the assembly height (HEIGHT in feet), and the fuel conductivity (FUELCD in pcu/hr-ft-°C). Four values of fuel conductivity are given. The second and third values are for the Mark 15 fuel slugs while the first and fourth are for the USH and inner housing. Since the USH and inner housing have no fuel, their core conductivity is the same as for the aluminum cladding. The variables in these DATA statements must be properly subscripted in the preceeding DIMENSION statements.

After the DATA statements, a number of DO loops are used to redefine the DIAME, DIAM, HEIGHT, and thermal conductivity variables with the variable names that are used in the remainder of the program. The integer KTB is then defined as the number of tubes in an assembly. The USH and inner housing for the Mark 15 are included in the KTB variable. For a Mark 16B assembly, with an USH, three fuel tubes, and either an inner target or housing, KTB would equal 5. After KTB is defined, several parameters are assigned default values if required by the input data. Then, constant values for the density and specific heat of heavy water are defined.

The next variable is the elevation term, ELEV. It represents the static head from the top of the Mark 15 slug column to the bottom of the reactor tank. It is a summation of

- o total slug length, 156.96 inches
- o bottom fitting insert length, 14 inches
- o length of monitor pin between the bottom of the reactor tank to the lower end of the bottom fitting insert, 1.82 inches
- o spacer length between the bottom fitting insert and the lower most slug of the Mark 15 slug column, 5.52 inches

The D_2O density that is used with the elevation difference is referenced at 65°C, roughly the average of the entering and exiting flow temperatures. This 65°C is a 'standard' value for the average assembly temperature and is used in several other limits codes. The ELEV term is used in the code to help determine the fluid saturation pressure at any point in each channel in the assembly by using the experimentally determined equations which are discussed in the following paragraphs. Once the local saturation pressure is known, the amount of subcooling in the channel can be calculated. In the current coding, the amount of subcooling has no effect on the assembly heat transfer characteristics. However, it does effect the $BOSF_N$ parameter.

The next section of the assembly subroutine contains experimentally derived equations. The first set of equations defines the flow splits into the individual channels. These equations and the other experimental results for the Mark 15 are given in Reference 13. Once the channel flows (gpm) are determined, the bulk channel velocities (ft/sec) are calculated. The pressure loss through the bottom fitting insert is then calculated. The appropriate logic is used to reference the correct bottom fitting insert equations. These equations are different for different reactors and also for different shell hole ranges. If the input data references a nonexistant bottom fitting, an error message is printed. After the bottom fitting equations, experimentally derived equations for the pressure loss through the core and per foot of channel length are given.

The pressure loss equations are used to calculate the pressure in each flow channel. Once the pressure is calculated, the saturation temperature can be determined. Since the actual channel temperature is calculated in the DOTT subroutine, the subcooling at each level in each channel is available.

The next section of the assembly subroutine is the power fraction and volumetric heat generation values. These two variables, PF(NU) and RPHI(I,NU), are determined from the GLASS[9] computer code. Appendix C discusses how to calculate these values.

The tube core had to be divided into more than three regions for the Mark 15 assembly. The reason is a third order equation for q''' in Equation 8 did not adequately model the actual GLASS data. Figure 15 shows a representative second order q''' from Equation 8 and the actual GLASS data for a Mark 15 fuel tube. The agreement is not satisfactory. The reasons are that the Mark 15 is a thick wall tube with low thermal conductivity. These two factors combine to give the poor agreement in Figure 15.

The Mark 15 fuel tube core was divided into ten regions to provide adequate RPHI data. Five regions were chosen for input into CREDIT, one inner, one outer, and three interior regions. The five RPHI equations were then used by CREDIT to determine the a_i values in Equation 8. The resulting nondimensional expression for q''' was plotted and compared with the data from the ten regions in GLASS. The initial comparisons were not satisfactory and different inner regions were chosen to generate the RPHI equations. The final comparisons for the two Mark 15 fuel tubes are shown in Figures 16 and 17 for 0% ^{235}U burnup and in Figures 18 and 19 for 14.5% ^{235}U burnup.

The RPHI variable in CREDIT is a double subscripted variable and is normally written as RPHI(I,NU). The second subscript denotes the tube number where the outermost tube (the USH) is NU=1, the second tube is NU=2, etc. The first subscript denotes the radial position of the volumetric heat generation. For example, for the middle fuel tube of the Mark 16B assembly

- RPHI(1,3) is the volumetric heat generation at $D_{2,3}$, the outer core diameter
- RPHI(3,3) is the volumetric heat generation at $D_{3,3}$, the inner core diameter
- RPHI(2,3) is the volumetric heat generation at $(D_{2,3} + D_{3,3})/2$, the middle of the core

The difference in RPHI(I,NU) for the Mark 15 assembly when compared to current assemblies is that for a given tube NU, I ranges from one to five. For non-Mark 15 assemblies, I ranges from one to three.

The power fraction for each tube, PF(NU), is the other variable which is obtained from GLASS. The power fraction polynomials are given for each tube in an assembly and are normalized such that for a given burnup, their sum equals one. By normalizing the power fractions, the actual tube power is simply calculated by CREDIT as a product of the tube power fraction and

the input assembly power in MW. For the Mark 15, the ^{235}U burnup range on the power fractions is 0% to 14.5%. If a burnup greater than 14.5% is specified in the input data, an error message is printed.

After the PF(NU) equations, the assembly subroutine then renormalizes the PF(NU) equations such that their sum equals one. Then, the subroutine calculates the assembly power if thermocouple data is provided. If no thermocouple data is provided, subroutine DITTY is called. After calling DITTY, the HOTCHA subroutine is called only if the user wants to calculate HCF from thermocouple data.

Sample Data Input

A sample data input for CREDIT is in Table 13 while Table 14 is a general listing of the input variables. Table 15 matches up some of the input values in Table 13 with the proper variable names to give an idea of the output that Table 13 will generate.

NOMENCLATURE

C_j	See Equation 20
C_p	Specific heat, pcu/lbm-°C
CV	Control Volume
B_j	Integration constant for tube j, defined by Equation 15
$D_{1,j}$	Outer diameter of outer cladding for tube j, ft
$D_{2,j}$	Inner diameter of outer cladding for tube j, ft
$D_{3,j}$	Outer diameter of inner cladding for tube j, ft
$D_{4,j}$	Inner diameter of inner cladding for tube j, ft
e	energy per unit mass, pcu/lbm
$h_{1,j}$	convective heat transfer coefficient for outside surface of tube j, pcu/hr-ft^2-°C
$h_{4,j}$	convective heat transfer coefficient for inside surface of tube j, pcu/hr-ft^2-°C
k_{c_j}	cladding thermal conductivity of tube j, pcu/hr-ft-°C c
k_{f_j}	fuel thermal conductivity of tube j, pcu/hr-ft-°C
ΔL	assembly length increment, ft
M	order plus one of the volumetric heat generation polynomial
M_j	mass flow of channel j, lbm/hr
$\tilde{n}$	unit vector normal to control surface
P_s	shaft work
P_τ	shear work
$\tilde{q}$	heat transfer vector, pcu/hr-ft^2
q'''	volumetric heat generation, pcu/hr-ft^3
Q	heat generation for a total tube, pcu/hr

V	channel velocity, ft/sec
v	volume of control volume in Equation 1, ft^3
r	radius, ft
$R_{1,j}$	$D_{1,j}/2$
$R_{2,j}$	$D_{2,j}/2$
$R_{3,j}$	$D_{3,j}/2$
$R_{4,j}$	$D_{4,j}/2$
t	temperature, °C
$T_{1,j}$	temperature of outer diameter of outer cladding for tube j, °C
$T_{2,j}$	temperature of inner diameter of outer cladding for tube j, °C
$T_{3,j}$	temperature of outer diameter of inner cladding for tube j, °C
$T_{4,j}$	temperature of inner diameter of inner cladding for tube j, °C
T_j	bulk temperature of coolant channel j, °C
T_{j-1}	bulk temperature of coolant channel j-1, °C
ε	scaling factor
ρ	density, lbm,/ft^3
σ	control volume surface
ϕ	parameter which determines the fraction of assembly heat in the i^{th} level

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TABLE 1
COMMON CHARACTERISTICS FOR THE MK16B PARAMETERS IN TABLE 2

% ^{235}U Burnup	0%
Number of Shell Holes	62 (P Reactor)
Li - Al loading, g/ft	1.2
Inlet Temperature, °C	35
Assembly Power, MW[a]	6.0
Assembly Flow, gpm	300

Tube metal temperatures include heat transferred from bulk moderator.

a. Does not include heat transferred from bulk moderator (95°C).

TABLE 2
MARK 16B OPERATING CHARACTERISTICS WITH THE
OLD AND REVISED CREDIT PROGRAM

	OLD CREDIT	REVISED CREDIT
Channel effluent temperature, °C		
Channel 1 (Outer)[a]	110.4	108.9
Channel 2 (Outer Middle)	111.4	112.3
Channel 3 (Inner Middle)	103.7	104.1
Channel 4 (Inner)	92.9	91.7
Assembly effluent temperature, °C	106.7	106.9
Maximum nominal heat flux, kpcu/(hr)(ft^2)		
Tube 2 (Outer Fuel) - Outer Surface	248	243
- Inner Surface	288	294
Tube 3 (Middle Fuel) - Outer Surface	291	291
- Inner Surface	309	310
Tube 4 (Inner Fuel) - Outer Surface	187	192
- Inner Surface	199	196
Minimum $BOSF_n$		
Tube 2 (Outer Fuel) - Outer Surface	2.637	2.695
- Inner Surface	2.654	2.579
Tube 3 (Middle Fuel) - Outer Surface	2.628	2.606
- Inner Surface	2.616	2.599
Tube 4 (Inner Fuel) - Outer Surface	4.396	4.315
- Inner Surface	3.952	4.068
Tube metal temperatures		
Tube 2 (Outer Fuel) - Outer Surface	157.0	159.1
- Maximum Core	165.2	167.2
- Inner Surface	155.2	156.8
Tube 3 (Middle Fuel) - Outer Surface	155.6	156.1
- Maximum Core	167.9	168.3
- Inner Surface	154.8	155.2
Tube 4 (Inner Fuel) - Outer Surface	132.2	130.3
- Maximum Core	140.2	138.4
- Inner Surface	130.7	129.2

TABLE 2, continued
MARK 16B OPERATING CHARACTERISTICS WITH THE
OLD AND REVISED CREDIT PROGRAM

	OLD CREDIT	REVISED CREDIT
Heat Splits		
Tube 2 (Outer Fuel) - Outer Surface	0.2113	0.1964
- Inner Surface	0.2307	0.2386
Tube 3 (Middle Fuel) - Outer Surface	0.2002	0.1908
- Inner Surface	0.1837	0.1946
Tube 4 (Inner Fuel) - Outer Surface	0.0918	0.0891
- Inner Surface	0.0776	0.0854

a. Includes heat transferred from bulk moderator (95°C)

TABLE 3
COMMON CHARACTERISTICS FOR THE MK22 PARAMETERS IN TABLE 4

% ^{235}U Burnup	0
Number of Shell Holes	36
Inlet Temperature, °C	35
Assembly Power, MW[a]	7.0

Tube metal temperatures include heat transferred from bulk moderator.

a. Does not include heat transferred from bulk moderator (95°C).

TABLE 4
MARK 22 OPERATING CHARACTERISTICS WITH THE
OLD AND REVISED CREDIT PROGRAM

	OLD CREDIT	REVISED CREDIT
Channel effluent temperature, °C		
Channel 1 (Outer)[a]	90.9	90.2
Channel 2 (Outer Middle)	101.7	100.4
Channel 3 (Inner Middle)	103.5	104.6
Channel 4 (Inner)	95.4	94.6
Assembly effluent temperature, °C	100.9	100.9
Maximum nominal heat flux, kpcu/(hr)(ft^2)		
Tube 2 (Outer Target) - Outer Surface	3.9	3.6
- Inner Surface	15.1	15.2
Tube 3 (Outer Fuel) - Outer Surface	481	473
- Inner Surface	508	517
Tube 4 (Inner Fuel) - Outer Surface	447	451
- Inner Surface	452	447
Minimum $BOSF_n$		
Tube 2 (Outer Target) - Outer Surface	180	195
- Inner Surface	103	102
Tube 3 (Outer Fuel) - Outer Surface	2.543	2.619
- Inner Surface	2.768	2.690
Tube 4 (Inner Fuel) - Outer Surface	3.151	3.089
- Inner Surface	2.927	2.980
Tube metal temperatures		
Tube 2 (Outer Target) - Outer Surface	101.9	100.6
- Maximum Core	101.9	100.7
- Inner Surface	101.9	100.7
Tube 3 (Outer Fuel) - Outer Surface	158.6	161.6
- Maximum Core	180.2	182.7
- Inner Surface	156.8	158.6
Tube 4 (Inner Fuel) - Outer Surface	149.7	147.9
- Maximum Core	173.4	171.9
- Inner Surface	150.0	148.9

TABLE 4, continued
MARK 16B OPERATING CHARACTERISTICS WITH THE
OLD AND REVISED CREDIT PROGRAM

	OLD CREDIT	REVISED CREDIT
Heat Splits		
Tube 2 (Outer Target) - Outer Surface	0.0008	0.0006
- Inner Surface	0.0096	0.0096
Tube 3 (Outer Fuel) - Outer Surface	0.3032	0.2825
- Inner Surface	0.2907	0.3060
Tube 4 (Inner Fuel) - Outer Surface	0.2092	0.2009
- Inner Surface	0.1767	0.1905

a. Includes heat transferred from bulk moderator (95°C)

TABLE
5
VARIABLES USED IN SOLVING
EQS. 5 AND 21

$$\eta = R_{1,j}^{\frac{h_{1,j}}{k_{c_j}}} \ln\frac{R_{1,j}}{R_{2,j}}$$

$$\mu = R_{4,j}^{\frac{h_{4,j}}{k_{c_j}}} \ln\frac{R_{3,j}}{R_{4,j}}$$

$$\omega = R_{4,j}^{\frac{h_{4,j}}{k_{f_j}}} \ln\frac{R_{2,j}}{R_{3,j}}$$

$$\theta' = \left(\ln\frac{R_{2,j}}{R_{3,j}}\right)\left(\frac{1}{k_{f_j}} \sum_{i=1}^{M} a_i \frac{R_{3,j}^{i+1}}{i+1}\right)$$

$$\psi = \theta' - C_j - (\omega + \mu)T_j + \eta T_{j-1}$$

$$\alpha = \frac{D_{4,j}}{D_{1,j}} \frac{h_{4,j}}{h_{1,j}}$$

$$\beta = \alpha T_j + T_{j-1} + \frac{Q\phi}{\Delta L \pi D_{1,j} h_{1,j}}$$

TABLE
6
FIRST PAGE OF OUTPUT FOR LONG PRINT OPTION

DITTY-IV SUMMARY CALCULATION OF MK42 HCF- 0% BURNUP 101

FUEL LENGTH, FT	12.50	STD FUEL LENGTH, FT	12.50	DIST BETWN TOPS OF FUELS	0.0
MODERATOR TEMP	95.00	MODERATOR VELOCITY	4.00	MOD HEAT TRANS COEF	1050.
MOD INLET PRESSURE	21.70	MOD PRES LOSS /FT	-0.47	CONY	0.
VARK	0.	COOLANT DENSITY	67.70	ITG	0
HEAT CAPACITY	0.997	FLUX SHAPE	0.	TYPE EDIT	1.
MIN ASSY POWER	3.00	MAX ASSY POWER	7.00	# POWER INCREMENTS	2.
MIN INLET TEMP	25.00	MAX INLET TEMP	45.00	# INLET TEMP INCREMENTS	2.
# OF LENGTH INCREMENTS	150	ASSEMBLY FLOW RATE,GPM	360.0		
ENDFITTING TYPE	1	NO. OF SHELL HOLES	70		

FLUX SHAPES- INPUT

0.57	0.91	1.10	1.17	1.17	1.13	1.05	0.92	0.84	0.80	0.80	0.85	0.94	1.07	1.17	1.22	1.23	1.17	1.02	0.76
0.57	0.91	1.10	1.17	1.17	1.13	1.05	0.92	0.84	0.80	0.80	0.85	0.94	1.07	1.17	1.22	1.23	1.17	1.02	0.76
0.57	0.91	1.10	1.17	1.17	1.13	1.05	0.92	0.84	0.80	0.80	0.85	0.94	1.07	1.17	1.22	1.23	1.17	1.02	0.76
0.57	0.91	1.10	1.17	1.17	1.13	1.05	0.92	0.84	0.80	0.80	0.85	0.94	1.07	1.17	1.22	1.23	1.17	1.02	0.76
0.57	0.91	1.10	1.17	1.17	1.13	1.05	0.92	0.84	0.80	0.80	0.85	0.94	1.07	1.17	1.22	1.23	1.17	1.02	0.76

NUMBER OF TUBES 5

TABLE 7

SECOND PAGE OF OUTPUT FOR LONG PRINT OPTION

DITTY-IV SUMMARY — CALCULATION OF MK42 HCF- 0% BURNUP
ASSEMBLY POWER= 3.000 — INLET TEMP= 25.000 — MODERATOR TEMP.= 95.000

	SURF	TUBE 1	TUBE 2	TUBE 3	TUBE 4	TUBE 5	TUBE
DIAMETER,IN	1	4.1100	3.7000	2.9360	2.0840	1.3780	
	2	4.0800	3.6400	2.8760	2.0240	1.3280	
	3	4.0400	3.4940	2.6500	1.7980	1.1750	
	4	4.0100	3.4340	2.5900	1.7180	1.1250	
RADIAL POWER	2	1.0000	1.0191	1.0126	1.0064	1.0000	
	(2-3)/2	1.0000	1.0101	1.0000	1.0000	1.0000	
	3	1.0000	1.0000	1.0012	1.0018	1.0000	
POWER FRACTION		0.00001	0.22447	0.48500	0.28618	0.00435	
CLAD CONDUCTIVITY		120.00	120.00	120.00	120.00	120.00	
CORE CONDUCTIVITY		120.00	100.00	100.00	100.00	120.00	

MAX TEMP	1	150	63.83	132	68.19	125	93.06	131	92.25	150	62.28
	2	150	63.49	132	69.41	124	97.31	131	95.66	150	62.29
		150	63.26	132	70.25	124	102.73	125	100.12	150	62.29
	3	150	63.03	132	69.12	125	99.19	131	97.11	150	62.19
	4	150	62.68	132	67.66	125	95.61	131	93.10	150	62.12
MAX HEAT FLUX	1	0	0.	124	61042.	124	202094.	124	169092.	27	5665.
	4	1	55017.	124	75209.	27	176650.	124	154146.	150	4061.
BOSF MIN-NOM	1	1	7.595	124	20.019	124	7.595	124	8.199	27	265.605
	4	1	27.086	124	20.409	124	7.933	124	7.847	150	270.201
HEAT FLUX	1	1	-53677.	124	61042.	124	202094.	124	169092.	27	5665.
	4	1	55017.	124	75209.	124	174774.	124	154146.	150	4061.
TSUB	1	1	17.21	124	91.33	124	91.05	124	82.22	27	112.41
	4	1	118.45	124	91.05	124	82.22	124	84.03	150	103.41
BULK DT	1	1	70.00	124	23.52	124	23.91	124	32.63	27	6.34
	4	1	0.78	124	23.91	124	32.63	124	30.56	150	8.48

AVG SURFACE HEAT SPLIT	1	-0.0943	0.0976	0.2569	0.1558	0.0028
	4	0.0959	0.1221	0.2254	0.1362	0.0016

	CHANNEL 1	CHANNEL 2	CHANNEL 3	CHANNEL 4	CHANNEL 5	CHANNEL
FLOW, GPM	77.760	142.920	101.700	35.820	1.800	
VELOCITY, FPS	13.566	18.864	18.167	14.629	0.388	
EQUIVALENT DIAM.	0.2950	0.4520	0.4430	0.2960	1.1250	
INLET PRESSURE	58.157	58.822	58.101	59.089	41.234	
PRESS LOSS PER FT	0.6608	0.7096	0.6555	0.7894	-0.4706	
EFFLUENT TEMP	53.02	54.20	64.46	62.19	33.48	
TSAT AT EXIT	138.87	138.91	138.88	138.40	136.89	
MIN BO HEAT FLUX	150 1167851.	150 1456026.	150 1291979.	150 1128188.	150 1097264.	

