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PINTEMP: A Computer Program for Fuel Element Design Calculations

by

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PINTEMP

A COMPUTER PROGRAM FOR FUEL ELEMENT

DESIGN CALCULATIONS

by

Jerry F. Kerrisk

ABSTRACT

The computer program PINTEMP has been written to perform design calculations for fuel elements in the EBR-II reactor. The program calculates fuel element and sodium coolant temperatures, thermal stresses in the clad, and fission gas generated in the fuel during steady state irradiation.

I. INTRODUCTION

The computer program PINTEMP calculates temperatures in fuel elements being irradiated in EBR-II. The program considers only single elements and assumes one-dimensional (radial), steady state heat flow. For the calculation, an element is partitioned into a series of concentric cylindrical regions. The outer region transfers heat to a coolant flowing axially along the element. The coolant temperature is defined by integration of the element power generation from the inlet to the axial plane of interest.

Fuel element fission power generation can be defined from the input of linear power as a function of axial location, or it can be calculated from input fuel composition and peak fission rates. Power generation from fission heat is allowed in only one region. An auxiliary heat generation, generally considered gamma heating, can be applied to any number of regions.

If desired, the program will correct the input region radii for thermal expansion. This requires an iterative procedure at any axial location since the dimen-

sions of a region affect the heat conduction through the region. Iteration continues until the maximum temperature change from one iteration to the next is less than 0.01%.

Thermal property data for a number of materials of interest are stored in the program. This allows the material which composes a particular region to be specified without the additional input of properties. The thermal conductivity is considered to be a function of temperature. The coolant is assumed to be sodium, so that sodium enthalpy, heat capacity and density are also stored as functions of temperature.

In addition to calculating temperatures, the program calculates a number of other items of interest. Thermal stresses are calculated in hollow cylindrical regions using the plane strain assumption and stainless steel properties. Tangential and radial stresses are determined. The program also calculates the fission gas generated in the fuel at a specified goal burnup, and the irradiation time required to achieve the goal burnup in EBR-II. Radial and axial temperature plots can be made.

II. PROGRAM OUTLINE

The fuel element is divided into a number of concentric cylindrical regions. For any region i , the temperature is defined by the equation

$$\nabla(K_i(T_i) \nabla T_i) = -q_i, \quad (1)$$

where T_i is the temperature, q_i is the volumetric energy generation, and $K_i(T_i)$ is the thermal conductivity in region i . The temperature dependence of the thermal conductivity is assumed to be

$$K_i(T_i) = a_i + b_i T_i + c_i T_i^2, \quad (2)$$

where a_i , b_i , and c_i are constants for region i . Using the Kirchhoff transformation and standard solution methods,¹ the solution to Eq. (1) can be written as

$$T_i \left(1 + \frac{1}{3} \frac{b_i}{a_i} T_i + \frac{1}{3} \frac{c_i}{a_i} T_i^2\right) = A_i - \frac{q_i}{a_i} \frac{r^2}{4} \quad (3)$$

for $i = 1$, and

$$\begin{aligned} & T_i \left(1 + \frac{1}{3} \frac{b_i}{a_i} T_i + \frac{1}{3} \frac{c_i}{a_i} T_i^2\right) \\ &= A_i + B_i \ln\left(\frac{r}{r_i}\right) - \frac{q_i}{a_i} \frac{r^2}{4} \end{aligned} \quad (4)$$

for $i > 1$. The quantity r_i is the outside surface radius of region i , and A_i and B_i are constants which must be determined using boundary conditions. It should be noted that Eqs. (3) and (4) are implicit functions of T_i , so that for any given values of the constants and radius, T_i must be obtained by some iterative technique.

The boundary conditions applied at the region surfaces match the temperature and heat flux for internal boundaries. Thus

$$T_i(r_i) = T_{i+1}(r_i)$$

and

$$k_i(T_i) \left(\frac{\partial T_i}{\partial r}\right)_{r_i} = k_{i+1}(T_{i+1}) \left(\frac{\partial T_{i+1}}{\partial r}\right)_{r_i}$$

at the interface between regions i and $i + 1$. The boundary condition between the outer region surface and the flowing coolant is

$$-k_n(T_n) \left(\frac{\partial T_n}{\partial r}\right)_{r_n} = h(T_s(z)) (T_n(r_n) - T_s(z))$$

where the subscript n denotes the outer region, $h(T_s(z))$ is the heat transfer coefficient to the coolant, and $T_s(z)$ is the bulk coolant temperature at the axial location z .

Assuming the value of $T_s(z)$ is known, the boundary conditions allow the constants A_i and B_i in Eqs. (3) and (4) to be calculated for each region. The B_i are first calculated from

$$B_{i+1} = \frac{a_i}{a_{i+1}} B_i - \frac{r_i^2}{2a_{i+1}} (q_i - q_{i+1}),$$

and the requirement that $B_1 = 0$ (see Eq. (3)). The outside surface ($r = r_n$) temperature is then calculated as

$$T_n(r_n) = T_s(z) - \frac{1}{h(T_s(z))} \left[\frac{a_n B_n}{r_n} - \frac{q_n r_n}{2} \right],$$

and A_n is calculated from

$$\begin{aligned} A_n &= T_n(r_n) \left(1 + \frac{1}{3} \frac{b_n}{a_n} T_n(r_n) + \frac{1}{3} \frac{c_n}{a_n} T_n^2(r_n)\right) \\ &\quad + \frac{q_n r_n^2}{4 a_n}. \end{aligned}$$

Subsequent A_i are determined by calculating A_{i-1} from the known A_i and the surface temperature of the interface between regions $i-1$ and i ,

$$\begin{aligned} A_{i-1} &= \left\{ \frac{\left(1 + \frac{1}{3} \frac{b_{i-1}}{a_{i-1}} T_i(r_{i-1}) + \frac{1}{3} \frac{c_{i-1}}{a_{i-1}} T_i^2(r_{i-1})\right)}{\left(1 + \frac{1}{3} \frac{b_i}{a_i} T_i(r_{i-1}) + \frac{1}{3} \frac{c_i}{a_i} T_i^2(r_{i-1})\right)} \right. \\ &\quad \left. \left(A_i + B_i \ln\left(\frac{r_{i-1}}{r_i}\right) - \frac{q_i r_{i-1}}{2 a_i} \right) \right\} \\ &\quad + \frac{q_{i-1} r_{i-1}^2}{4 a_{i-1}}. \end{aligned}$$

This completes a definition of the constants in Eqs. (3) and (4) in terms of $T_s(z)$.

The coolant temperature at any axial location z is calculated from the inlet coolant temperature ($z = 0$) and the total energy generated from the inlet up to z . If $Q_T(z)$ is the total power generation per unit length at the axial location z , then

$$H(T_s(z)) = \frac{1}{W} \int_0^z Q_T(z') dz' + H_0,$$

where $H(T_s(z))$ is the coolant enthalpy at the temperature $T_s(z)$, H_0 is the inlet coolant enthalpy, and W is the mass flow rate of the coolant. The coolant temperature is calculated from the known functional relationship between $T_s(z)$ and $H(T_s(z))$. Using the calculated value of $T_s(z)$ and the scheme previously defined for determining the constants A_i and B_i , Eqs. (3) and (4) can be used to calculate the temperature at any radial location in any region at the axial location z .

The volumetric energy generation in any region can have two components, fission heating and gamma heating. Fission heating is allowed in only one region. Fission heating data can be input as the linear power at a series of axial locations. If this option is used, the volumetric energy generation is calculated from the linear power and the region dimensions. Fission heating can also be calculated from input data on the fuel composition and peak fission rates for ^{235}U , ^{238}U , ^{239}Pu , and ^{241}Pu . Fission rates for ^{235}U , ^{239}Pu , and ^{241}Pu are estimated from the input fission rate data. The program has stored data on relative axial fission rates and peak to axial average fission rates for the fissionable isotopes. These data were obtained from the EBR-II Guide,² but can be easily modified by changing a data statement. The volumetric energy generation at any axial location is calculated from the product of the isotope concentration, the peak fission rate for that isotope, and the relative axial fission rate for that isotope at the axial location. The energy generation for each fissionable isotope is summed to give the total volumetric energy generation from fission. The fission energy is assumed to be 196 MeV/fission. This includes a contribution from gamma heating

in the fission region so that an additional gamma heating contribution is not assumed. Gamma heating in the other materials is input as a power per unit mass (W/g) for each material. The volumetric energy generation from gamma heating is calculated from the power per unit mass, the region density and dimensions, and stored relative axial gamma heating data obtained from the EBR-II Guide.² In practice only stainless steel gamma heating is considered for usual element designs.

The thermal conductivity of each material is defined as a polynomial in temperature (Eqs. (2)). Table I lists the coefficients used for the materials currently available in the program. The thermal conductivity of $(\text{U}, \text{Pu})\text{C}$ fuel was obtained from an evaluation of experimental data from five sources.³⁻⁷ All experimental conductivities were corrected to 100% theoretical density before the evaluation, using the expression

$$k_p = k_0 \left(\frac{1-p}{1-p_0} \right),$$

where k_0 and k_p are the conductivities at zero pore volume fraction and at pore volume fraction p , respectively. The thermal conductivity of $(\text{U}, \text{Pu})\text{N}$ was obtained from an evaluation of the experimental data from four sources.^{5,6,8,9} Porosity corrections similar to those made for the carbide were made for the nitride. The thermal conductivities of stainless steel,¹⁰ sodium,¹¹ helium,¹² and fission gas were obtained from standard reference sources. The fission gas was assumed to be 15% krypton and 85% xenon. Since thermal conductivities of krypton and xenon were not available at high temperatures, the high temperature behavior was estimated from the thermal conductivity of argon. Between 200°C and 500°C the ratio of the thermal conductivity of krypton to that of argon is 0.55,¹² and the ratio of the thermal conductivity of xenon to that of argon is 0.35.¹² Thus, fission gas thermal conductivity k_{fg} was estimated as

$$k_{fg} = (0.15)(0.55) k_{\text{Ar}} + (0.85)(0.35) k_{\text{Ar}} = 0.35 k_{\text{Ar}},$$

where k_{Ar} is the thermal conductivity of argon.¹² In addition to simple conduction, a linear approximation to radiation transport across a gas gap is allowed.¹³

TABLE I
THERMAL CONDUCTIVITY COEFFICIENTS
 $k = a + bT + cT^2$ with T in $^{\circ}\text{C}$ and k in $\text{W/cm}^{\circ}\text{C}$

Material ^(a)	a	b	c
(U ₃ Pu ₂)C	0.1270	1.062×10^{-4}	-2.797×10^{-8}
(U ₃ Pu ₂)N	0.1252	7.228×10^{-5}	-2.033×10^{-8}
304 or 316 Stainless Steel	0.1383	1.568×10^{-4}	-1.446×10^{-9}
Sodium	0.9182	-5.373×10^{-4}	8.778×10^{-8}
Helium	1.494×10^{-3}	3.063×10^{-6}	-1.888×10^{-10}
Fission Gas	7.321×10^{-5}	1.258×10^{-7}	-1.106×10^{-11}

^(a) Solids are 100% theoretical density. Fuel thermal conductivities corrected for porosity using the relation $k_p = k_o \left(\frac{1-p}{1+p} \right)$, where k_o and k_p are the conductivities at zero porosity and pore fraction p .

