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HTCAP-1 - A Program for Calculating Operating Temperatures in HFIR Target Irradiation Experiments

M. J. Kania
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HTCAP-1 — A PROGRAM FOR CALCULATING OPERATING TEMPERATURES IN HFIR TARGET IRRADIATION EXPERIMENTS

M. J. Kania
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HTCAP-1 — A PROGRAM FOR CALCULATING OPERATING TEMPERATURES IN HFIR TARGET IRRADIATION EXPERIMENTS

M. J. Kania and A. M. Howard*

ABSTRACT

The thermal modeling code, HTCAP-1, calculates in-reactor operating temperatures of fueled specimens contained in the High Flux Isotope Reactor (HFIR) target irradiation experiments (HT-series). Temperature calculations are made for loose particle and bonded fuel rod specimens. Maximum particle surface temperatures are calculated for the loose particles and centerline and surface temperatures for the fuel rods. Three computational models are employed to determine fission heat generation rates, capsule heat transfer analysis, and specimen temperatures. Gamma heating of all capsule components is considered along with the fission heat of the fuel. Thermal expansion and irradiation-induced dimensional changes, based upon previous postirradiation examinations (PIE) on HT-series experiments, are considered in the temperature calculations. Fuel specimen temperatures and fission power histories are calculated at daily intervals for each irradiation cycle.

This report is also intended to be a users' manual, and the application of HTCAP-1 to the HT-34 irradiation capsule is presented. The appendices give a complete FORTRAN listing, a summary of required input data, a data preparation guide, a listing of the input data, a tabular output from the thermal analysis from HT-34, and a listing of the plotting routine HTPLOT together with a data preparation guide and its application to the example thermal analysis of HT-34.

INTRODUCTION

The original HTCAP code[1] was designed to calculate in-reactor operating temperatures of coated particles irradiated loose in the High Flux Isotope Reactor (HFIR) Target series of irradiation experiments. This code was used quite successfully for calculating temperatures in

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series of capsules HT-12 through 15 (ref. 2) and HT-17 through 19 (ref. 3). Following these series, however, more complex capsule designs were introduced. The new designs contained loose test particles in specially designed holders and test fuel in bonded fuel rods that replaced some of the holders. The fuel rods could easily contain both fissile and fertile test fuel whereas in the past, each holder contained only fertile test or fissile driver fuel.

As a result of the changes in capsule design, revisions to the HTCAP code were required to provide detailed time-temperature histories for all irradiation specimens. These revisions have led to the HTCAP-1 thermal modeling code which is now being routinely used for the postirradiation thermal analysis of fueled HT-irradiation capsules. This report describes the modifications that have been incorporated into the HTCAP-1 code, which is a self-contained code that (1) calculates total heat generated within the capsule, (2) performs a modified one-dimensional heat transfer analysis of the HT-capsule, and (3) predicts fuel specimen temperatures. Surface and centerline temperatures for bonded fuel rods and maximum particle surface temperatures for loose particles are determined at user-supplied time intervals for each HFIR irradiation cycle.

This report also serves as a users' manual for the HTCAP-1 thermal code; therefore, several areas referring to the heat transfer calculations have been duplicated from the original HTCAP report. The HTCAP-1 is written in ORNL-FORTRAN language for the ORNL complier. A complete program listing is included in Appendix A. A description of the input data deck and a data preparation guide are presented in Appendix B. A listing of the input data and a tabular output from the thermal analysis of an example is contained in Appendix C. A description of the plotting package HTPLOT used to obtain graphic plots of the punched output from HTCAP-1 and an example of its use are contained in Appendix D.

GENERAL DESCRIPTION AND MODIFICATIONS

Three computational models in the HTCAP code were integrated into the basic design of an HT-capsule. The primary purpose of these three models were:

1. fission heat generation rate determination for each test particle holder;
2. temperature calculations at nodal material boundaries across sample holder;
3. maximum particle surface temperature calculation for test particles within sample holders.

The HTCAP-1 code utilized these computational models and, in addition, has made provisions for optimizing the code when necessary.

The basic capsule design used in HT-irradiation experiments has remained unchanged. The capsule contains four tapered graphite magazines within an aluminum primary containment vessel. The taper is necessary for flat temperature distribution along the length of the magazines. Each magazine contains 13 positions for test or driver fuel and a top and bottom end-plug, which may or may not be fueled. The 13 fuel positions may consist of graphite holders which hold loose particles, bonded fuel rods, or a mixture of both. The four graphite magazines are located symmetrically with respect to the reactor horizontal mid-plane (HMP), as is shown in Fig. 1. The two magazines in the middle, closest to the HMP on either side, are the high-temperature, high-fluence magazines. The magazine at the top and the one at the bottom of the capsule are the low-temperature, low-fluence magazines. Upon loading the magazines into the aluminum containment vessel, the capsule is outgassed and then backfilled with an inert gas, such as helium, argon, or neon, at a pressure slightly above one atmosphere and sealed.

Figure 2 is an x-radiograph of the HT-34 irradiation capsule.[4] This capsule illustrates the complexity of some irradiation experiments and the requirements for a detailed thermal analysis. The test fuel for HT-34, as for all HT capsules, was coated particles of the fertile type — ThO_2 kernel material — and was contained in loose particle holders. The driver fuel was fabricated in the form of bonded fuel rods with approximately the same dimensions as the holders, 9.78-mm diam (0.375-in.) by 6.98-mm long (0.275-in). In addition to uranium (7.07% ^{235}U enriched) driver particles, some rods also contained special fertile test particles. A description of the heavy-metal loading diagram for the ORNL high-temperature magazine of HT-34 is given in Table 1. From this table, one

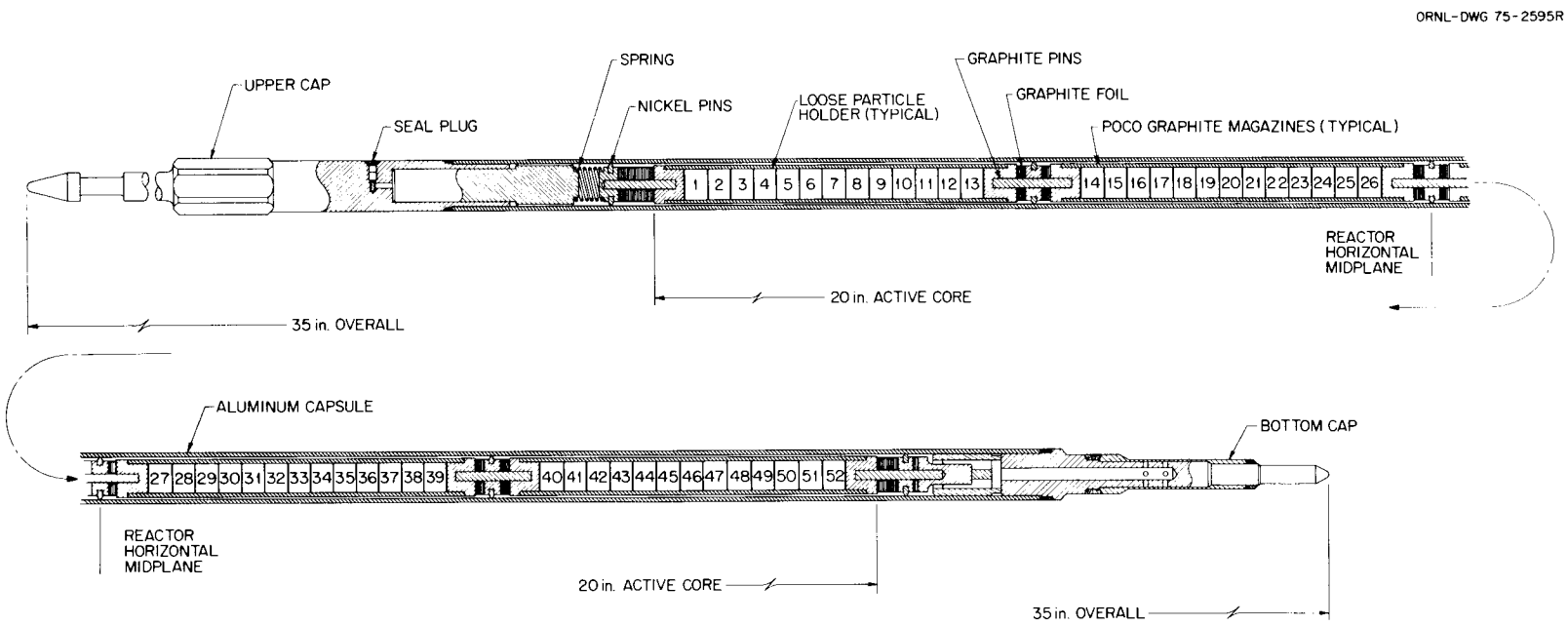

Fig. 1. Target Capsule Typical of HT-12, -13, -14, -15, -17, -18, -19.

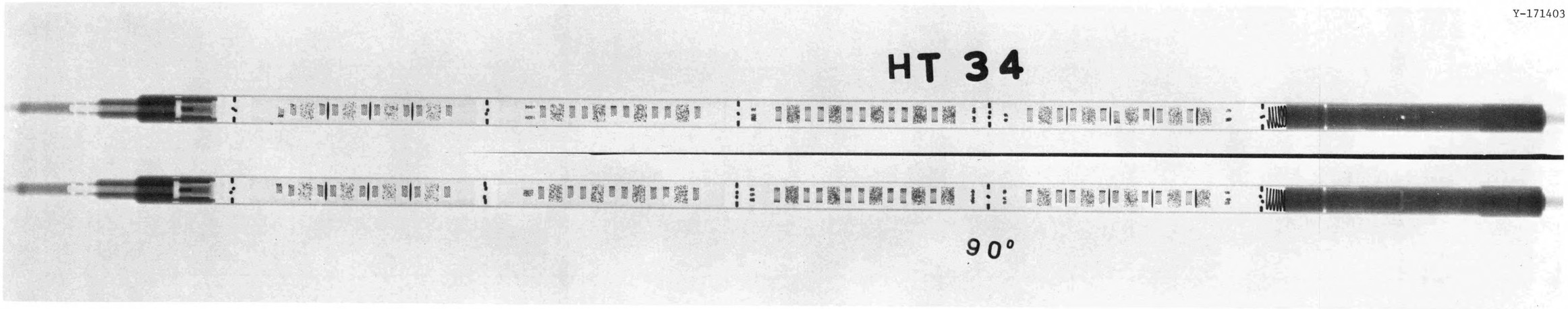

Fig. 2. X-Radiograph of HT-34 Irradiation Capsule.

Table 1. Loading Scheme for ORNL High-Temperature Magazine for Irradiation Experiment HT-34

Position	Specimen Type	Fuel Loading (g)			Particle[a] Batch	Coating Type
		^{238}U	^{235}U	^{232}Th		
End-Plug 26-1	Loose		Inert		OR-2730-1	Biso
27	Loose			0.0228	A-765	Biso
28	Rod	0.0120	0.0009	0.0145	A-834/OR-2576H	Triso/Triso
29	Loose			0.0228	A-780	Biso
30	Loose			0.0228	A-785	Biso
31	Rod	0.0120	0.0009	0.0145	A-835/OR-2576H	Triso/Triso
32	Loose			0.0228	A-806	Biso
33	Loose			0.0228	A-762	Biso
34	Rod	0.0120	0.0009	0.0145	A-837/OR-2576H	Triso/Triso
35	Loose			0.0228	A-782	Biso
36	Loose			0.0228	A-786	Biso
37	Rod	0.0120	0.0009	0.0145	A-836/OR-2576H	Triso/Triso
38	Loose			0.0228	A-787	Biso
39-1	Loose			0.0114	OR-1975T	Biso
39-2	Loose			0.0114	OR-2013T	Biso
End-Plug 26-3			Inert		OR-2722-1	Biso
					OR-2725-1	Biso

[a]In bonded fuel rods, particle batch OR-2576H is the uranium driver particle.

can see that there were two end-plugs containing inert particles, nine loose particle holders containing only fertile particles, and four fuel rods containing both fissile and fertile particles.