EFFLUENT, MIXED-MEAN TEMPERATURE 57.53

TABLE
8
THIRD PAGE OF OUTPUT FOR LONG PRINT OPTION

DITTY-IV SUMMARY CALCULATION OF MK42 HCF- 0% BURNUP

INDIVIDUAL CHANNEL HOT SUBCHANNEL FACTORS

	CHAN 1	CHAN 2	CHAN 3	CHAN 4
HCF VALUES	0.0	0.0	1.270	1.289

HT1 = 1.1600

TABLE
9
FOURTH PAGE OF OUTPUT FOR LONG PRINT OPTION

DITTY-IV DETAILS CALCULATION OF MK42 HCF- 0% BURNUP 101
ASSEMBLY POWER= 3.000 INLET TEMP= 25.000 MODERATOR TEMP.= 95.000

VERTICAL POS.	15	30	45	60	75	90	105	120	135	150
TUBE 1										
SURFACE TEMP- OD	47.716	49.599	51.518	53.303	54.929	56.539	58.295	60.227	62.173	63.833
CORE-CLADDING TEMP-OD	47.196	49.100	51.041	52.846	54.489	56.117	57.892	59.845	61.812	63.491
MAX FUEL TEMPERATURE	46.847	48.765	50.720	52.538	54.194	55.833	57.621	59.589	61.570	63.261
AVG CORE TEMPERATURE	46.847	48.765	50.720	52.538	54.194	55.833	57.621	59.589	61.570	63.261
CORE-CLADDING TEMP-ID	46.498	48.430	50.399	52.230	53.898	55.549	57.350	59.332	61.328	63.031
SURFACE TEMP- ID	45.970	47.923	49.913	51.764	53.450	55.119	56.940	58.943	[illegible]	62 683
TUBE 2										
SURFACE TEMP- OD	46.362	51.843	53.248	52.289	53.096	56.673	62.511	66.841	67.850	63.481
CORE-CLADDING TEMP-OD	47.364	53.031	54.363	53.189	53.905	57.573	63.651	68.112	69.018	64.185
MAX FUEL TEMPERATURE	48.022	53.813	55.100	53.782	54.435	58.164	64.408	68.969	69.818	64.682
AVG CORE TEMPERATURE	47.735	53.476	54.785	53.527	54.204	57.908	64.088	68.620	69.506	64.500
CORE-CLADDING TEMP-ID	46.989	52.606	53.975	52.869	53.604	57.242	63.273	67.752	68.753	64.089
SURFACE TEMP- ID	45.702	51.094	52.563	51.726	52.566	56.090	61.844	66.200	67.373	63.302
TUBE 3										
SURFACE TEMP- OD	67.978	76.245	76.409	71.933	71.225	76.312	85.862	92.083	91.506	79.927
CORE-CLADDING TEMP-OD	71.229	80.107	80.064	74.937	73.978	79.378	89.688	96.308	[illegible]	82.353
MAX FUEL TEMPERATURE	75.151	84.801	84.556	78.695	77.470	83.278	94.535	101.685	100.411	[illegible]
AVG CORE TEMPERATURE	73.944	83.373	83.214	77.600	76.472	82.166	93.146	100.153	[illegible]	84.829
CORE-CLADDING TEMP-ID	71.884	81.013	81.100	76.013	75.130	80.693	91.267	98.131	97.345	84.225
SURFACE TEMP- ID	68.778	77.383	77.745	73.357	72.772	78.081	87.[illegible]79	94.536	94.174	82.536
TUBE 4										
SURFACE TEMP- OD	63.520	71.780	72.883	69.808	69.918	75.073	84.277	90.765	91.366	82.246
CORE-CLADDING TEMP-OD	66.457	75.229	76.101	72.398	72.249	77.662	87.521	94.326	94.567	84.092
MAX FUEL TEMPERATURE	70.305	79.733	80.288	75.751	75.255	80.997	91.702	98.910	98.668	86.420
AVG CORE TEMPERATURE	69.239	78.469	79.108	74.800	74.399	80.046	90.511	97.602	97.491	85.737
CORE-CLADDING TEMP-ID	67.958	76.938	77.647	73.590	73.283	78.801	88.955	95.878	95.902	84.734
SURFACE TEMP- ID	64.661	73.032	73.972	70.601	70.569	75.781	85.176	91.714	92.123	82.475
TUBE 5										
SURFACE TEMP- OD	30.459	34.708	38.514	41.541	44.293	47.408	51.379	55.789	59.830	62.282
CORE-CLADDING TEMP-OD	30.548	34.807	38.599	41.601	44.341	47.460	51.447	55.859	59.882	62.286
MAX FUEL TEMPERATURE	30.675	34.941	38.706	41.666	44.386	47.507	51.510	55.923	59.921	62.287
AVG CORE TEMPERATURE	30.635	34.901	38.677	41.649	44.374	47.495	51.493	55.906	59.906	62.259
CORE-CLADDING TEMP-ID	30.673	34.937	38.698	41.651	44.364	47.481	51.481	55.886	59.869	62.193
SURFACE TEMP- ID	30.663	34.918	38.672	41.620	44.328	47.440	51.431	55.828	59.803	62.124

AVERAGE TEMPERATURE OF ENTIRE TUBE CORE

TUBE	TEMPERATURE
1	55.09
2	58.84
3	85.39
4	82.74
5	46.73

AVERAGE CLAD TEMPERATURES

TUBE	OUTER CLAD OD	OUTER CLAD ID	INNER CLAD OD	INNER CLAD ID
1	55.81	55.38	54.80	54.37
2	57.42	58.44	58.12	56.85
3	78.95	82.34	83.68	80.73
4	77.16	80.06	81.37	78.01
5	46.62	46.68	46.72	46.68

TABLE
10
FIFTH PAGE OF OUTPUT FOR LONG PRINT OPTION

DITTY-IV DETAILS CALCULATION OF MK42 HCF- 0% BURNUP 101
ASSEMBLY POWER= 3.000 INLET TEMP= 25.000 MODERATOR TEMP.= 95.000

VERTICAL POS.			15	30	45	60	75	90	105	120	135	150
HEAT FLUX	OD TUBE	1	-49649.	-47672.	-45656.	-43782.	-42074.	-40384.	-38541.	-36512.	-34469.	-32725.
	ID TUBE	1	50891.	48865.	46799.	44877.	43127.	41395.	39507.	37428.	35333.	33544.
HEAT FLUX	OD TUBE	2	47737.	56556.	53102.	42831.	38505.	42844.	54249.	60525.	55581.	33511.
	ID TUBE	2	62334.	73202.	68363.	55354.	50231.	55760.	69191.	75155.	66801.	38109.
HEAT FLUX	OD TUBE	3	154486.	183488.	173656.	142742.	130777.	145680.	181753.	200745.	184318.	115214.
	ID TUBE	3	150793.	176269.	162891.	128963.	114500.	126837.	159624.	174551.	153979.	82002.
HEAT FLUX	OD TUBE	4	138908.	163187.	152240.	122494.	110275.	122442.	153416.	168464.	151406.	87328.
	ID TUBE	4	121421.	143877.	135342.	110070.	99962.	111205.	139174.	153350.	139178.	83194.
HEAT FLUX	OD TUBE	5	5001.	5591.	4833.	3410.	2707.	2926.	3795.	3988.	2959.	271.
	ID TUBE	5	608.	1090.	1513.	1831.	2113.	2448.	2906.	3423.	3874.	4061.
3D HEAT FLUX	CHANNEL	1	1461638.	1425799.	1389968.	1356782.	1326466.	1296726.	1265098.	1231165.	1197344.	1167851.
3D HEAT FLUX	CHANNEL	2	1855505.	1809078.	1761071.	1718096.	1680687.	1643152.	1599486.	1548889.	1497558.	1456026.
3D HEAT FLUX	CHANNEL	3	1790124.	1729007.	1666462.	1611829.	1565781.	1520184.	1466518.	1403701.	1340560.	1291979.
3D HEAT FLUX	CHANNEL	4	1543424.	1494450.	1443890.	1398994.	1360371.	1321797.	1276666.	1224041.	1170689.	1128188.
3D HEAT FLUX	CHANNEL	5	1129870.	1131087.	1130883.	1129501.	1127198.	1123947.	1119473.	1113458.	1105895.	1097264.
HEAT SPLIT	OD TUBE	1	-0.11106	-0.09049	-0.09258	-0.10983	-0.11682	-0.10093	-0.07695	-0.06631	-0.06938	-0.11252
	ID TUBE	1	0.11301	0.09208	0.09421	0.11176	0.11887	0.10271	0.07830	0.06748	0.07061	0.11450
HEAT SPLIT	OD TUBE	2	0.09613	0.09664	0.09694	0.09673	0.09624	0.09640	0.09751	0.09896	0.10072	0.10373
	ID TUBE	2	0.12350	0.12306	0.12277	0.12299	0.12352	0.12343	0.12235	0.12088	0.11909	0.11605
HEAT SPLIT	OD TUBE	3	0.24687	0.24880	0.25156	0.25581	0.25939	0.26010	0.25922	0.26044	0.26505	0.28300
	ID TUBE	3	0.23604	0.23413	0.23114	0.22639	0.22246	0.22183	0.22301	0.22183	0.21690	0.19730
HEAT SPLIT	OD TUBE	4	0.15756	0.15706	0.15654	0.15582	0.15525	0.15517	0.15531	0.15514	0.15454	0.15225
	ID TUBE	4	0.13376	0.13449	0.13515	0.13598	0.13668	0.13687	0.13684	0.13715	0.13797	0.14087
HEAT SPLIT	OD TUBE	5	0.00375	0.00356	0.00329	0.00287	0.00252	0.00245	0.00254	0.00243	0.00200	0.00031
	ID TUBE	5	0.00044	0.00067	0.00099	0.00148	0.00190	0.00198	0.00187	0.00201	0.00252	0.00451

TABLE 11

SIXTH PAGE OF OUTPUT FOR LONG PRINT OPTION

DITTY-IV DETAILS CALCULATION OF MK42 HCF- 0% BURNUP 101
ASSEMBLY POWER= 3.000 INLET TEMP= 25.000 MODERATOR TEMP.= 95.000

VERTICAL POS.		15	30	45	60	75	90	105	120	135	150
COOLANT TEMP.- CHANNEL	1	28.19	31.30	34.40	37.23	39.76	42.22	44.87	47.75	50.60	53.02
COOLANT TEMP.- CHANNEL	2	27.33	30.51	33.81	36.69	39.13	41.56	44.48	47.95	51.47	54.20
COOLANT TEMP.- CHANNEL	3	28.17	32.71	37.35	41.34	44.61	47.84	51.72	56.36	61.01	64.46
COOLANT TEMP.- CHANNEL	4	28.11	32.20	36.44	40.13	43.21	46.27	49.95	54.34	58.79	62.19
COOLANT TEMP.- CHANNEL	5	25.36	25.67	26.16	26.80	27.54	28.39	29.40	30.59	31.97	33.48
SATURATION TEMP- CHANNEL	1	143.76	143.24	142.72	142.19	141.65	141.11	140.56	140.00	139.44	138.87
SATURATION TEMP- CHANNEL	2	144.13	143.58	143.02	142.46	141.89	141.31	140.72	140.12	139.52	138.91
SATURATION TEMP- CHANNEL	3	143.73	143.21	142.69	142.17	141.64	141.10	140.55	140.00	139.44	138.88
SATURATION TEMP- CHANNEL	4	144.23	143.62	143.00	142.37	141.74	141.09	140.43	139.76	139.09	138.40
SATURATION TEMP- CHANNEL	5	132.84	133.31	133.78	134.23	134.69	135.14	135.58	136.02	136.46	136.89
LOCAL-TO-AVG FLUX- TUBE	1	1.0016	1.1809	1.1055	0.8936	0.8075	0.8973	1.1237	1.2357	1.1153	0.6534
LOCAL-TO-AVG FLUX- TUBE	2	1.0016	1.1809	1.1055	0.8936	0.8075	0.8973	1.1237	1.2357	1.1153	0.6534
LOCAL-TO-AVG FLUX- TUBE	3	1.0016	1.1809	1.1055	0.8936	0.8075	0.8973	1.1237	1.2357	1.1153	0.6534
LOCAL-TO-AVG FLUX- TUBE	4	1.0016	1.1809	1.1055	0.8936	0.8075	0.8973	1.1237	1.2357	1.1153	0.6534
LOCAL-TO-AVG FLUX- TUBE	5	1.0016	1.1809	1.1055	0.8936	0.8075	0.8973	1.1237	1.2357	1.1153	0.6534

AVERAGE TEMPERATURE OF ENTIRE CHANNEL

CHANNEL	TEMPERATURE
1	40.93
2	40.71
3	46.56
4	45.16
5	28.54

TABLE 12
NONIDEALITY FACTORS USED TO CALCULATE MARK 16B HCF

	FACTOR	VALUE
	H_t	1.16
h_i factors →	h_m	1.02
	h_{cmx}	1.02
	h_{rx}	1.05
	h_p	1.02
	h_e	1.03

TABLE 13

SAMPLE DATA INPUT FOR CREDIT

```
       PROJECT: T5365                   MEMBER: CREDSAM                         DATE: 82/10/14
       LIBRARY: EDIT                    LEVEL:  01.99                           TIME: 08:07
       TYPE:    DATA                    USERID: T5365                           PAGE: 01 OF 01
START
 COL   ----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

  1    CALCULATION OF MK42  PARAMETERS                                                  101
  2     220    5    1    18    1   70    0    0     1.0     0.0     0.0      0          102
  4      0.0   360.0     25.0    45.0      2.0     3.0     7.0     2.0     0.0          103
  4      0.0     0.0      0.0     0.0                                                   104
  4      0.0     0.0      0.0     0.0     0.0     0.0     0.0     0.0                   105
  3     0.39    0.64    0.81    0.92    0.99    1.05    1.14    1.20    1.24    1.28    307
  3     1.31    1.32    1.33    1.33    1.21    1.04    0.90    0.76    0.61    0.42    308
  3     0.39    0.64    0.81    0.92    0.99    1.05    1.14    1.20    1.24    1.28    307
  3     1.31    1.32    1.33    1.33    1.21    1.04    0.90    0.76    0.61    0.42    308
  3     0.39    0.64    0.81    0.92    0.99    1.05    1.14    1.20    1.24    1.28    307
  3     1.31    1.32    1.33    1.33    1.21    1.04    0.90    0.76    0.61    0.42    308
  3     0.39    0.64    0.81    0.92    0.99    1.05    1.14    1.20    1.24    1.28    307
  3     1.31    1.32    1.33    1.33    1.21    1.04    0.90    0.76    0.61    0.42    308
  3     0.39    0.64    0.81    0.92    0.99    1.05    1.14    1.20    1.24    1.28    307
  3     1.31    1.32    1.33    1.33    1.21    1.04    0.90    0.76    0.61    0.42    308
```

TABLE 14
DATA INPUT

Input Card	Input Field	Column	Format	Symbol	Description
1	-	1-80	20 A4	TITLE	Description of problem as desired
2	1	1-4	I4	ITG	For Mark 16 only 0 if no inner target 25 if 0.25 g/ft ^{6}Li 60 if 0.60 g/ft ^{6}Li 100 if 1.00 g/ft ^{6}Li For Mark 16B only* 0 if no inner target 40 if 0.4 g/ft ^{6}Li 85 if 0.85 g/ft ^{6}Li 120 if 1.2 g/ft ^{6}Li
2	2	6-9	I4	NT	Number of axial power shapes read 0 if CONY = 1 or 2 1 if one axial power shape for all tubes No. tubes if more than one axial power shape input
2	3	11-14	I4	ILAST	>0 if last problem in set
2	4	16-19	I4	MONI	Assembly Selection 1 if Mark 14 2 if Mark 16 3 if Mark 30 4 if Mark 18 with target 5 if Mark 18 w/o target 6 if Mark 40 7 if Mark 53 8 if Mark 53A 9 if Mark 22 10 if Mark 41 11 if Mark 16B 12 if Mark OX1 13 if Mark R35 14 if Mark R40 15 if Mark US1 16 if Mark US2 17 if Thoria

*See the comment cards in Subroutine CREDIT, labeled P5596001 in SRL. REAC. SOURCE, for additional ITG definitions for other assemblies (MK42, OX2).

TABLE 14, continued
DATA INPUT

Input Card	Input Field	Column	Format	Symbol	Description
					18 if Mark 42 19 if Mark OX2 20 if Mark 15
2	5	21-24	I4	IEF	End fitting type 1 if P Reactor,* 2 if K, C Reacator, A Pin* 3 if K Reactor, B Pin* 4 if P Reactor, 20-40 shell holes, double pressure plate design 5 if P Reactor, 40-80 shell holes, double pressure plate design 6 if KC Reactors, A Pin, 20-50 shell holes, double pressure plate design
2	6	26-29	I4	INS	Number of holes in bottom fitting shell
2	7	31-34	I4	NABCD	Selection for Mark 30 assemblies 1 if Mark 30A 2 if Mark 30B 3 if Mark 30C 4 if Mark 30D
2	8	36-39	I4	NBF	Bottom fitting type Mark 30 assemblies in P 1 if 1.67" PP and high flow sampler 2 if 1.67" PP and low flow sampler 3 if 0.97" PP and low flow sampler
2	9	41-47	F 7.2	PRINT	0 if DITTY summary 1 if long print
2	10	49-55	F 7.2	CONY	0 if axial power shape read in 1 if natural fuel - standard length 2 if enriched fuel - standard length

* One pressure plate

TABLE 14, continued
DATA INPUT

Input Card	Input Field	Column	Format	Symbol	Description
2	11	57-63	F 7.2	SPTH	0 if no special thermocouple data 1 if special thermocouple data
2	12	64-70	I8	NCOBAD	0 if using CREDIT code 1 if using COBAD code
3	1	1-7	F 7.2	EXPOS	% burnup for enriched fuel; MWD for natural or depleted fuel
3	3	9-15	F 7.2	TFLOW	Assembly flow, gpm
3	3	17-23	F 7.2	TMIN	Minimum inlet temperature, °C - plenum inlet temperature if reactor data (monitor pin TC- Δ Ts) used.
3	4	25-31	F 7.2	TMAX	Maximum inlet temperature, °C = TMIN if no temperature increments are used
3	5	33-39	F 7.2	TSTEP	Number of increments for inlet temperature = 0 if no increments used
3	6	41-47	F 7.2	PMIN	Minimum assembly power, MW = 0 if reactor data used
3	7	49-55	F 7.2	PMAX	Maximum assembly power, MW = 0 if reactor data used
3	8	57-63	F 7.2	PSTEP	Number of power increments = 0 if no increments used
3	9	64-70	F 7.2	DECK	= 1.0 if a Ditty IV card deck is needed $\neq$ 1.0 if no Ditty IV card deck is needed
4	1	1-7	F 7.2	DTMP(1)	Δ T indicated by monitor pin (MP) thermocouple A
4	2	9-15	F 7.2	DTMP(2)	Δ T indicated by MP TC-B
4	3	17-23	F 7.2	DTMP(3)	Δ T indicated by MP TC-C

TABLE 14, continued
DATA INPUT

Input Card	Input Field	Column	Format	Symbol	Description
4	4	25-31	F 7.2	DTMP(4)	ΔT indicated by MP TC-D
Card 4 is blank if reactor data not used -					
5	1	1-7	F 7.2	BULK	Moderator temperature, °C
5	2	9-15	F 7.2	HMOD	Heat transfer coefficient-outer surface tube 1, pcu/(hr)(Ft^2)(°C)
5	3	17-23	F 7.2	SELMNT	Length of reactor core, ft
5	4	25-31	F 7.2	Y	Distance from top of fuel in question to top of reactor core, ft
5	5	33-39	F 7.2	PMOD	Coolant pressure in moderator at top of core, psia
5	6	41-47	F 7.2	CSUBLM	Pressure drop/ft of moderator, psi
5	7	49-55	F 7.2	VMOD	Moderator velocity, ft/sec
5	8	56-	F 7.2	FUDGE1	Fraction of flow (excluding axial purge) to channel 3 of Mark 41 assembly.
If card 5 is left blank, program will use standard values for the assembly, except for FUDGE1 and Y. The Y variable has no default value.					
6	1	1-7	F 7.2	SPTC(1,1)	ΔT from special thermocouple in subchannel (1,1)
6	2	9-15	F 7.2	SPTC(1,2)	Subchannel (1,2)
6	3	17-23	F 7.2	SPTC(1,3)	Subchannel (1,3)
6	4	25-31	F 7.2	SPTC(1,4)	Subchannel (1,4) (see Figures 1A, 2A)

Repeat card 6 for all channels - program will currently handle up to 16 channels (16 special thermocouples) - use blank cards if less than 16 channels.

Card 6 is omitted if no thermocouple data is used.

TABLE 14, continued
DATA INPUT

Input Card	Input Field	Column	Format	Symbol	Description
7	1-10	1-70	10(F6.3,1X)	TWFH(K,J) K=1,10	Axial power shape
7	1-10	1-70	10(F6.3,1X)	TWFM(K,J) K-11,20	Axial power shape

Use two cards, type 7, for each axial power shape (APS) input. If more than one APS input, must input one set for each tube.

TABLE 15
EXPLANATION OF SAMPLE DATA INPUT
IN TABLE 13

ITG	Lithium loading of 2.2 g/ft.
NT	Five axial flux shapes are read into the program.
ILAST	The last problem set for this computational run.
MONI	Selecting the Mark 42 assembly.
IEF	Assuming a P reactor bottom fitting insert.
INS	Using 70 shell holes in the bottom fitting insert.
PRINT	Want a long print.
EXPOS	Assuming 0% burnup for the power fraction and radial power profile equations in the assembly subroutine.
TFLOW	Picked a 360 gpm total assembly flow.
TMIN	Minimum plenum inlet temperature of 25°C selected.
TMAX	Maximum plenum inlet temperature of 45°C selected.
TSTEP	Equals 2. Means the plenum inlet temperature will be 25, 35, and 45°C for this computational run.
PMIN	Minimum assembly power is 3.0 MW.
PMAX	Maximum assembly power is 7.0 MW.
PSTEP	Equals 2. Means the assembly power will equal 3.0, 5.0, and 7.0 MW for each of the different plenum inlet temperatures.
TWFH	Five axial power shapes, one for each tube in the assembly (USH, three fuels, one target), are read into the program.
NOTE:	Card 6 is omitted in this data input. Also, the card 5 values are zero which means the computer code selects default parameters. These parameters are selected in the assembly subroutine.