The heat transfer coefficient between the sodium coolant and the outside region surface (h) is calculated from¹⁴

$$\text{Nu} = 5.0 + 0.025 (\text{Pe})^{0.8}$$

where the Nussalt number is defined as

$$\text{Nu} = h D_e / k,$$

and the Peclet number is defined as

$$\text{Pe} = D_e G C_p / k.$$

In these definitions D_e is the equivalent diameter of the flow channel, k is the thermal conductivity of the sodium (see Table I), C_p is the heat capacity of the sodium, and G is the mass velocity of the sodium. The equivalent diameter of a flow channel is calculated as 4 times the flow area divided by the wetted solid perimeter. The sodium heat capacity is calculated from

where C_p is in joules/g $^{\circ}\text{C}$ and T_k is the temperature in K.¹⁵ The enthalpy of sodium is calculated by integrating the heat capacity

$$H(T) - H(T_o) = \int_{T_o}^T C_p(T') dT'.$$

The thermal stresses in hollow cylindrical regions are calculated from the known temperature distribution in the region, and the relations¹⁶

$$\sigma_{r_i}(r) = \frac{\alpha E}{1-\nu} \frac{1}{r^2} \left[\frac{(r^2 - r_{i-1}^2)}{(r_i^2 - r_{i-1}^2)} \int_{r_{i-1}}^{r_i} T_i(r) r dr - \int_{r_{i-1}}^r T_i(r) r dr \right],$$

and

$$C_p = 0.8815 + 2.793 \times 10^{-3} T_k + 9.782 \times 10^{-6} T_k^2$$

$$\sigma_{\theta_i}(r) = \frac{\alpha E}{1-\nu} \frac{1}{r^2} \left[\frac{(r_i^2 + r_{i-1}^2)}{(r_i^2 - r_{i-1}^2)} \int_{r_{i-1}}^{r_i} T_i(r) r dr + \int_{r_{i-1}}^r T_i(r) r dr - T_i(r) r^2 \right],$$

where $\sigma_{r_i}(r)$ and $\sigma_{\theta_i}(r)$ are the radial and tangential thermal stresses in region i at the radial location r , α is the thermal expansion coefficient, E is Young's modulus, and ν is Poisson's ratio. The integrals required are evaluated numerically. The material constant $\frac{\alpha E}{1-\nu}$ for stainless steel is calculated from

$$\frac{\alpha E}{1-\nu} = \left(\frac{8.8948}{1-0.3} \right) \left(470.1 + 0.1043T - 1.955 \times 10^{-4} T^2 \right),$$

where the result has the units kPa/ $^{\circ}$ C and T is in $^{\circ}$ C.

When the fission energy generation is calculated from the fuel composition, the fission gas generation in the fuel can also be calculated. This calculation uses an input value of the peak goal burnup in at.%, the peak/axial average fission rate ratios for the various fissionable isotopes obtained from the EBR-II Guide,² and the fission product yield data of Meek and Rider.¹⁷ Yields of ^{83}Kr , ^{84}Kr , ^{85}Kr , ^{86}Kr , ^{131}Xe , ^{132}Xe , ^{134}Xe , and ^{136}Xe are calculated for the fuel element. The ^{85}Kr generation is not corrected for decay. In addition, the program estimates the irradiation time based on the input fission rates and the goal burnup.

Two other properties used during the calculations are material densities and thermal expansion coefficients. The material densities are used to interconvert material weights and volumes where required. The thermal expansion coefficients are used for correction of the region radii. Table II lists the values in use and the references for the thermal expansion data.

III. PROGRAM LISTING

Appendix A contains a listing of PINTEMP. It includes the main program (PINTEMP), three function subroutines (THC, THCR, and TEMPR), and two subroutines

TABLE II
MISCELLANEOUS MATERIAL PROPERTIES

	Material Density (100% TD) g/cm ³	Thermal Expansion Coefficient ($^{\circ}$ C) ⁻¹	Thermal Expansion Reference
(U,Pu,C)	13.43	1.2×10^{-5}	18
(U,Pu,N)	14.16	0.9×10^{-5}	8
304 or 316 Stainless Steel	8.0	1.85×10^{-5}	19

(TEMCAL and FISCAS). In addition to the routines shown in Appendix A, there are a number of Los Alamos Scientific Laboratory standard program library subroutines which are called. These include a set of spline parameter evaluation and spline integration routines, and 35 mm film plotting routines.

A description of the input data required for the program is contained in the program listing.