The original HTCAP thermal code could not handle this geometry or the mixed fissile-fertile fuel loadings in the driver fuel rods. The HTCAP-1 code includes modifications that allow the complete thermal analysis of such a design as the HT-34 capsule, these include:

1. fission heat generation rates that are calculated using the CACA subroutine which replaces the FABGEN[5] subroutine (CACA is a modified version of the CACA-2 code;[6]
2. test specimen temperature calculations for fuel rods as well as loose particles (surface and centerline temperatures for rods);
3. gamma heating source term — extended to include that due to the heavy metal kernels;
4. up-date of dimensional change characteristics of the graphite holders and magazines plus dimensional change data for bonded fuel rods (all data from previous HT-irradiation experiments).

COMPUTATIONAL MODELS

Fission heat generation rates are calculated using a modified version of the CACA-2 computer code. In its original form, CACA-2 is a fast-running, heavy isotope and fission product concentration calculational code used for experimental irradiation capsules. For the HTCAP-1 application, its primary purpose is to calculate fuel fission power production rates in a known neutron flux as a function of irradiation time. Provisions in CACA-2 that permit fission product birthrates as a function of irradiation time have been deleted. The calculational method is a fourth-order Runge-Kutta method with an experimentally optimized time of 6 h.

One- or two-group flux data and cross-sectional data may be used. However, for most HT-capsule thermal analyses, only one-group integrated data have been used. Provisions are available to specify both position and time dependence for the integrated flux. A maximum fourth order in axial position, Z, and maximum fifth order in time, t, can be used to characterize the HFIR Target Facility.

$$\phi(z,t) = Z(z)^{*}T(t) \ , \tag{1}$$

where

$Z(z)$ = axial dependence with respect to reactor HMP.

$T(t)$ = scaling factor to correct for time pertubations.

For most cases, only a position dependent functional form of Eq. (1) is used. Here $T(t) = 1$, and the axial position-dependent total integrated flux[7] for the HFIR Target Facility is

$$\phi(z) = [5.278 - 4.12\text{E-}02^{*}(z^2) + 1.389\text{E-}04^{*}(z^4)]E + 19 \text{ neut/m}^2\text{-s} \ , \tag{2}$$

where Z = distance from the reactor HMP (in.). By providing a functional form for the flux and the position of each fueled region, the code calculates an average flux integrated over the fueled region for fission power production rate determination.

$$\langle\phi\rangle = \int_b^a \phi(z)dz \Big/ \int_b^a dz \tag{3}$$

where $a(b)$ = distance from the top (bottom) of fueled region with respect to reactor HMP (in.). Seventeen isotopes from ^{232}Th through ^{241}Pu are modeled in the heavy nuclide chain of CACA-2, described in Fig. 3. Eight of these nuclides are considered fissionable. Table 2 is a listing of each isotope and the one-group cross sections to be used with the total integrated one-group flux of Eq. (2). In Table 2, fission cross sections are denoted by (n,f) and capture cross sections by (n,γ). Both flux and cross-sectional data sets can be easily changed as new data become available.

Each of the four graphite magazines is divided into 15 longitudinal sections containing a particle holder, fuel rod, or end-plug along with its surrounding portion of the graphite magazine and aluminum primary

Table 2. Cross-Sectional Data Set for the HFIR Target Facility for use With the Total Integrated Flux

Cross Section	Nuclide	Reaction	Cross Section (barn)
1	^{232}Th	(n,f)	0.012
2	^{234}Pa	(n,f)	2000.0
3	^{233}U	(n,f)	215.0
4	^{235}U	(n,f)	215.0
5	^{238}U	(n,f)	0.047
6	^{238}Np	(n,f)	700.0
7	^{239}Pu	(n,f)	351.0
8	^{241}Pu	(n,f)	442.0
9	^{232}Th	(n,γ)	4.32
10	^{233}Pa	(n,γ)	36.6
11	^{234}Pa	(n,γ)	200.0
12	^{233}U	(n,γ)	22.0
13	^{234}U	(n,γ)	48.1
14	^{235}U	(n,γ)	39.3
15	^{236}U	(n,γ)	10.0
16	^{237}U	(n,γ)	140.0
17	^{238}U	(n,γ)	5.42
18	^{237}Np	(n,γ)	60.0
19	^{238}Np	(n,γ)	18.0
20	^{239}Np	(n,γ)	11.0
21	^{238}Pu	(n,γ)	160.0
22	^{239}Pu	(n,γ)	153.0
23	^{240}Pu	(n,γ)	356.0
24	^{241}Pu	(n,γ)	142.0
25	^{242}Pu	(n,γ)	35.0

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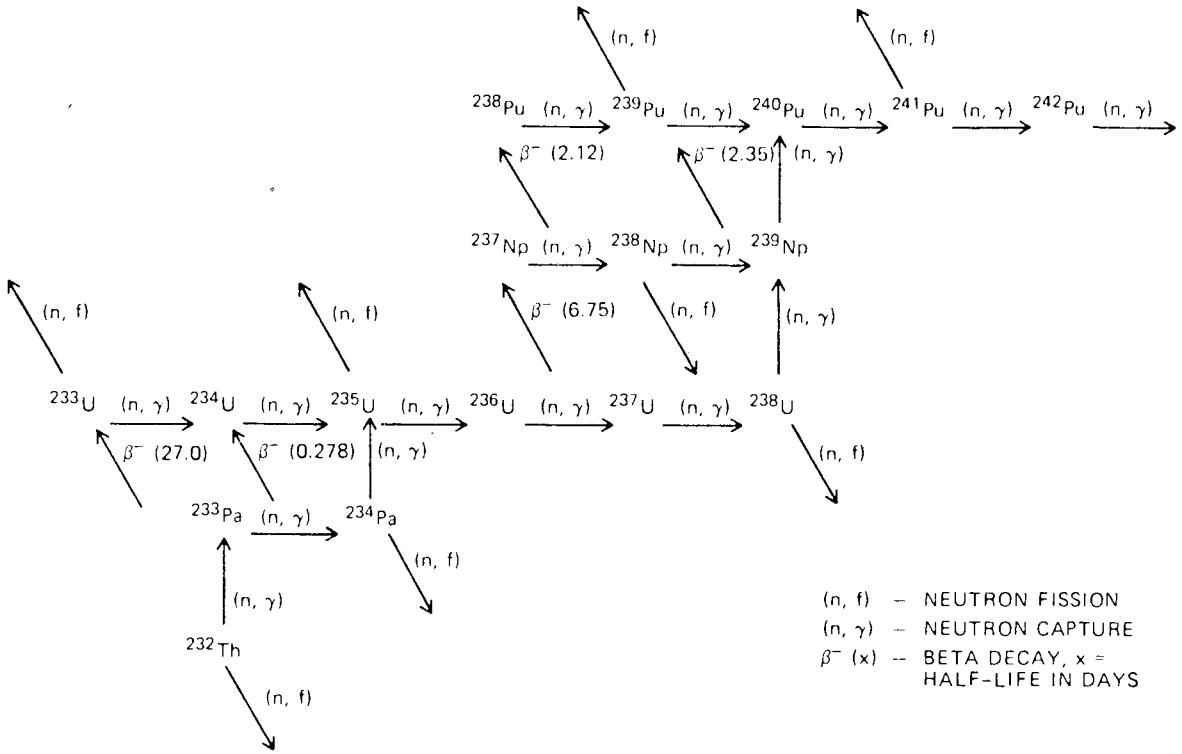

Fig. 3. The Heavy Nuclide Chain Modeled by CACA-2.

containment. Figure 4(a) and 4(b) illustrate a longitudinal section of a particle holder and a fuel rod respectively. Each section is further subdivided into cylindrical regions specified by the inner and outer radii of each material boundary.

During the initial irradiation period for an HT capsule, the primary source of fission heat is from the uranium driver particles in the fuel rods or particle holders positioned along the length of the magazines. However, this reverses as ^{233}U is bred into the ThO_2 particles and ^{235}U is depleted. The major source of heat then becomes the ThO_2 particles. Whenever a specific particle holder or fuel rod generates more heat than its adjacent holders or rods, an axial flow of heat within the HT-capsule is initiated. To account for this axial flow of fission heat, the heat generation rates calculated with the CACA routine are used to determine a linear heat rate for each longitudinal section illustrated in Fig. 5.

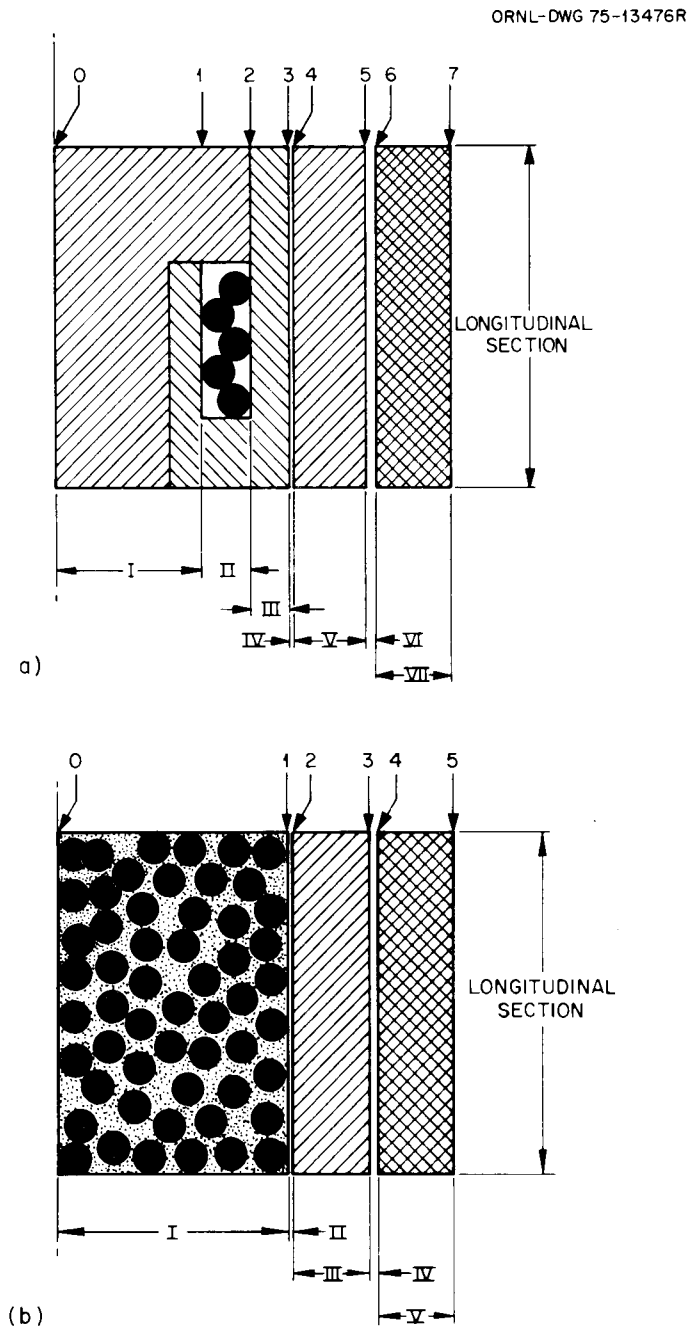

Fig. 4. Region Description of an HT-Capsule Longitudinal Section for (a) Loose Particle Holder, and (b) for Bonded Fuel Rod.