FIGURE 1

VARIATION IN MARK 16B HEAT
SPLIT VALUES FOR THE MIDDLE FUEL TUBE

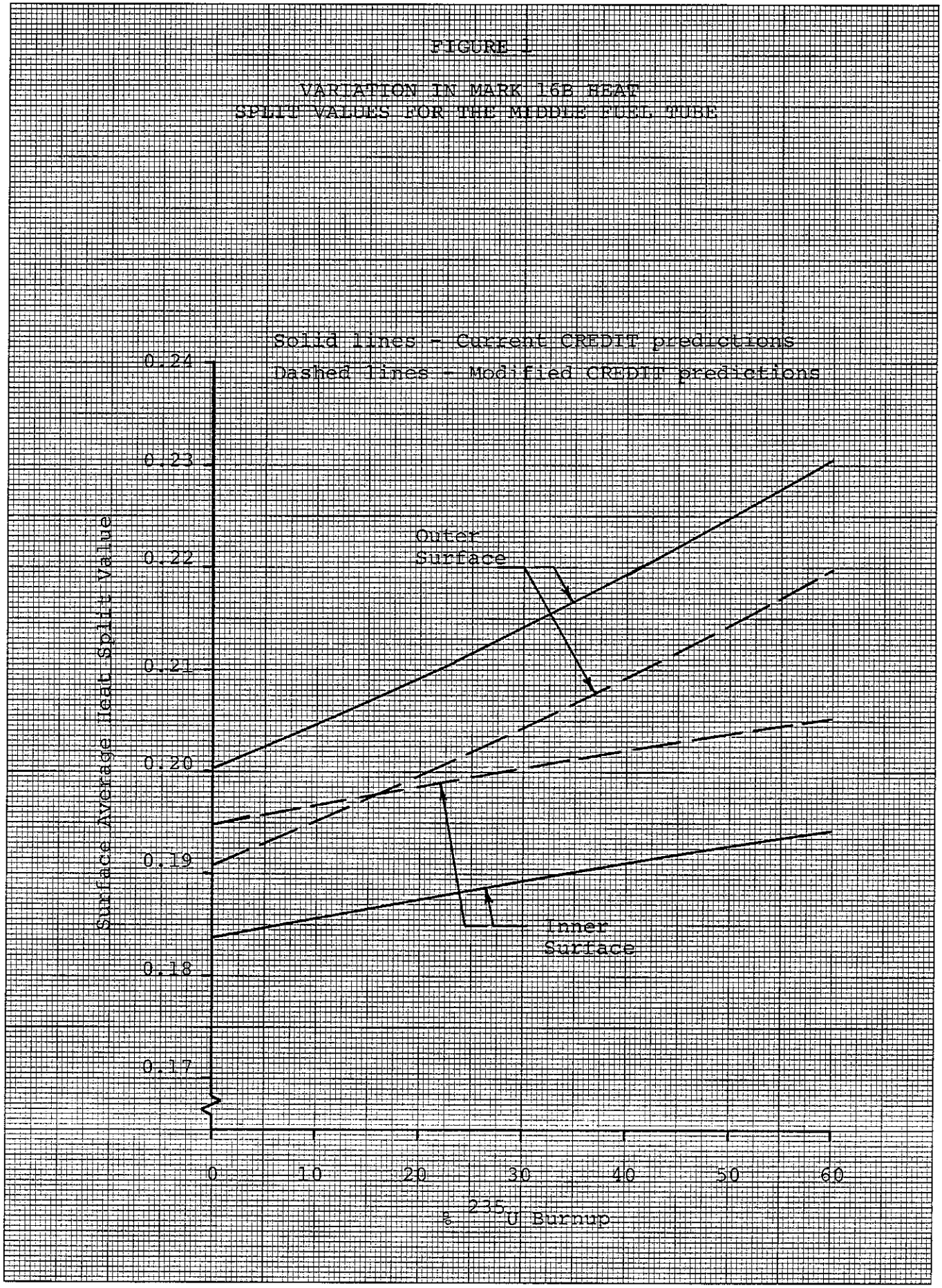


FIGURE 2

VARIATION IN MARK 16B $BOSE_n$ VALUES FOR THE MIDDLE FUEL TUBE

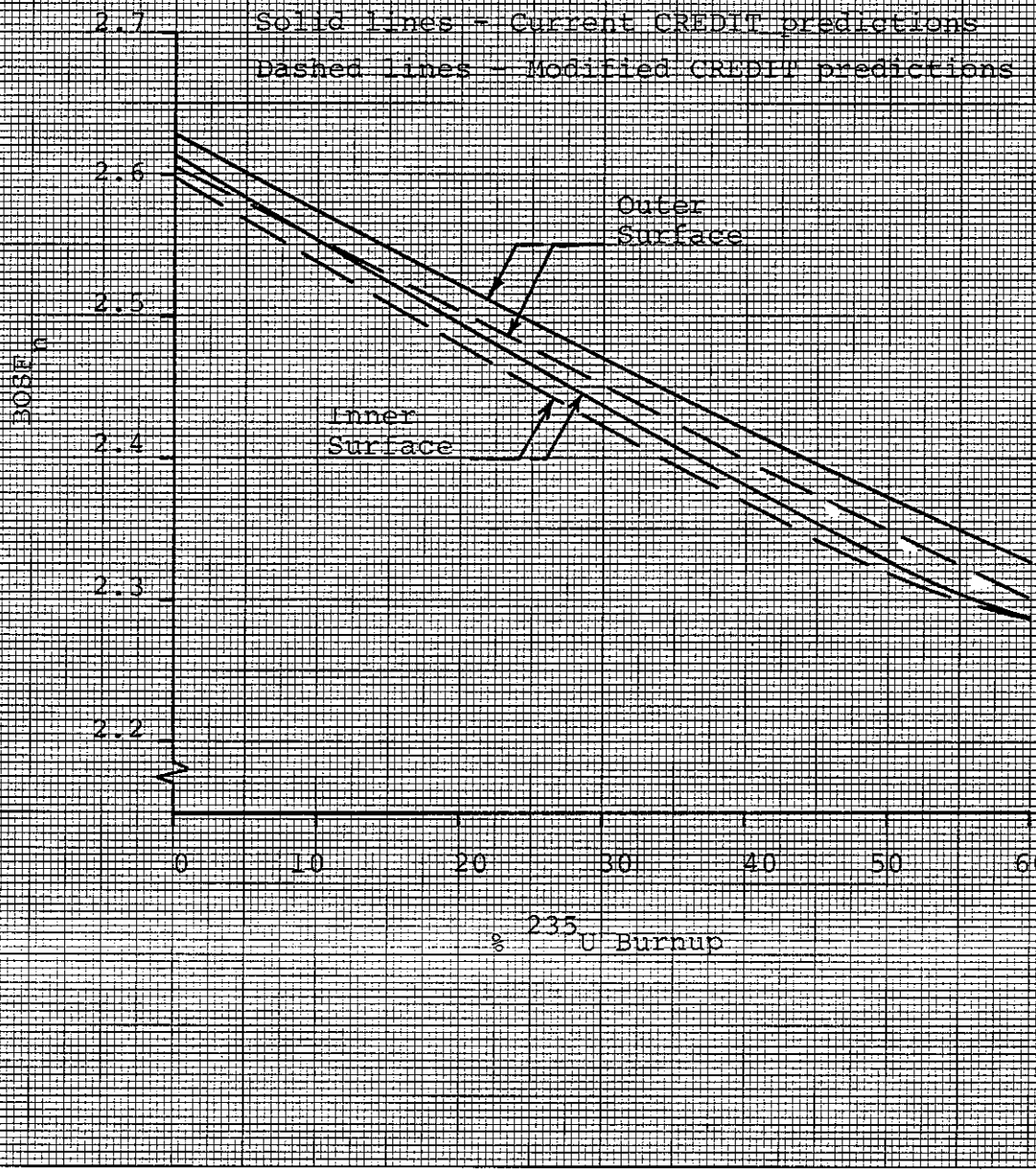


FIGURE 3

DIFFERENCES IN MARK 16B
HCF VALUES BETWEEN THE 16 (H)
MANUAL AND THE MODIFIED CREDIT CODE

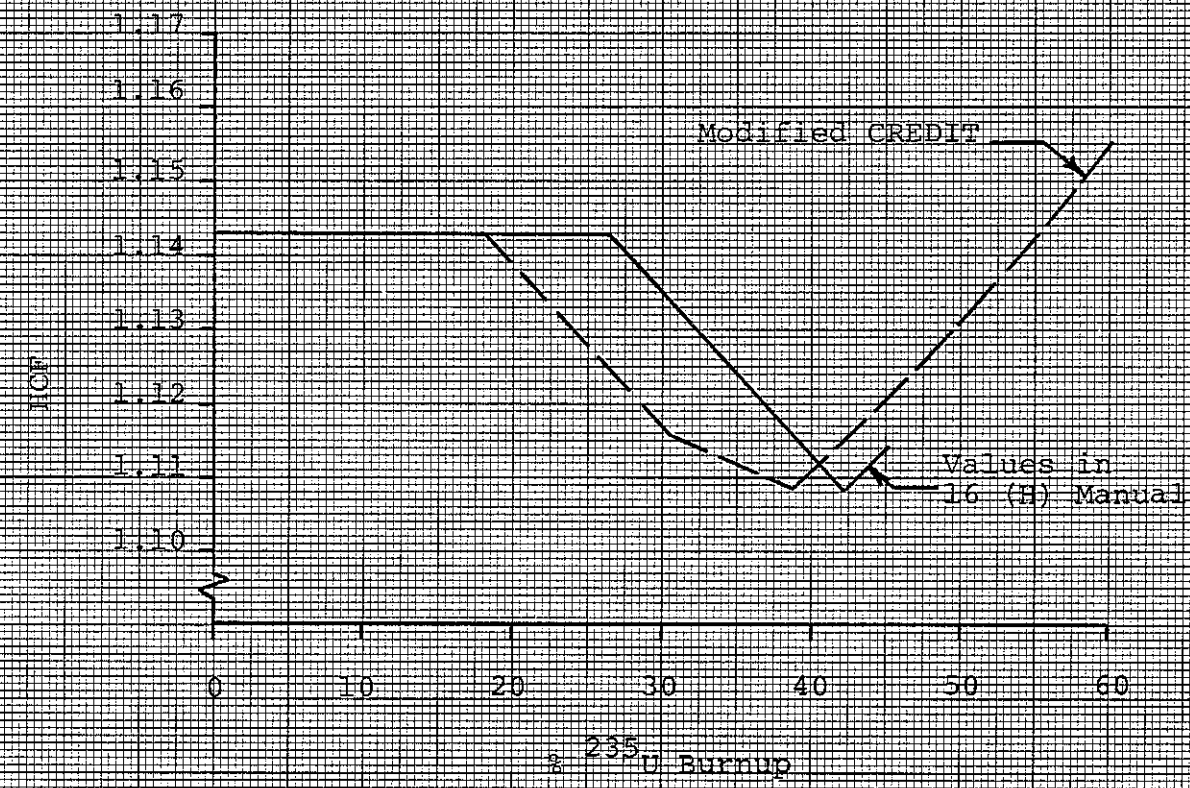


FIGURE 4

VARIATION IN MARK 22 HEAT SPLIT VALUE FOR THE OUTER FUEL TUBE

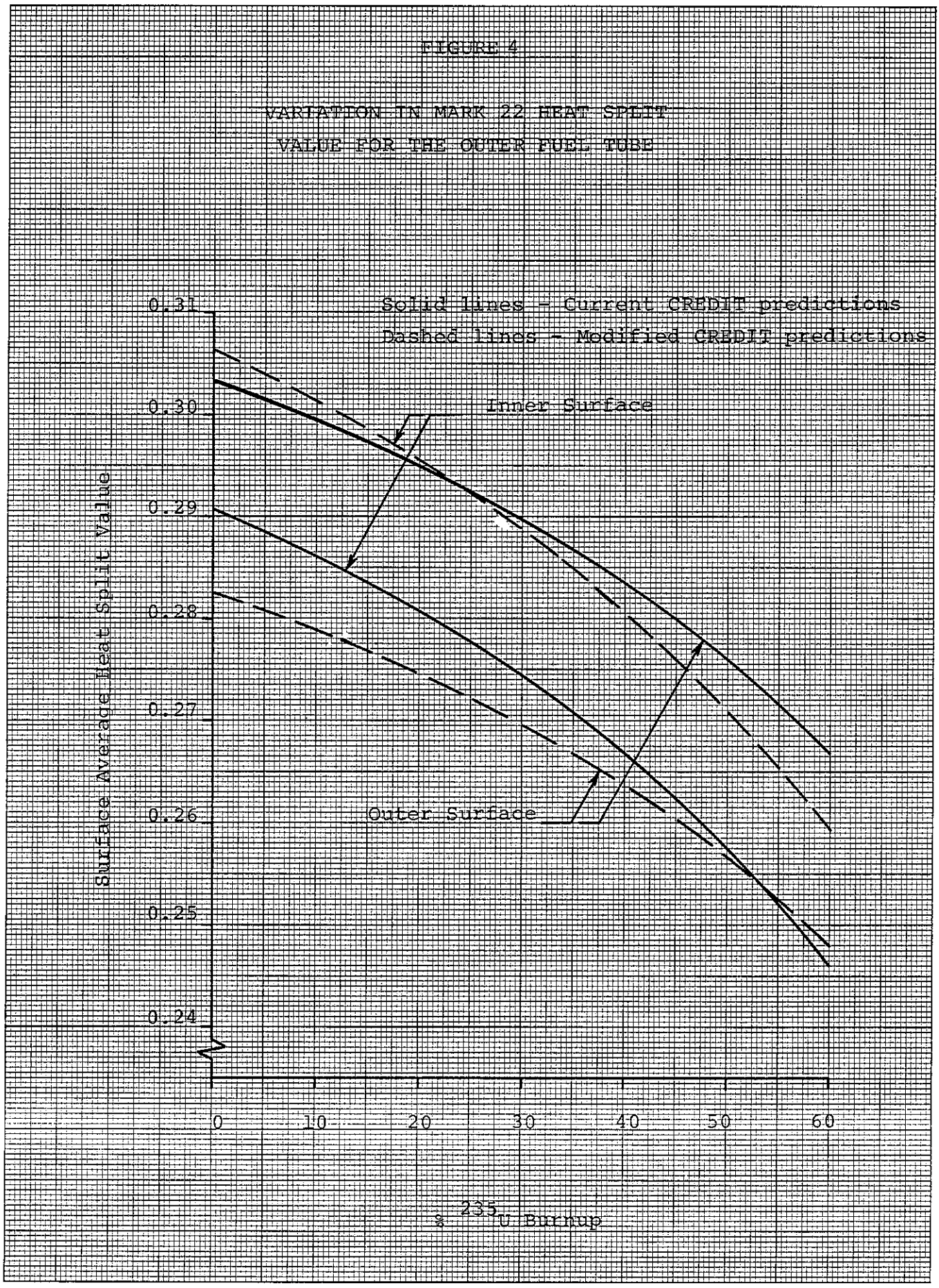


FIGURE 5

VARIATION IN MARK 22 $BOSF_n$

VALUES FOR THE OUTER FUEL TUBE

Solid lines - current CREDIT predictions

Dashed lines- modified CREDIT predictions

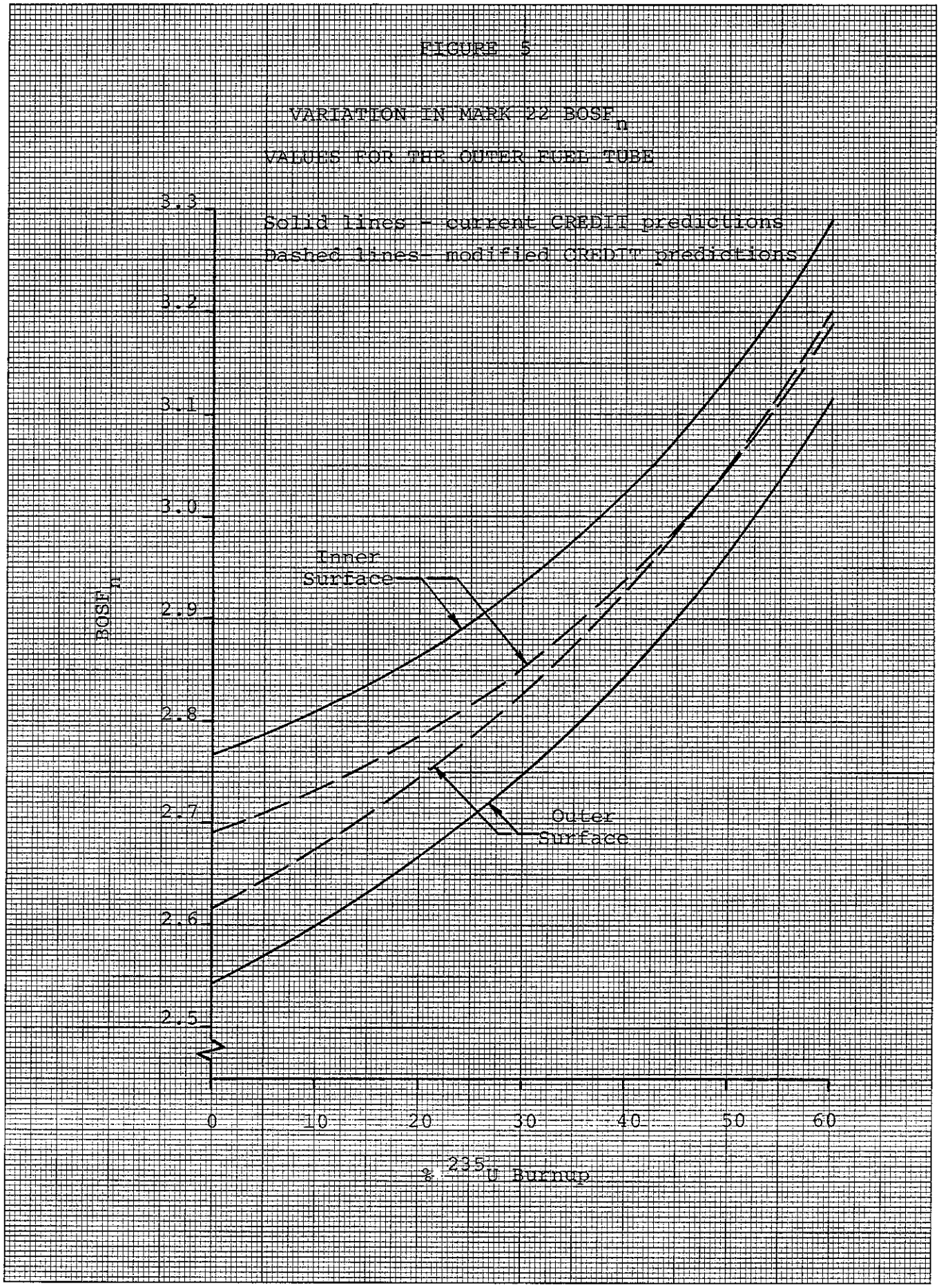


FIGURE 6

DIFFERENCES IN MARK 22 HCF VALUES
BETWEEN THE 22 (H) MANUAL AND THE
MODIFIED CREDIT CODE

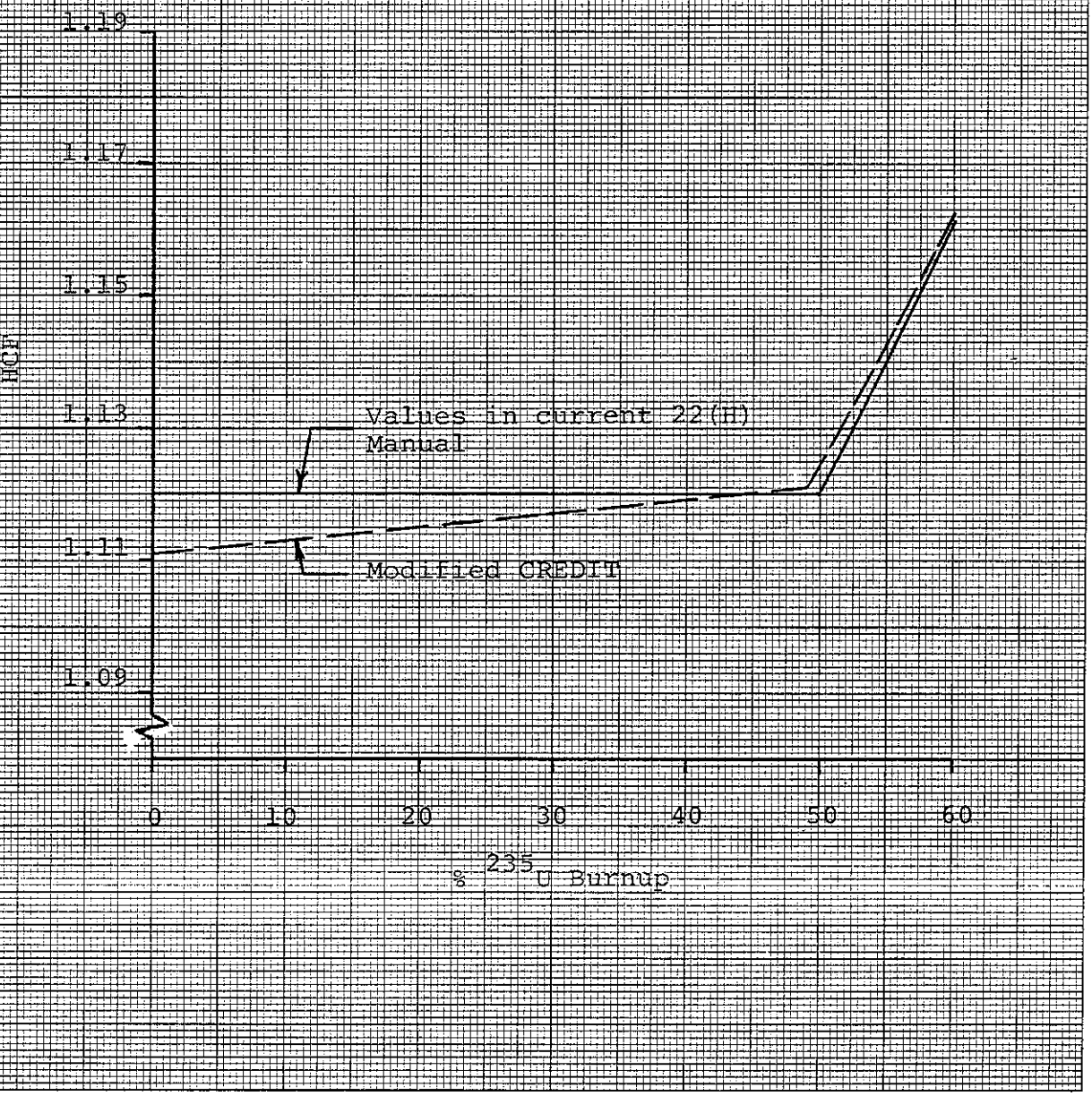


FIGURE 7

SYMMETRIC CROSS SECTION OF ONE TUBE FROM AN ASSEMBLY

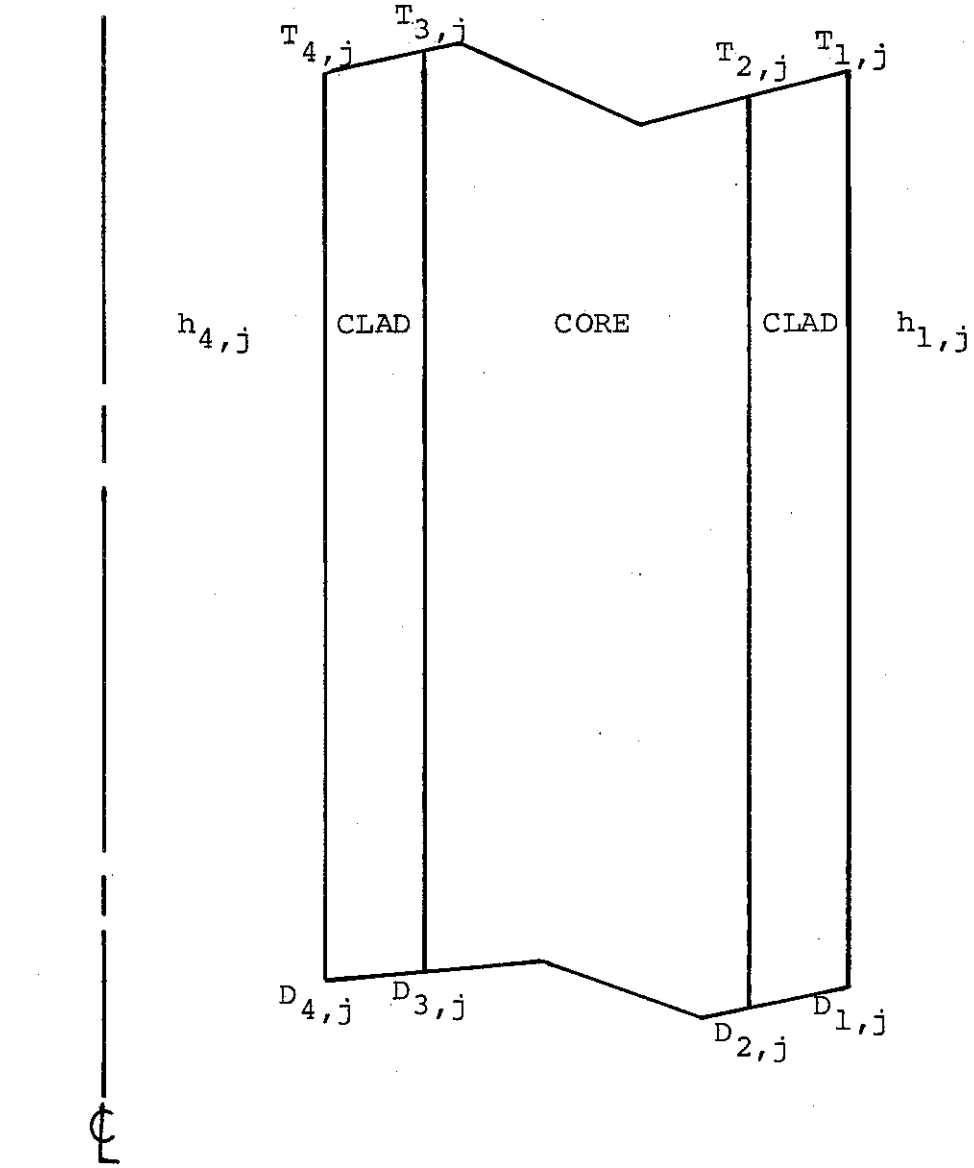


FIGURE 8

HEAT TRANSFER MODES FROM AN
INDIVIDUAL TUBE

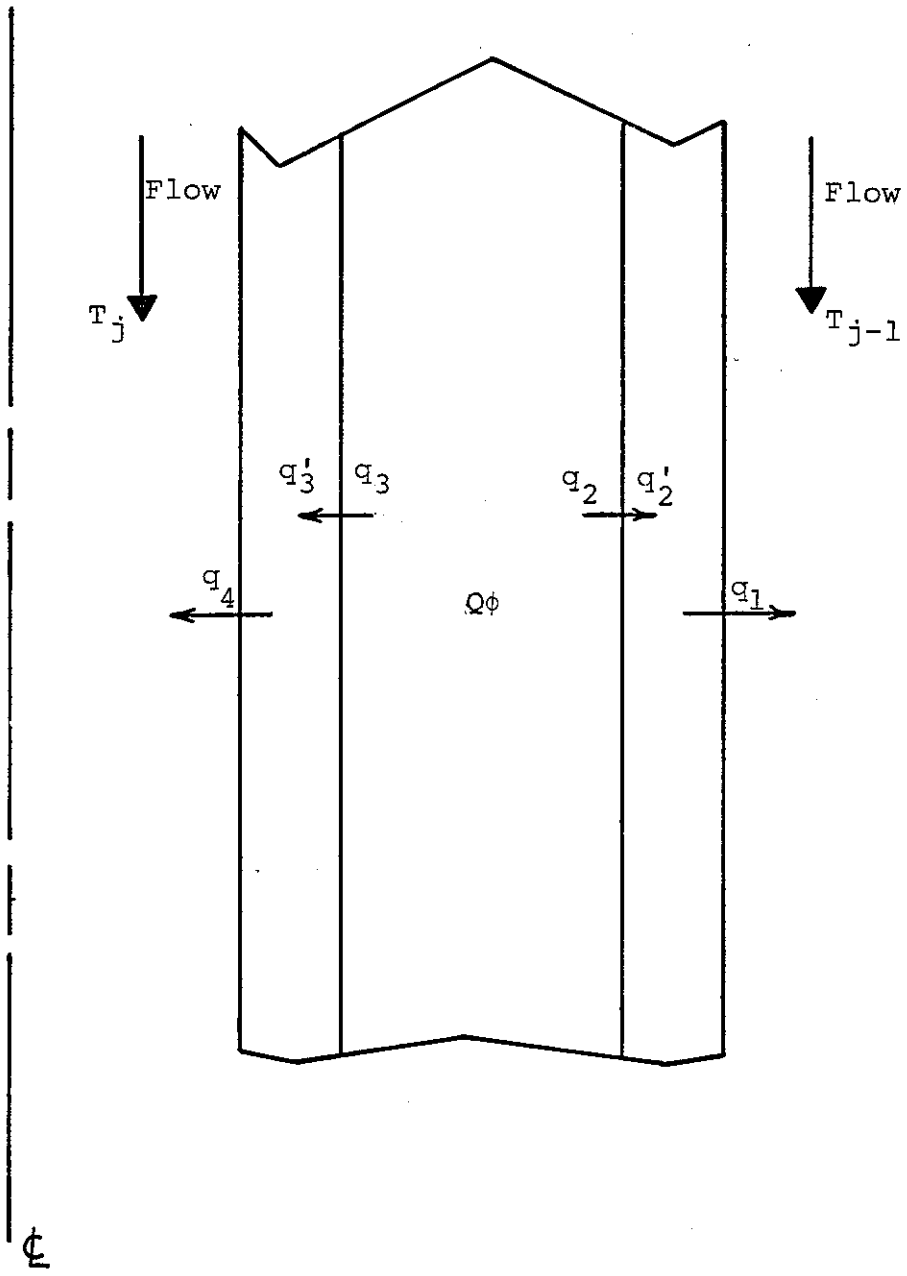


FIGURE 9

CONTROL VOLUME FOR BULK COOLANT TEMPERATURE CALCULATION

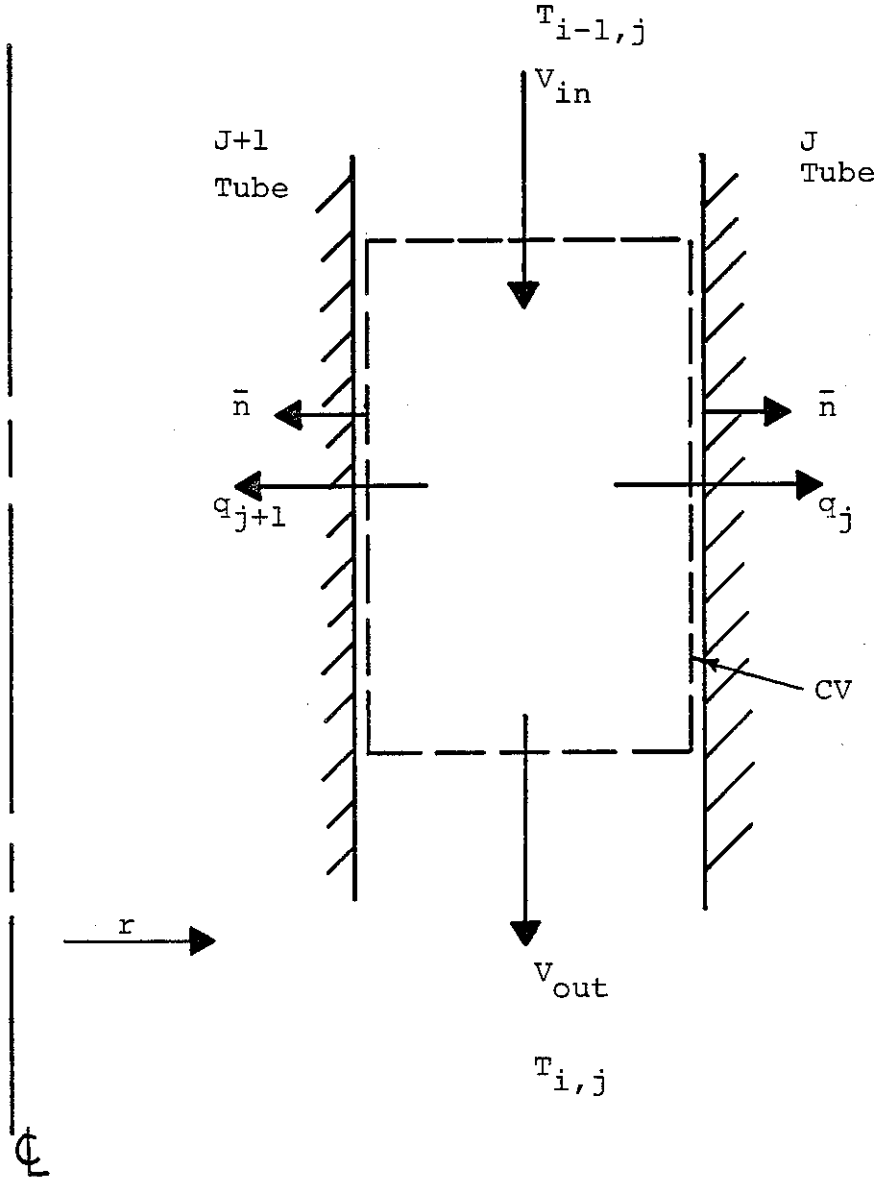


FIGURE 10

CONTROL VOLUME FOR ENTIRE TUBE

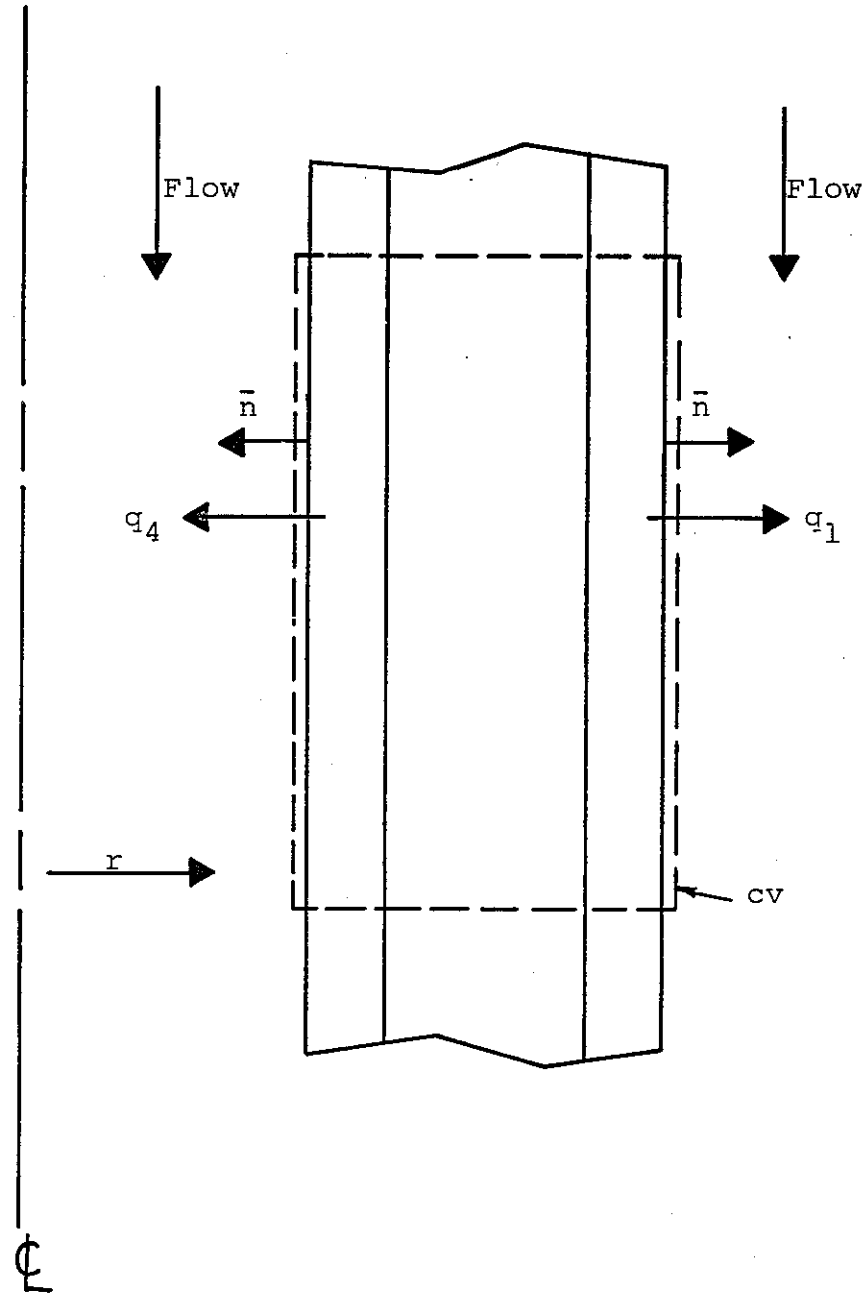


FIGURE 11

CONTROL VOLUME FOR THE INNER CLADDING

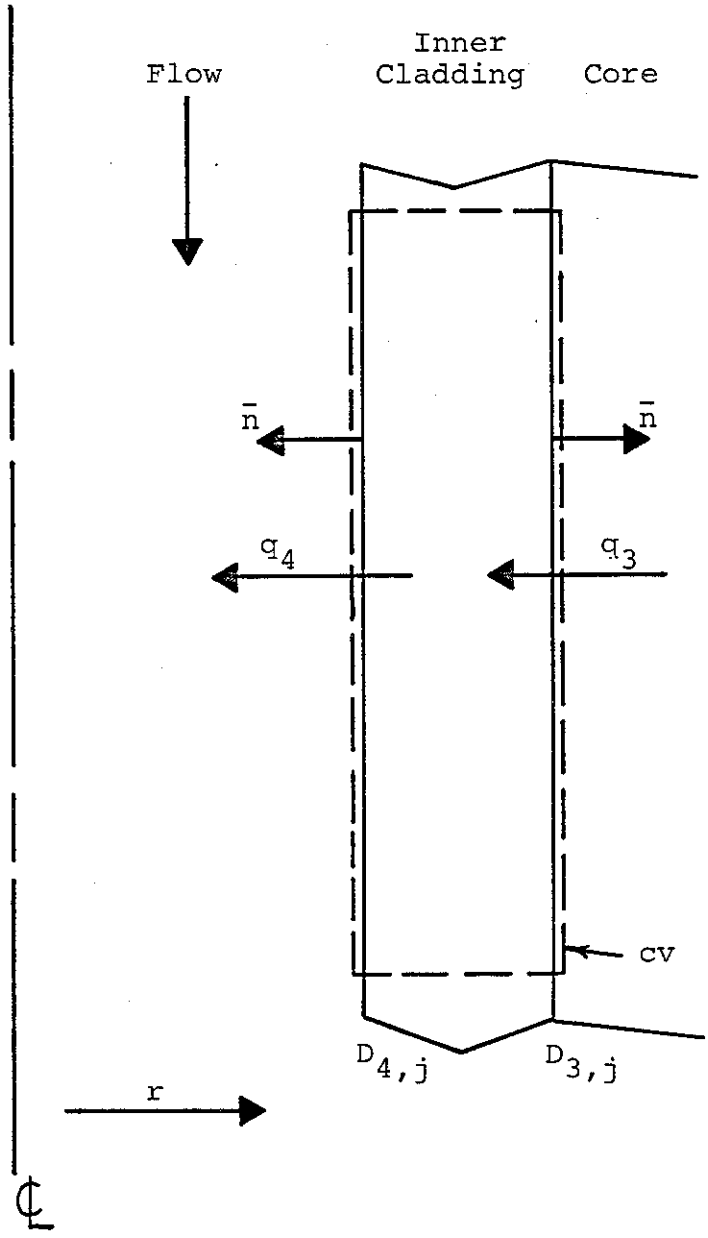


FIGURE 12

CONTROL VOLUME FOR OUTER CLADDING

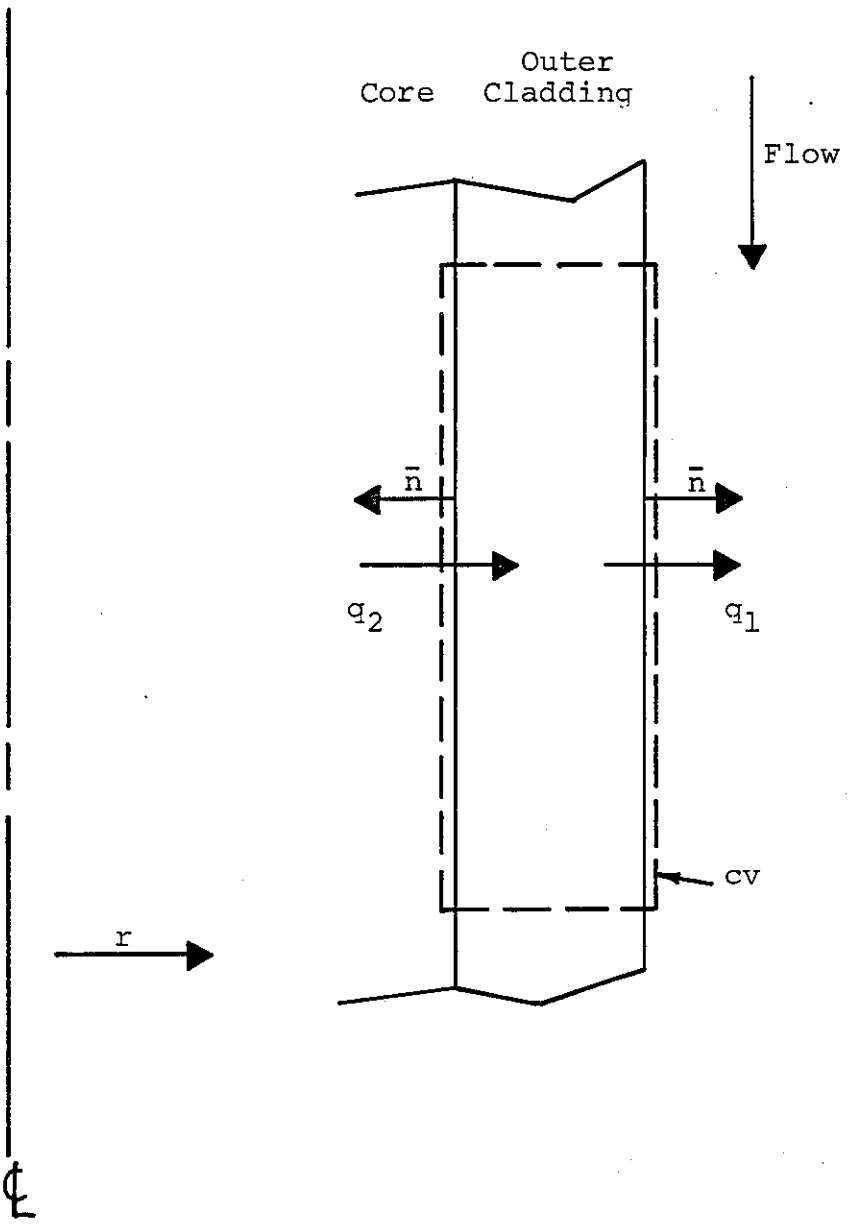


FIGURE 13

DIAGRAM OF A FOUR TUBE ASSEMBLY SHOWING
THE NOMENCLATURE USED
IN THE CODE

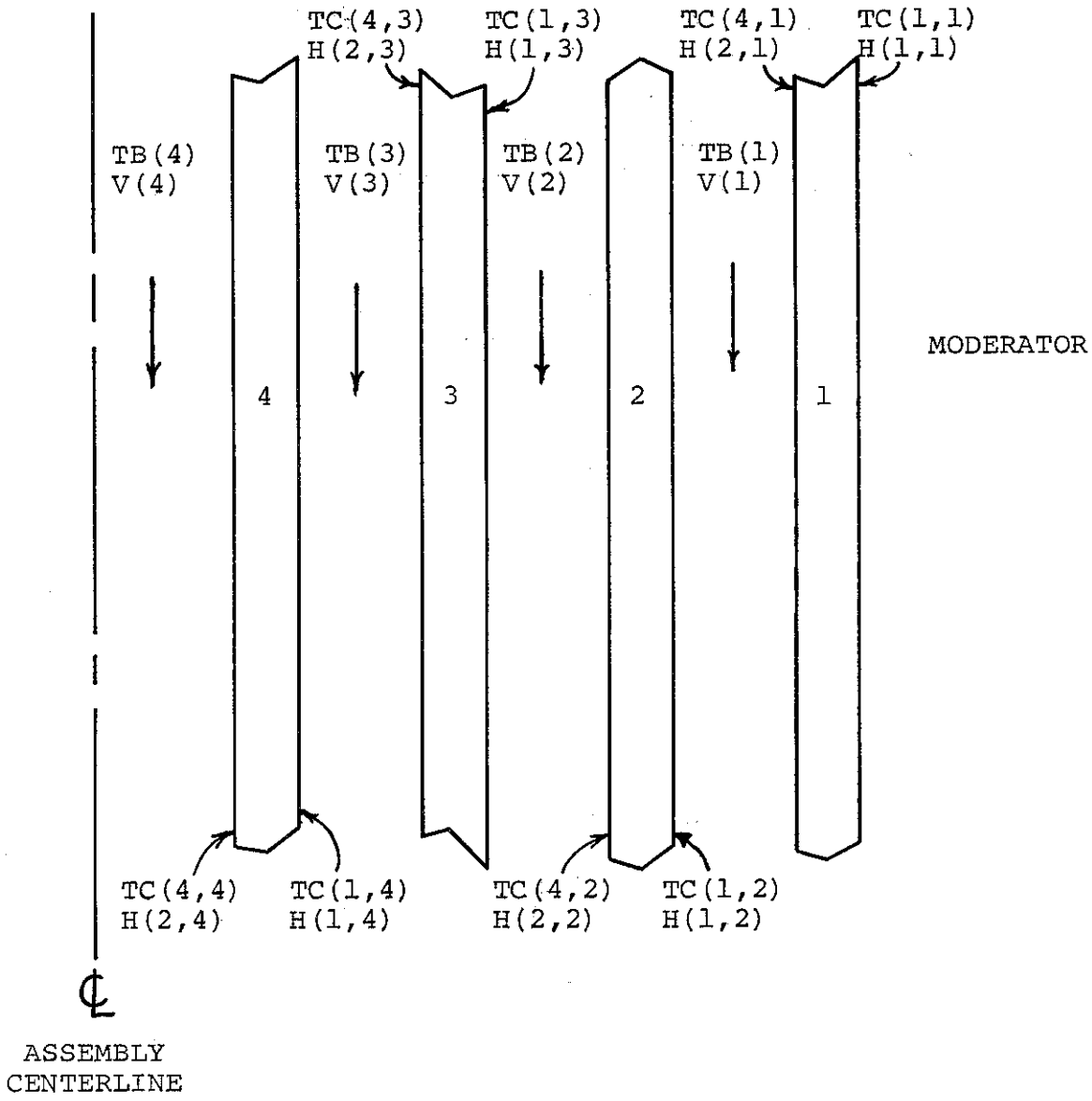


FIGURE 14

METHOD FOR DETERMINING HCF
FOR MARK 16B ASSEMBLY

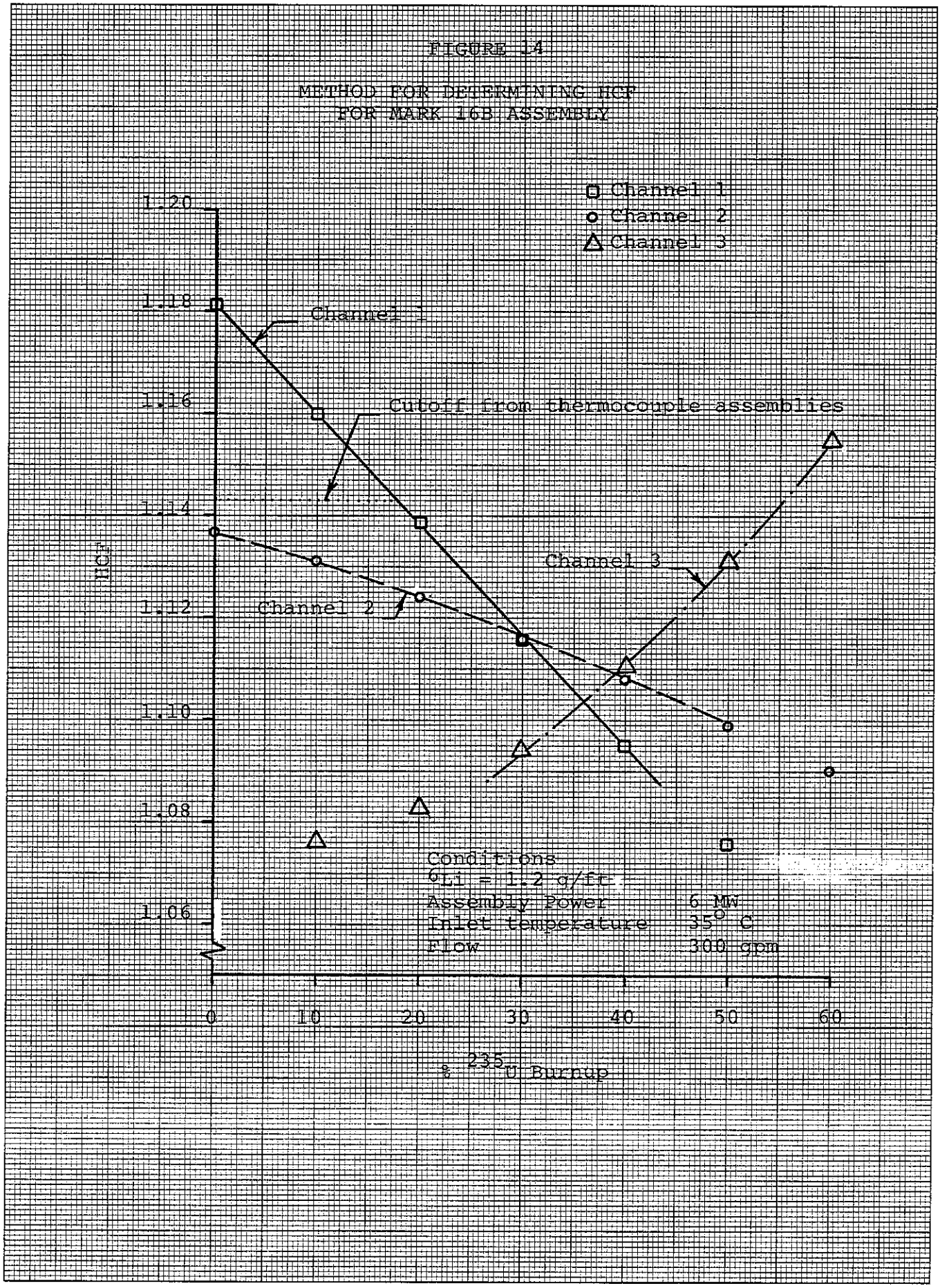


FIGURE 15
COMPARISON OF OLD CREDIT PREDICTIONS AND
GLASS DATA FOR THE MARK 15

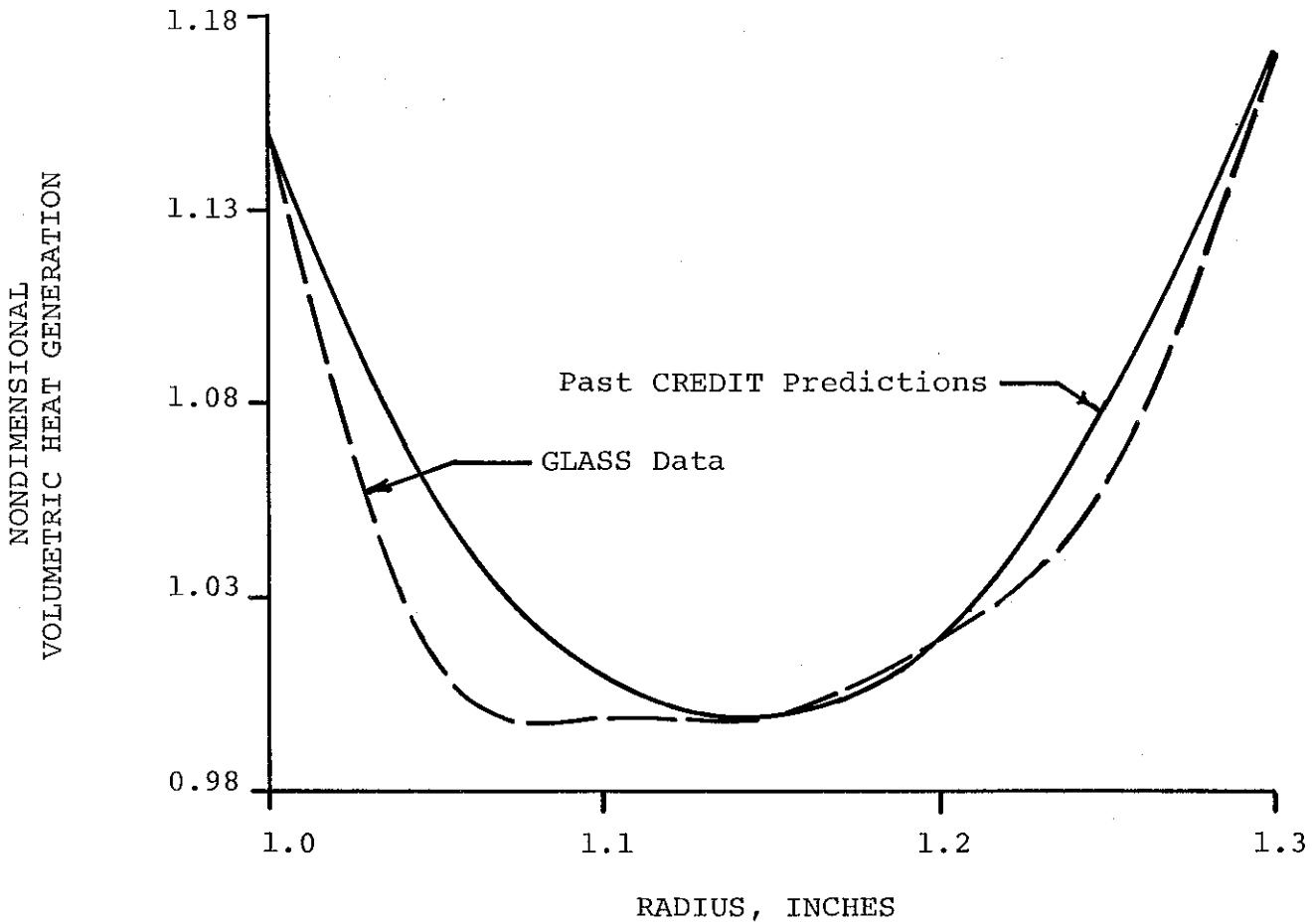


FIGURE 16
COMPARISON OF CREDIT AND GLASS RESULTS FOR THE
OUTER MARK 15 FUEL TUBE AT 0% ^{235}U BURNUP

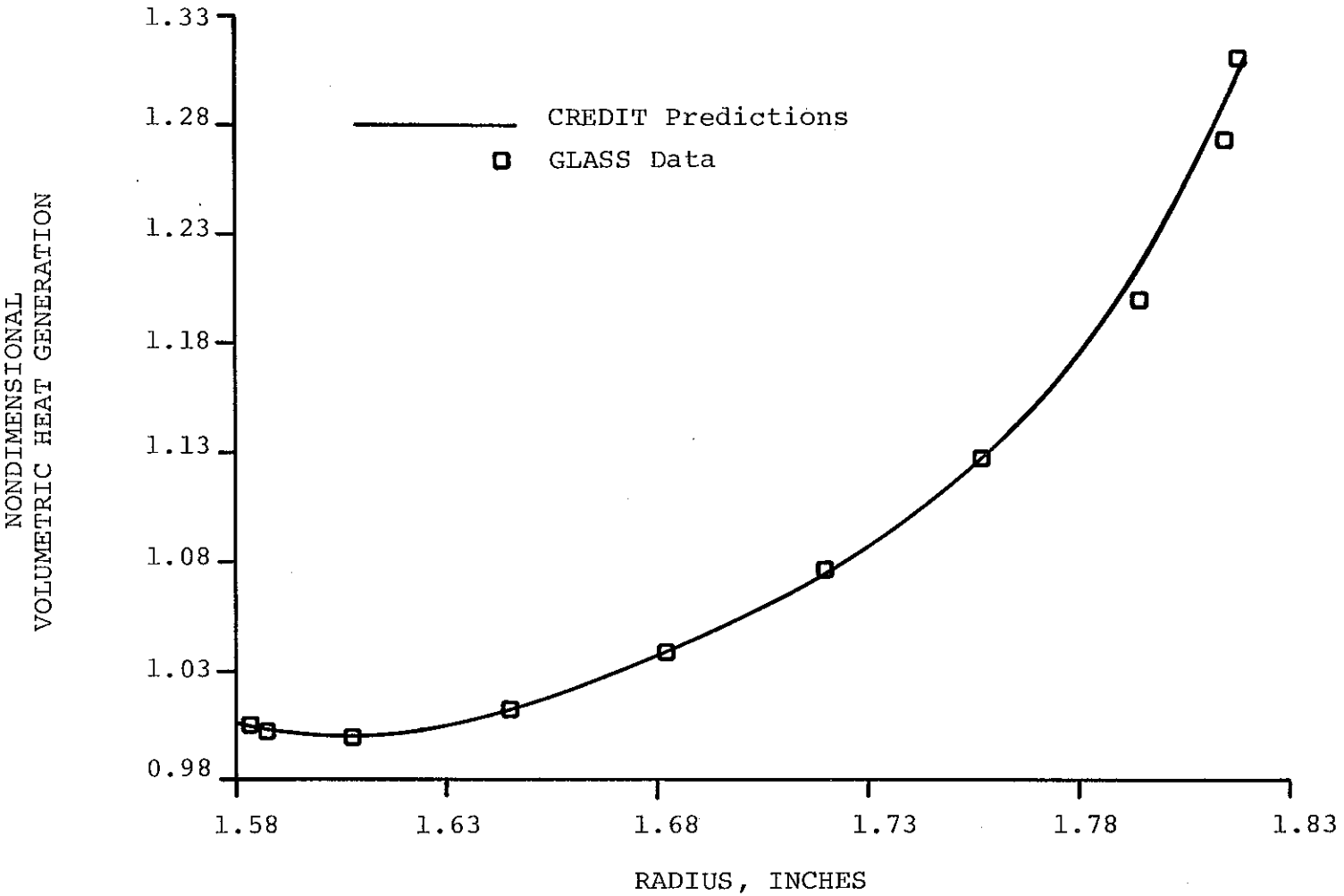


FIGURE 17
COMPARISON OF CREDIT AND GLASS RESULTS FOR THE
INNER MARK 15 FUEL TUBE AT 0% ^{235}U BURNUP

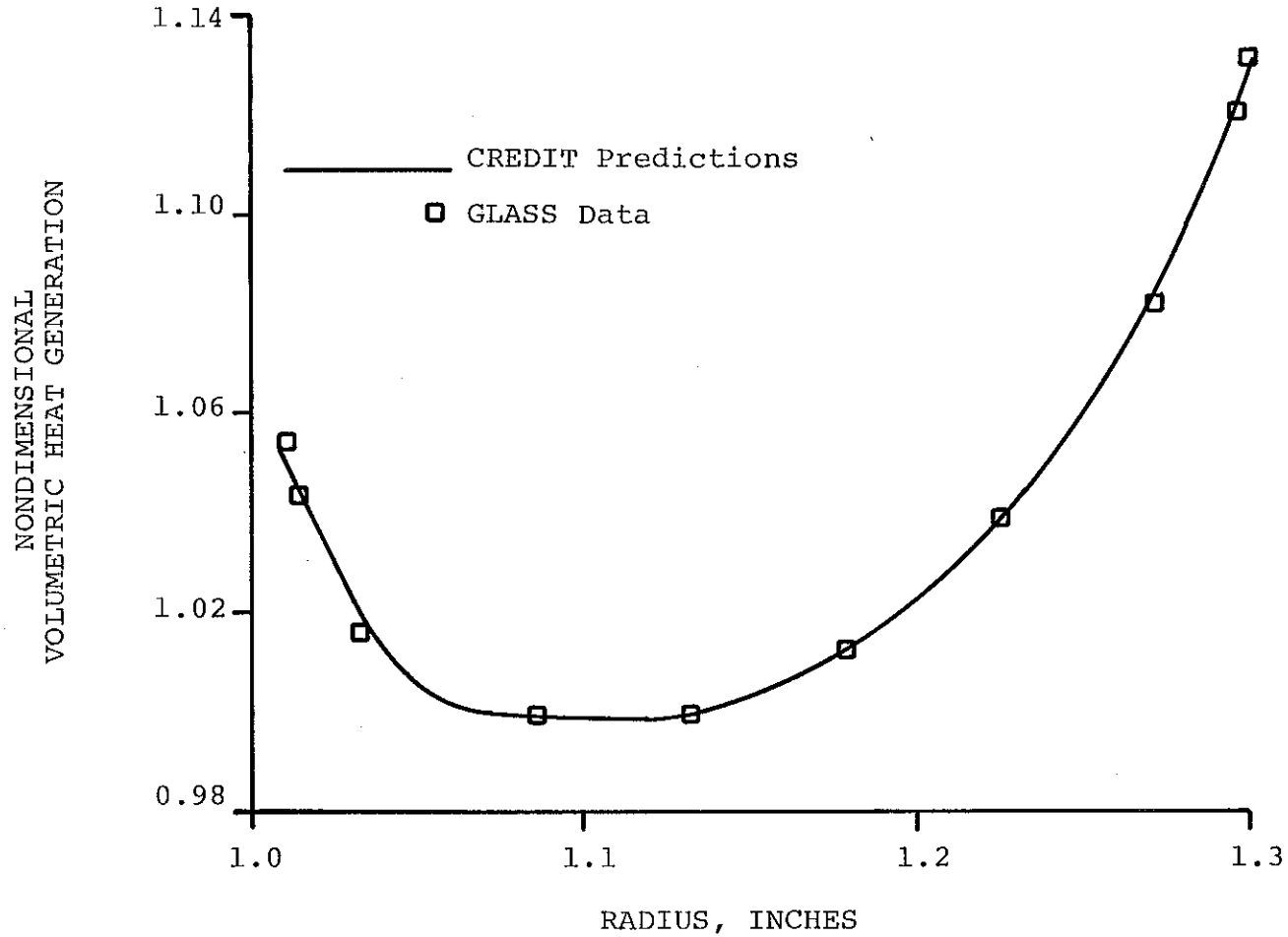


FIGURE 18
COMPARISON OF CREDIT AND GLASS RESULTS FOR THE
OUTER MARK 15 FUEL TUBE AT 14.5% ^{235}U BURNUP

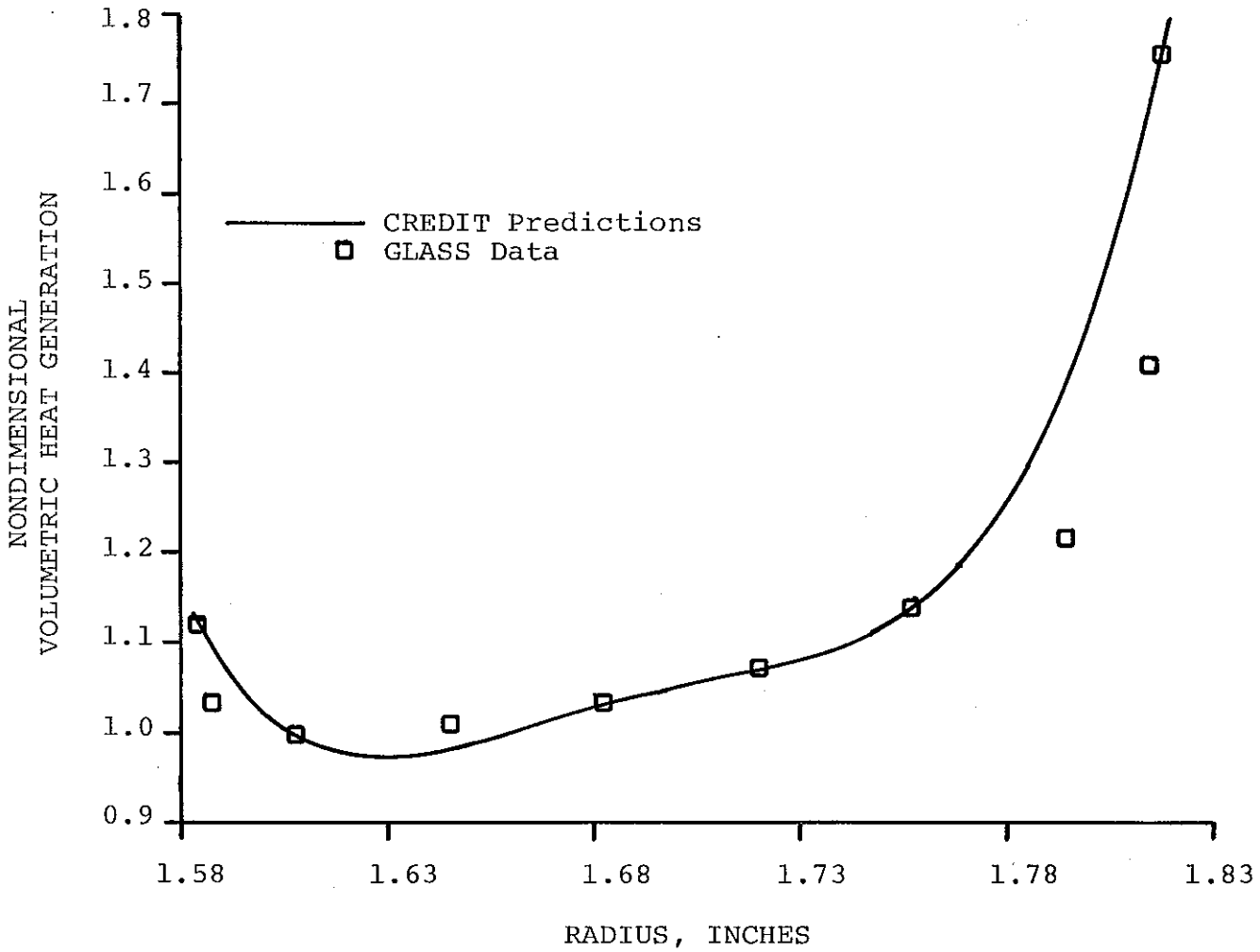
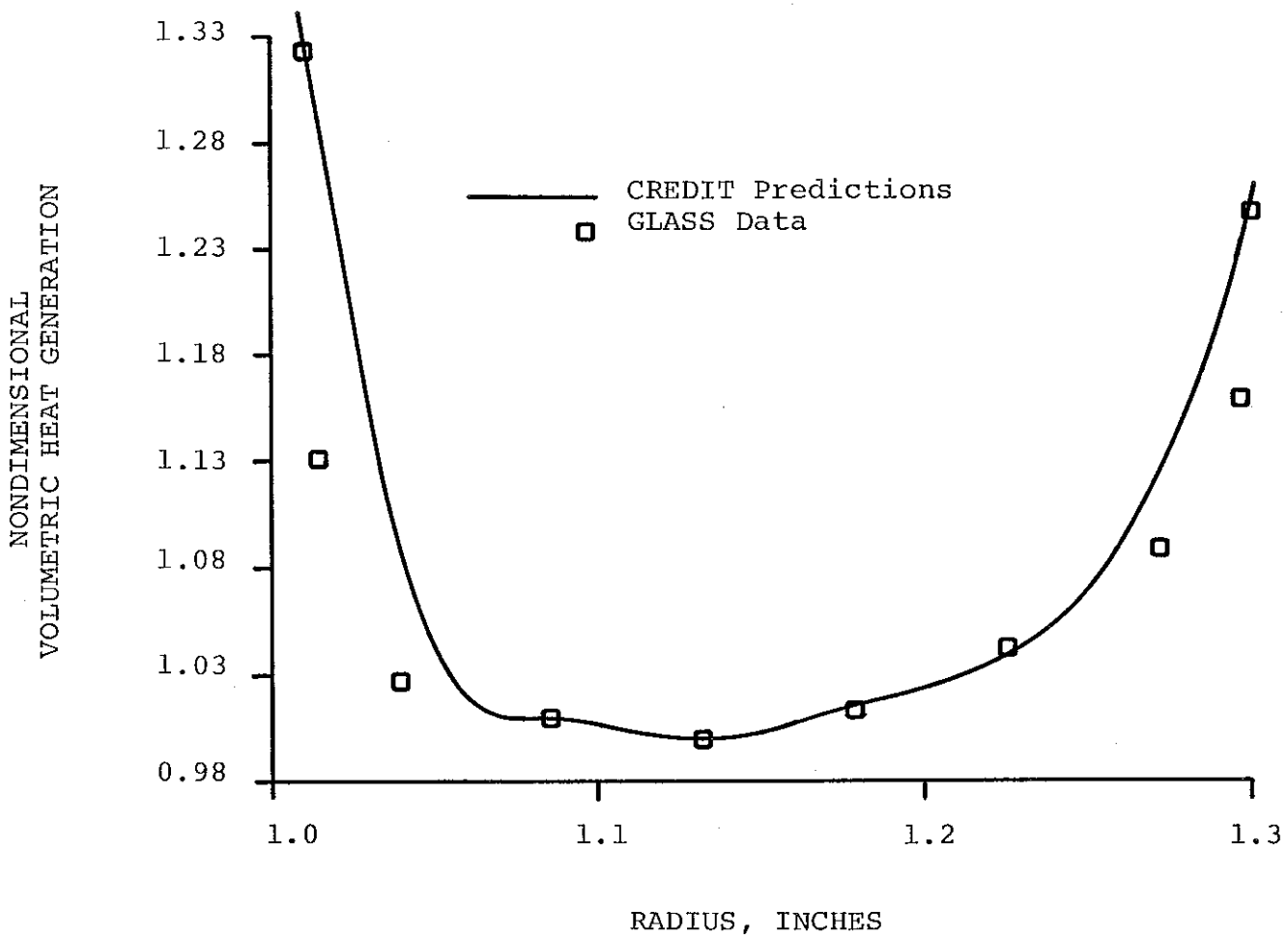


FIGURE 19
COMPARISON OF CREDIT AND GLASS RESULTS FOR THE
INNER MARK 15 FUEL TUBE AT 14.5% ^{235}U BURNUP



APPENDIX A
SAMPLE HCF CALCULATION