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APPENDIX A

PINTEMP COMPUTER PROGRAM LISTING

LASL Identification:
LP-0501

```

C      PROGRAM PINTEMP(INP,OUT,FILM)
C
C      PROGRAM CALCULATES TEMP OF A FUEL PIN IN EBR-II
C
C      FUEL PIN DESCRIBED BY CONCENTRIC CYLINDERS
C      REGION 1 ASSUMED TO BE A SOLID CYLINDER
C      REGIONS 2+ ARE HOLLOW CYLINDERS
C
C      ONE DIMENTIONAL HEAT FLOW EQN SOLVED IN R DIRECTION FOR
C      VARIOUS Z PLANES - ASSUME AXISYMMETRIC
C
C      FLOWING SODIUM OUTSIDE PIN
C
C      FISSION ENERGY GENERATION INPUT OR CALCULATED FROM U AND PU CONCENTRATION
C
C      GAMMA HEATING CALCULATED FOR EACH REGION
C
C      SPLINE INTERPOLATION AND INTEGRATION ROUTINES USED TO CALCULATE
C      AXIAL VARIATIONS
C
C      THERMAL STRESS CALCULATED IN HOLLOW CYLINDER REGIONS
C      PLANE STRAIN CALCULATION
C
C      PROGRAM CALCULATES FISSION GAS GENERATED TO GOAL BURNUP
C
C      INDEX NOTATION
C
C      I = REGION INDEX          NI = NR REGIONS          MI = MAX NR REGIONS
C      M = MATERIAL INDEX        NM = NR MATERIALS
C      K = RADIUS INDEX          NK = NR RADII             MK = MAX NR K
C      JI = FISSIONABLE ISOTOPE INDEX          NJI = NR FI
C      JL = AXIAL LOCN INDEX FOR AF, AE, AND ZL          NJL = NR JL
C      JG = AXIAL LOCN INDEX FOR AG AND ZG          NJG = NR OF JG
C      JR = ROW INDEX          1 TO 9          NJR = NR ROWS
C      NZ = AXIAL LOCN INDEX FOR DFE AND ZFE          NNZ = NR NZ          MNZ = MAX NR NZ
C      J = GENERAL INDEX
C      IRP = RADIAL INDEX IN TEMP FOR AXIAL PLOT          IRPM = TOTAL NR IN PLOT
C      NZC = INDEX IN Z PLANE LOOP          NZT = COUNT OF NR OF Z PLANES
C
C      DATA INPUT
C
C      CARD          TITLE          1 CARD          FORMAT 20
C      SET 1          HEAD=PROBLEM TITLE          COL 1-80
C
C      CARD          GENERAL PROBLEM DATA          1 CARD          FORMAT 25
C      SET 2          NI=NR RADIAL REGIONS
C                      ZP1=CORE LOCATION
C                      ZP2=LOCATION IN SUBASSEMBLY
C                      NP1=1=NO AXIAL PLOT          =1=AXIAL PLOT
C                      NFF=1=CALC FISSION ENERGY GENERATION FROM FUEL COMPOSITION
C                      =2=INPUT AXIAL LOCN AND KW/M
C                      NA=0=NO THERMAL EXPANSION CORRECTION OF RADII
C                      =1=CONNECT RADII FOR THERMAL EXPANSION
C                      ZHF=LOCN OF BOTTOM OF FUEL STACK FROM CORE MIDPLANE CM
C                      ZFCL=TOTAL FUEL COLUMN LENGTH CM
C                      SNA=JULK SODIUM FLOW RATE AT INLET CC/SEC
C                      ANA=SODIUM FLOW RATE AREA CMSQ

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C      DNA=EQUIV DIAM OF SODIUM FLOW CHANNEL CM
C      TNA=SODIUM INLET TEMP C
C      NSA=INDICATOR FOR S/A FLOW DATA CALC
C          =0=USE QNA, ANA, DNA AS READ IN
C          =1=CLAC FOR AN A-198 S/A INPUT FGPM
C          =2=CALC FOR E-19 OR N-19 S/A SPECIFY NTP AND FGPM
C      NTP=PIN LOCATION IN E-19 OR N-19 S/A
C          =1=CENTER PIN
C          =2=EDGE PIN
C          =3=CORNER PIN
C      FGPM=TOTAL S/A FLOW RATE IN GPM
C
C      CARD REGION DATA NI CARDS FORMAT 29
C      SET 3 NR(I)=REGION NUMBER
C          RNM(I)=REGION NAME
C          MN(I)=REGION MATERIAL NUMBER
C          RS(I)=OUTSIDE RADIUS OF REGION CM
C          NRC(I)=NR OF RADII TO CALC TEMP 2=INSIDE AND OUTSIDE SURF ONLY
C          NRPL(I)=0=SURF TEMP NOT IN AXIAL PLOT
C              =1=INCLUDE SURF TEMP IN AXIAL PLOT
C          PTD(I)=PERCENT THEORETICAL DENSITY OF REGION
C          NST(I)=0=DO NOT CALC THERMAL STRESS FOR THIS REGION
C              =1=CALC THERMAL STRESS IN REGION AT SAME RADII AS TEMPS
C          PERC(I)=PERCENT HOLES (NA) IN LINER IF MN(I) = 5
C              =PERCENT HE IN GAS BOND IF MN(I) = 8 OR 10
C
C      CARD PEAK GAMMA HEATING FOR EACH MATERIAL 1 CARD FORMAT 35
C      SET 4 QGNG(M)=PEAK GAMMA HEATING W/GM M=1,N4
C
C      CARD FISSION ENERGY GENERATION DATA
C      SET 5 TYPE OF DATA AND FORMAT OF CARD SET 5 DEPENDS ON NFE
C
C      IF NFE=1 2 CARDS
C          FIRST CARD FORMAT 53
C          NRFE=REGION NR WHERE FISSION ENERGY GEN
C          NFEA=SPARE
C          WU=WEIGHT PERCENT URANIUM
C          WPU=WEIGHT PERCENT PLUTONIUM
C          U235=WEIGHT PERCENT U235 IN U
C          U233=WEIGHT PERCENT U233 IN U U238=100-U233-U235
C          PU239=WEIGHT PERCENT PU239 IN PU
C          PU240=WEIGHT PERCENT PU240 IN PU
C          PU241=WEIGHT PERCENT PU241 IN PU PU242=100-PU239-PU240-PU241
C          BUMX=GOAL BURNUP MAXIMUM ATOM PERCENT
C          SECOND CARD FORMAT 55
C          F(JI)=PEAK FISSION RATE FISS/SEC GM FOR FISSIONABLE
C              ISOTOPES U235,U238,PU239,AND PU240
C          FRC=FISSION RATE CORRECTION FACTOR IF=0 SET TO 1.0
C
C      IF NFE=2 2 OR MORE CARDS
C          FIRST CARD FORMAT 73
C          NRFE=REGION NR WHERE FISSION ENERGY GEN
C          NNZ=NR OF ZFE,QFE PAIRS TO BE INPUT
C          SECOND CARD(S) AS MANY AS REQUIRED FORMAT 75
C          ZFE(NZ)=AXIAL LOCN FROM BOTTOM OF FUEL CM
C          FIRST ZFE MUST BE ZERO TO ALLOW INTEGRATION FROM 0 TO Z
C          LAST ZFE MUST BE FUEL COL LENGTH TO ALLOW CALC OF OUTLET NA TEMP
C          QFE(NZ)=KW/M AT ZFE(NZ)
C              NZ=1,NNZ
C
C      CARD Z PLANE DATA UP TO 50 CARDS ALLOWED FORMAT 110
C      SET 6 Z=LOCN OF Z PLANE FROM BOTTOM OF FUEL

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C          NPLR=0=NO RADIAL PLOT AT THIS Z PLANE
C          =1= RADIAL PLOT AT THIS Z PLANE
C          NEGATIVE Z STOPS INPUT GO TO NEXT PROBLEM
C
C      OTHER VARIABLES
C
C      RO(I)=OUTSIDE REGION RADIUS CORRECTED FOR THERMAL EXPANSION CM
C      XMATN(M)=MATERIAL NAMES
C      DENM(M)=MATERIAL DENSITY GM/CC
C      P(J,M)=COEF IN THERMAL COND EQN J=1 TO 3
C      EPS(M)=MATERIAL EMISSIVITY
C      KIR(I)=K INDEX OF INSIDE RADIUS OF REGION I
C      KOR(I)=K INDEX OF OUTSIDE RADIUS OF REGION I
C      AF(JL,JI)=AXIAL VARIATION OF FISSION RATE AT ZL(JL) FOR FI JI IN ROW NBS
C      AE(JL,JI)=AE(JL,JI) CORRECTED FOR ROW
C      ZL(JL)=AXIAL LOCN OF AE AND AF
C      AG(JG,M)=AXIAL VARIATION OF GAMMA HEAT AT ZG(JG) FOR MATERIAL M
C      ZG(JG)=AXIAL LOCN OF AG
C      GG(I)=GAMMA HEATING IN REGION I W/CC
C      GGL(I)=LINEAR GAMMA HEATING IN REGION I AT PEAK KW/M
C      R(K)=RADIUS OF CALC TEMP CM
C      T(K)=CALC TEMP C
C      GM(JI)=DENSITY OF FI JI GM/CC
C      GE(JI)=FISSION ENERGY GEN OF FI JI W/CC
C      A(I) AND H(I)=CONSTANTS IN TEMP EQN OF REGION I
C      Q(I)=TOTAL ENERGY GEN IN REGION I W/CC
C      TPL(NZC,IRP)=PLOT TEMP AT AXIAL LOCN NZC AND RADIAL LOCN IRP
C      ZPL(NZC)=Z LOCN AT NZC
C      AGZ(M)=INTERPOLATED VALUE OF AG AT Z FOR MATERIAL M
C      AGZINT(M)=INTEGRATION OF AG FROM 0 TO Z
C      ST(K)=TANGENTIAL THERMAL STRESS AT RADIUS R(K)
C      SR(K)=RADIAL THERMAL STRESS AT RADIUS R(K)
C      VAR(K) AND WT(K) ARE UTILITY VARIABLES USED IN STRESS CALC
C      TAB, TOP, STRA, STRB, AND STRC ARE UTILITY VARIABLES USED IN SPLINE ROUTINES
C      AAG, AAF, AND AGE ARE PARTIAL DERIV OF AG, AF, AND GE USED
C          IN THE SPLINE ROUTINES
C
C      FNA=FRACTION OF MOLFS(SODIUM) IN LINER FSS=1-FNA
C      HNA=ENTHALPY OF INLET SODIUM J/GM
C      DENA=DENSITY OF INLET SODIUM GM/CC
C      ZM=Z PLANE LOCN FROM CORE MIDPLANE
C      QIZ=TOTAL GAMMA ENERGY GEN FROM 0 TO Z
C      VOL=VOLUME/CM OF FISSION ENERGY GEN REGION CMSQ
C      QPIS=FISSION ENERGY GEN AT Z W/CC
C      QFIS=TOTAL FISSION ENERGY GEN FROM 0 TO Z
C      JTO=TOTAL ENERGY GEN FROM 0 TO Z
C      JGLT=LINEAR GAMMA HEAT FOR ALL REGIONS AT PEAK KW/M
C      HZ=HEAT TRANSFER COFF AT Z W/CMSQ C
C      NATI=NUMBER OF THERMAL EXPANSION ITERATIONS
C
C      FUNCTIONS AND SUBROUTINES USED
C
C      THC(M,T) RETURNS THERMAL COND OF MATERIAL M AT TEMP T
C      THCK(M,T) RETURNS A SPECIAL FUNCTION OF THERMAL COND
C      TEMPR(I,R) RETURNS THE TEMP NOT CORRECTED FOR VARIABLE THERMAL CONDUCT
C          OF REGION I AT RADIUS R
C      H(T) RETURNS THE ENTHALPY OF SODIUM IN J/GM AT T
C      CP(T) RETURNS THE HEAT CAPACITY OF SODIUM IN J/GM C AT T
C      DENFXM(T) RETURNS THE DENSITY OF SODIUM IN GM/CC AT T
C
C      SUBROUTINE TEMPCAL CALCULATES ACTUAL TEMP FROM UNCORRECTED TEMP

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C
C SUBROUTINE FISSGAS CALCULATES THE FISSION GAS PRODUCTION AND
C FHR=II AND AT GOAL BURNUP
C
C PARAMETER (MI = 10), (MK = 50), (NM = 10), (NJI = 7), (MNZ = 20),
C 1 (NJL = 20), (NJR = 9), (MI2 = 2*MI), (NJG = 20)
C
C DIMENSION HEAD(8), NR(MI),RNM(MI), MN(MI), RO(MI), NRC(MI),GG(MI)
C 1,NRPL(MI), R(MK), T(MK), F(NJI), GM(NJI), GF(NJI), FINM(NJI)
C 2,7FF(MNZ), SFE(MNZ), TAB(3),PERC(MI), A(MI), B(MI), Q(MI)
C 3,TPL(50,MI2), ZPL(50), STRA(100), STRB(100), STRC(100), IOP(2)
C 4,PTD(MI), KIP(MI), KOR(MI), EPS(NM), RS(MI), ALFA(NM),QGL(MI)
C DIMENSION XMATN(NM), P(3,NM), QGNG(NM), DENM(NM),POD(MI)
C DIMENSION AG(NJG,NM), AF(NJL,NJI),PA(NJR,NJI),ZL(NJL),ZG(NJG)
C 1,AG(NJG,NM), WAF(NJL,NJI), WGF(MNZ), AGZ(NM), AGZINT(NM)
C 2,AL(NJL,NJI)
C DIMENSION XTITR(2), XTITZ(5), YTITL(2), PLANE(5),CHVNM(19)
C DIMENSION SR(MK), ST(MK), VAR(MK), WT(MK), WST(MI)
C COMMON/DATA/P
C COMMON/DATA/A,B,RCL,RO,Q,MN,PTD
C COMMON/DATA/RCM,RS
C COMMON/DATA/WJ,APU,U235,U233,U238,PU239,PU240,PU241,PU242
C COMMON/DATA/F,PA,GM
C
C FUNCTION DEFINITIONS
C
C SODIUM ENTHALPY FXN JOULES/GM (REF ANL-8020)
C H(TH)=(0.88145*(TH+273.0)) + (1.39635E-4*((TH+273.0)**2))
C 1 = (0.97824E+5/(TH+273.0)) + 97.6345
C DERIV OF SODIUM ENTHALPY FXN
C CP(TH) = 0.88146 + (2.79271E-4*(TH+273.0))
C 1 + (0.97824E+5/((TH+273.0)**2))
C SODIUM DENSITY FXN RESULT IN GM/CC REF ANL-7323
C DENSFXN(TH) = ( 59.566 - (7.9584E-5*((1.8*TH)+32.0))
C 1 = (0.2872E-6*((1.8*TH)+32.0)**2))
C 2 + (0.06035E-9*((1.8*TH)+32.0)**3))/62.43
C E*ALFA FUNCTION FOR 316/304 STAINLESS STEEL RESULT IN PSI/C
C RESULT DIVIDED BY 1-POISSONS RATIO = 0.7 FOR PLANE STRAIN CALC
C EALFA(TH)=(470.0937) + (0.10430541*TH) = (1.9554452E-4*TH*TH))/0.7
C
C MATERIAL DATA
C
C MATERIAL 1 = (U,PU)C FUEL
C MATERIAL 2 = (U,PU)N FUEL
C MATERIAL 3 = 304/316 STAINLESS STEEL
C MATERIAL 4 = SODIUM
C MATERIAL 5 = LINER TUBE COMPOSED FROM SS AND SODIUM
C MATERIAL 6 = HELIUM GAS
C MATERIAL 7 = FISSION GAS
C MATERIAL 8 = HELIUM=FISSION GAS MIXTURE ONLY 1 PER PROBLEM
C MATERIAL 9 = RADIATION CONDUCTION FOR USE WITH MATERIAL 10 ONLY
C MATERIAL 10 = HELIUM=FISSION GAS MIXTURE WITH RADIATION ONLY 1 PER PROB
C
C DATA FOR MATERIALS 5 , 8 , AND 10 CALCULATED AT REGION DATA INPUT
C
C DATA (XMATN(M),M=1,10)/10H (U,PU)C ,10H (U,PU)N ,10H 316 SS ,
C 10H SODIUM ,10H LINER TUBE ,10H HELIUM GAS, 10H FISSION GAS ,
C 210H HE+FG MIX ,10H RAD COND , 10H HE+FG+RAD /