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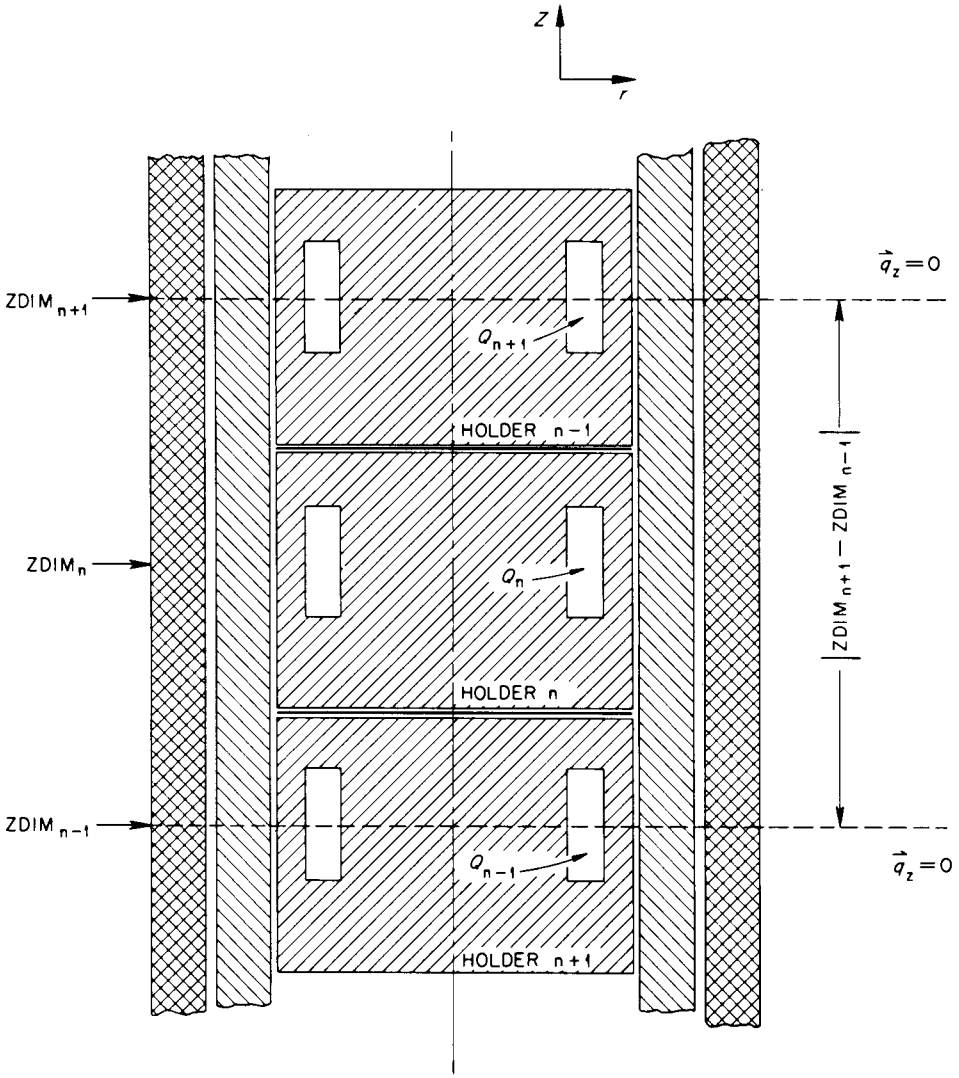


$$LHR_n = \left\{Q_n + \tfrac{1}{2}(Q_{n-1} + Q_{n+1})\right\} \Big/ \left\{\left|ZDIM_{n+1} - ZDIM_{n-1}\right|\right\}$$

WHERE Q_n = FISSION HEAT OF nth HOLDER

$ZDIM_n$ = DISTANCE FROM REACTOR HMP OF nth HOLDER

$\vec{q}_z$ = HEAT FLUX IN AXIAL DIRECTION

Fig. 5. Linear Heat Rate Determination

This calculation is accomplished by adding to the heat produced in each holder or fuel rod, Q_n^f, one-half of the heat generated in the two holders or fuel rods adjacent to it, $1/2(Q_{n-1}^f + Q_{n+1}^f)$. This sum is then integrated over the distance between the midpoints of the two adjacent

holders or fuel rods, $ZDIM_{n+1} - ZDIM_{n-1}$. The linear heat rate (LHR) in kW/ft for holder or fuel rod n is described by Eq. (4):

$$LHR_n = [Q_n^f + 0.5(Q_{n-1}^f + Q_{n+1}^f)]/(ZDIM_{n+1} - ZDIM_{n-1}) \ . \tag{4}$$

A second major source of heat produced in the HT-capsules is that due to gamma heating of capsule components, such as, aluminum containment, graphite magazines and holders, heavy metal fuel, and carbonaceous matrix of fuel rods. The experimentally determined gamma heating rate (in the HFIR Target Facility) for graphite[8] is shown in Fig. 6. This curve is also representative of the gamma heating rate of aluminum in this facility. However, gamma heating rates for other materials, such as the metal fuel — thorium and uranium — is not well known. Some experiments have been performed to determine these rates but the data has not been conclusive. For the HTCAP-1 code a maximum value, nearly twice that of graphite at the HMP, was chosen. As indicated in Fig. 6, the gamma heating rate is axially-dependent. This dependence was found by least squares fitting the data plotted in Fig. 6. A third-order fit was determined and the spatial dependence was assumed characteristic of the

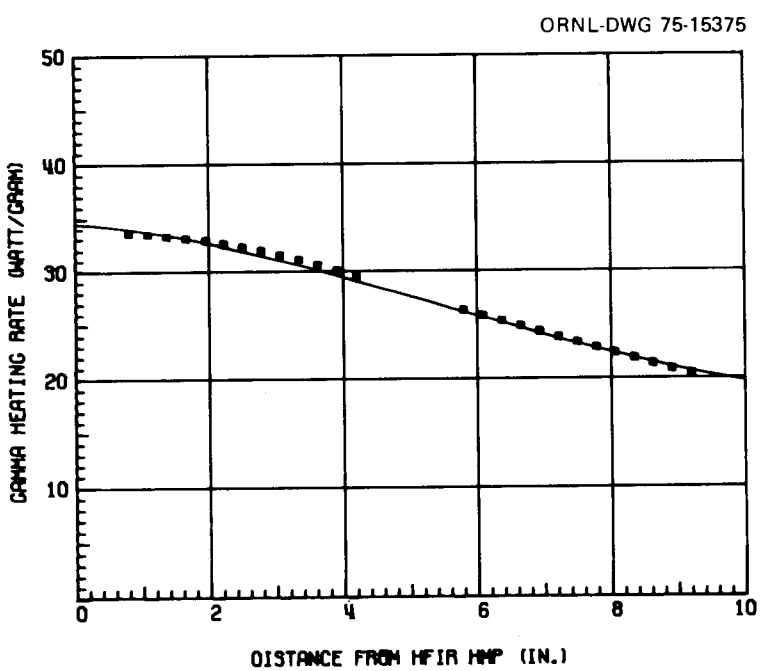


Fig. 6. Gamma Heating Rate in the HFIR Target Region.

reactor. Equations (5) and (6) describe the gamma heating rates for graphite, PGAM, and for the heavy metal fuel, PGAN. The gamma heating rate (in W/g) for aluminum is the same as that for graphite, PGAM.

$$PGAM_n(Z) = 34.554[1.00 - 1.881E\text{-}02^*(Z) - 6.181E\text{-}03^*(Z)^2 + 3.749E\text{-}04^*(Z)^3] , \quad (5)$$

$$PGAN_n(Z) = 65.000[1.00 - 1.881E\text{-}2^*(Z) - 6.181E\text{-}3^*(Z)^2 + 3.749E\text{-}4^*(Z)^3] , \quad (6)$$

where Z = axial distance of midpoint of holder n to the reactor HMP (in.). The gamma heat generated in the ith non-fueled region, (W) is given by

$$Q_i^{\gamma} = PGAM_n(Z)^* V_i^* \rho_i , \quad (7)$$

where

V_i = volume of the ith region (cm^3),
ρ_i = density of the material in the ith region (g/cm^3).

In region II of the special graphite holders where loose particles are contained, the gamma heat (W) is given by

$$Q_2^{\gamma} = PGAM_n(Z)^* V_2^* \rho_2 + PGAN_n(Z)^* V_2^* \rho_2' , \quad (8)$$

where ρ'_2 = heavy metal density in the fueled region of holder and the total heat generated (W) in any longitudinal section is

$$Q_n^t = LHR_n^*(1\ ft)^* 10^3 W/kW + PGAN_n^* V_2^* \rho_2' + PGAM_n \sum_{i=1}^{J} V_i \rho_i , \quad (9)$$

where J = total number of regions in the nth longitudinal section.

Temperature calculations are based on the same solution to the one-dimensional conductive heat equation with uniform heat generation as used in the HTCAP program. The initial step in these calculations is to determine the outer surface temperature of the aluminum containment vessel. If the average coolant temperature and the heat transfer coefficient at the surface is known, the outer surface temperature can be determined from Eq. (10):

$$T_s = T\sim + Q_t/hA_n \ , \tag{10}$$

where

$T\sim$ = average coolant temperature,

Q_t = total heat generated within nth longitudinal section as determined from Eq. (9),

h = surface heat transfer coefficient,

A_n = surface area of aluminum containment vessel for nth section.

Proceeding radially inward, material surface temperatures are calculated based on the solution to the one-dimensional conductive heat equation. This solution is described in Eq. (11):

$$T_{i-1} = T_i + G_i(R_i^2 - R_{i-1}^2)/4k_i + \left(q_{i-1}R_{i-1}/k_i - G_iR_{i-1}^2/2k_i\right) \ln(R_i/R_{i-1}) \ , \tag{11}$$

where

T_{i-1} = temperature at inside radius of ith region,

T_i = temperature at outside radius of ith region (known temperature calculated previously),

G_i = volumetric heat source for ith region,

R_{i-1} = inside radius of ith region,

R_i = outside radius of ith region,

k_i = thermal conductivity of ith region based on average temperature of the region,

q_{i-1} = heat flux incident on inside surface of ith region.

The volumetric heat source is described by

$$G_i = Q_i/V_i \ , \tag{12}$$

except for the fueled regions [II in Fig. 4(a) and I in Fig. 4(b)], where

$$G_2 = \mathrm{LHR}_n{}^*(1\ \mathrm{ft})^*10^3\mathrm{W/kW} + Q_2 \ . \tag{13}$$

The incident heat flux on the inside surface is described by

$$q_{i-1} = \left[\mathrm{LHR}_n{}^*(1\ \mathrm{ft})^*10^3\mathrm{W/kW} + \sum_{k=1}^{i-1} Q_k^{\gamma}\right] / \left[2\pi R_{i-1}(1\ \mathrm{ft})\right] \ , \tag{14}$$

except for the fueled annulus [region II in Fig. 4(a)], where

$$q_1^{\gamma} = Q_1 \ / \left[2\pi R_1(1\ \mathrm{ft})\right] \ . \tag{15}$$

The HTCAP-1 program contains polynominals describing the thermal conductivity, k_i, as a function of temperature for each material in the HT capsule. Initially, k_i, is evaluated at T_i. For each succeeding iteration up to a total of 5, k_i is evaluated at the average region temperature, $\langle T \rangle = (T_i + T_{i-1})/2$.

For the gas gap regions [IV and VI in Fig. 4(a), and II and IV in Fig. 4(b)], the temperature at the inside surface is calculated from an energy balance between the total heat transferred through the region and that transferred by conduction and radiation. The general energy balance equation is

$$Q_i = \sigma F_\varepsilon (T_{i-1}^4 - T_i^4) 2\pi R_i (1\ \mathrm{ft}) - \frac{k_i (T_{i-1} - T_i) 2\pi (1\ \mathrm{ft})}{\ln(R_{i-1}/R_i)} \ , \tag{16}$$

where

$$Q_i = \mathrm{LHR}_n{}^*(1\ \mathrm{ft}) + \mathrm{PGAM}(z) \sum_{k=1}^{i} V_k \rho_k,$$

T_i = temperature (°K) of outside radius of gas gap (known from previous calculation),

T_{i-1} = unknown temperature (°K) of gas gap inside surface,

σ = Stefan-Boltzmann constant (for black body),

$$F_\varepsilon = \text{emissivity factor} = \left[\frac{1}{1/\varepsilon_{i-1} + (R_{i-1}/R_i)^*(1/\varepsilon_i - 1)}\right].^9$$

The gas gap inside surface temperature is calculated by initially equating T_{i-1} to T_i and incrementing T_{i-1} by +20°C (35°F) until the sum of the radiation and conduction terms exceeds Q_i. At this point, the increment is changed to −3°C (5°F). The temperature at which Q_i becomes dominant again is assumed to be the solution for T_{i-1}. After each temperature increment, the thermal conductivity of the region is re-evaluated at the mean temperature, $\langle T \rangle$.

The dimensions of each region are recalculated as a function of temperature and fast neutron fluence (E>0.18 MeV) after the initial set of temperature calculations. Dimensional changes resulting from thermal expansion are calculated as described in the GENGTC program.[10] Changes due to accumulated fast fluence are based on experimental results from the postirradiation examination of previous HT-capsules. Dimensional change data measured on graphite holders from capsules HT-14, -15, -19, -28, and -29 were used for the graphite sample holders.[11] These data are shown in Fig. 7 and a least squares fit of these data was put into HTCAP-1. For the graphite magazines, dimensional change data from magazines in capsules HT-31, -32, and -33 were used.[12–14] These data are shown in Fig. 8 and a least squares fit is used in HTCAP-1 for irradiation-induced dimensional changes of the graphite magazines. To model the shrinkage of the warm-molded fuel rods, data from capsule HT-30, (Fig. 9) was fit and input into the program.