The procedure on how to calculate the horizontal flat portion of a HCF curve for a Mark 16B with a 2.4 g/ft ^{6}Li loading is given in this section.

The HCF_n parameter in Equation 22 needs to be determined. Since the h_i parameters in Equation 22 are unchanged, once the new HCF_n is determined the actual HCF can be calculated. The new HCF_n is determined for channel 1 since this channel as seen in Figure 14 provides the limiting (maximum) HCF for burnups up to 40% and 50% ^{235}U burnup. The definition of HCF_n

$$HCF_{n_{new}} = \frac{\Delta T_{channel}}{\Delta T_{assembly}} \quad \frac{\Delta T_{subchannel}}{\Delta T_{channel}} \quad \frac{\Delta T_{assembly}}{\Delta T_{HP}}$$

where $HCF_{n_{new}}$ = nominal HCF_n for 2.4 g/ft ^{6}Li loading

can be rewritten as

$$HCF_{n_{new}} = \frac{\left(\frac{\Delta T_{ch}}{\Delta T_{assy}}\right)_{new}}{\left(\frac{\Delta T_{ch}}{\Delta T_{assy}}\right)_{old}} \quad \left(\frac{\Delta T_{ch}}{\Delta T_{assy}}\right)_{old} \quad \frac{\Delta T_{sc}}{\Delta T_{ch}} \quad \frac{\Delta T_{assy}}{\Delta T_{HP}}$$

$$= \frac{\left(\frac{\Delta T_{ch}}{\Delta T_{assy}}\right)_{new}}{\left(\frac{\Delta T_{ch}}{\Delta T_{assy}}\right)_{old}} \quad HCF_{n_{old}} \qquad (A1)$$

The problems with this expression are $HCF_{n_{old}}$ and $(\Delta T_{ch}/\Delta T_{assy})_{old}$ do not exist for a 2.4 g/ft ^{6}Li loading for a Mark 16 assembly. The Mark 16 assembly values should be used instead of the Mark 16B values because the original thermocouple data[10] were for Mark 16 assemblies.

The Mark 16 values in Equation A1 require one to make some assumptions. First, assume that HCF_{old} equals 1.182 which

was obtained by extrapolating from the horizontal 1.0 g/ft HCF curve in Reference 14 for a Mark 16 assembly. The 1.182 value is the extrapolated HCF_n for the Mark 16 with a 2.4 g/ft ^6Li loading. Next, assume that the numerical value of $(\Delta T_{ch}/\Delta T_{assy})_{old}$ is for a Mark 16 with a 1.0 g/ft ^6Li loading. This temperature ratio is needed for both a 0% and 20% ^{235}U burnup. The $HCFn_{new}$ in Equation A1 is calculated for both these burnups and the most restrictive value is then used in Equation 22 to calculate the actual HCF. When calculating the temperature ratios, one must use the same assembly operating parameters that were used in developing the HCF curves in Reference 14. These parameters are 300 gpm flow, 6 MW power, and an inlet temperature of 35°C. The number of shell holes in the bottom fitting insert and the assumed axial flux shape have a negligible effect on HCF.