C DATA (DENM(M),M=1,10)/ 13.43,14.16,8.0,0.9,4.8,0.0,0.0,0.0,0.0,
C 12.0 /
C DATA (QGNG(M),M=1,10) /10*0.0 /
C DATA (EPS(M),M=1,10) / 0.5,0.5,0.2,0.1,0.2,1.0,1.0,1.0,1.0,1.0/

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DATA (ALFA(M),M=1,101)/ 1.2E-5,0.95E-5,1.85E-5,0,0,1.85E-5,0.0,
10,0,0,0,0,0,0,0 /
DATA (P(M),M=1,30)/ 0.12704271,1.0615922E-4,-2.7972363E-3,
1 0.12521091, 7.2282037E-5, -2.0326063E-8,
2 0.13032240, 1.5676010E-4, -1.4457896E-9,
3 0.91824191, -5.3734757E-4, 8.1783766E-8,
4 0.0,0.0,0.0,0,
5 1.4936968E-3, 3.0626658E-6, -1.8875619E-10,
6 0.73209979E-4, 1.258107978E-7, -1.105792494E-11,
7 0.0,0.0,0.0,0,
8 2.5621967E-2, -9.2672545E-5, 1.1247254E-07,
9 0.0,0.0,0.0,0 /

C
C   RELATIVE AXIAL GAMMA HEATING
C
C   FUEL
DATA (AG(JG),JG=1,56)/ 2(0.65,0.75,0.77,
1 0.75,0.73,0.78,0.85,0.88,0.93,0.95,
10.975,0.990,0.998,1.00,0.999,0.995,0.985,0.975,0.95,0.93,0.85,
20.82,0.72,0.64,0.70,0.71,0.70,0.60)/
C   STAINLESS STEEL
DATA (AG(JG),JG=57,84)/ 0.20,0.30,0.40,
1 0.54,0.64,0.74,0.81,0.875,0.925,0.950,
10.975,0.990,0.998,1.00,0.999,0.995,0.985,0.975,0.950,0.92,0.87,
20.82,0.75,0.68,0.61,0.46,0.35,0.26 /
C   SODIUM
DATA (AG(JL),JL=85,112)/ 28*1.0 /
C   OTHER MATERIALS
DO 1006 M=5,NM
DU 6 JG=1,NJG
6 AG(JG,M)= AG(JG,3)
1006 CONTINUE
C   AXIAL LOCN OF AG DATA
DATA (ZG(JG),JG=1,28)/ -21.431,-19.717,-18.002,
1 -17.16,-16.288,-14.573,-12.859,-11.144,
2-9.450,-7.715,-6.001,-4.286,-2.572,-0.857,0.857,2.572, 4.286,
36.001,7.715,9.450,11.144,12.859,14.573,16.288,17.16,18.002,
419.717,21.431 /

C
C   RELATIVE AXIAL FISSION RATE
C   RELATIVE AXIAL FISSION RATES WERE ESTIMATED OUTSIDE OF THE CORE
C   REGION BY A CONSERVATIVE DIRECT EXTRAPOLATION FROM THE ENDS.
C
C   U235 AND U233
DATA (AF(JL),JL=1,56)/2(0.941,0.927,0.913,0.898,0.884,0.876,0.891,
10.910,0.934,0.958,0.976,0.987,0.997,1.00,0.999,0.991,0.982,0.968,
20.949,0.928,0.903,0.880,0.862,0.870,0.881,0.891,0.903,0.913) /
C   U238
DATA (AF(JL),JL=57,84)/ 0.290,0.348,0.400,0.530,0.610,0.715,0.788,
10.850,0.898,0.930,0.960,0.985,0.995,1.00,0.999,0.990,0.975,0.955,
20.925,0.887,0.835,0.780,0.680,0.570,0.500,0.420,0.368,0.227 /
C   PU239
DATA (AF(JL),JL=85,112)/0.892,0.874,0.854,0.842,0.832,0.840,0.870,
10.899,0.927,0.950,0.970,0.985,0.996,1.00,0.999,0.993,0.980,0.963,
20.943,0.918,0.883,0.852,0.825,0.816,0.828,0.845,0.862,0.881 /
C   PU240
DATA (AF(JL),JL=113,140)/0.42,0.468,0.518,0.620,0.660,0.742,0.810,
10.860,0.907,0.940,0.969,0.987,0.995,1.00,0.999,0.992,0.975,0.955,
20.925,0.890,0.850,0.850,0.797,0.730,0.655,0.605,0.566,0.524,0.442 /
C   SET PU241=PU239 AND PU242=PU240
DO 7 JL=1,NJL
AF(JL,6)= AF(JL,4)

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7 AE(JL,7)= AE(JL,5)
C   AXIAL LOCN OF AF AND AE DATA
   DATA (ZL(JL),JL=1,28) / -20,574,-19,717,-18,860,-17,145,-16,288,
1=14,573,-12,859,-11,144,-9,430,-7,715,-6,001,-4,286,-2,572,-0,857,
20,857,2,572,4,286,6,001,7,715,9,430,11,144,12,859,14,573,16,288,
317,145,18,002,18,860,20,574 /
C
C   PEAK/AXIAL FISSION RATE
C
C   U235 AND U233
   DATA (PA(JR),JR=1,18) / 2(1,085,1,083,1,085,1,079,1,074,1,067,
11,052,1,025,1,019) /
C   J238
   DATA (PA(JR),JR=19,27) / 1,159,1,166,1,159,1,163,1,157,1,156,
11,154,1,165,1,175 /
C   PU239
   DATA (PA(JR),JR=28,36) / 1,102,1,100,1,102,1,090,1,092,1,085,
11,068,1,037,1,022 /
C   PU240
   DATA (PA(JR),JR=37,45) / 1,145,1,149,1,145,1,146,1,142,1,139,
11,153,1,129,1,115 /
C   NBS = 0
C   SET PU241=PU239 AND PU242=PU240
   DO 8 JR=1,NJR
   PA(JR,6) = PA(JR,4)
8 PA(JR,7) = PA(JR,5)
C   FISSIONABLE ISOTOPE NAMES
   DATA (FINM(JI),JI=1,7) / 5H U235,5H U233,5H U238,5HPU239,
15HPU240,5HPU241,5HPU242 /
C
C   SET UP SPLINE FXN FOR AG
C
   IOP(1)=5 $ IOP(2)=5 $ L=1
   DO 10 M = 1,NM
10 CALL SPL1D1(NJL,ZL,AG(1,M),*AG(1,M),IOP,L,STRA,STRB,STRC)
   PI = 3,141592654
   RCL=0,0
   RCM=0,0
10 IRPM=0
   NZT=0
   NEND = 0
C
C   DATA INPUT
C
   READ 20,HEAD
20 FORMAT(8A10)
   PRINT 21,HEAD
21 FORMAT(1H1//8A10)
   READ 25, NI, ZP1, ZP2,NPL,NFE,NA,ZBF,ZFCL,GNA,ANA,DNA,TNA
1,NSA,NTP,FGPM
   IF(NI,EQ,0) STOP 5
25 FORMAT(I3,A3,A3,3I3,6F6,3,2I3,2F6,3)
C   CHECK FOR FLOW INPUT DATA
   IF(NSA,NE,1) GO TO 2020
C   FOR A=19 S/A
   GNA = FGPM*65,083333/19,0
   ANA = 0,4259
   DNA = 2,2515
   GO TO 2030
2020 IF(NSA,NE,2) GO TO 2030
C   FOR E=19 OR A=19 S/A
   IF(NTP,NE,1) GO TO 2025

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C     FOR CENTER PIN
      QNA = FCPM*63.083333/27.870
      ANA = 0.3304
      DNA = 0.5343
      GO TO 2030
2023 IF(NTP.NF.2) GO TO 2026
C     FOR EDGE PIN
      QNA = FCPM*63.083333/16.8909
      ANA = 0.4968
      DNA = 0.5737
      GO TO 2030
2026 IF(NTP.NF.3) GO TO 2030
C     FOR CORNER PIN
      QNA = FCPM*63.083333/15.2434
      ANA = 0.5609
      DNA = 0.5402
2030 IF(QNA.GT.0.0 .A. ANA.GT.0.0 .A. DNA.GT.0.0) GO TO 2040
      PRINT 2032,QNA,ANA,DNA,NSA,NTP,FGPM
2032 FORMAT(/'* INPUT NA FLOW DATA ERROR STOP 6*/
1* QNA = *,1PE14,7,X,*ANA = *,1PE14,7,X,*DNA = *,1PE14,7/
2* NSA = *,14,7,X,*NTP = *,14,7,X,*FGPM = *,1PE14,7)
      STOP 6
2040 IF(TNA.LE.0.0) TNA = 371.0
      IF(ZFCL.LE.0.0) ZFCL = 34.29
      IF(ZBF.EQ.0.0) ZBF = -17.15
26  FORMAT(I1)
      DECODE(1,26,ZP1)NR0W
C     CALC ENTHALPY OF INLET NA
      HNA = H(TNA)
C     CALC DENSITY OF INLET NA
      DENA = DENSFXN(TNA)
      PRINT 30,NI,ZP1,ZP2,ZBF,ZFCL,QNA,ANA,DNA,TNA,DENA,HNA
30  FORMAT(/'* THIS PROBLEM HAS *,13,* RADIAL REGIONS*/
1* THE PIN IS LOCATED IN CORE LOCATION *,A3,* AND POSITION *,A3,
2* IN THE SUBASSEMBLY*/
3* THE BOTTOM OF THE FUEL COLUMN IS *,F7,3,* CM FROM THE CORE MIDPL
4ANE AND THE FUEL COLUMN LENGTH IS *,F7,3,* CM*/
5* THE NA COOLANT DATA ARE*/
6* FLOW RATE = *,1PE12,5,* CC/SEC*,9X,*FLOW AREA = *,1PE12,5,* CMSQ
7*/
8* EQUIV DIAM = *,1PE12,5,* CM*,9X,*INLET TEMP = *,1PE12,5,* DEG C*
9/* THE INLET SODIUM DENSITY = *,1PE12,5,* G/CC*/
1* THE INLET SODIUM ENTHALPY = *,1PE12,5,* J/GM*/
      IF(CA.NE.0) PRINT 1031
      IF(NPL.EQ.0) PRINT 32
      IF(NPL.EQ.1) PRINT 33
1031 FORMAT(* THERMAL EXPANSION CORRECTION OF RADII REQUESTED*/)
32  FORMAT(* AXIAL TEMPERATURE PLOT WAS NOT REQUESTED*/)
33  FORMAT(* AXIAL TEMPERATURE PLOT REQUESTED*/)
C
C     INPUT REGION DATA
C
      DO 27 I=1,NI
      READ 28,NR(I),RNM(I),MN(I),RS(I),NRC(I),NRPL(I),PTD(I),NST(I)
1,NFAC,PERC(I)
      RO(I) = RS(I)
28  FORMAT(I3,A9,I3,F15.7,2I3,F6.3,2I3,F6.3)
      IF(RNM(I).GT.NI) PRINT 1025,I,MN(I)
      IF(MN(I).GT.NM) STOP 3
1025 FORMAT(/'* MATERIAL NUMBER GREATER THAN MAXIMUM ALLOWED*/
1* REGION = *,I3,5X,*MATERIAL NUMBER = *,I4/
2* STOP 3 NEAR STATEMENT 28*)

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      IF(NRC(I),LT,2) NRC(I) = 2
      IF(PTD(I),LE,0.0) PTD(I) = 100.0
      POD(I) = PTD(I)/100.0
C     THERMAL CONDUCTIVITY OF POROUS MATERIALS IS CORRECTED BY THE
C     FACTOR (1+P)/(1-P).
2/ PTD(I) = (PTD(I)/100.)/(2.-PTC(I)/100.)
C     INPUT PEAK GAMMA HEATING RATES
      READ 35,(UGWG(M),M=1,NM)
35 FORMAT(12F6.2)
      NLIN = 0
      K = 0
      GGLT = 0.0
      PRINT 21,HEAD
      DO 43 I=1,N1
C     CALC MATERIAL DATA FOR MN(I)= 5 OR 8 OR 10
      IF(MN(I),NE,5) GO TO 1020
      FNA = PERC(I)/100.0
      FSS = 1.0-FNA
C     SET UP LINER (M=5) VALUES FROM SS AND NA
      DO 5 J=1,3
5 P(J,5) = (FSS*P(J,3))+( FNA*P(J,4))
      DENM(5) = ( FSS*DENM(3))+( FNA*DENM(4))
1020 IF(MN(I),NE,8 .A. MN(I),NE,10 ) GO TO 1035
      M=MN(I+1)
      M1 = MN(I-1)
      FAC1 = PERC(I)/100.0
      FAC2 = (1.0/EPS(M1)) + ((RO(I-1)/RO(I))*((1.0/EPS(M))-1.0))
      FAC2 = (RO(I)-RO(I-1))/FAC2
      FAC3 = 1.0-FAC1
      DO 1022 J=1,3
      P(J,8) = (FAC1*P(J,6)) + (FAC3*P(J,7))
      DENM(8) = (FAC1*DENM(6)) + (FAC3*DENM(7))
      IF(MN(I),NE,10) GO TO 1022
      P(J,10) = P(J,8) + (FAC2*P(J,9))
1022 CONTINUE
1035 NMX = MN(I)
      GG(I) = UGWG(NMX)*DENM(NMX)*PTD(I)
      GGL(I) = 0.1*GG(I)*PI*((NS(I)**2)-(NS(I-1)**2))
      GGLT = GGLT + GGL(I)
      DR = (RO(I)-RO(I-1))/FLOAT(NRC(I)-1)
      NRCX=NRC(I)
      KIR(I) = K+1
      DO 37 IKX=1,NRCX
      K = K+1
      SR(K) = 0.0
      ST(K) = 0.0
37 R(K) = RO(I-1) + (DR*FLOAT(1KX-1))
      KOR(I) = K
      IF(NLIN,(1,50) GO TO 38
      PRINT 21,HEAD
      NLIN = 0
38 PRINT 40, NR(I),NMN(I),MN(I),XMATN(NMX),POD(I)
40 FORMAT(// * DATA FOR REGION NUMBER *,I3,10X,* REGION NAME IS *,A9/
1 * REGION MATERIAL NUMBER = *,I3,5X,* REGION MATERIAL IS *,A10,
1 * A1 *,2F6.1,* PERCENT THEORETICAL DENSITY*)
      FAC1 = 100.0-PERC(I)
      IF(MN(I),NE,5) GO TO 1030
      N3=3 * N4=4
      PRINT 1028,PERC(I),N4,XMATN(4),FAC1,N3,XMATN(3)
1028 FORMAT(* THIS REGION IS *,F6.1,* PERCENT MATERIAL *,I2,2X,A10,
1 * AND *,F6.1,* PERCENT MATERIAL *,I2,2X,A10)
1030 IF(MN(I),NE,8 .A. MN(I),NE,10) GO TO 1034

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      N6=6      N7=7
      PRINT 1028,PERC(I),N6,XMATN(6),FAC1,N7,XMATN(7)
      IF(MN(I).EQ.10) PRINT 1032
1032  FORMAT(1H+,97Y,* WITH RADIATION ACROSS IT*)
1034  CONTINUE
      PRINT 1036,RO(I-1),RO(I),GG(I),UGL(I)
1036  FORMAT(* INNER RADIUS = *,1PE12.5,* CM*,7X,* OUTER RADIUS = *,
11PE12.5,* CM*/
      3* THE PEAK GAMMA HEATING IN THIS REGION = *,1PE12.5,* W/CC*,
42X,* = *,1PE12.5,* KW/M**
      NRGX = K = NRC(I) + 1
      PRINT 41,(R(IKX),IKX=NRGX,K)
41  FORMAT(* TEMPERATURES WILL BE CALCULATED AT THE FOLLOWING RADII
1(CM)*
2 (1P8E15.5))
      IF(IST(I).EQ.0) GO TO 1045
      IF(IST(I).EQ.1 .A. MN(I).EQ.3) GO TO 1045
      PRINT 1040,I
1040  FORMAT(* THERMAL STRESS CALCULATION REQUESTED FOR REGION *,I3,
1* NO CALCULATION WILL BE PERFORMED SINCE THE REGION IS NOT STAIN-
LESS STEEL*)
      NST(I) = 0
1045  CONTINUE
      IF(MRPL(I).EQ.0) GO TO 43
      PRINT 42
42  FORMAT(* THE INNER AND OUTER RADII OF THIS REGION WILL BE INCLUDED
1 IN AXIAL TEMPERATURE PLOTS*)
      IRPM = IRPM + 2
43  NLIN = 9 + MRPL(I)
      IRPM = IRPM + 1
      NK = K
      PRINT 1047,UGL1
1047  FORMAT(// * THE PEAK LINEAR GAMMA HEATING FOR ALL REGIONS = *,
11PE12.5,* KW/M**
C
C      CHECK FOR TYPE OF FISSION ENERGY INPUT
C
      IF(MFF.EQ.1) GO TO 50
      IF(MFF.EQ.2) GO TO 70
      PRINT 45,NFE
45  FORMAT(// * FISSION ENERGY CALC TYPE DESIGNATION NOT WITHIN PROBLE
1* LIMITS*// * NFE = *,I6,10X,* STOP 1 NEAR STATEMENT 45*)
      STOP 1
C
C      INPUT DATA FOR FISSION ENERGY CALC FROM COMM
C
50  READ 53,CH11,1FPA,      40,0P0, 235, 1231,P0230,P0200,P0201,0UMV
53  FORMAT(213,0F0.3)
      R AC 55,F(1),F(3),F(4),F(5),FNC
      1F1P0,1E,0.0)  FNC0.0
55  FORMAT(0E12,7)
      F(2)=1.050F(1)
      F(6)=1.750F(4)
      F(7)= 0.10F(4)
C      MULTIPLY FISSION WEIGHTS BY FNC
      DO 47 J=1,13
47  F(J) = FNC*F(J)
      J235 = 100.0 + 0.235 = 0.235
      P0202 = 100.0 + P0230 + P0200 + P0201
      * = P0202F
      P04 = P0000000100000000
      P01 = P0000000100000000