Three analytical expressions are contained in the HTCAP-1 program to model the irradiation-induced dimensional changes of the graphite holders, graphite magazines, and driver fuel rods. Accumulated fast neutron fluence is determined by multiplying the analytic expression for the fast

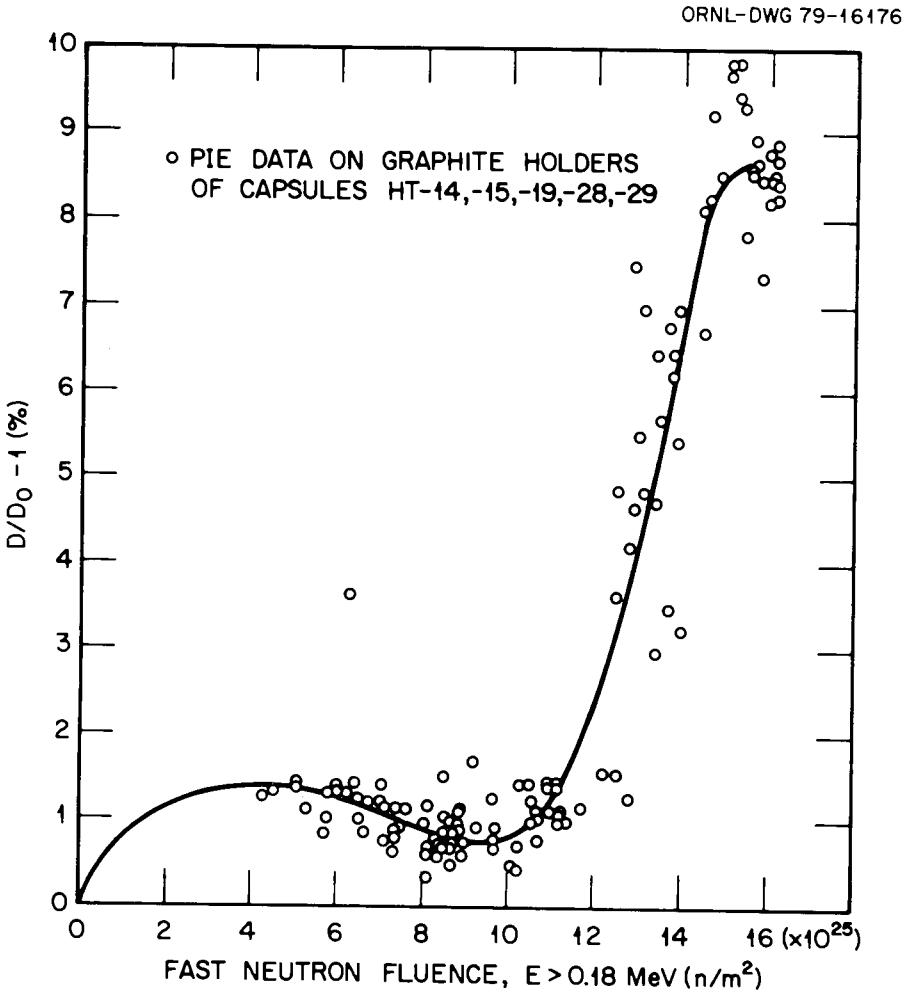


Fig. 7. Irradiation-Induced Dimensional Changes for Graphite Sample Holders Irradiated in HT-14, -15, -19, -28, and -29.

damage flux, evaluated at a particular axial position, by the number of accrued full power days. For each time iteration the radii are corrected and the temperature calculations repeated until the difference between two successive iterations is $\leq$3°C.

The computational model PARTMP[1] is employed for those loose particle holders to determine particle surface operating temperatures. These calculations are based on the average power generated per particle, the particle diameter, and the average temperature of the fueled annulus outside diameter (OD) within each loose particle holder. The exact arrangement is not known; however, previous results[15] indicate that the temperature difference between annulus walls, across gaps of 600- to 1350-μm-wide, is on the order of 20°C or less.

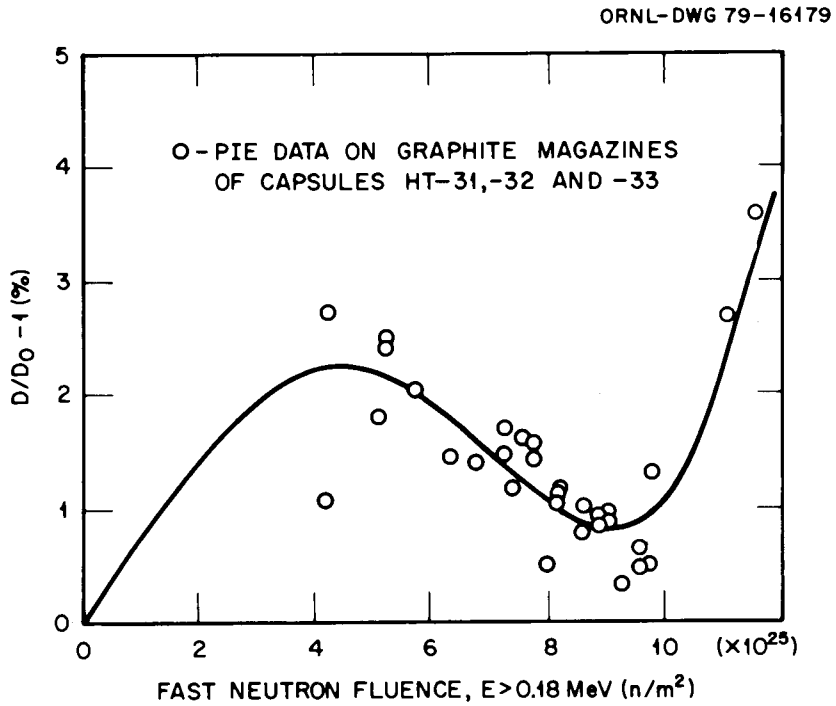


Fig. 8. Irradiation-Induced Dimensional Changes for Graphite Magazines Irradiated in HT-Capsules — HT-31, -32, and -33.

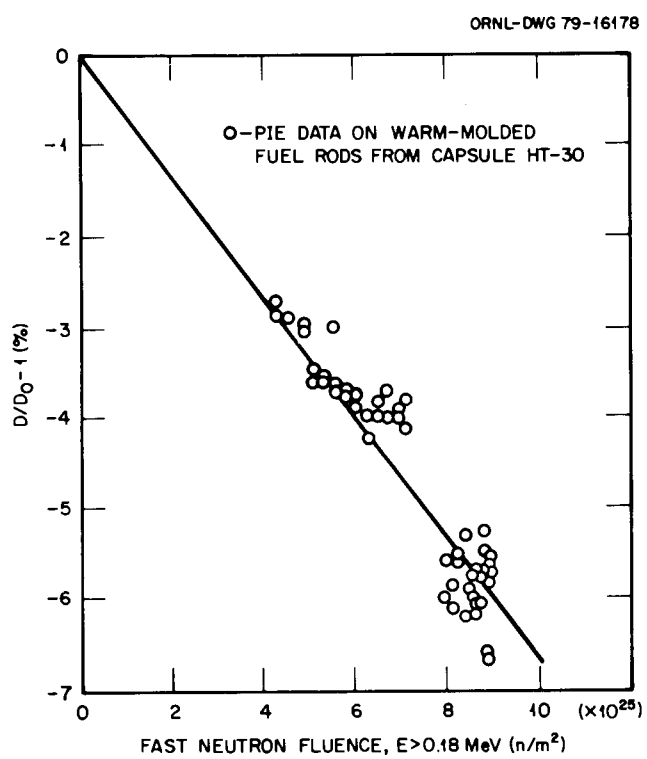


Fig. 9. Irradiation-Induced Shrinkage of Warm-Molded Fuel Rods Irradiated in Capsule HT-30.

The computational model, PARTMP, considers this small ΔT to be negligible, and the particle is assumed to be surrounded by a shell of inert gas whose surface temperature is at some ambient temperature, that is, the same as the annulus OD. In reality, the particle is most likely to be in contact with one of the annulus walls and with one or more other particles. In this case, each point of contact would represent a high-conductance path for heat to escape, thereby reducing the particle surface temperature. The surface temperature predicted by the PARTMP model then represents a maximum operating temperature.

The total heat transfer rate from the particle surface to the surrounding gas shell is by conduction through gas and radiation from particle surface to gas sphere surface, representing a fixed boundary. Equation (17) describes an energy balance for this process:

$$Q_p = \sigma F_\varepsilon (T_1^4 - T_2^4) A_1 + \frac{k_g (T_1 - T_2) A_{gm}}{(r_2 - r_1)} , \tag{17}$$

where

Q_p = heat transfer rate per particle;

F_ε = emissivity factor = $\dfrac{1}{1/\varepsilon + (r_1^2/r_2^2)^*(1/\varepsilon - 1)}$,

assuming $\varepsilon_1 = \varepsilon_2 = \varepsilon$;

T_1 = temperature of particle surface (°K);

T_2 = ambient temperature of gas shell surface equal to fuel annulus OD temperature (°K);

k_g = thermal conductivity of gas surrounding loose particles;

A_1 = surface area of particle ($4\pi r^2$);[16]

A_{gm} = geometric mean surface area ($4\pi r_1 r_2$, r_2 = radius associated with volume of particle plus gas shell).

The surface and centerline temperatures for the fuel rods are calculated based upon the solution to the one-dimensional heat equation in cylindrical coordinates. This is the same as described in Eq. (11). For this case, only the first two terms on the right side of the equation are non-zero. Applying this to region I of the fuel rod provides the following:

$$T_0 = G_1{}^*(R_s^2)/4^*k_1 + T_1 \ , \tag{18}$$

where

T_0 = fuel rod centerline temperature,

R_s = radius of the fuel rod,

T_1 = fuel rod surface temperature.

INPUT AND CALCULATIONAL PROCEDURES

A flow chart describing the HTCAP-1 program is shown in Fig. 10. A full listing of the program and subroutines is presented in Appendix A. Appendix B provides a detailed data preparation guide of input variables and formats, along with the data deck arrangement.

Data input for the HTCAP-1 program has been arranged to describe a complete fueled magazine as follows:

1. reactor operation over irradiation period (card types 1–8);
2. coated particle fuel in their respective holders or fuel rods (card types 9–10);
3. complete magazine including sample holders, fuel rods, end-plugs, graphite magazine, and aluminum containment vessel (card types 11–17).

All dimensional data (r and z) are input as design dimensions in English units. Card type 12 requires that the user provide a smeared density and thermal conductivity for the fueled regions applicable to the fuel rods and sample holders. A procedure for calculating these values is outlined in Appendix B. Card type 17 also requires the user to calculate the initial fissile and fertile isotope number densities (nuclei/barn-cm) in the fueled region of each irradiation position. The calculational procedure is as follows:

1. Call CACA subroutine to compute fission heat generation rates for each irradiation position on a day-to-day basis for each irradiation cycle.
2. Compute linear heat generation rates (LHR_n) for each irradiation position on a day-to-day basis for each irradiation cycle.