The numbers for channel 1 of the Mark 16 are

$$\left(\frac{\Delta T_{ch}}{\Delta T_{assy}}\right)_{old} = 1.006 \text{ at } 0\% \ ^{235}Bu$$

$$\left(\frac{\Delta T_{ch}}{\Delta T_{assy}}\right)_{old} = 0.975 \text{ at } 20\% \ ^{235}Bu$$

while the Mark 16B numbers are

$$\left(\frac{\Delta T_{ch}}{\Delta T_{assy}}\right)_{new} = 1.064 \text{ at } 0\% \ ^{235}Bu$$

$$\left(\frac{\Delta T_{ch}}{\Delta T_{assy}}\right)_{new} = 1.014 \text{ at } 20\% \text{ Bu}$$

The $HCF_{n_{new}}$ values are calculated to be

$$HCF_{n_{new}} = \frac{1.064}{1.006}(1.182) = 1.250 \text{ at } 0\% \ ^{235}U \text{ Bu}$$

$$HCF_{n_{new}} = \frac{1.014}{0.975} \quad (1.182) \quad = \quad 1.229 \text{ at } 20\% \ ^{235}U \text{ Bu}$$

The limiting $HCF_{n_{new}}$ is at 0% burnup so this value would be substituted into Equation 22 to give an actual HCF of 1.259. Thus, an HCF of 1.259 would be used for a Mark 16B assembly with a 2.4 g/ft ^{6}Li loading when using a 4-5 year USH.

The Mark 16B numbers in this example should not be used in any production situation because a non-standard lattice pattern in GLASS was used to provide input to the CREDIT code.

APPENDIX B
DESCRIPTION OF CREDIT SUBROUTINES

The appendix summarizes the contents of the important subroutines in the CREDIT code. Some of the subroutines have many comment statements which give the user a better idea of how the subroutine works. Since only portions of the DOTT and MAINV subroutines and all of the MARK 15 assembly subroutine were written by the authors of this report, the use of comment statements varies widely between subroutines. Also, the other subroutines may have some minor errors which the authors are unaware of at this time.

A flowchart of the CREDIT code is shown in Figure B1.

MAIN or CREDIT subroutine

This subroutine is the main section or starting point of the CREDIT computer program. Figure B2 is a flow chart for this 'subroutine'. The section for reading in data contains some logic statements which determines whether thermocouple data or axial flux shapes are read into the program. Although not shown in the flow chart, the value of the variable MONI determines which of twenty assembly subroutines are used. Only one assembly subroutine is shown in the Figure B2 flowchart.