```

```

GM(1) = DEN*WU*U235/10000.0
GM(2) = DEN*WU*U233/10000.0
GM(3) = DEN*WU*U238/10000.0
GM(4) = DEN*WPU*PU239/10000.0
GM(5) = DEN*WPU*PU240/10000.0
GM(6) = DEN*WPU*PU241/10000.0
GM(7) = DEN*WPU*PU242/10000.0
FAC1 = 196.0*1.602E-13
DO 60 JI=1,NJI
60 GF(JI) = FAC1*F(JI)*GM(JI)
DO 1057 JI=1,NJI
F6 = 0.1814*SQR(1.0-(1.0/PA(NBS,JI)))/2.54
FNR = 0.1814*SQR(1.0-(1.0/PA(NROW,JI)))/2.54
DO 1055 JL=1,NJL
AF(JL,JI) = AE(JL,JI)*COS(FNR*ZL(JL)*2.0)/COS(F6*ZL(JL)*2.0)
1055 CONTINUE
1057 CONTINUE
C SET UP SPLINE FXN FOR AF
DO 1060 JI=1,NJI
1060 CALL SPL1D1(NJL,ZL,AF(1,JI),WAF(1,JI),IOP,L,STRA,STRB,STRC)
PRINT 21,HEAD
PRINT 62,NRFE,DEN,WU,WPU,U235,U233,U238,PU239,PU240,PU241,PU242
62 FORMAT(//* FISSION ENERGY GENERATION IN REGION *,I3* CALCULATED FR
10% COMPOSITION*/
2* DENSITY = *,F7.3,* GM/CC*,7X,*%I PERCENT U = *,F8.3,7X,
3*%T PERCENT PU = *,F8.3/
4* URANIUM ISOTOPIC CONTENT*/
5* U235 = *,F8.3,7X,*U233 = *,F8.3,7X,*U238 = *,F8.3/
6* PLUTONIUM ISOTOPIC CONTENT*/
7* PU239 = *,F8.3,6X,*PU240 = *,F8.3,6X,*PU241 = *,F8.3,6X
*PU242 = *,F8.3)
C CALC VOL AND WEIGHT OF FISSION ENERGY REGION
VFUL = ZFCL*PI*((RS(NRFE)**2)-(RS(NRFE=1)**2))
WFUL = VFUL*DEN
PRINT 1065,NRFE,VFUL,WFUL
1065 FORMAT(//* CALCULATED VOLUME AND WEIGHT OF REGION *,I3/
1* VOLUME = *,1PE11.4,* CC*,10X,*WEIGHT = *,1PE11.4,* GM*)
PRINT 63,FNC
63 FORMAT(//* INPUT FISSION RATES MULTIPLIED BY CORRECTION FACTOR = *
1,F8.5)
PRINT 64
64 FORMAT(//* PEAK FISSION ENERGY GENERATION*/
1 * ISOTOPE*,7X,*GM/CC*,9X,*%ATTS/CC*,7X,*FISS/GM SEC*)
PRINT 66,(FINM(JI),GM(JI),GF(JI),F(JI),JI=1,NJI)
66 FORMAT(4X,A5,5X,1PE11.4,5X,1PE11.4,5X,1PE11.4)
C CALCULATE PEAK AND AVERAGE LINEAR POWER AND TOTAL POWER
FAC2=0.0 $ FAC3=0.0
DO 1067 JI=1,NJI
FAC2 = FAC2 + GF(JI)
1067 FAC3 = FAC3 + (GF(JI)/PA(NROW,JI))
FAC1 = PI*((RS(NRFE)**2)-(RS(NRFE=1)**2))
FAC4 = FAC3*FAC1*ZFCL/1000.0
FAC2 = FAC2*FAC1/10.0
FAC3 = FAC3*FAC1/10.0
PRINT 1069,NRFE,FAC2,FAC3,FAC4
1069 FORMAT(//* LINEAR AND TOTAL FISSION POWER IN REGION *,I3/
1* PEAK LINEAR POWER = *,F8.3,* KW/M*/
2* AXIAL AVERAGE LINEAR POWER = *,F8.3,* KW/M*/
3* TOTAL POWER = *,F8.3,* KW*)
IF(BUMX.LE.0.0) GO TO 90
PRINT 21,HEAD
CALL FISGAS(NROW,WFUL,ZFCL,BUMX,VFUL)