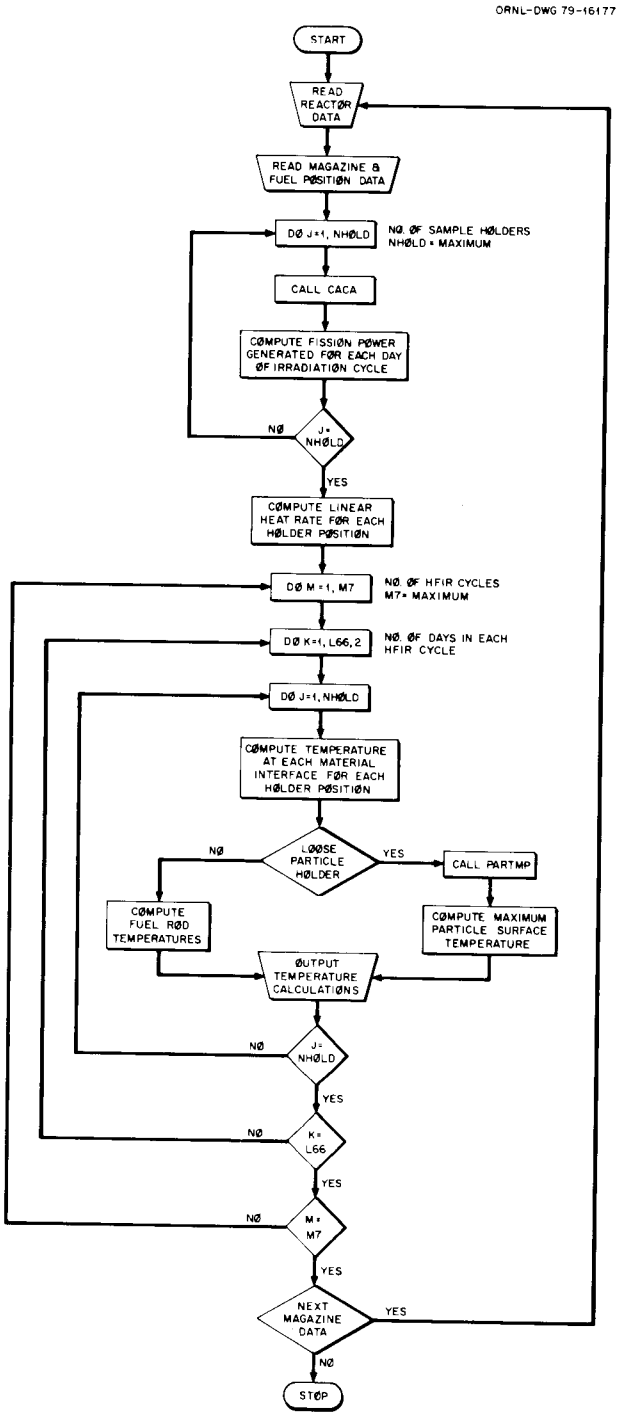


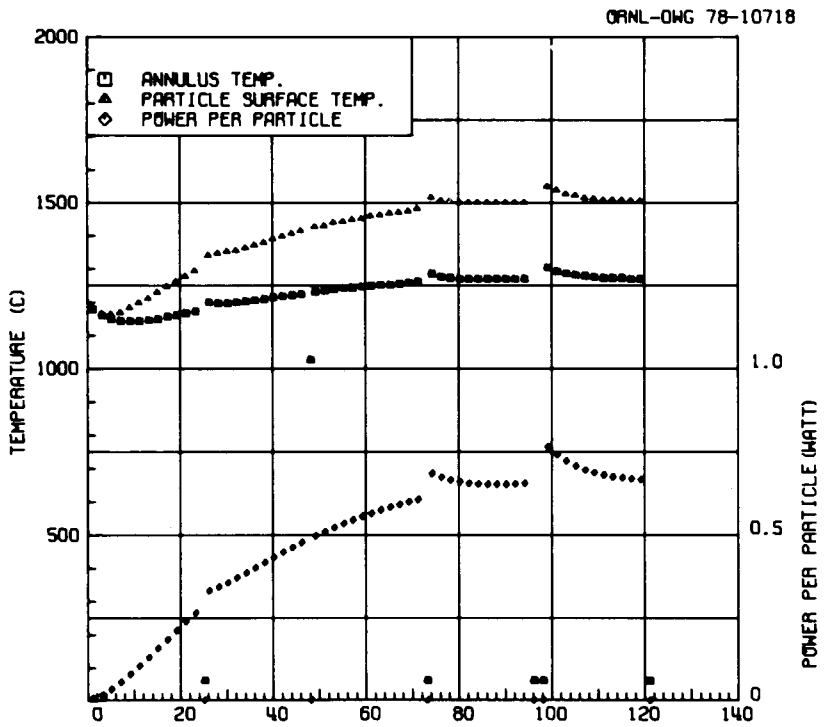
Fig. 10. Flow Chart for the HTCAP-1 Program.

3. Compute temperature at each material interface (radial node) for each end-plug, sample holder, and fuel rod.
   (a) initially based on cold dimensions;
   (b) recalculate considering irradiation-induced and temperature-dependent dimensional changes;
   (c) continue until solution converges within 3°C;
   (d) for loose particle holders, call PARTMP subroutine to compute maximum particle surface temperatures; for fuel rods, calculate linear heat rate and rod centerline temperatures;
   (e) for loose particles, output maximum particle surface temperature, graphite holder temperature, and power produced per particle; for fuel rods, output centerline temperature, surface temperature, and linear heat rate.

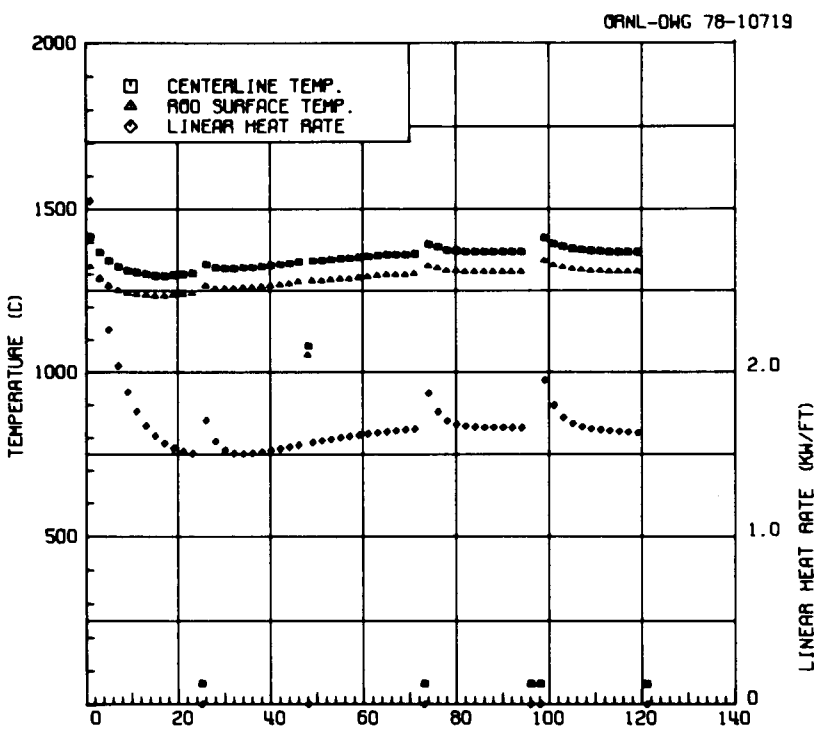
EXAMPLE OF THERMAL ANALYSIS CALCULATION

The thermal analysis of the ORNL High-Temperature Magazine of Capsule HT-34 is presented as an example of the use and results obtained with the HTCAP-1 thermal modeling code. The loading scheme for this magazine was presented in Table 1, and the irradiation history is presented in Table 3. Table C-1 (Appendix C) describes the input data deck used for this thermal analysis, and Tables C-2 and C-3, present the temperature calculations, in tabular form, for each coated particle holder and each fuel rod respectively. Results are presented at two-day intervals beginning with day 1 of each applicable HFIR irradiation cycle.

In addition to the tabular output, punched data was also obtained for use with the plotting routine HTPLOT. This program and its application to this sample problem are presented in Appendix D. The punched output data and the HTPLOT program are used to graphically display the time-temperature-power histories for the irradiated fuel. Figure 11 shows such histories for the loose ThO_2 particles irradiated in holder 30 and for fuel rod 31. For the loose particles in holder 30, [Fig. 11(a)] the upper curve represents the maximum particle surface temperature, the middle curve represents the fuel annulus (holder temperature), and the lower curve represents the power produced per particle from fission. For fuel



(a) TIME FROM BEGINNING OF IRRADIATION (DAYS)



(b) TIME FROM BEGINNING OF IRRADIATION (DAYS)

Fig. 11. Time-Temperature and Power Histories for Fuel Specimens Irradiated in HT-34 experiment: (a) Loose Particles from Graphite Holder 30, and (b) Warm-Molded Fuel Rod 31. All data are calculated with the HTCAP-1 thermal modeling code at two-day intervals over irradiation lifetime.

Table 3. HFIR Operating History During Irradiation of HT-34

HFIR Cycle	Began	Ended	Accumulated Irrad. Time (100 MWd)	HTCAP-1 Cycle	Total Time in Cycle (d)	Full Power Time (d)
150	7/25/77	8/17/77	22.9	1	25	23
151	8/19/77	9/11/77	45.7	2	23	23
152	9/11/77	10/04/77	68.4	3	25	23
153	10/06/77	10/29/77	90.8	4	25	22
154[a]	10/31/77	11/23/77	109.4	5	23	21

[a]The HFIR was shut down for 55.3 h (from 0500 11/07/77 to 1200 11/09/77) during cycle 154.

rod 31 [Fig. 11(b)], the upper curve represents the rod centerline temperature, the middle curve represents the rod surface temperature, and the lower curve represents the linear heat rate of the rod. Time-temperature-power histories for the remaining particle holders and fuel rods are contained in Appendix D.

Peak-calculated particle surface temperatures were near 1500°C, with an average life temperature near 1350°C. As can be seen from Fig. 11(a), the temperature is only constant for the last two irradiation cycles. The peak temperature for the fuel rod occurred at the beginning of life, as expected, because of the fissile ^{235}U present in the rod. However, the presence of the ^{232}Th and ^{238}U can also be seen from the increasing linear heat rate during the last two cycles. The turnaround point where fission of ^{235}U is no longer the dominant heat source occurs during the second irradiation cycle. Peak fuel rod centerline temperatures are near 1500°C, with an average life temperature of 1350°C.

CONCLUSION

The HTCAP-1 computer code presented in this report is the evolution of the thermal modeling of HFIR Target Facility irradiation capsules over the past four years. It is a valuable analytic tool for calculating the extremes in temperatures for various fuel configurations in the accelerated experiments. Detailed time-temperature and particle or fuel rod

power histories can be obtained for multiple fuel samples over the entire irradiation lifetime in a relatively short time. Computation times for a typical HT-capsule containing 52 fueled samples, over a five-cycle irradiation, requires less than 4 min on the IBM 360/91 with a core storage requirement of $\geq$270K. Coupled with the plotting package HTPLOT, final data can be obtained in graphic form.

The flexibility of the HTCAP-1 code is such that it can incorporate updated data, with respect to the nuclear environment of the Target Facility, material thermal properties, and material irradiation stability as they become available. The most recent neutronics data for the Target Facility are currently contained in the code. The irradiation stability of the Poco-graphite components and bonded fuel rods were obtained from previous PIE on none HT-capsule experiments. The HTCAP-1 is a routine part of the postirradiation evaluation procedure for HT-capsules at ORNL.