This 'subroutine' contains many comment statements which defines program variables.

REVISE subroutine

This subroutine performs no calculations. It simply writes a list of statements at the beginning of each output block. There is one output block for each input data set such as given in Table 13. The statements which REVISE writes simply state the date of the last revision to the subroutines in the CREDIT code. The number of revisions to the subroutine is also given. Table B1 is a sample set of output data from the REVISE subroutine. In Table B1, the Mark 15 assembly subroutine is not listed because this subroutine was created during this work; it was not revised. All of the remaining subroutines are listed in Table B1.

ADECK Subroutine

The ADECK subroutine is used to punch a Ditty deck. This feature is not used in standard CREDIT calculations. The user can decide whether this subroutine is used by the appropriate value of the input variable DECK.

DITTY Subroutine

This subroutine is the control subroutine for the CREDIT program. As shown in Figure B1, this subroutine references five (counting MAINV) other subroutines. The flow chart is given in Figure B3.

The initial section of DITTY is devoted to calculating the axial step for the heat transfer calculations. Then, logic statements determine whether a read in (data input) or computed axial flux shape is used. Next, the variable APHI is calculated. This variable is used to distribute axially the assembly and tube heat generation rates. DITTY then initializes variables, calls CHEKUP to verify input data, and prints as part of the output the input data. SINDEX is then called. However, the results from SINDEX are not printed as part of any output data.

The remainder of DITTY is a nested set of two DO loops which increment on assembly power and plenum inlet temperature. Inside these nested DO loops,

- The DOTT subroutine is called.
- The PRINT subroutine is called if a long printout is required.
- Many important assembly parameters are printed as part of the standard output.
- The assembly effluent temperature is calculated.
- The HCF for Mark 42, Mark 22, and Mark 16/16B assemblies is calculated.
- A check is performed to determine if the assembly effluent temperature exceeds the saturation temperature at the assembly exit.

CHEKUP Subroutine

This subroutine checks the input data for errors and assigns standard values to some data if this data is input as zero. It is called from the DITTY subroutine.

SINDEX Subroutine

This subroutine calculates the axial shape index for a given flux shape. It is called from the DITTY subroutine.

DOTT Subroutine

This subroutine contains the assembly heat transfer calculations and the necessary logic to determine various maximum and minimum parameters. The heat transfer theory is discussed in the section, 'Heat Transfer Model', of this report.

In Figure B4, a flow chart for the heat transfer calculations in DOTT is given. The logic for determining the maximum and minimum values of parameters such as the maximum core temperature and minimum $BOSF_n$ is not shown in Figure B4. Subroutine DOTT is the most complex and longest subroutine in the CREDIT code.

The first section in DOTT initializes the parameters needed for the matrix inversion. The variable 'NR' is an integer equal to the number of coefficients in the volumetric heat generation profile

$$q'''(r) = \sum_{i=1}^{N} a_i r^{i-1}$$

across each tube in the assembly. At this moment, N equals three for all but the Mark 15 assembly, where N equals five. The MC and MS parameters are necessary input for the matrix inversion technique in the MAINV subroutine. Once the matrix is inverted, the a_i values in the previous equation are determined and labeled as A(I,NU). In this subroutine, the tube number is denoted by NU.

After the matrix calculations, many of the subroutine variables are initialized.

The main section of the DOTT subroutine is next and is the DO loop which marches down the assembly. This DO loop contains all the heat transfer calculations and is broken up into several blocks. The first block calculates the scaling factor for the a_i values in Equation 8. Successive blocks in turn calculate

- C_j term in Equation 20
- Second term of the B_j expression in Equation 15
- Saturation pressure at each axial length increment for each channel
- Moderator saturation pressure as a function of distance from the top of the assembly.

- Convective heat transfer coefficients for each tube surface in the assembly
- Bulk coolant temperature for each channel in the assembly
- Clad surface temperatures for each tube
- Core-clad interface temperatures for each tube
- Maximum core temperature for each tube
- Average core temperature for each tube
- Heat flux in pcu/ft^2-hr for each tube surface
- Burnout heat flux on the outer surface of the USH
- Burnout heat flux for each tube surface in the assembly
- $BOSF_n$ for each tube surface in the assembly

The remainder of this DO loop collects data for the short and long output options. The flow chart in Figure B4 only goes as far as the maximum tube core temperature calculations.

The remaining six statements in DOTT calculate the heat split values for each tube surface.

MAINV Subroutine

The subroutine is called by the DOTT subroutine and is used to invert matrices. The procedure used in MAINV is actually the LEQT1F subroutine in the IMSL[6] library. The initial portion of MAINV is used to initial the matrices into the format used by the LEQT1F subroutine. Once this is completed, LEQT1F is called. Then, the solution vector is redefined in terms of the BVCT variable.

LONG Subroutine

The LONG subroutine is used to print output for a long edit. A long edit prints the main assembly heat transfer characteristics every fifteen axial length increments. Generally, long edits are specified since it involves no increase in computer CPU time and the additional data is sometimes needed to analyze trends.

HOTCHA Subroutine

This subroutine is used to calculate hot subchannel factors given assembly thermocouple data. Reference 15 discusses the equations which are programmed in this subroutine. If needed, the HOTCHA subroutine is called from the assembly subroutine.

MARK 42 Subroutine

The MARK 42 subroutine is representative of most of the twenty assembly subroutines in the CREDIT code. Slight coding differences exist with those assemblies which do not have different heat generation characteristics for different lithium loadings. However, the general layout of each assembly subroutine is similar to the MARK 42 subroutine flow chart in Figure B5. Of all the assembly subroutines, the MARK 15 subroutine is perhaps the easiest to follow because it has several comment cards.

The initial section of the MARK 42 subroutine defines various assembly parameters such as

- Outer and inner clad diameters (inches)
- Equivalent diameters (inches) of each flow channel
- Assembly clad and core thermal conductivities (pcu/hr-ft-°C)
- Assigns, if needed, default values to several variables on moderator characteristics

Next, the individual channel flows (gpm) and fluid velocities (ft/sec) are calculated. A logical IF statement then selects the bottom endfitting type so that the correct pressure drop through the bottom endfitting insert is calculated. Then, the pressure losses are calculated from the top of core to channel exit and for the pressure loss per foot for each flow channel. The necessary logic is used so that the correct pressure loss equations for the different reactors are selected.

After the section on pressure loss characteristics, the heat generation and power fraction equations for each tube in the assembly are given. Because information on four different lithium loadings for Mark 42 assemblies is included in this subroutine, four sets of heat generation and power fraction equations are included in the MARK 42 subroutine.

Once the heat generation and power fractions are determined, the tube power fractions are renormalized. IF an assembly power is not specified, thermocouple data is then used to calculate an assembly power. The DITTY subroutine is then called. Next, HOTCHA is called if HCF are to be calculated from thermocouple data. If HCF calculations are not needed, control passes back to the MAIN or 'CREDIT' subroutine.

Error Messages

The CREDIT code can print a number of error messages which are intended as warning messages. These warnings can indicate that incorrect input data exists or that specified conditions exceed the valid range of certain equations programmed into the coding. Some of the more important messages are discussed below

- 'Coolant Pressures May Be In Error Due To Extrapolation In End Fitting Equation' - The equations which calculate the pressure drop through a bottom endfitting insert are experimentally determined. As such, there is a specified range of shell holes for which the equation is valid. This error message is printed if the user specifies in the input data a shell hole number which exceeds the shell hole range of the endfitting equation. This message is printed from the assembly subroutine.

- 'Radial Flux Factors May Be in Error ... For Per Cent Burnup With Target' - The radial heat generation and power fraction equations for each tube in an assembly are developed from GLASS[9] results. These results are valid for only a certain burnup range. If the user requests results for a burnup outside the specified range, the message is printed. When this happens, the code uses the correlating equations past their valid burnup. This message is printed from the assembly subroutine.

- 'Channel Effluent Temp Exceeds Saturation Temp --- Beware of Results' - This message is printed from the DITTY subroutine and indicates that two phase flow would occur for the specified input data.

- The CHEKUP subroutine can print any one of a dozen messages indicating that some of the input data is missing.

- 'IER=129' - This message is printed from the MAINV subroutine. It is a message from the IMSL subroutine LEQT1F which indicates that you have an algorithmically singular matrix.

- 'The HCF values cannot be calculated. The nonideality factors for this assembly are not programmed in the code' - This message is self-explanatory. It indicates that the code needs to be modified before calculating HCF values for this particular assembly. This message is printed from the DITTY subroutine.