```

```

      GO TO 90
C
C      INPUT FISSION ENERGY AS KW/M
C
70 READ 73,NRFE, NNZ
73 FORMAT(2I3)
  READ 75,(ZFE(NZ),QFE(NZ),NZ=1,NNZ)
75 FORMAT(12F6,3)
  PRINT 21,HEAD
  PRINT 70,NRFE,NNZ
78 FORMAT(//* FISSION ENERGY GENERATION IN REGION *,I3,* INPUT AT *,
  I13,* AXIAL LOCATIONS*/
  2* AXIAL LOCN FROM*/
  5* BOTTOM OF FUEL (M*,8X,*K*/M*,8X,*WATTS/CC*/)
  FAC1 = PI*((RS(NRFE)**2)-(RS(NRFE=1)**2))/10.0
  DO 82 NZ = 1,NNZ
  FAC2 = QFE(NZ)/FAC1
  PRINT 80,ZFE(NZ),QFE(NZ),FAC2
80 FORMAT(5X,F7.3,15X,F8.3,4X,1PE11.4)
82 QFE(NZ)=FAC2
  IF(ZFE(1).EQ.0.0) GO TO 95
  PRINT 92
92 FORMAT(//* FIRST ZFE NOT N.B. INTEGRATION NOT POSSIBLE*/
  1* STOP 4 NEAR STATEMENT 92*)
  STOP 4
95 CONTINUE
C
  SET UP SPLINE COEF FOR QFE INTERP AND INTEG
  L=1
  CALL SPL101(NNZ,ZFE,QFE,NRFE,IOP,L,STRA,STRB,STNC)
90 CONTINUE
C
C      START RADIAL TEMP CALC AT AXIAL LOCATIONS
C
  DO 299 NZC = 1, 50
  PRINT 21,HEAD
  READ 110, Z, NPLR
  IF(Z.GE.0.0) GO TO 108
  Z = ZFCL
  NEND = 1
108 ZPL(NZC) = Z
110 FORMAT( E12.7,I3)
  ZM = Z + ZHF
C
C      CALC GAMMA HEAT
C
C      FIND REL GAMMA HEAT AT Z AND INTEG FM 0 TO Z
115 L=1
  DO 120 M=1,NN
  CALL SPL102(NJG,ZG,AG(1,M),WAG(1,M),L,ZM,TAB)
  AGZINT(M) = SPLINT(NJG,ZG,AG(1,M),WAG(1,M),L,ZBF,ZM)
120 AGZ(M) = TAB(1)
  IF(ZM.GF.-21.43 .A. ZM.LE.21.43) GO TO 125
  PRINT 112 ,Z,ZM
112 FORMAT(//* Z PLANE OUTSIDE LIMITS OF GAMMA HEATING DATA*/
  1* PLANE IS *,F8.3,* CM ABOVE BOTTOM OF FUEL AND *,F8.3,* CM FROM C
  2DKE MIDPLANE*/
  3* GAMMA HEATING INTEGRATION NOT CORRECT FOR THIS Z*)
125 CONTINUE
C
  CALC W/CC FROM GAMMA HEAT AT Z AND TOTAL TO Z
  QTZ = 0.0
  DO 128 I=1,N1
  MNX=MN(I)

```

```

      Q(I) = QG(I)*AGZ(MNX)
120 QIZ = QIZ + (QG(I)*PI*((RS(I)**2)-(RS(I-1)**2))*AGZINT(MNX))
C
C   CHECK FOR TYPE OF FISSION ENERGY CALC
C
      VOL = PI*((RS(NRFE)**2)-(RS(NRFE-1)**2))
      IF(NRFE.EQ.2) GO TO 150
C   CALC W/CC FROM FISSION
      QFIS=0.0      $ QFIST = 0.0      $ L=1
      DO 135 JI=1, NJI
      CALL SPL1D2(NJL,ZL,AF(1,JI),WAF(1,JI),L,ZM,TAB)
      QFIS = (TAB(1)*QF(JI)) + QFIS
      FAC1 = SPLINT(NJL,ZL,AF(1,JI),WAF(1,JI),L,ZBF,ZM)
135 QFIST = QFIST + (FAC1*QF(JI)*VOL)
      GO TO 174
C   CALC FISSION ENERGY FROM INPUT KW/M
150 L=1
      CALL SPL1D2(NNZ,ZFE,QFE,WQFE,L,Z ,TAB)
      QFIS = TAB(1)
      FAC1 = SPLINT(NNZ,ZFE,QFE,WQFE,L,0.0,Z)
      QFIST = FAC1*VOL
C
C   CALC BULK NA TEMP
C
170 QTOT = (QIZ + QFIST)/(QNA*DENNA)
      TS = ((QTOT + MNA)/1.3) + 25.0
      NITER = 99
      DO 175 J=1, NITER
      DTS = (QTOT+MNA-H(TS))/CP(TS)
      TS = TS + DTS
      IF(ABS(DTS/TS).LT.1.0E-6) GO TO 179
175 CONTINUE
      PRINT 177, NITER,Z,QTOT,MNA,TS,DTS
177 FORMAT(/// ** CALC OF TS DID NOT CONVERGE AFTER *,I3,* ITERATIONS*/
1* Z = *,F8.3,7X,*QTOT = *,1PE14.6,7X,*MNA = *,1PE14.6/
2* TS = *,1PE14.6,7X,*DTS = *,1PE14.6//
3* STOP 2   ** FAR STATEMENT 177*)
      STOP 2
179 IF(ENEND.EQ.0) GO TO 183
      QTP = (QIZ + QFIST)/1000.0
      DELTNA = TS - TNA
      PRINT 180,TS,DELTNA,QTP
180 FORMAT(/// ** THE BULK NA TEMPERATURE AT THE TOP OF THE FUEL COLUMN =
1* *,F8.2,* C**
2* THE BULK NA TEMPERATURE RISE = *,F8.2,* C**
3* THE TOTAL ELEMENT POWER INCLUDING GAMMA HEATING = *,F8.3,* KW*)
      GO TO 314
C
C   CALC HEAT TX COEFF
C
185 FAC1 = (QNA*QW*DENNA*CP(TS))/(MNA*THC(4,TS))
      FAC2 = 5.0 + (0.025*(FAC1**0.8))
      AL = FAC2*VHC(4,TS)/MNA
C
C   CALC CONSTANTS IN TEMPERATURE EQN
C
      CALC H(1)
      WAI1 = 1
      J(NHFF) = H(NHFF) + QFIS
184 B(1)=0.2
      WIA=NI-1
      DO 185 J=1,NI

```

```

      M = MN(I)
      M1 = MN(I+1)
185 B(I+1) = (B(I)*PTD(I)*P(1,M) / (PTD(I+1)*P(1,M1)))
      I = ((0.5*(RO(I)**2)*(Q(I)-Q(I+1)))/(PTD(I+1)*P(1,M1)))
C     CALC OUTSIDE REGION SURF TEMP
      M = MN(NI)
      FAC1 = -(((P(1,M)*PTD(NI)*B(NI)/RO(NI))
195 I = (Q(NI)*RO(NI)*0.5)/HZ) + TS
C     CALC A(NI)
      A(NI) = (FAC1*THCR(M,FAC1)) + (Q(NI)*(RO(NI)**2)/(4.0*P(1,M)*PTD(I
1)))
C     CALC OTHER A(I)
      DO 195 I=1,NIA
      IH = NI-I+1
      M = MN(IH)
      M1 = MN(IH-1)
      CALL TEMPCAL(IH,RO(IH-1),FAC1)
195 A(IH-1) = (TEMPCAL(IH,RO(IH-1))*THCR(M1,FAC1)/THCR(M,FAC1))
      I = (Q(IH-1)*(RO(IH-1)**2)/(4.0*PTD(IH-1)*P(1,M1)))
C
C     TEMPERATURE CALCULATION
C
      NOUT = 0
      I=1
      DO 210 K=1,NK
      IF(I.GT.NI) GO TO 212
      CALL TEMPCAL(I,R(K),T(K))
      IF(ABS((T(K)-VAR(K))/T(K)).GT.1.0E-4) NOUT = NOUT + 1
      VAR(K) = T(K)
      IF(K.LT.KOR(I)) GO TO 210
      I=I+1
210 CONTINUE
      GO TO 214
212 PRINT 213,K,I,N1,NK,7
213 FORMAT(/,* I,GT, NI IN TEMPERATURE CALC LOOP AT STM 210*/
1 * K = *,I4,5X,* I = *,I4,5X,* N1 = *,I4,5X,* NK = *,I4,5X,* Z = *,
21PE15,5)
C     ADJUST RADII FOR THERMAL EXPANSION
214 CONTINUE
      IF(NOUT.EQ.0) GO TO 215
      IF(NA.EQ.0) GO TO 215
      DO 2210 I=1,N1
      M = MN(I)
      IF(ALFA(M).LE.0.0) GO TO 2210
      KS=MN(I)
      KF=MOR(I)
      FAC1 = 1.0 + (ALFA(M)*((0.5*(T(KS)+T(KF)))-25.0))
      RO(I-1) = FAC1*RS(I-1)
      RO(I) = FAC1*RS(I)
2210 CONTINUE
      K=0
      DO 1218 I=1,N1
      IF(MN(I).NE.10) GO TO 1212
      M=MN(I+1)
      M1 = MN(I-1)
      FAC2 = (1.0/EPS(M1)) + ((RO(I-1)/RO(I))*((1.0/EPS(M))-1.0))
      FAC2 = (RO(I)-RO(I-1))/FAC2
      DO 1211 J=1,3
1211 P(J,10) = P(J,9) + (FAC2*P(J,9))
1212 DR = (RO(I)-RO(I-1))/FLOAT(NRC(I)-1)
      NRC1 = NRC(I)
      DO 1216 IKX=1,NRCX