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APPENDIX A

FORTRAN Listing of HTCAP-1

```
C**FTN,M,L,E,G.
      PROGRAM HTCAP1
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 LHR
      INTEGER*4 HW,CHAIN,ANAME,STEMP,NG,FUEL
      DIMENSION TITLE(18),ZDIM(15),NDS(15),RDIM(9,15),E(9,15),MX(9,15),H
     1W(9,15),F9(15,30,8),        PGAM(15),V(9,15),G(9,15),P(9,15),A(9,1
     25),Q(9,15),Q9(15),T(10,15),YQ(9,15),Z(6,9),ANAME(15),AN(17,15),
     3CHAIN(15),Z00(15),Z10(15),DIA(15),STEMP(15),RF(15),RBF(15),RLTI(15
     4),PNO(15),ZYX(15,9),PW(30,15),TCD(30,15),TPI(30,15),B1NM(15),B2NM(
     515),PGAN(15),ZZ1(6),ZZ2(6),CONC(17),PHI(2),S(25,2),SUMC(15),STKF(1
     65,30,8),TCL(30,15),TSR(30,15),LHR(30,15),TS(30,15),PDEN(30,15),R(3
     70,15),NAMER(15),NAMEP(15),FUEL(15),AVERP(15),AVERR(15)
      COMMON/BLOK1/JJJ,IDATA,AL,VOL,M7,L6(30),L9(30),FTC(6,2),SR(25,2),N
     1G,POWER,FLM(2),FL(2),TTI,TSTEP,IFP
C*****************************************************************************
C*                                                                           *
C*     THE HTCAP1 PROGRAM CALCULATES TEMPERATURES FOR HFIR TARGET CAPSULES.  *
C*     IT HAS BEEN MODIFIED SO THAT TEMPERATURES FOR FUEL RODS AND/OR        *
C*     PARTICLE HOLDERS CAN BE CALCULATED.  THIS PROGRAM UTILIZES A          *
C*     PROGRAM, 'GENGTC', AUTHORED BY HALL C. ROLAND.                        *
C*                                                                           *
C*     'HTCAP1' CONSISTS OF A MAIN PROGRAM AND TWO MAJOR SUBROUTINES,        *
C*     'CACA' AND 'PTLTM'.  'CACA', AUTHORED BY E.J. ALLEN, AND ITS          *
C*     SUBROUTINES CALCULATE FISSION POWER.  'PTLTM' CALCULATES PARTICLE     *
C*     HOLDER SURFACE TEMPERATURES.  CALCULATIONS ARE MADE FOR EACH DAY      *
C*     DURING A HFIR CYCLE.  BOTH FULL POWER DAYS AND DOWN DAYS ARE          *
C*     CONSIDERED.                                                           *
C*                                                                           *
C*****************************************************************************
C*
C*                    DATA FOR MATERIAL Z(I,J)
C*        I=1  POCO GRAPHITE
C*         =2  U OR TH FUELED REGION
C*         =3  ALUMINUM CONTAINMENT VESSEL
C*         =4  ARGON BACKFILL GAS
C*         =5  NEON BACKFILL GAS
C*         =6  HELIUM BACKFILL GAS
C*
C*        J=1     MATERIAL DENSITY (GM/CC)
C*         =2-6   COEFFICIENTS FOR MATERIAL THERMO CONDUCTIVITY (4TH ORDER
C*         =7-9   COEFFICIENTS FOR MATERIAL DIMENSIONAL CHANGE CHARACTERIS
C*
      DATA (Z(1,J),J=1,9)/1.79,17.34,0.0,0.0,0.0,0.0,0.0,11.6302,4.9709E-3,-
     12.808E-6/
      DATA (Z(3,J),J=1,9)/2.6989,117.0,0.0039,0.163E-4,0.813E-7,0.596E-1
     10,12.16,.00302,0.0/
      DATA (Z(4,J),J=1,9)/1.7838E-3,7.985E-3,1.924E-5,-3.607E-9,-2.792E-
     112,1.288E-15,0.0,0.0,0.0/
      DATA(Z(5,J),J=1,9)/0.0,.026,.327E-4,-.484E-8,.782E-12,-.536E-16,0.
     .0,0.0,0.0/
      DATA (Z(6,J),J=1,9)/0.0,.083,.91E-4,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0/
 10   READ 6225,(TITLE(I),I=1,18)
      READ 6235,NHOLD,M7,ND3,IDATA,NG
      READ 6235,(L6(I),L9(I),I=1,M7)
      READ 6435,IPOL1,IPOL2,FLXI,FLXF
      NPOL1=IPOL1+1
```

```
      NPOL2=IPOL2+1
      READ 6375,(ZZ1(I),I=1,NPOL1) $ IF(NG.EQ.1) GO TO 12
      READ 6375,(ZZ2(I),I=1,NPOL2)
      GO TO 13
   12 DO 13 I=1,5
      ZZ2(I)=0.0
   13 CONTINUE
      DO 15 J=1,NG
      READ 3000,(FTC(I,J),I=1,6)
 3000 FORMAT(6F10.0)
   15 READ 6295,(S(I,J),I=1,25)
      READ 6415,N9,T9,R9,H9,D1,D6
      READ 6445,(DIA(J),RF(J),RBF(J),RLTI(J),ZDIM(J),Z00(J),Z10(J),PNC(J
     1),ND9(J),J=1,NHOLD)
      READ 6005,(B1NM(J),B2NM(J),J=1,NHOLD)
 6005 FORMAT(6(A8,A3))
      T9=T9+460.0
      PRINT 6305
C*    READ DATA FOR EACH HOLDER IN MAGAZINE
      DO 20 J=1,NHOLD
      READ 6450,ANAME(J),CHAIN(J),STEMP(J),FUEL(J)
 6450 FORMAT(4I4)
      READ 6425,(ZYX(J,K),K=1,8)
      ZYX(J,9)=0.0
      ZYX(J,2)=57.78*ZYX(J,2)
      N9D=ND9(J)
      READ 6295,(RDIM(I,J),I=1,N9D)
      READ 6295,(E(I,J),I=1,N9D)
      READ 6235,(MX(I,J),I=1,N9D)
      READ 6235,(HW(I,J),I=1,N9D)
      READ 6365,(AN(I,J),I=1,17),AH
 20   CONTINUE
C*     M=CYCLE NUMBER AND K=DAY NUMBER
C*                    FUEL=0   LOOSE PARTICLES IN HOLDER
C*                         =1   FUEL ROD
      DO 40 J=1,NHOLD
      IF(FUEL(J).EQ.1)GO TO 17
   16 KKK=CHAIN(J) $ JJJ=J $ R0=RDIM(1,J) $ R1=RDIM(2,J) $ GO TO 18
   17 KKK=CHAIN(J) $ JJJ=J $ R0=RDIM(1,J)
   18 Z0=Z00(J) $ Z1=Z10(J)
      PHI(1)=(1.0E+15/(Z1-Z0))*(ZZ1(1)*(Z1-Z0)+ZZ1(2)/2.0*(Z1**2-Z0**2)+
     .ZZ1(3)/3.0*(Z1**3-Z0**3)+ZZ1(4)/4.0*(Z1**4-Z0**4)+ZZ1(5)/5.0*(Z1**
     .5-Z0**5))
      IF(NG.EQ.1) GO TO 19
      PHI(2)=(1.0E+15/(Z1-Z0))*(ZZ2(1)*(Z1-Z0)+ZZ2(2)/2.0*(Z1**2-Z0**2)+
     .ZZ2(3)/3.0*(Z1**3-Z0**3)+ZZ2(4)/4.0*(Z1**4-Z0**4)+ZZ2(5)/5.0*(Z1**
     .5-Z0**5))
   19 AL=ABS(Z1-Z0)*2.54
      IF(FUEL(J).EQ.1)GO TO 25
   24 VOL=3.14159*AL*(2.54**2)*(R1**2-R0**2)
      GO TO 23
   25 VOL=3.14159*(2.54**2)*(R0**2)*AL
   23 SUMC(J)=0.0
      DO 30 I=1,17
      CONC(I)=AN(I,J)
      SUMC(J)=SUMC(J)+CONC(I)
   30 CONTINUE
```

```
      CALL CACA(CONC,S,PHI,SUMC,STKP)
   40 CONTINUE
      DO 90 M=1,M7
      N6=L6(M)
      N9=L9(M)
      DO 80 K=1,N6
      DO 70 J=1,NHOLD
      IF(J.GT.1)GO TO 50
      F98=STKP(1,K,M)+.5*STKP(2,K,M)
      F99=F98/(ZDIM(2)-.2188)
      F9(1,K,M)=F99*12.0
      GO TO 70
50    IF(J.EQ.15) GO TO 60
      F98=STKP(J,K,M)+.5*STKP(J-1,K,M)+.5*STKP(J+1,K,M)
      F99=F98/(ZDIM(J+1)-ZDIM(J-1))
      F9(J,K,M)=F99*12.0
      GO TO 70
60    F98=STKP(15,K,M)+.5*STKP(14,K,M)
      F99=F98/(ZDIM(2)-.2188)
      F9(15,K,M)=F99*12.0
70    CONTINUE
80    CONTINUE
90    CONTINUE
      DO 900 M=1,M7
      IF(IDATA)100,110,110
100   PRINT 6015,M
6015  FORMAT(1H1,' DIMENSIONAL CHANGES FOR HOLDERS DURING CYCLE ',I2)
      PRINT 6025
6025  FORMAT(1H0,10X,'INITIAL RADIUS   FINAL RADIUS  DAMAGE FLUENCE')
      PRINT 6035
6035  FORMAT('  HOLDER        (IN)            (IN)          (N/CM**2)')
110   L66=L6(M)
      L99=L9(M)
      DO 730 K=1,L66,2
      DO 130 J=1,NHOLD
      DO 120 I=1,9
      R(I,J)=RDIM(I,J)
120   CONTINUE
130   CONTINUE
      C9=0.
      NIN=1
      AL=12.
      NUMR=0 $ NUMP=0
      DO 720 J=2,14
      DO 140 L=1,9
      Z(2,L)=ZYX(J,L)
140   CONTINUE
150   N9D=ND9(J)
      IF(K-L9(M))160,160,170
160   PGAM(J)=34.5540116-.6498723*ZDIM(J)-.21359252*(ZDIM(J)**2)+1.29554
     12E-2*(ZDIM(J)**3)
      PGAN(J)=65.0*(1.0-1.8807434E-2*ZDIM(J)-6.1814102E-3*(ZDIM(J)**2)+3
     ..7493244E-4*(ZDIM(J)**3))
      GO TO 180
 170  PGAM(J)=0.0 $ PGAN(J)=0.0
180   DO 290 I=1,N9D
190   IF(I-1)200,200,210
```

```
200   V(I,J)=(R(I,J)**2)*AL*0.0018181
      GO TO 220
210   V(I,J)=(R(I,J)**2-R(I-1,J)**2)*AL*0.0018181
220   NT=HW(I,J)
      G(I,J)=PGAM(J)*Z(NT,1)*96646.
      IF(NT-2)240,230,240
 230  IF(FUEL(J).EQ.1)GO TO 22
  21  P(I,J)=V(I,J)*G(I,J)+FS(J,K,M)*3413. $ GO TO 250
  22  G(I,J)=G(I,J)+PGAN(J)*SUMC(J)*1.E+3*96646./2.563
      P(I,J)=V(I,J)*G(I,J)+FS(J,K,M)*3413.
      GO TO 250
 240  P(I,J)=V(I,J)*G(I,J)
 250  A(I,J)=0.043633*R(I,J)*AL
260   IF(I-1)280,280,270
270   P(I,J)=P(I,J)+P(I-1,J)
280   Q(I,J)=P(I,J)/A(I,J)
290   CONTINUE
      Q9(J)=P(ND9(J),J)/A(NDS(J),J)
300   T5=Q9(J)/H9
310   T(N9D,J)=T5+T9
      FFLUX=1.178517-2.95535E-3*ZDIM(J)-6.10752E-3*ZDIM(J)**2-1.9206E-4*
     1ZDIM(J)**3+1.003E-5*ZDIM(J)**4
      F1=1.0E+21
      IF(M.NE.1) GO TO 340
      IF(K-L99)320,320,330
320   F2=FFLUX*DFLOAT(K)*8.64E+19
      GO TO 390
330   F2=FFLUX*DFLOAT(L99)*8.64E+19
      GO TO 390
340   K25=0
      M25=M-1
      DO 350 M2=1,M25
      K25=K25+LS(M2)
350   CONTINUE
      IF(K-L99)360,360,370
360   K2=K25+K
      GO TO 380
370   K2=K25+L99
380   F2=FFLUX*DFLOAT(K2)*8.64E+19
390   F3=F2/F1
      F40=1.0+9.33991E-3*F3-2.05226E-3*(F3**2)+1.27655E-5*(F3**3)+7.439E
     .-5*(F3**4)-1.4031E-5*(F3**5)+1.02604E-6*(F3**6)-2.595E-8*(F3**7)
      F41=1.0+6.69104E-3*F3+5.14204E-4*(F3**2)-4.06037E-4*(F3**3)+2.5898
     .2E-5*(F3**4)
420   N9D=ND9(J)
      N8D=N9D+2
430   DO 530 I3=2,N9D
      I2=N8D-I3
      I1=I2-1
      NT=HW(I2,J)
      T(I1,J)=T(I2,J)
      RLG=R(I1,J)*DLOG(R(I2,J)/R(I1,J))
      IF(MX(I2,J))460,460,440
440   DO 450 L=1,5
      B=(T(I1,J)+T(I2,J))/2.-460.
      AK=Z(NT,2)+Z(NT,3)*B+Z(NT,4)*B**2+Z(NT,5)*B**3+Z(NT,6)*B**4
      T(I1,J)=T(I2,J)+G(I2,J)*(R(I2,J)**2-R(I1,J)**2)/(576.*AK)
```

```
      T(I1,J)=T(I1,J)+P(I1,J)*RLG/(12.*A(I1,J)*AK)
      T(I1,J)=T(I1,J)-G(I2,J)*R(I1,J)*RLG/(288.*AK)
 450  CONTINUE
      YQ(I2,J)=AK
      GO TO 530
 460  N=1
      X=35.
      F0=1./(1./(E(I1,J)+1.E-8)+R(I1,J)/R(I2,J)*(1./(E(I2,J)+1.E-8)-1.))
 470  T(I1,J)=T(I1,J)+X
      Q1=0.1714*F0*A(I1,J)*((T(I1,J)/100.)**4-(T(I2,J)/100.)**4)
      B=(T(I1,J)+T(I2,J))/2.-460.
      AK=Z(NT,2)+Z(NT,3)*B+Z(NT,4)*B**2+Z(NT,5)*B**3+Z(NT,6)*E**4
      YQ(I2,J)=AK
      Q2=A(I1,J)*AK*12.*(T(I1,J)-T(I2,J))/RLG
      Q3=Q1+Q2
      IF(Q3-P(I2,J))480,530,500
 480  IF(N-1)470,470,490
 490  GO TO 530
 500  IF(N-1)520,520,510
 510  GO TO 470
 520  N=2
      X=-5.
      GO TO 470
 530  CONTINUE
C*    CALCULATE DIMENSIONAL CHANGE CHARACTERISTICS FOR ALL RADIAL NODES
      N9D=ND9(J) $ N7D=N9D+1
      DO 650 I4=1,N9D,2
      I5=N7D-I4 $ NT=HW(I5,J) $ IF(NIN.NE.1) GO TO 600
      IF(FUEL(J).EQ.0)GO TO 533
 532  IF(I5.EQ.3.AND.N9D.EQ.5)GO TO 540
      IF(I5.EQ.5.AND.N9D.EQ.7)GO TO 540
      IF(I5.EQ.3.AND.N9D.EQ.7)GO TO 560
      IF(I5.EQ.1)GO TO 580 $ GO TO 600
 540  R(I5,J)=R(I5,J)*F41 $ R(I5-1,J)=R(I5-1,J)*F41 $ GO TO 600
 560  R(I5,J)=R(I5,J)*F40 $ R(I5-1,J)=R(I5-1,J)*F40 $ GO TO 600
 580  IF(NT.EQ.1)GO TO 586
      R(I5,J)=R(I5,J)*(1.00031-6.56503E-3*F3)
      GO TO 590
 586  R(I5,J)=R(I5,J)*F40
 590  B=T(I5,J)-530.0 $ GO TO 610
 600  B=(T(I5,J)+T(I5-1,J))/2.0-530.0 $ IF(I5.EQ.1)GO TO 590
 610  A7=(Z(NT,7)+Z(NT,8)*B+Z(NT,9)*B**2)*1.0E-6
      R(I5,J)=R(I5,J)+(RDIM(I5,J)*(1.0+A7*B)-R(I5,J))/3.0
      IF(I5.EQ.1)GO TO 650
      R(I5-1,J)=R(I5-1,J)+(RDIM(I5-1,J)*(1.0+A7*B)-R(I5-1,J))/3.0
      GO TO 650
 533  IF(I5.EQ.3.AND.N9D.EQ.5)GO TO 541
      IF(I5.EQ.5.AND.N9D.EQ.7)GO TO 541
      IF(I5.EQ.3.AND.N9D.EQ.7)GO TO 561
      IF(I5.EQ.1)GO TO 581 $ GO TO 601
 541  R(I5,J)=R(I5,J)*F41 $ R(I5-1,J)=R(I5-1,J)*F41 $ GO TO 601
 561  R(I5,J)=R(I5,J)*F40 $ R(I5-1,J)=R(I5-1,J)*F40 $ GO TO 601
 581  IF(NT.EQ.1)GO TO 587 $ IF(STEMP.EQ.1)GO TO 585
      R(I5,J)=R(I5,J)*DEXP(-1.688784E-2*F3+2.3093E-3*(F3**2)-6.234E-5*(F
     .3**3)) $ GO TO 591
 585  R(I5,J)=R(I5,J)*DEXP(-1.758992E-2*F3+2.89406E-3*(F3**2)-9.125E-5*(
     .F3**3)) $ GO TO 591
```

```
  587 R(I5,J)=R(I5,J)*F40
  591 B=T(I5,J)-530.0 $ GO TC 611
  601 B=(T(I5,J)+T(I5-1,J))/2.0-530.0 $ IF(I5.EQ.1)GC TC 591
  611 A7=(Z(NT,7)+Z(NT,8)*B+Z(NT,9)*B**2)*1.0E-6
      R(I5,J)=R(I5,J)+(RDIM(I5,J)*(1.0+A7*B)-R(I5,J))/3.0
      IF(I5.EQ.1)GO TO 650
      R(I5-1,J)=R(I5-1,J)+(RCIM(I5-1,J)*(1.0+A7*B)-R(I5-1,J))/3.0
  650 CONTINUE
      N9D=ND9(J)
      N8D=N9D+2
      DO 670 I6=2,N9D
      I8=N8D-I6
      I7=I8-1
      DELTR=R(I8,J)-R(I7,J)
      IF(DELTR-0.0005)660,660,670
 660  R(I7,J)=R(I8,J)-0.0005
 670  CONTINUE
      NIN=NIN+1
      C9=C9+1.
      IF(C9-8.0)150,150,680
  680 IF(FUEL(J).EQ.0)GO TO 691
C*    NUMR COUNTS THE NUMBER OF FUEL RODS IN EACH MAGAZINE WHILE
C*    NUMP COUNTS THE NUMBER OF PARTICLE HOLDERS
      NUMR=NUMR+1 $ L=NUMR
      LHR(K,L)=(STKP(J,K,M)*12.0/.2684)
      TSR(K,L)=5.0/9.0*(T(1,J)-492.0)
      PDEN(K,L)=G(1,J)/96646.0+LHR(K,L)/(617.78*R(1,J)**2)*1000.0
      TS(K,L)=(PDEN(K,L)*(2.54**2*R(1,J)**2))/(4.*Z(2,2)/57.8)
      TCL(K,L)=TS(K,L)+TSR(K,L)
      NAMER(L)=ANAME(J)
      IF(K.EQ.L99.OR.K.EQ.L99-1)GO TO 710
      GO TO 720
  691 NUMP=NUMP+1 $ L=NUMP
      N9D=ND9(J)
      DO 700 I222=1,3
      T(I222,J)=T(I222,J)-460.
  700 T(I222,J)=5./9.*(T(I222,J)-32.)
      DP=DIA(J)
      PP=STKP(J,K,M)
      POWER=PP*1000./PNO(J)
      L3=HW(6,J)
      CALL PTLTM(POWER,RDIM(2,J),RDIM(1,J),T(1,J),T(2,J),TP,DF,FNO(J),L3
     .)
      TOD(K,L)=T(2,J)
      PW(K,L)=POWER
      TPI(K,L)=TP
      NAMEP(L)=ANAME(J)
      IF(K.EQ.L99.OR.K.EQ.L99-1)GO TO 710
      GO TO 720
  710 IF(IDATA.GE.0)GO TO 720
      F27=F2*8.64E+4
      PRINT 6045,(ANAME(J),RCIM(I,J),R(I,J),F27,I=1,N9D)
 6045 FORMAT(I8,4X,F10.5,5X,F10.5,5X,E11.4)
      PRINT 6275
  720 CONTINUE
 730  CONTINUE
      IF(IDATA.EQ.0) GO TO 870
```