TABLE
B1
SAMPLE OUTPUT FOR REVISE
SUBROUTINE

```
********** SUBROUTINE ++CREDIT ********** REVISION # 09---09/30/82---BY JEM **********
********** SUBROUTINE ++REVISE ********** REVISION # 09---09/30/82---BY JEM **********
********** SUBROUTINE +++ADECK ********** REVISION # 01---09/30/82---BY JEM **********
********** SUBROUTINE +++DITTY ********** REVISION # 04---09/30/82---BY JEM **********
********** SUBROUTINE +CHECKUP ********** REVISION # 01---09/30/82---BY JEM **********
********** SUBROUTINE ++SINDEX ********** REVISION # 01---09/30/82---BY JEM **********
********** SUBROUTINE ++++DOTT ********** REVISION # 02---09/30/82---BY JEM **********
********** SUBROUTINE +++MAINV ********** REVISION # 01---09/30/82---BY JEM **********
********** SUBROUTINE ++++LONG ********** REVISION # 02---09/30/82---BY JEM **********
********** SUBROUTINE ++HOTCHA ********** REVISION # 01---09/30/82---BY JEM **********
********** SUBROUTINE ++MARK14 FOR MARK 14  ASSEMBLY REVISION # 01---09/30/82---BY JEM **********
********** SUBROUTINE ++MARK16 FOR MARK 16  ASSEMBLY REVISION # 03---09/30/82---BY JEM **********
********** SUBROUTINE ++MARK30 FOR MARK 30  ASSEMBLY REVISION # 01---09/30/82---BY JEM **********
********** SUBROUTINE ++MRK18A FOR MARK 18A ASSEMBLY REVISION # 01---09/30/82---BY JEM **********
********** SUBROUTINE ++MARK18 FOR MARK 18B ASSEMBLY REVISION # 01---09/30/82---BY JEM **********
********** SUBROUTINE ++MARK40 FOR MARK 40  ASSEMBLY REVISION # 01---09/30/82---BY JEM **********
********** SUBROUTINE ++MARK53 FOR MARK 53  ASSEMBLY REVISION # 01---09/30/82---BY JEM **********
********** SUBROUTINE ++MRK53A FOR MARK 53A ASSEMBLY REVISION # 01---09/30/82---BY JEM **********
********** SUBROUTINE ++MARK22 FOR MARK 22  ASSEMBLY REVISION # 01---09/30/82---BY JEM **********
********** SUBROUTINE ++MARK41 FOR MARK 41  ASSEMBLY REVISION # 02---09/30/82---BY JEM **********
********** SUBROUTINE ++MRK16B FOR MARK 16B ASSEMBLY REVISION # 04---09/30/82---BY JEM **********
********** SUBROUTINE ++MRKOX1 FOR MARK OX1OXIDE ASSEMBLY REVISION # 04 ---09/30/82---BY JEM **********
********** SUBROUTINE ++MRKR35 FOR MARK R35 ASSEMBLY REVISION # 03---09/30/82---BY JEM **********
********** SUBROUTINE ++MRKR40 FOR MARK R40 ASSEMBLY REVISION # 03---09/30/82---BY JEM **********
********** SUBROUTINE ++MRKUS1 FOR MARK US1 ASSEMBLY REVISION # 06---09/30/82---BY JEM **********
********** SUBROUTINE ++MRKUS2 FOR MARK US2 ASSEMBLY REVISION # 01---09/30/82---BY JEM **********
********** SUBROUTINE ++THORIA FOR THORIA   ASSEMBLY REVISION # 01---09/30/82---BY JEM **********
********** SUBROUTINE ++MARK42 FOR MARK 42  ASSEMBLY REVISION # 03---09/30/82---BY JEM **********
********** SUBROUTINE ++MRKOX2 FOR MARK OX2 ASSEMBLY REVISION # 03---09/30/82---BY JEM **********
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FIGURE B1

DIAGRAM SHOWING HOW THE VARIOUS SUBROUTINES IN CREDIT ARE CALLED IN THE CODING

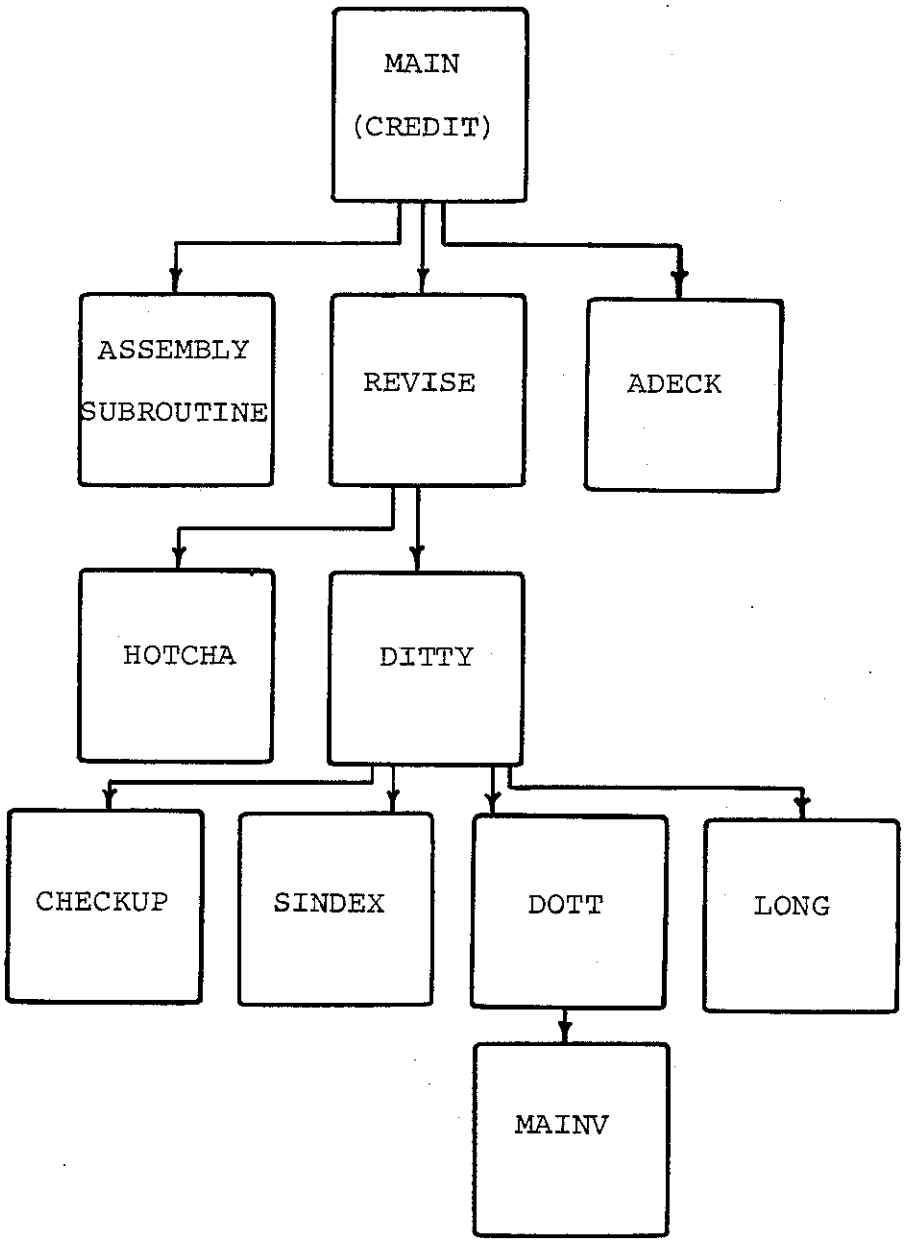


FIGURE B2

FLOW CHART FOR THE MAIN SECTION OF THE CREDIT COMPUTER CODE

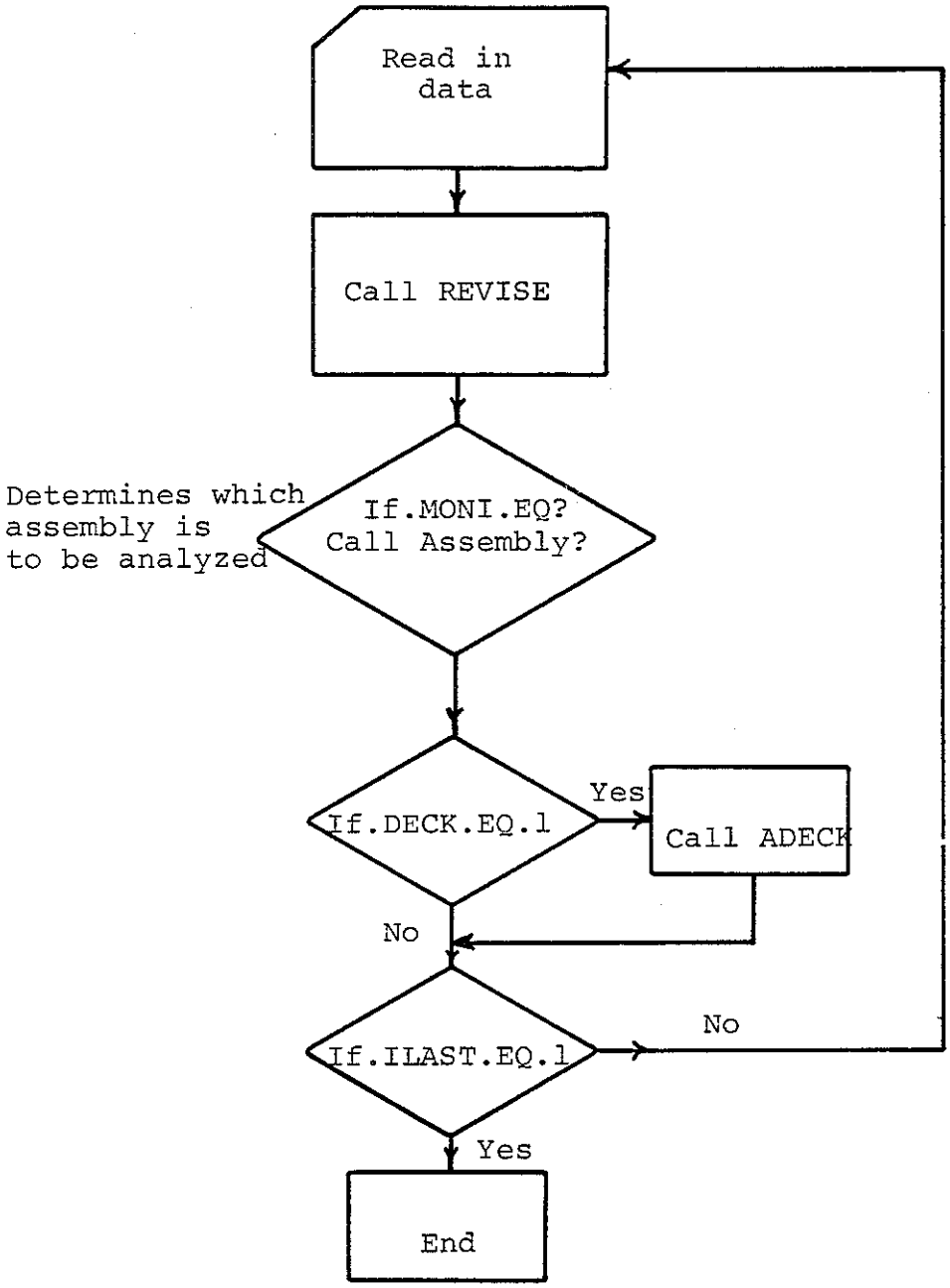


FIGURE B3

FLOW CHART FOR THE DITTY SUBROUTINE
OF THE CREDIT COMPUTER CODE

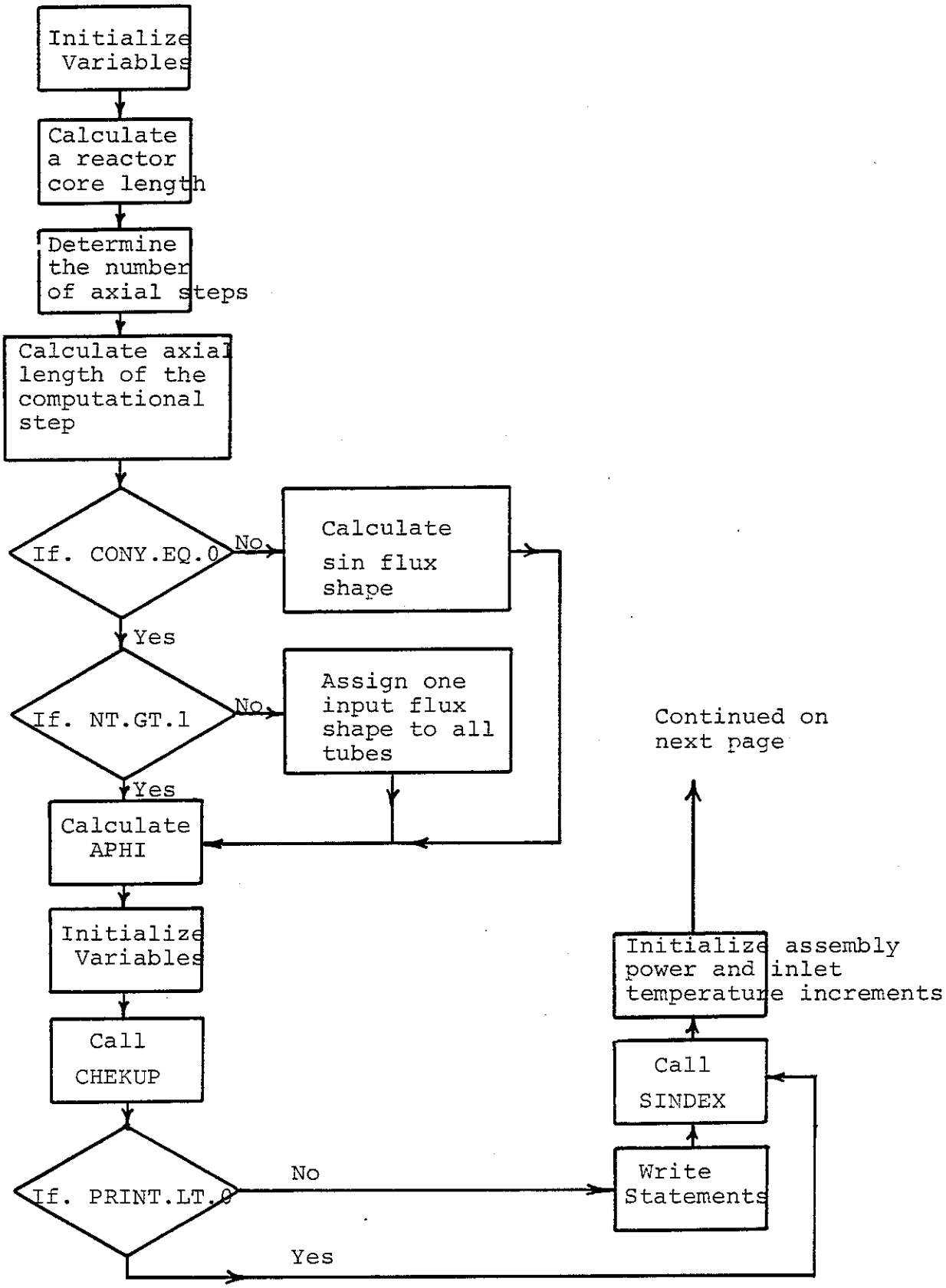


FIGURE B3, continued

FLOW CHART FOR THE DITTY SUBROUTINE
OF THE CREDIT COMPUTER CODE

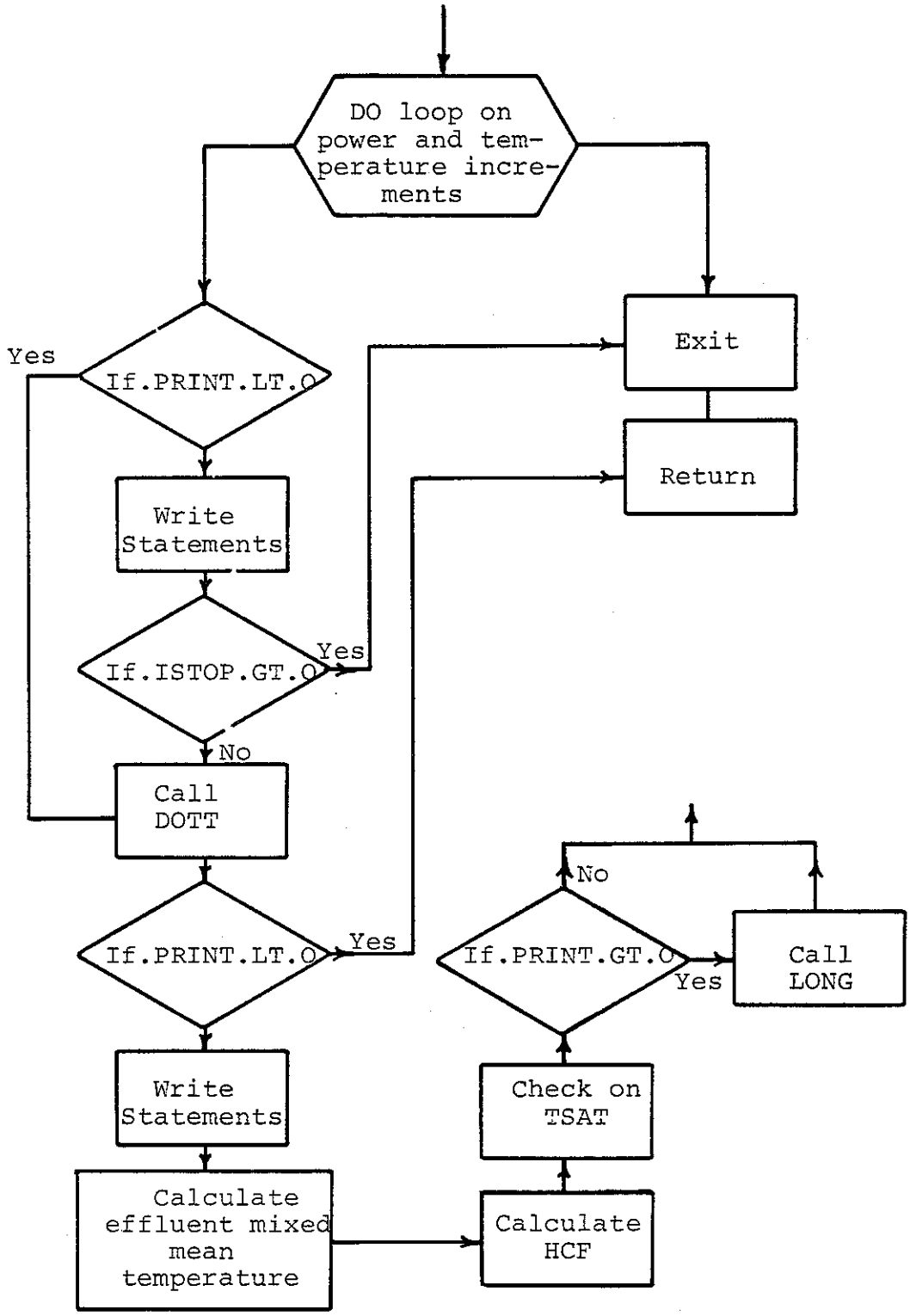


FIGURE B4

FLOW CHART FOR DOTT SUBROUTINE

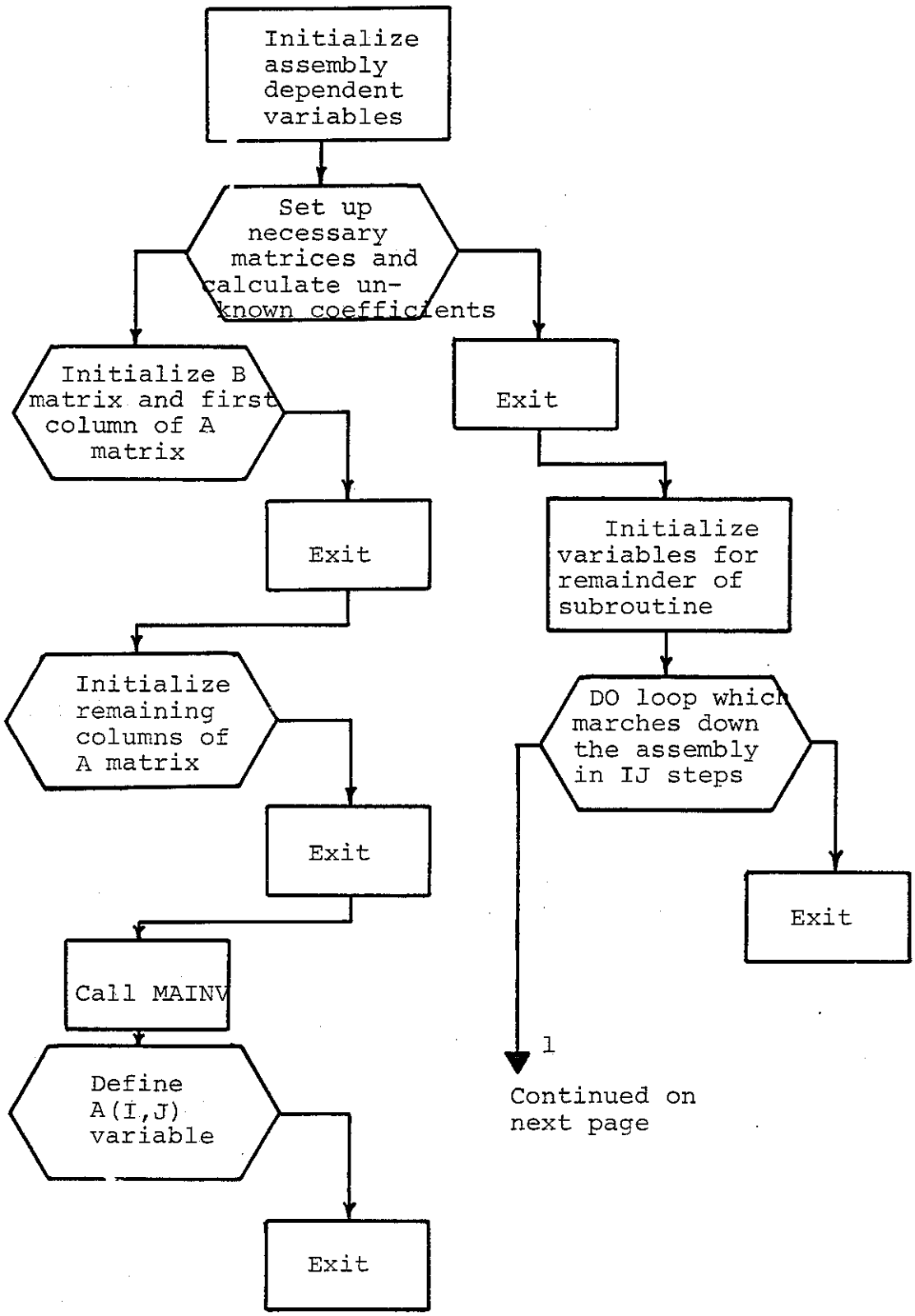


FIGURE B4 , CONTINUED
FLOW CHART FOR DOTT SUBROUTINE

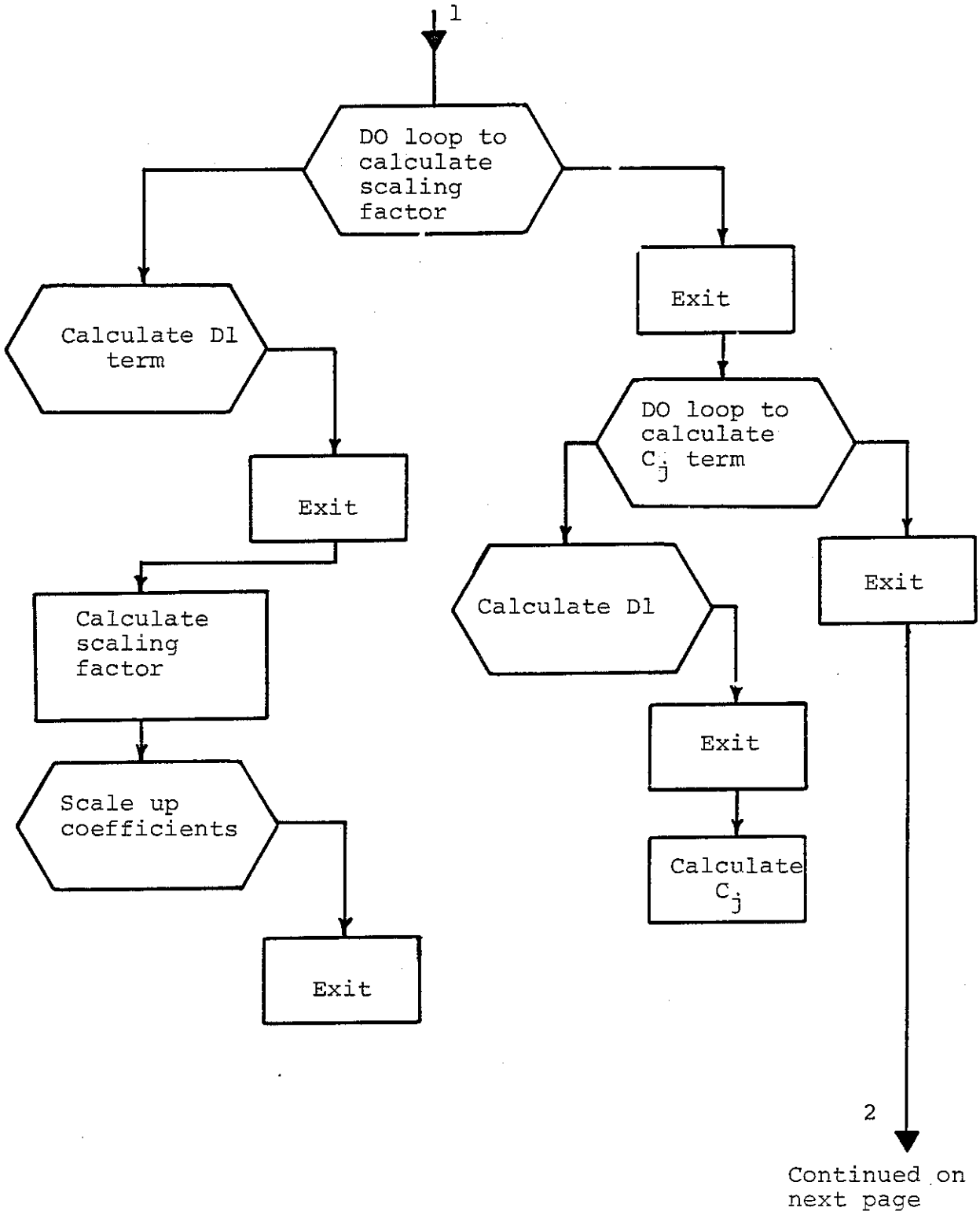


FIGURE B4 , CONTINUED
FLOW CHART FOR DOTT SUBROUTINE

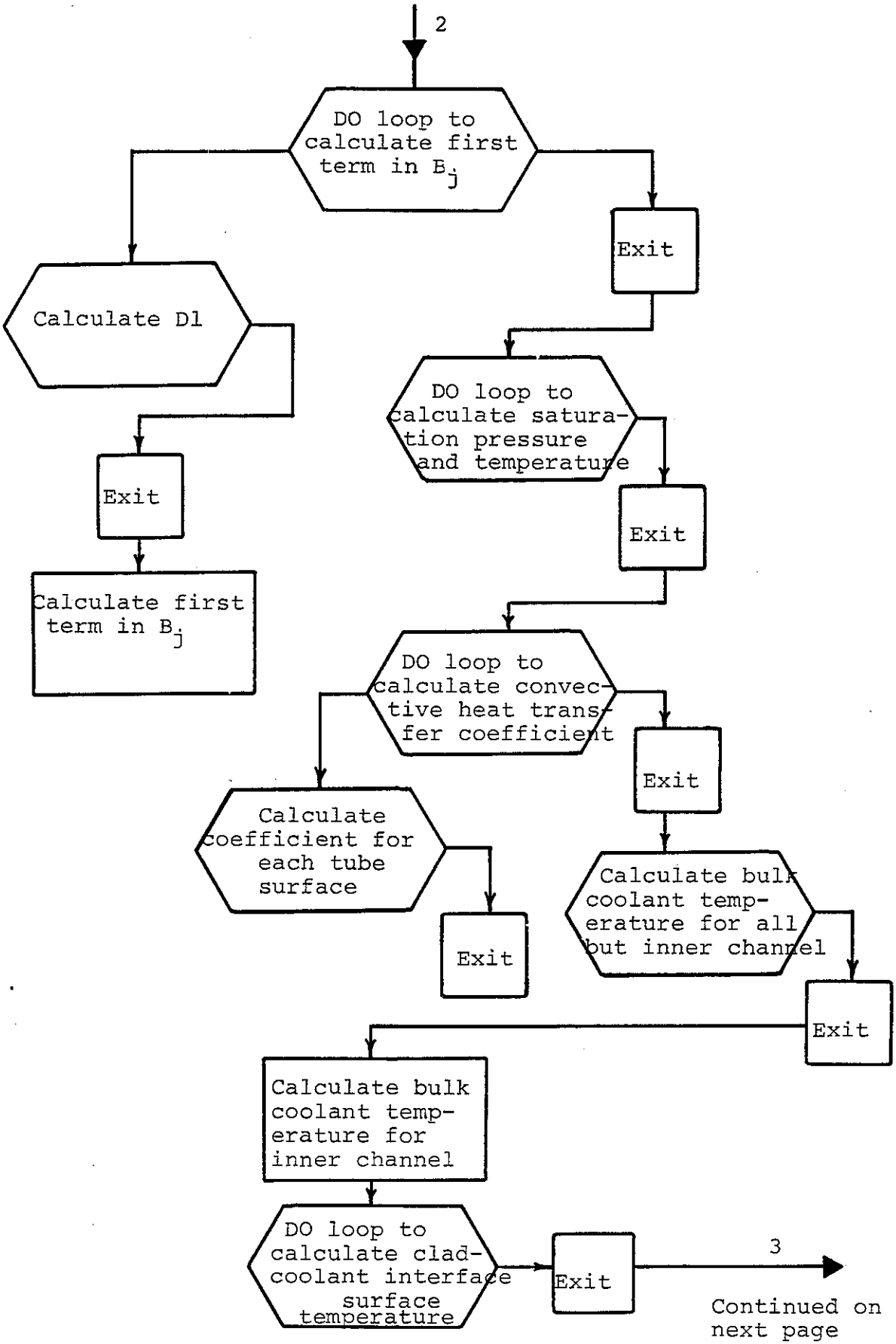


FIGURE B4 , CONTINUED
FLOW CHART FOR DOTT SUBROUTINE

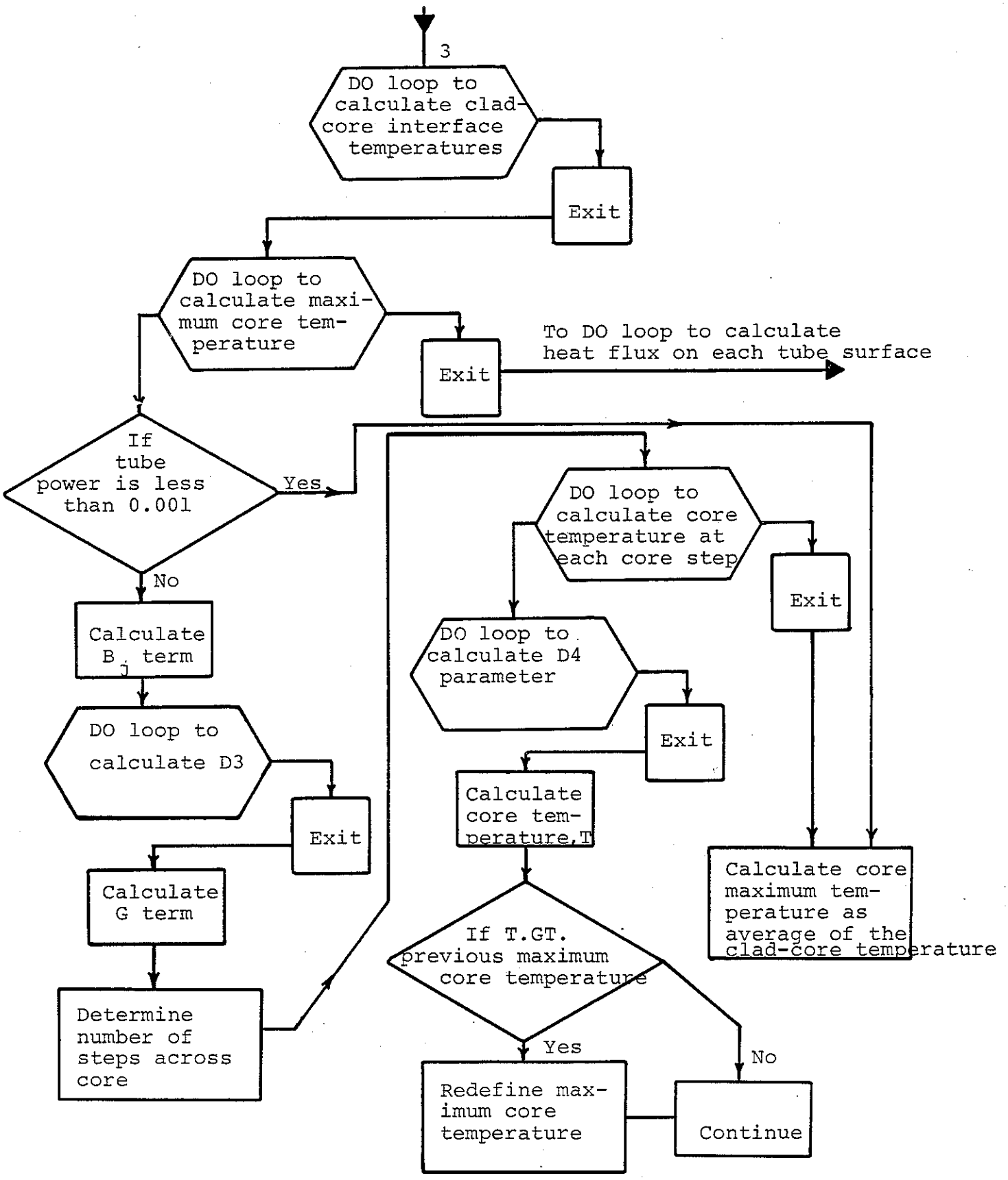
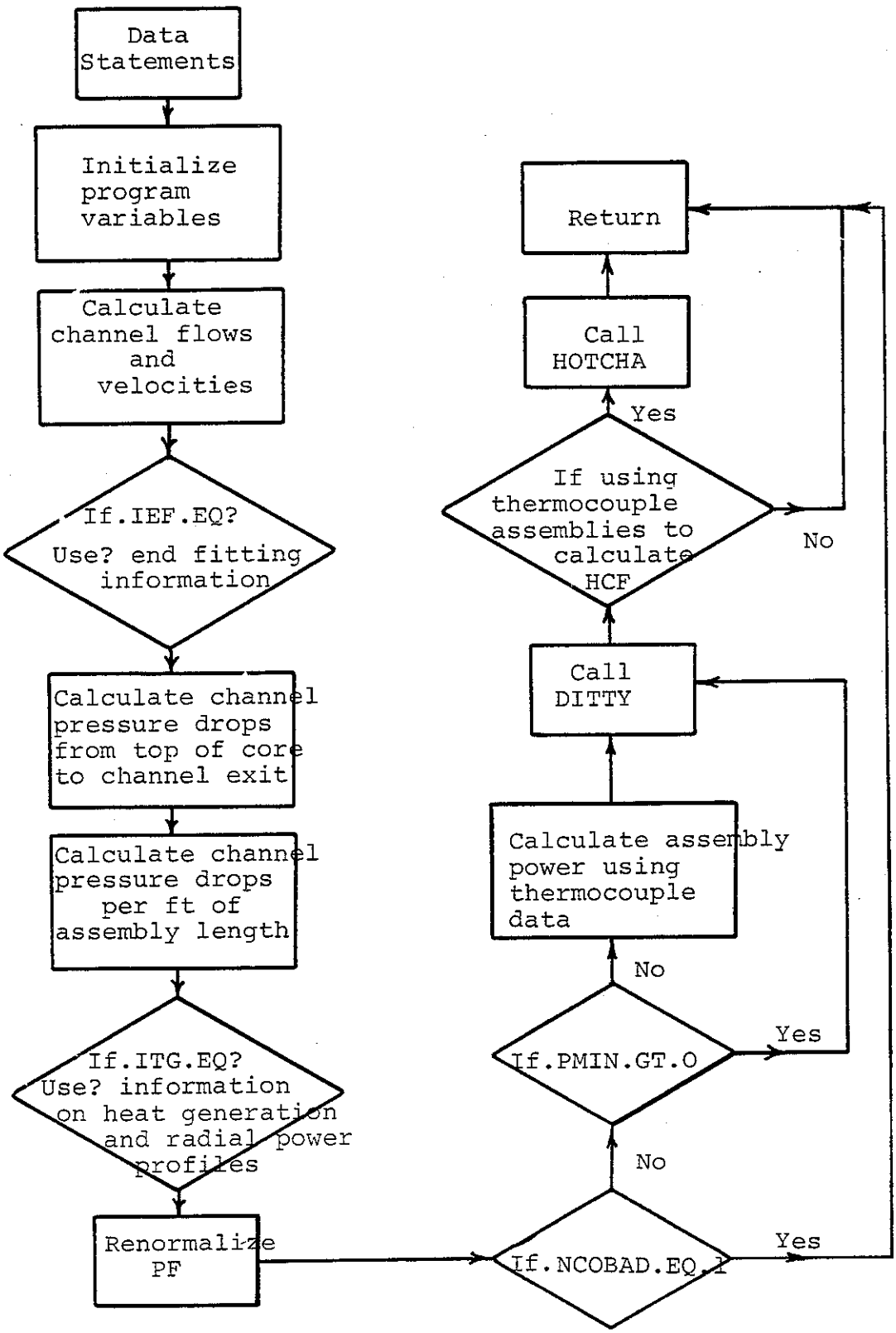


FIGURE
B5
FLOW CHART FOR MARK 42 ASSEMBLY SUBROUTINE
IN THE CREDIT COMPUTER CODE



APPENDIX C
CALCULATION OF RPHI AND PF VARIABLES

GLASS computer code data is used to generate the RPHI and PF correlations that are found in the assembly subroutine. The procedure for calculating these two variables is discussed in this appendix. The sample numbers and tables in this appendix are for a Mark 42 assembly with a zero lithium loading.

When running the GLASS code to provide data for the RPHI variable for non Mark 15 assemblies, it is necessary to subdivide each tube core into at least 3 and preferably 5 regions. Axial power variations are accounted for by the axial flux shape read in as part of the input data. For a three fuel tube assembly with each fuel tube subdivided into 5 regions, the GLASS subregion power edit page shown in Table C1 is printed. Since Table C1 is for a zero MWD exposure, the underlined numbers in Table C1 form the first line in Table C2. The remainder of the Table C2 numbers are then obtained from the equivalent of Table C1 for the remaining MWD exposures. Before calculating the RPHI expressions, the Table C2 results must be nondimensionalized for each fuel tube. Usually, the values for one of the three columns for each tube is smaller than the other two columns. Table C3 lists the normalized values for the Table C2 numbers. As an example, consider the inner fuel tube where the smallest power values in Table C2 are in the middle column. For each MWD exposure, the inner and outer column values are divided by the middle column value for that MWD exposure.

The normalized values in Table C3 are used to develop the RPHI correlations. At the bottom of each column in Table C3 is the correct RPHI subscript notation that would be used in the Mark 42 assembly subroutine. Since these correlations are a function of percent burnup, it is first necessary to correlate MWD exposure as a function of percent burnup for a particular isotope. Table C4 provides the information for correlating MWD exposure as a function of percent isotope burnup.

The tube power fraction, PF, is the second variable obtained from GLASS data. Table C5 lists the assembly power data for each tube. However, the Table C5 numbers omit the power contribution of the (n,α) contribution. Table C6 lists the powers for each of these two contributions and the sum of these powers. The tube power column in Table C6 is actually a summation of the Table C5 powers for the tube core and the cladding on each side of the core. The contribution of the (n,α) reaction is under the 'Capture' column. For the target tube at zero MWD exposure, the (n,α) contribution is determined by summing the two numbers which are inside the rectangle of Table C7 and multiplying the sum by 2.3436×10^{-17}. This constant converts the units from

captures/sec/(cm of height) to MW/ft. The (n,α) powers in Table C6 are small because this example had a zero lithium loading in the target tube. For nonzero loadings, the (n,α) contribution is not negligible and should not be omitted.

Once each tube power is calculated, the total assembly power is available. Table C8 lists the total assembly power values and the corresponding tube power fractions.

The RPHI correlations are generally first order expressions. Second order polynomials are only used when the correlation coefficient for the first order fit is less than 0.99. For the PF correlations, third order polynomials are generally used. Higher order expressions are only used if the third order correlation coefficient is less than 0.99.

TABLE C1

GLASS Subroutine Power Edit Table

CELL NUMBER = 5

SUBREGION POWER EDIT (MW/FT)

SUBREGION	TOTAL POWER ==DEPOSIT==	FISSION POWER ===SOURCE====	PHOTON POWER ===DEPOSIT==	VOLUME (CM**2)	TOTAL POWER MW/FT/CM**2	FISSION POWER MW/FT/CM**2	PHOTON POWER MW/FT/CM**2	REG	POWER MW/FT
91	0.20775E-03	0.0	0.20775E-03	0.64130E+01	0.32395E-04	0.0	0.32395E-04	43	2.0775E-04
92	0.48983E-04	0.0	0.48983E-04	0.58271E+00	0.84060E-04	0.0	0.84060E-04	44	4.8983E-05
93	0.51864E-04	0.0	0.51864E-04	0.62047E+00	0.83589E-04	0.0	0.83589E-04		
94	0.53820E-04	0.0	0.53820E-04	0.64682E+00	0.83207E-04	0.0	0.83207E-04		
95	0.56377E-04	0.0	0.56377E-04	0.67318E+00	0.83747E-04	0.0	0.83747E-04	45	1.6206E-04
96	0.73907E-04	0.0	0.73907E-04	0.87525E+00	0.84441E-04	0.0	0.84441E-04	46	7.3907E-05
97	0.17111E-03	0.0	0.17111E-03	0.51441E+01	0.33263E-04	0.0	0.33263E-04	47	1.7111E-04
98	0.12321E-03	0.0	0.12321E-03	0.14253E+01	0.86444E-04	0.0	0.86444E-04	48	1.2321E-04
99	0.44540E-02	0.46981E-02	0.10349E-03	0.83395E+00	0.53409E-02	0.56336E-02	0.12409E-03		
100	0.45191E-02	0.47649E-02	0.10663E-03	0.85465E+00	0.52876E-02	0.55753E-02	0.12477E-03		
101	0.46452E-02	0.48990E-02	0.10861E-03	0.87536E+00	0.53066E-02	0.55966E-02	0.12408E-03		
102	0.46935E-02	0.49461E-02	0.11329E-03	0.89606E+00	0.52379E-02	0.55198E-02	0.12644E-03		
103	0.49190E-02	0.51891E-02	0.11376E-03	0.91679E+00	0.53654E-02	0.56600E-02	0.12409E-03	49	2.3231E-02
104	0.14003E-03	0.0	0.14003E-03	0.16113E+01	0.86907E-04	0.0	0.86907E-04	50	1.4003E-04
105	0.39445E-03	0.0	0.39445E-03	0.11621E+02	0.33941E-04	0.0	0.33941E-04	51	3.9445E-04
106	0.13912E-03	0.0	0.13912E-03	0.15931E+01	0.87324E-04	0.0	0.87324E-04	52	1.3912E-04
107	0.74561E-02	0.78679E-02	0.17196E-03	0.12242E+01	0.60905E-02	0.64269E-02	0.14046E-03		
108	0.77665E-02	0.82066E-02	0.16877E-03	0.12449E+01	0.62385E-02	0.65920E-02	0.13556E-03		
109	0.78046E-02	0.82408E-02	0.17525E-03	0.12656E+01	0.61666E-02	0.65113E-02	0.13847E-03		
110	0.79146E-02	0.83537E-02	0.18069E-03	0.12863E+01	0.61528E-02	0.64942E-02	0.14047E-03		
111	0.82143E-02	0.86744E-02	0.18347E-03	0.13071E+01	0.62845E-02	0.66365E-02	0.14037E-03	53	3.9156E-02
112	0.19347E-03	0.0	0.19347E-03	0.21958E+01	0.88111E-04	0.0	0.88111E-04	54	1.9347E-04
113	0.52846E-03	0.0	0.52846E-03	0.15645E+02	0.33778E-04	0.0	0.33778E-04	55	5.2846E-04
114	0.18319E-03	0.0	0.18319E-03	0.21063E+01	0.86970E-04	0.0	0.86970E-04	56	1.8319E-04
115	0.34177E-02	0.35553E-02	0.12616E-03	0.10383E+01	0.32918E-02	0.34243E-02	0.12151E-03		
116	0.33869E-02	0.35195E-02	0.12852E-03	0.10469E+01	0.32352E-02	0.33618E-02	0.12276E-03		
117	0.35486E-02	0.36949E-02	0.12780E-03	0.10555E+01	0.33619E-02	0.35005E-02	0.12108E-03		
118	0.35137E-02	0.36536E-02	0.13114E-03	0.10642E+01	0.33018E-02	0.34333E-02	0.12323E-03		
119	0.35870E-02	0.37306E-02	0.13322E-03	0.10729E+01	0.33434E-02	0.34772E-02	0.12417E-03	57	1.7454E-02
120	0.19680E-03	0.0	0.19680E-03	0.22316E+01	0.88191E-04	0.0	0.88191E-04	58	1.9680E-04
121	0.40233E-03	0.0	0.40233E-03	0.11902E+02	0.33805E-04	0.0	0.33805E-04	59	4.0233E-04
122	0.38543E-03	0.0	0.38543E-03	0.43235E+01	0.89146E-04	0.0	0.89146E-04	60	3.8543E-04
123	0.65391E-03	0.0	0.65391E-03	0.19538E+02	0.33468E-04	0.0	0.33468E-04		