```

```

      K=K+1
1216 R(K):= R0(I-1) + (DR*FLOAT(IXK-1))
1218 CONTINUE
      NAIT = NAIT + 1
      IF(NAIT.LT.100) GO TO 1214
      PRINT 1217
      GO TO 215
1217 FORMAT(/* THE THERMAL EXPANSION CORRECTION SCHEME DID NOT CONVERGE
1 AFTER 100 ITERATIONS*)
1219 GO TO 184
C
C   SET UP AXIAL PLOT TEMPS
C
      215 IF(NPL.EQ.0) GO TO 227
      IRP=1
      DO 225 I=1,N1
      IF(MRPL(I).EQ.0) GO TO 225
      DO 220 K=1,NK
      IF(K.NE.KIR(I)) GO TO 217
      TPL(NZC,IRP) = T(K)
      IRP=IRP+1
      GO TO 220
      217 IF(K.NE.KOR(I)) GO TO 220
      TPL(NZC,IRP) = T(K)
      IRP= IRP+1
      220 CONTINUE
      225 CONTINUE
      TPL(NZC,IRPM) = TS
C   COUNT NUMBER OF Z PLANES FOR AXIAL PLOT
      NZT = NZT +1
      227 CONTINUE
C
C   THERMAL STRESS CALC FOR HOLLOW CYLIND REGIONS 2+
C
      DO 1227 K=1,NK
      1227 VAR(K) = T(K)*R(K)
      DO 1220 I=1,N1
      IF(MST(I).EQ.0) GO TO 1220
      IF(I.NE.1) GO TO 1203
      PRINT 1201
      1201 FORMAT(/* STRESS CALCULATION IN REGION 1 REQUESTED BUT CANNOT BE P
      1ERFORMED ON A SOLID CYLINDER*)
      GO TO 1220
      1203 KS = KIR(I)
      KF = KOR(I)
      DENOM = (R(KF)**2)-(R(KS)**2)
      ASQ = R(KS)**2
C   SET UP SPLINE COEF FOR INTEGRATION
      L=1
      CALL SPLIN1(NRC(I),R(KS),VAR(KS),WT(KS),TOP,L,STRA,STRB,STRC)
      CON = EALFA(0.5*(T(KS)+T(KF)))
      CON = 6.894757*CON
      DO 1208 K=KS,KF
      1208 SH(K) = SPLINT(NRC(I),R(KS),VAR(KS),WT(KS),L,R(KS),R(K))
      SUMT = SR(KF)
      DO 1210 K=KS,KF
      RSQ = R(K)**2
      ST(K) = CON*((RSQ+ASQ)*SUMT/DENOM) + SR(K) - (VAR(K)*R(K))/RSQ
      1210 SR(K) = ((-SR(K)) + ((RSQ-ASQ)*SUMT/DENOM))*CON/RSQ
      1220 CONTINUE
C
C   OUTPUT TEMP AT THIS Z PLANE

```

C

```

      Q(NRFF) = Q(NRFF) - QFIS
      QLIN = QFIS*VOL/IN.0
229 PRINT 230,Z,2M,TS,MZ,QTOT,QLIN
230 FORMAT(/' RADIAL TEMPERATURE VARIATION AT Z = *,F7.3,* CM ABOVE THE
1E BOTTOM OF THE FUEL COLUMN = *,F7.3,* CM FROM THE CORE MIDPLANE*
2//' THE BULK SODIUM TEMPERATURE = *,F8.2,* C*,5X,' THE HEAT TRANSFE
3R COEFFICIENT = *,1PE12.4,* W/CM2 C*/
4* THE ENTHALPY INCREASE OF THE BULK SODIUM = *,1PE12.4,* J/GM*,
412X,' THE LINEAR FISSION POWER = *,0PF8.3,* KW/M*///
55X,' REGION*,9X,' GAMMA HEAT*,4X,' FISSION HEAT*,6X,' RADIUS*,5X,
6* TEMPERATURE*,12X,' THERMAL STRESS KPA*/
723X,' W/CC*,11X,' W/CC*,12X,' CM*,12X,' C*,15X,' TANGENTIAL*,7X,
6* RADIAL*/)
      I=1
      DO 238 K=1,NK
      IF(I,NE,NRFF) QFH=0.0
      IF(I,EQ,NRFF) QFH=QFIS
      IF(K,EQ,KTR(I)) PRINT 235,NR(I),RNM(I),Q(I),QFH
      PRINT 234,R(K),T(K)
      IF(I,ST(I),EQ,1) PRINT 232,ST(K),SR(K)
      IF(K,NF,KCR(I)) GO TO 238
      I=I+1
      PRINT 236
238 CONTINUE
      IF(KA,NF,0) PRINT 237,FAIT
237 FORMAT(/' THE NUMBER OF ITERATIONS REQUIRED TO CORRECT FOR THERMAL
1 EXPANSION = *,I3)
232 FORMAT(1H*,79X,1PPE15.5)
233 FORMAT(45X,1PE15.4,4X,0PF8.2)
235 FORMAT(1X,13,2X,A9,1PPE15.4)
236 FORMAT(1H )
      IF(K,PLN,EQ,0) GO TO 299

```

C

C

C

```

      RADIAL TEMP PLOT

      DATA YBT,XLR,XRR / 0.0,0.0,0.5 /
      DATA IXL,IXR,IYT,IYB / 120 , 960 , 50 , 910 /
      YTP = 1600.0
      IF(T(1),GT,YTP) YTP=2400.0
      CALL ADV(2)
      CALL FRAME(IXL,IXR,IYT,IYB)
      CALL LGA(IXL,IXR,IYT,IYB,XLR,XRR,YTP,YBT)
      NXINT=1 $ NYINT=8
      CALL DLENL(NXINT,NYINT)
      NXINT=5
      KYD=0 $ KXD=1
      CALL SLLIN(NYINT,KYD)
      CALL SHLIN(NXINT,KXD)
      DATA XTITR / 110RADIUS (CM) /
      DATA XTITZ / 40RAXIAL LOCATION FROM BOTTOM OF FUEL COLUMN (CM) /
      DATA YTITL / 150TEMPERATURE (C) /
      DATA PLANE/50HZ PLANE = CM ABOVE BOTTOM OF FUEL COLUMN /
      E-CODE(6,1230,PLANE(2))Z
1230 FORMAT(F6.2)
      DO 1235 I=1,21
      CALL CONVRT(40(I),170,XLR,XRR,IXL,IXR)
1235 CALL GVAL(IYT,IYB,IYB)
      CALL PLOT (NR,R,1,T,1,40,2)
      CALL ALPH(10,5,RZ,HEAD,1)
      CALL PLOT(10,20,50,PLANE,1)
      CALL ALPH(400,950,11,XTITR,1)

```

```

      CALL WLCV(10,570,15,YTITL,1)
      PRINT 240
240  FORMAT(//* RADIAL TEMPERATURE PLOT AT THIS Z PLANE*/)
299  CONTINUE
310  IF(NPL.EQ.0) GO TO 1A
C
C    AXIAL TEMP PLOT
C
      DATA XLZ,XRZ /0.0,40.0 /
      YTP = 1600.0
      NZTP = NZT/2
      IF (TPL(NZTP,1).GT.YTP) YTP = 2400.0
      CALL ADV(2)
      CALL FRAME(IXL,IXR,IYT,IYB)
      CALL DGA(IXL,IXR,IYT,IYB,XLZ,XRZ,YTP,YBT)
      NXINT=8 $ NYINT=8 $ KYD=0
      CALL DLNLN(NXINT,NYINT)
      KXD = 0
      CALL SLLIN(NYINT,KYD)
      CALL SBLIN(NXINT,KXD)
      DATA CRVNM/2H 1,2H 2,2H 3,2H 4,2H 5,2H 6,2H 7,2H 8,2H 9,
1 3H 10,3H 11,3H 12,3H 13,3H 14,3H 15,3H 16,3H 17,3H 18,3H 19 /
      NRCH=7
      DO 1350 IHP=1,IRPM
      IF (IHP.GT.9) NRCH=3
      CALL PLOT(NZT,ZPL,1,TPL(1,IHP),1.44,1)
1350  CALL TCP(NRCH,CRVNM(IHP))
      CALL WLCV(10,24,80,HEAD,1)
      CALL WLCV(270,950,46,XTITZ,1)
      CALL WLCV(10,570,15,YTITL,1)
      PRINT 315
315  FORMAT(//* AXIAL TEMPERATURE PLOT COMPLETED*/)
      GO TO 1B
      END

```

```

C    FUNCTION THC(M,T)
      RETURNS THERMAL COND OF MATERIAL M AT TEMP T
      PARAMETER (NM=5)
      COMMON/DATA/P(3,NM)
      THC = P(1,M) + (P(2,M)*T) + (P(3,M)*T*T)
      RETURN
      END

```

```

C    FUNCTION THCR(M,T)
      RETURNS THERMAL COND PARAMETER FXN OF MATERIAL M AT TEMP T
      PARAMETER (NM=5)
      COMMON/DATA/P(3,NM)
      THCR = 1.0 + ( (P(2,M)*T)/(2.0*P(1,M)))
1 + ( (P(3,M)*T*T)/(3.0*P(1,M)))
      RETURN
      END

```

```

      FUNCTION TEMPR(I,R)
      PARAMETER (NM=5),(MI=10)
      COMMON/DATA/P(3,NM)
      COMMON/DATB/A(MI),R(MI),RCL,RO(-1),R(MI),MN(MI),PTD(MI)

```



```

M=MN(I)
IF(I.EQ.1) GO TO 10
TEMPR = A(I) + (B(I)*ALOG(R/RO(I))) - (Q(I)*R*(P(1,M)*PTD(I)*
14,M))
RETURN
10 TEMPR = A(I) - (Q(I)*R*(P(1,M)*PTD(I)*4.0))
RETURN
END

```

```

SUBROUTINE TEMPCAL(I,R,T)
PARAMETER (NM=5),(MI=10)
COMMON/DATA/P(3,NM)
COMMON/DATA/A(MI),B(MI),RCL,RO(MI),Q(MI),MN(MI),PTD(MI)
M = MN(I)
CON = TEMPR(I,R)
TN = CON
DO 10 J=1,3
10 TN = CON/THCR(M,TN)
DO 20 J=1,25
TC = THCR(M,TN)
DTN = (CON-(TN*TC))/(TC+(TN*((0.5*P(2,M)/P(1,M))
1 + (2.0*P(3,M)*TN/(3.0*P(1,M))))))
TN = TN + DTN
IF(ABS(DTN/TN).LT.1.E-6) GO TO 30
20 CONTINUE
PRINT 22,I,R,M,DTN,TN
22 FORMAT(//* TEMPCAL DID NOT CONVERGE ON A TEMPERATURE*/
2* REGION = *,I3,5X,*RADIUS = *,1PE15,5,5X,*MATERIAL = *,I3,5X,
3*ACTN = *,1PE15,5,5X,*TN = *,1PE15,5)
RETURN
30 T = TN
RETURN
END