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      IF(M.GT.1) GO TO 789
      PRINT 6305
      PRINT 6225,(TITLE(I),I=1,18)
      PRINT 6275
      PRINT 6255,NHOLD
      PRINT 6265,M7,ND3
      DO 740 I=1,M7
      PRINT 6285,I,L6(I),L9(I)
740   CONTINUE
      PRINT 6275
      PRINT 6275
      PRINT 6275
      PRINT 6275
      PRINT 6055
6055  FORMAT(35X,' PARTICLE GEOMETRY')
      IF(NUMR.GE.1)GO TO 757
      GO TO 777
 757  PRINT 6065
      PRINT 6076
6076  FORMAT(1X,'FUEL ROD #   BATCH #     (MICRON)        (CM)          (CM)
     .          (CM)')
      DO 767  J=2,14
      IF(FUEL(J).EQ.0)GO TO 767
      PRINT 6085,ANAME(J),B1NM(J),B2NM(J),DIA(J),RF(J),RBF(J),RLTI(J)
 767  CONTINUE
      IF(NUMP.EQ.0)GO TO 789
 777  PRINT 6065
      PRINT 6075
6075  FORMAT(1X,' HOLDER #   EATCH #     (MICRON)        (CM)          (CM)
     .          (CM)')
      DO 779 J=2,14
      IF(FUEL(J).EQ.1)GO TO 779
      PRINT 6085,ANAME(J),B1NM(J),B2NM(J),DIA(J),RF(J),RBF(J),RLTI(J)
 779  CONTINUE
 789  NUMR=0 $ NUMP=0
      DO 800 J=2,14
      IF(FUEL(J).EQ.0)GO TO 791
      NUMR=NUMR+1 $ L=NUMR
      AVERR(L)=0.0
      CNTR=0.0
      DO 790 K=1,L66,2
      IF(K.GT.L99)GO TO 790
      AVERR(L)=AVERR(L)+TCL(K,L)
      CNTR=CNTR+1.0
 790  CONTINUE
      AVERR(L)=AVERR(L)/CNTR
      GO TO 800
 791  NUMP=NUMP+1 $ L=NUMP
      AVERP(L)=0.0
      CNTR=0.0
      DO 792 K=1,L66,2
      IF(K.GT.L99)GO TO 792
      AVERP(L)=AVERP(L)+TOD(K,L)
      CNTR=CNTR+1.0
 792  CONTINUE
      AVERP(L)=AVERP(L)/CNTR
 800  CONTINUE
```

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      IF(NUMR.GE.1)GO TO 803
      GO TO 806
  803 PRINT 6095
 6095 FORMAT(1H1,' TIME-TEMPERATURE HISTORY OF FUEL ROD CENTERLINE TEMPE
     .RATURE')
      PRINT 6105
 6105 FORMAT(1H0,22X,' CENTERLINE TEMPERATURE ( C) FOR SPECIFIC FUEL ROD
     .S')
      PRINT 6115,(NAMER(L),L=1,NUMR)
      DO 805 K=1,L66,2
      PRINT 6125,M,K,(TCL(K,L),L=1,NUMR)
  805 CONTINUE
      PRINT 6155,(AVERR(L),L=1,NUMR)
      IF(NUMP.EQ.0)GO TO 810
      PRINT 6097
 6097 FORMAT(1H0,' TIME-TEMPERATURE HISTORY OF ANNULUS C.D. TEMPERATURE'
     1)
      GO TO 807
  806 PRINT 6096
 6096 FORMAT(1H1,' TIME-TEMPERATURE HISTORY OF ANNULUS C.D. TEMPERATURE'
     1)
  807 PRINT 6106
 6106 FORMAT(1H0,22X,' TEMPERATURE(C) FOR ANNULUS OF SPECIFIC HOLDERS')
      PRINT 6115,(NAMEP(L),L=1,NUMP)
      DO 808 K=1,L66,2
      PRINT 6125,M,K,(TOD(K,L),L=1,NUMP)
  808 CONTINUE
      PRINT 6155,(AVERP(L),L=1,NUMP)
  810 NUMR=0 $ NUMP=0
      DO 840 J=2,14
      IF(FUEL(J).EQ.0)GO TO 831
      NUMR=NUMR+1 $ L=NUMR
      AVERR(L)=0.0
      CNTR=0.0
      DO 830 K=1,L66,2
      IF(K.GT.L99)GO TO 830
      AVERR(L)=AVERR(L)+TSR(K,L)
      CNTR=CNTR+1.0
  830 CONTINUE
      AVERR(L)=AVERR(L)/CNTR
      GO TO 840
  831 NUMP=NUMP+1 $ L=NUMP
      AVERP(L)=0.0
      CNTR=0.0
      DO 832 K=1,L66,2
      IF(K.GT.L99)GO TO 832
      AVERP(L)=AVERP(L)+TPI(K,L)
      CNTR=CNTR+1.0
  832 CONTINUE
      AVERP(L)=AVERP(L)/CNTR
  840 CONTINUE
      IF(NUMR.GE.1)GO TO 843
      GO TO 845
  843 PRINT 6135
 6135 FORMAT(1H0,' TIME-TEMPERATURE HISTORY OF FUEL ROD SURFACE TEMPERAT
     .URE')
      PRINT 6145
```