124	0.73387E-03	0.0	0.73387E-03	0.21545E+02	0.34062E-04	0.0	0.34062E-04	61	1.3878E-03
125	0.44358E-03	0.0	0.44358E-03	0.12411E+02	0.35742E-04	0.0	0.35742E-04		
126	0.41896E-03	0.0	0.41896E-03	0.12411E+02	0.33758E-04	0.0	0.33758E-04		
127	0.51005E-03	0.0	0.51005E-03	0.12411E+02	0.41097E-04	0.0	0.41097E-04		
128	0.49618E-03	0.0	0.49618E-03	0.12411E+02	0.39980E-04	0.0	0.39980E-04		
129	0.34225E-03	0.0	0.34225E-03	0.12411E+02	0.27577E-04	0.0	0.27577E-04		
130	0.33860E-03	0.0	0.33860E-03	0.12411E+02	0.27283E-04	0.0	0.27283E-04		
131	0.47770E-03	0.0	0.47770E-03	0.12106E+02	0.39461E-04	0.0	0.39461E-04		
132	0.40704E-03	0.0	0.40704E-03	0.12106E+02	0.33624E-04	0.0	0.33624E-04		
133	0.54725E-03	0.0	0.54725E-03	0.12106E+02	0.45206E-04	0.0	0.45206E-04		
134	0.53210E-03	0.0	0.53210E-03	0.12106E+02	0.43954E-04	0.0	0.43954E-04		
135	0.32130E-03	0.0	0.32130E-03	0.12106E+02	0.26542E-04	0.0	0.26542E-04		
136	0.31865E-03	0.0	0.31865E-03	0.12106E+02	0.26323E-04	0.0	0.26323E-04	61	5.1537E-03

RADIAL POWER SHAPE COMPUTED IN GLASS

TUBE 1	RP(2)= 8.9146E-05	RP(2+3/2)= 8.9146E-05	RP(3)= 8.9146E-05
TUBE 2	RP(2)= 3.3434E-03	RP(2+3/2)= 3.3619E-03	RP(3)= 3.2918E-03
TUBE 3	RP(2)= 6.2845E-03	RP(2+3/2)= 6.1666E-03	RP(3)= 6.0905E-03
TUBE 4	RP(2)= 5.3654E-03	RP(2+3/2)= 5.3066E-03	RP(3)= 5.3409E-03

TABLE C2
Radial Powers

	Inner Fuel			Middle Fuel			Outer Fuel		
MWD	Inner	Middle	Outer	Inner	Middle	Outer	Inner	Middle	Outer
0	53409	53066	53654	60905	61666	62845	32918	33619	33434
25.016	48905	48623	49095	56546	57224	58177	29027	29606	29434
66.541	42493	42288	42621	50373	50939	51618	23345	23762	23621
98.572	37324	37171	37418	44934	45409	45911	18745	19045	18937
124.870	33152	33034	33224	40349	40752	41137	15324	15550	15471
145.440	29718	29624	29775	36219	36559	36862	13261	13441	13380
161.833	26864	26786	26906	32621	32909	33154	12133	12286	12237

TABLE C3
Normalized Radial Powers

	Inner Fuel			Middle Fuel			Outer Fuel		
MWD	Inner	Middle	Outer	Inner	Middle	Outer	Inner	Middle	Outer
0	1.0065	1.0	1.0111	1.0	1.0125	1.0319	1.0	1.0213	1.0157
25.016	1.0058	1.0	1.0097	1.0	1.0120	1.0288	1.0	1.0199	1.0140
66.541	1.0048	1.0	1.0079	1.0	1.0112	1.0247	1.0	1.0179	1.0118
98.572	1.0041	1.0	1.0066	1.0	1.0106	1.0217	1.0	1.0160	1.0102
124.870	1.0036	1.0	1.0058	1.0	1.0100	1.0195	1.0	1.0147	1.0096
145.440	1.0032	1.0	1.0051	1.0	1.0094	1.0178	1.0	1.0136	1.0090
161.833	1.0029	1.0	1.0045	1.0	1.0088	1.0163	1.0	1.0126	1.0086
RPHI	(3,4)	(2,4)	(1,4)	(3,3)	(2,3)	(1,3)	(3,2)	(2,2)	(1,2)

TABLE C4

TOTAL ISOTOPIC ENRICHMENT (GM/FT)
****

TIME (MWD)	AL	LI6	T	HE3	O
0.0	0.138832E+04	0.590501E-17	0.296080E-17	0.296080E-17	0.521241E+02
20.0000	0.138822E+04	0.590501E-17	0.876464E-17	0.296080E-17	0.521241E+02
40.0000	0.138810E+04	0.590501E-17	0.149560E-16	0.296080E-17	0.521240E+02
60.0000	0.138798E+04	0.590501E-17	0.216756E-16	0.296080E-17	0.521240E+02
80.0000	0.138785E+04	0.590501E-17	0.290494E-16	0.296080E-17	0.521239E+02
99.9999	0.138770E+04	0.590501E-17	0.372214E-16	0.296080E-17	0.521239E+02
119.9999	0.138753E+04	0.590501E-17	0.463860E-16	0.296080E-17	0.521238E+02
139.9999	0.138734E+04	0.590501E-17	0.569084E-16	0.296080E-17	0.521238E+02
159.9999	0.138712E+04	0.590501E-17	0.694085E-16	0.296080E-17	0.521238E+02
179.9997	0.138683E+04	0.590501E-17	0.851371E-16	0.296080E-17	0.521237E+02

TIME (MWD)	PU238	PU239	PU240	PU241	PU242
0.0	0.362542E+00	0.125478E+01	0.213792E+02	0.925952E+01	0.231133E+02
20.0000	0.370405E+00	0.841398E+00	0.182309E+02	0.817992E+01	0.237514E+02
40.0000	0.371258E+00	0.562674E+00	0.152531E+02	0.714226E+01	0.242581E+02
60.0000	0.364705E+00	0.379063E+00	0.124523E+02	0.613411E+01	0.246379E+02
80.0000	0.350754E+00	0.261897E+00	0.987198E+01	0.514595E+01	0.248846E+02
99.9999	0.329618E+00	0.189209E+00	0.755656E+01	0.418660E+01	0.249847E+02
119.9999	0.301701E+00	0.144396E+00	0.553581E+01	0.327661E+01	0.249166E+02
139.9999	0.267027E+00	0.115428E+00	0.381864E+01	0.243553E+01	0.246524E+02
159.9999	0.225644E+00	0.941070E-01	0.241450E+01	0.167664E+01	0.241551E+02
179.9997	0.177356E+00	0.749410E-01	0.133495E+01	0.101437E+01	0.233612E+02

TIME (MWD)	XE135	SM149	U234	U235OLD	U236
0.0	0.118635E-03	0.384694E-02	0.318263E-02	0.729702E-03	0.169002E-03
20.0000	0.991145E-04	0.276742E-02	0.331819E-02	0.759876E-03	0.190718E-03
40.0000	0.852210E-04	0.243393E-02	0.343673E-02	0.793002E-03	0.214745E-03
60.0000	0.723071E-04	0.210012E-02	0.352984E-02	0.825922E-03	0.241758E-03
80.0000	0.601093E-04	0.177176E-02	0.359000E-02	0.855127E-03	0.272296E-03
99.9999	0.486112E-04	0.147124E-02	0.361016E-02	0.877013E-03	0.306827E-03
119.9999	0.379467E-04	0.119287E-02	0.358288E-02	0.888215E-03	0.345811E-03
139.9999	0.282201E-04	0.937754E-03	0.349821E-02	0.884706E-03	0.390044E-03
159.9999	0.195110E-04	0.703044E-03	0.334332E-02	0.861249E-03	0.440732E-03
179.9997	0.119346E-04	0.490492E-03	0.309797E-02	0.809734E-03	0.500021E-03

TIME (MWD)	U237	U238	U239	NP237	NP238
0.0	0.664535E-06	0.438277E-06	0.327829E-11	0.547145E-03	0.287222E-05
20.0000	0.701569E-06	0.530747E-06	0.385355E-11	0.546903E-03	0.324948E-05
40.0000	0.843701E-06	0.646600E-06	0.503019E-11	0.539624E-03	0.344569E-05
60.0000	0.101182E-05	0.798121E-06	0.662319E-11	0.525156E-03	0.362802E-05
80.0000	0.120637E-05	0.997493E-06	0.876450E-11	0.503802E-03	0.376925E-05
99.9999	0.144028E-05	0.126128E-05	0.117754E-10	0.476183E-03	0.389405E-05
119.9999	0.172633E-05	0.161549E-05	0.161212E-10	0.443026E-03	0.398944E-05
139.9999	0.210179E-05	0.210726E-05	0.228881E-10	0.404787E-03	0.410099E-05
159.9999	0.262168E-05	0.282771E-05	0.343973E-10	0.361699E-03	0.425547E-05
179.9997	0.340925E-05	0.398359E-05	0.568440E-10	0.313373E-03	0.449063E-05

TABLE C5

GLASS Power Data

CELL NAME= MK42 CELL VERSION= MK42***5 >>> ASSEMBLY TOTAL <<<

REGION POWER EDIT (MW/FT)

TIME (MWD)	DS-01-01	CL-01-01	TT-01-01	CL-01-02	CO-01-01
0.0	0.0002	0.0000	0.0002	0.0001	0.0002
25.0155	0.0002	0.0001	0.0002	0.0001	0.0002
66.5414	0.0002	0.0001	0.0002	0.0001	0.0002
98.5717	0.0002	0.0001	0.0002	0.0001	0.0002
124.8705	0.0002	0.0001	0.0002	0.0001	0.0002
145.4397	0.0002	0.0001	0.0002	0.0001	0.0002
161.8332	0.0003	0.0001	0.0002	0.0001	0.0002
175.1704	0.0003	0.0001	0.0002	0.0001	0.0002
179.9997	0.0003	0.0001	0.0002	0.0001	0.0002
TIME (MWD)	CL-02-01	FT-01-01	CL-02-02	CO-02-01	CL-03-01
0.0	0.0001	0.0232	0.0001	0.0004	0.0001
25.0155	0.0001	0.0213	0.0001	0.0004	0.0001
66.5414	0.0001	0.0185	0.0001	0.0004	0.0001
98.5717	0.0001	0.0163	0.0002	0.0004	0.0002
124.8705	0.0001	0.0144	0.0002	0.0004	0.0002
145.4397	0.0001	0.0130	0.0002	0.0005	0.0002
161.8332	0.0002	0.0117	0.0002	0.0005	0.0002
175.1704	0.0002	0.0107	0.0002	0.0005	0.0002
179.9997	0.0002	0.0103	0.0002	0.0005	0.0002
TIME (MWD)	FT-02-01	CL-03-02	CO-03-01	CL-04-01	FT-03-01
0.0	0.0392	0.0002	0.0005	0.0002	0.0175
25.0155	0.0363	0.0002	0.0005	0.0002	0.0154
66.5414	0.0323	0.0002	0.0006	0.0002	0.0124
98.5717	0.0288	0.0002	0.0006	0.0002	0.0099
124.8705	0.0258	0.0002	0.0006	0.0002	0.0081
145.4397	0.0232	0.0002	0.0006	0.0002	0.0070
161.8332	0.0208	0.0002	0.0007	0.0002	0.0064
175.1704	0.0189	0.0003	0.0007	0.0002	0.0062
179.9997	0.0182	0.0003	0.0007	0.0003	0.0062
TIME (MWD)	CL-04-02	CO-04-01	MO-01-01	MO-01-01	MO-01-02
0.0	0.0002	0.0004	0.0004	0.0014	0.0052
25.0155	0.0002	0.0004	0.0004	0.0014	0.0053
66.5414	0.0002	0.0004	0.0004	0.0015	0.0056
98.5717	0.0002	0.0004	0.0004	0.0015	0.0058
124.8705	0.0002	0.0005	0.0004	0.0016	0.0060
145.4397	0.0002	0.0005	0.0005	0.0017	0.0063
161.8332	0.0003	0.0005	0.0005	0.0018	0.0066
175.1704	0.0003	0.0005	0.0005	0.0019	0.0069
179.9997	0.0003	0.0006	0.0005	0.0019	0.0071
TIME (MWD)	TOTAL---				
0.0	0.0897				
25.0155	0.0832				

TABLE C6
Tube Powers

	Target Tube			Inner Fuel			Middle Fuel			Outer Fuel		
MWD	Capture*	Tube**	Total***	Capture	Tube	Total	Capture	Tube	Total	Capture	Tube	Total
0	0.0001	0.0003	0.0004	0.0016	0.0234	0.0250	0.0030	0.0395	0.0425	0.0018	0.0179	0.0197
25.016	0.0001	0.0004	0.0005	0.0017	0.0215	0.0232	0.0030	0.0366	0.0396	0.0018	0.0158	0.0176
66.541	0.0001	0.0004	0.0005	0.0017	0.0187	0.0204	0.0031	0.0326	0.0357	0.0018	0.0128	0.0146
98.572	0.0001	0.0004	0.0005	0.0018	0.0166	0.0184	0.0032	0.0292	0.0324	0.0019	0.0103	0.0122
124.870	0.0001	0.0004	0.0005	0.0018	0.0147	0.0165	0.0033	0.0262	0.0295	0.0020	0.0085	0.0105
145.440	0.0001	0.0004	0.0005	0.0019	0.0133	0.0152	0.0035	0.0236	0.0271	0.0021	0.0074	0.0095
161.833	0.0001	0.0004	0.0005	0.0021	0.0121	0.0142	0.0037	0.0212	0.0249	0.0023	0.0069	0.0092

*Tube power due to (n,) reaction of ^{6}Li.
**Tube power due to all other nuclear reactions.
***Total tube power

TABLE C7

Table With (n,α) Reaction Values

CELL NAME= MK42 CELL VERSION= MK42***5 REGION NAME= TT-01-01 REGION NUMBER= 45

FLUX AND POWER EDITS FOR EACH SPECTRUM CALCULATION

TIME= 0.0 (MWD)

FEWGROUP	FLUX*VOL	FLUX	FLUX RATIO	FISS. RATE	CAPT. RATE
1	0.354157E+15	0.182511E+15	0.150044E+01	0.0	0.253130E+12
2	0.236036E+15	0.121638E+15	0.100000E+01	0.0	0.226536E+13

TOTAL REGION POWER = 0.162061E-03 (MW/FT) TOTAL GAMMA HEATING = 0.162061E-03 (MW/FT)

REGION REACTION RATE (1/SEC) ISOTOPE (ATM/B-CM-SEC)

ISOTOPE	FISSION	CAPTURE	CONCENTRATION	PRODUCTION	DEPLETION	NET PRODUCTION
AL	0.0	0.251850E+13	0.602893D-01	0.0	0.129788E-11	-0.129788E-11
LI6	0.0	0.162205E-02	0.100000D-19	0.0	0.835907E-27	-0.835907E-27
T	0.0	0.176634E-20	0.100000D-19	0.554636E-26	0.178038E-28	0.552856E-26
HE3	0.0	0.914051E-02	0.100000D-19	0.178038E-28	0.471045E-26	-0.469265E-26

TIME= 25.02 (MWD)

FEWGROUP	FLUX*VOL	FLUX	FLUX RATIO	FISS. RATE	CAPT. RATE
1	0.378488E+15	0.195049E+15	0.146971E+01	0.0	0.274374E+12
2	0.257525E+15	0.132712E+15	0.100000E+01	0.0	0.246991E+13

TOTAL REGION POWER = 0.165915E-03 (MW/FT) TOTAL GAMMA HEATING = 0.165915E-03 (MW/FT)

REGION REACTION RATE (1/SEC) ISOTOPE (ATM/B-CM-SEC)

ISOTOPE	FISSION	CAPTURE	CONCENTRATION	PRODUCTION	DEPLETION	NET PRODUCTION
AL	0.0	0.274428E+13	0.602837D-01	0.0	0.141423E-11	-0.141423E-11
LI6	0.0	0.176979E-02	0.100000D-19	0.0	0.912042E-27	-0.912042E-27
T	0.0	0.651750E-20	0.338067D-19	0.605168E-26	0.601888E-28	0.599149E-26
HE3	0.0	0.997333E-02	0.100000D-19	0.601888E-28	0.513964E-26	-0.507945E-26

TABLE C8
Tube Power Fraction

MDW	TOTAL ASSEMBLY POWER*	TUBE POWER FRACTIONS Target	Inner Fuel	Middle Fuel	Outer Fuel
0	0.0876	0.0046	0.2854	0.4852	0.2249
25.016	0.0809	0.0062	0.2868	0.4895	0.2176
66.541	0.0712	0.0070	0.2865	0.5014	0.2051
98.572	0.0635	0.0079	0.2898	0.5102	0.1921
124.870	0.0570	0.0088	0.2895	0.5175	0.1842
145.440	0.0523	0.0096	0.2906	0.5182	0.1816
161.833	0.0488	0.0102	0.2910	0.5102	0.1885
Power Fraction designation in the CREDIT assembly subroutine		PF5	PF4	PF3	PF2