```

```

SUBROUTINE FISSGAS(NR,W,FCL,BMAX,VOL)
PARAMETER (NI=7), (NJ=8), (NJR=9)
DIMENSION Y(NI,NJ), F(NI), PA(NJR,NI), PL(NI), ATM(NI),
1 AFP(NI), AFA(NI), FP(NI), YKR(4), XFE(4), GM(NI)
COMMON/FATO/AL,WPU,U235,U233,U238,PU239,PU240,PU241,PU242
COMMON/DATA/F,PA,GM

```

```

C
C SUBROUTINE CALCULATES THE MOLES OF FISSION PRODUCTS GENERATED IN
C FUEL SAMPLE CONTAINING URANIUM AND PLUTONIUM IRRADIATED IN EBR-2
C
C FISSION PRODUCT YIELDS OBTAINED FROM NECD-12154 (JAN 1972)
C
C AXIAL FISSION VARIATION CALCULATED ASSUMING CHOPPED COSINE AXIAL
C VARIATION EACH FI CALCULATED SEPARATELY BASED ON P(I,K) DATA
C
C
C Y(I,J) = NR OF MOLES OF FP J FROM FI 1 PER 100 MOLES OF I FISSIONED
C
C PL(I) = PA(K,I) CORRECTED FOR FUEL COLUMN LESS THAN 13.5 IN
C
C FISSIONABLE ISOTOPE IDENTIFICATION
C I=1=U235 2=U233 3=U238 4=PU239 5=PU240 6=PU241 7=PU242
C
C FISSION PRODUCT IDENTIFICATION

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C      J=1=KR83  2=KR84  3=KR85  4=KR86  5=XE131  6=XE132  7=XE134
C      8=XF136
C
C      RUN IDENTIFICATION  K RANGES FROM 1 TO 9
C
C      RUN RANGE IDENTIFICATION  N = 1 = RUNS UP TO 30
C                                  N = 2 = RUNS 31 TO 45
C                                  N = 3 = RUNS 46 TO 55
C                                  N = 4 = RUNS 56 +
C
C      ATM(I) = NR OF MOLES OF FI I
C      TATM = TOTAL NR OF MOLES OF ALL FI
C
C      AFP(I) = NR OF MOLES OF FI I THAT FISSION PER MOLE OF ALL FI THAT
C              FISSION AT PEAK LOCN
C      AFA(I) = NR OF MOLES OF FI I THAT FISSION PER MOLE OF ALL FI THAT
C              FISSION AVERAGED OVER THE FUEL COLUMN
C      PAV = PEAK TO AXIAL AVG FISSIONS FOR ALL FI
C
C      BMAX = MAXIMUM BURNUP  ATOM PERCENT
C      BAVG = AXIAL AVG BURNUP
C
C      FP(J) = NR OF MOLES OF FP J FORMED
C      TFP = TOTAL MOLES OF FP GAS
C
C      KKR(K) = MOLE PERCENT OF KRYPTON ISOTOPES
C      KXE(M) = MOLE PERCENT OF XENON ISOTOPES
C
C      VTIC DATA
C
C      U235  I=1  J=1,8
C      DATA (Y(J),J=1,50,7)/0.6297, 1.0796, 0.3214, 1.8512, 3.2122,
C      14.5125, 4.0810, 5.8388 /
C      U233  I=2  J=1,8
C      DATA (Y(J),J=2,51,7)/1.1200, 1.7400, 0.5520, 2.7300, 4.0600,
C      15.2900, 5.9700, 6.5700 /
C      U238  I=3  J=1,8
C      DATA (Y(J),J=3,52,7)/0.4124, 0.8498, 0.1730, 1.3647, 3.6639,
C      15.3277, 7.5299, 6.7500 /
C      PU239  I=4  J=1,8
C      DATA (Y(J),J=4,53,7)/0.3496, 0.5339, 0.1418, 0.8025, 4.1960,
C      15.3659, 7.2590, 6.8320 /
C      PU240  I=5  J=1,8
C      DATA (Y(J),J=5,54,7)/0.30, 0.50, 0.10, 0.80, 4.0, 5.0, 7.0, 7.0 /
C      PU241  I=6  J=1,8
C      DATA (Y(J),J=6,55,7)/0.2350, 0.3880, 0.0830, 0.6630, 3.3300,
C      14.7720, 8.0500, 7.5200 /
C      PU242  I=7  J=1,8
C      DATA (Y(J),J=7,56,7)/0.30, 0.50, 0.10, 0.80, 4.0, 5.0, 7.0, 7.0 /
C
C      CALC FUEL COL LENGTH CORRECTION AND FISSION RATE AT BURNUP SAMPLE
C      LOCATION
C      DO 52 I=1,NI
C      FAC = 0.1814*SQRT(1.0 - (1.0/PA(NR,I)) )1/2,54
C      PL(I) = (FCL *FAC)/SIN(FCL *FAC)
C 52 CONTINUE
C      CALC NR OF MOLES OF FI
C 60 CONTINUE
C      ATM(1) = W*WU*U235/235.044
C      ATM(2) = W*WU*U233/233.04
C      ATM(3) = W*WU*U238/238.051

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      ATM(4) = W*WPU*PU239/239.052
      ATM(5) = W*WPU*PU240/240.054
      ATM(6) = W*WPU*PU241/241.06
      ATM(7) = W*WPU*PU242/242.06
      TATM = 0.0
      DO 65 I=1,NI
      ATM(I) = ATM(I)/10000.0
65  TATM = TATM + ATM(I)
C  CALC NR MOLES OF FI FISSIONED
      SUMA = 0.0
      SUMP = 0.0
      DO 72 I=1,NI
      AFA(I) = 0.0
      AFP(I) = 0.0
      FAC = F(I)*ATM(I)/F(1)
      AFP(I) = AFP(I) + FAC
      AFA(I) = AFA(I) + (FAC/PL(I))
      SUMP = SUMP + AFP(I)
72  SUMA = SUMA + AFA(I)
      PAV = SUMP/SUMA
      DO 74 I=1,NI
      AFP(I) = AFP(I)/SUMP
74  AFA(I) = AFA(I)/SUMA
105 BAVG = BMAX/PAV
C  CALC FISSION PROD YIELDS
      TFP = 0.0
      DO 114 J=1,NJ
      FP(J) = 0.0
      DO 112 I=1,NI
112  FP(J) = (AFA(I)*Y(I,J)) + FP(J)
      FP(J) = FP(J)*TATM*BAVG/10000.0
114  TFP = TFP + FP(J)
C  CALC COMPOSITIONS OF KRYPTON AND XENON
      SUM1 = 0.0
      SUM2 = 0.0
      DO 122 M=1,4
      SUM1 = SUM1 + FP(M)
122  SUM2 = SUM2 + FP(M+4)
      DO 125 M=1,4
      XKR(M) = FP(M)*100.0/SUM1
125  KXE(M) = FP(M+4)*100.0/SUM2
C
C  OUTPUT SECTION
C
      PRINT 47,BMAX,NR
42  FORMAT(/* FISSION PRODUCT GENERATION AND EBR-II MWD AT GOAL BURNUP
1  OF *,F8.4,* ATOM PERCENT**/
2* FIFMENT IRRADIATED IN ROW *,I3//)
202 FORMAT(5X,*THE ORDER OF FISSIONABLE ISOTOPES IN OUTPUT INFORMATION
1  IS U235 U233 U238 PU239 PU240 PU241 PU242*/ )
      PRINT 205,(ATM(I),I=1,NI)
205  FORMAT(5X,*MOLES OF FISSIONABLE ISOTOPES*/
1(5X,1P8F15.5))
      PRINT 207,(AFP(I),I=1,NI)
207  FORMAT(/ 5X,*RELATIVE PEAK FISSIONS*/
1(5X,1P8F15.5))
      PRINT 209,(AFA(I),I=1,NI)
209  FORMAT(/ 5X,*RELATIVE AXIAL AVERAGE FISSIONS*/
1(5X,1P8F15.5))
      PRINT 211,PAV,BMAX,BAVG
211  FORMAT(/5X,*PEAK TO AVG FISSION RATIO = *,F8.5,
17X,*MAXIMUM BURNUP = *,F7.3,7X,*AXIAL AVERAGE BURNUP = *,F7.3//)

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      PRINT 213,(FP(J),J=1,NJ)
213 FORMAT(5X,*MOLES OF FISSION PRODUCTS GENERATED*/
15X,*KR83 = *,1PE15.5,4X,*KR84 = *,1PE15.5,4X,*KR85 = *,1PE15.5,4X,
2X,*KR86 = *,1PE15.5,
35X,*XE131 = *,1PE15.5,4X,*XE132 = *,1PE15.5,4X,*XE134 = *,1PE15.5,
44X,*XE136 = *,1PE15.5//)
      PRINT 215,TFP,SUM1,SUM2
215 FORMAT(5X,*TOTAL MOLES OF FISSION GAS = *,1PF15.5,7X,
1X,*MOLES KR = *,1PF15.5,7X,*MOLES XE = *,1PE15.5//)
      PRINT 217,(XKR(M),M=1,4)
217 FORMAT(5X,*KRYPTON ISOTOPIIC COMPOSITION MOLE PERCENT*/
15X,*KR83 = *,F7.3,4X,*KR84 = *,F7.3,4X,*KR85 = *,F7.3,4X,*KR86 = *
2,F7.3//)
      PRINT 219,(XXE(M),M=1,4)
219 FORMAT(5X,*XENON ISOTOPIIC COMPOSITION MOLE PERCENT*/
15X,*XE131 = *,F7.3,4X,*XE132 = *,F7.3,4X,*XE134 = *,F7.3,4X,
2X,*XE136 = *,F7.3//)
C      CALC EBR=II IRRADIATION TIME AND MWD
      RPOW = 62.5
      SUMM = 0.0
      DO 135 I=1,NI
135 SUMM = SUMM + (F(I)*GM(I))
      SUMM = SUMM*VOL/(TATM*6.023E+23)
      TIRR = RMAX/(SUMM*2400.0*3600.0)
      XMWD = TIRR*RPOW
      PRINT 225,TIRR,RPOW,XMWD
225 FORMAT(* IRRADIATION TIME = *,F7.1,* DAYS AT *,F6.2,* M* REACTOR P
10*FR FOR A TCTAL OF *,F8.1,* MWD IN EBR=II*)
      RETURN
      END

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