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6145 FORMAT(1H0,15X,' FUEL-ROD SURFACE TEMPERATURE ( C) FOR SPECIFIC FU
    .EL RODS')
     PRINT 6115,(NAMER(L),L=1,NUMR)
     DO 844 K=1,L66,2
     PRINT 6125,M,K,(TSR(K,L),L=1,NUMR)
 844 CONTINUE
     PRINT 6155,(AVERR(L),L=1,NUMR)
     IF(NUMP.EQ.0)GO TO 850
 845 PRINT 6136
6136 FORMAT(1H0,' TIME-TEMPERATURE HISTORY OF MAXIMUM PARTICLE SURFACE
    1TEMPERATURE',/)
     PRINT 6146
6146 FORMAT(15X,' PARTICLE SURFACE TEMPERATURE(C) FOR SPECIFIC HOLDERS'
    .)
     PRINT 6115,(NAMEP(L),L=1,NUMP)
     DO 846 K=1,L66,2
     PRINT 6125,M,K,(TPI(K,L),L=1,NUMP)
 846 CONTINUE
     PRINT 6155,(AVERP(L),L=1,NUMP)
 850 IF(NUMR.GE.1)GO TO 855
     GO TO 861
 855 PRINT 6165
6165 FORMAT(1H0,17X,'LINEAR HEAT RATE (KW/FT) FOR FUEL RODS')
     PRINT 6115,(NAMER(L),L=1,NUMR)
     DO 860 K=1,L66,2
     PRINT 6185,M,K,(LHR(K,L),L=1,NUMR)
 860 CONTINUE
     IF(NUMP.EQ.0)GO TO 865
 861 PRINT 6166
6166 FORMAT(1H0,' TIME-POWER GENERATION HISTORY FOR THC2 PARTICLES',/)
     PRINT 6176
6176 FORMAT(17X,' POWER GENERATION(WATTS) PER PARTICLE FOR HOLDERS')
     PRINT 6115,(NAMEP(L),L=1,NUMP)
     DO 862 K=1,L66,2
     PRINT 6185,M,K,(PW(K,L),L=1,NUMP)
 862 CONTINUE
 865 IF(IDATA)900,870,900
 870 PUNCH 6195,(TITLE(I),I=1,18)
6195 FORMAT(17A4)
     NUMR=0 $ NUMP=0
     DO 890 J=2,14
     IF(FUEL(J).EQ.0) GO TO 880
     NUMR=NUMR+1 $ L=NUMR
     PUNCH 6205,NAMER(L),M
     PUNCH 6215,(K,TCL(K,L),TSR(K,L),LHR(K,L),K=1,L66,2)
     GO TO 890
 880 NUMP=NUMP+1 $ L=NUMP
     PUNCH 6205,NAMEP(L),M
     PUNCH 6215,(K,TOD(K,L),TPI(K,L),PW(K,L),K=1,L66,2)
 890 CONTINUE
900  CONTINUE
     GO TO 10
6065 FORMAT(19X,'  PARTICLE DIA.  KERNEL RAD. BUFFER THICK. LTI THICK.'
    .)
6085 FORMAT(I6,4X,A8,A3,2X,F7.1,6X,F8.5,4X,F8.5,5X,F8.5)
6115 FORMAT(' CYCLE DAY',13I7)
6125 FORMAT(I4,I5,3X,13F7.0)
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€155 FORMAT(' AVERAGE     ',13F7.0)
€185 FORMAT(I4,I5,2X,13F7.3)
€205 FORMAT(2I4)
€215 FORMAT(4(I2,1X,F5.0,1X,F5.0,1X,F5.3))
€225 FORMAT(17A4,I1)
€235 FORMAT(18I4)
€255 FORMAT(' NUMBER OF PARTICLE HOLDERS = ',I2)
€265 FORMAT(1H0,' TOTAL NUMBER OF CYCLES = ',I2,'    STARTING DAY = ',I2
    1)
€275 FORMAT(1H0)
€285 FORMAT(' CYCLE ',I2,' HAS ',I2,' TOTAL DAYS WITH ',I2,' FULL POWER
    1 DAYS')
€295 FORMAT(9F8.0)
€305 FORMAT(1H1)
€365 FORMAT(8E9.3)
€375 FORMAT(9E8.0)
€415 FORMAT(I8,5F8.0)
€425 FORMAT(8E9.4)
€435 FORMAT(2I4,2E8.0)
€445 FORMAT(7F10.0,F5.0,I5)
     STOP
     END
```

```
      SUBROUTINE CACA(CONC,S,PHI,SUMC,STKP)
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL *4 ITAT(9,4),ISOT(30,2),TITR(25,2)
      REAL*4 AS(34)  /'TH232    PA233    PA234    U233     U234     U235     U
     1236     U237     U238     NP237    NP238    NP239    PU238    PU239    PU2
     140    PU241    PU242    '/
      REAL*4 BS(36)          /'TIME(DAYS)       FLUX(N/CM2SEC)   POWER(W/CC)
     1     FISSIONS/CCSEC  FISSIONS/CC      FIMA                MWD/MT
     1   POWER(KW/FT)     STICK POWER(KW) '/
      REAL*4 CS(44)          /'TH232FISPA234FISU233FIS U235FIS U238FIS NP2
     138FISPU239FISPU241FISTH232CAPPA233CAPPA234CAPU233CAP U234CAP U235C
     1AP U236CAP U237CAP U238CAP NP237CAPNP238CAPNP239CAPPU238CAPPU239CA
     1P'/
      REAL*4 DS(6)/'PU240CAPPU241CAPPU242CAP'/
      DIMENSION CON(18),FLUX(21,2),YP(18),Y(18),CONC(17),S(25,2),PHI(2),
     1SUMC(15),STKP(15,30,8),POW(21),FR(9),CST(17,10),FRST(9,10),DELT(21
     2)
      COMMON/BLOK1/JJJ,IDATA,AL,VOL,M7,L6(30),L9(30),FTC(6,2),SR(25,2),N
     1G,POWER,FLM(2),FL(2),TTI,TSTEP,IFP
      EQUIVALENCE (Y(1),CON(1))
      K=0
      DO 60 I=1,17
      DO 60 J=1,2
      K=K+1
   60 ISOT(I,J)=AS(K)
      K=0
      DO 61 I=1,9
      DO 61 L=1,4
      K=K+1
   61 ITAT(I,J)=BS(K)
      K=0
      DO 62 I=1,22
      DO 62 J=1,2
      K=K+1
   62 TITR(I,J)=CS(K)
      K=0
      DO 63 I=23,25
      DO 63 J=1,2
      K=K+1
   63 TITR(I,J)=DS(K)
      IFP=17 $ MFP=25 $ NTP=IFP+1 $ PI=3.14159 $ TSTEP=21600.
      M=1 $ NTIME=2*M7+1 $ DELT(1)=0.0
      DO 50 I=2,NTIME,2
      I1=I+1 $ DELT(I)=L9(M) $ DELT(I1)=L6(M)-L9(M) $ M=M+1
   50 CONTINUE $ ICT=0 $ IBR=0
      DO 28 I=1,NTIME
   28 POW(I)=0.0
      NCN=1 $ ICM=1 $ DAYS=1.0 $ N4=1 $ ADAY=1.0 $ N3=NCN
      DO 21 I=1,17
      CON(I)=CONC(I)
   21 CONTINUE $ CON(18)=0.0 $ T1=0.0 $ NS=0
      DO 490 K=1,NTIME,2
      DO 490 J=1,NG
      FLUX(K,J)=0.0
  490 FLUX(K+1,J)=PHI(J)
      DO 55 I=1,MFP
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```
      DO 55 J=1,NG
   55 SR(I,J)=S(I,J)
      DO 9 K=1,NTIME
      IF(K.EQ.1.OR.K.EQ.2)M=1 $ IF(K.GT.2)M=K/2
      POWER=POW(K)
      TTI=0.0
      K1=DELT(K)/ADAY+1.0
      A1=K1-1
      DO 32 J1=1,K1
      IF(J1.EQ.K1) GO TO 33
      T2=T1+ADAY*86400.
      GO TO 34
   33 A2=DELT(K)-ADAY*A1
      IF(J1.EQ.1) GO TO 38
      IF(A2.EQ.0.0) GO TO 400
   38 T2=T1+A2*86400.
   34 CONTINUE
      NS=NS+1
      TTL=(T2-T1)/TSTEP+1.0
      DO 335 J=1,NG
  335 FLM(J)=FLUX(K,J)/10.**24
      CALL DIFEQ(T1,T2,CON,TTL)
      FR(1)=T2/86400.
      FR(2)=0.0
      DO 167 I=1,NG
  167 FR(2)=FR(2)+FL(1)*1.E+24 $ FR(4)=0.0
      DO 168 I=1,NG
  168 FR(4)=FL(I)*1.E+24*(SR(1,I)*Y(1)+SR(2,I)*Y(3)+SR(3,I)*Y(4)+Y(6)
     .*SR(4,I)+Y(9)*SR(5,I)+Y(11)*SR(6,I)+Y(14)*SR(7,I)+Y(16)*SR(8,I))
     .+FR(4)
      FR(3)=FR(4)/3.468E+10 $ FR(5)=CCN(NTP)*1.0E+24
      IF(FR(5))226,226,227
  226 FR(6)=0.0 $ GO TO 228
  227 FR(6)=FR(5)/(SUMC(JJJ)*1.0E+24)
  228 FR(7)=FR(6)*0.8519E+6
      FR(8)=FR(3)*VOL*0.0304E/AL $ FR(9)=FR(8)*AL/(12.*2.54)
      IF(NTIME.EQ.1)GO TO 172 $ IF(M.GT.1)GO TO 190
      K4=IFIX(FR(1)) $ IF(K4.EQ.0)GO TO 172 $ STKP(JJJ,K4,M)=FR(9)
      GO TO 172
  190 K20=0 $ M2=M-1
      DO 198 N=1,M2
      K20=K20+L6(N)
  198 CONTINUE
      K4=IFIX(FR(1))-K20 $ IF(K4.EQ.0)GO TO 172 $ STKP(JJJ,K4,M)=FR(9)
  172 DO 173 I=1,IFP
  173 CST(I,NS)=CON(I)
      DO 174 I=1,9
  174 FRST(I,NS)=FR(I)
  400 IF(NS.EQ.10)GO TO 171 $ IF(K.NE.NTIME)GO TO 32
      IF(J1.EQ.K1)GO TO 171 $ GO TO 32
  171 IF(IDATA)177,31,31
  177 PRINT 130,(ITAT(1,J),J=1,4)
  130 FORMAT(2X,'CONC(ATOMS/EARN-CM)',50X,4A4)
      PRINT 131,(FRST(1,J),J=1,NS)
  131 FORMAT(22X,10(1X,F10.4))
      DO 132 I=1,IFP
  132 PRINT 133,(ISOT(I,J),J=1,2),(CST(I,L),L=1,NS)
```

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133 FORMAT(10X,2A4,4X,10(1X,E10.4))
    PRINT 134
134 FORMAT(1H0)
    DO 135 I=2,9
135 PRINT 136,(ITAT(I,J),J=1,4),(FRST(I,L),L=1,NS)
136 FORMAT(4X,4A4,2X,10(1X,E10.4),///)
 31 NS=0
 32 T1=T2
  9 CONTINUE
    RETURN
    END
    SUBROUTINE DIFEQ(X,XE,Y,TTL)
    IMPLICIT REAL*8 (A-H,O-Z)
    DIMENSION YI(18),Y(18),YF(18),AM1(30),AM2(30),AM3(30),AM4(30),B(40
   1)
    COMMON/BLOK1/JJJ,IDATA,AL,VOL,M7,L6(30),L9(30),FTC(6,2),SR(25,2),N
   1G,POWER,FLM(2),FL(2),TTI,TSTEP,IFP
    XF=X $ XS=XE $ FI=TTL $ NFP=IFP+8 $ H=(XS-XF)/FI $ N=IFP+1
    DO 10 J=1,N
10  YF(J)=Y(J)
    L=IFIX(TTL)
    DO 50 J=1,L
5   TTI=TTI+H/86400.
    DO 3 I=1,NFP
 3  B(I)=0.0
    DO 1 I=1,NG
    FL(I)=FLM(I)*(FTC(1,I)+FTC(2,I)*TTI+FTC(3,I)*TTI**2+FTC(4,I)*TTI**
   13+FTC(5,I)*TTI**4+FTC(6,I)*TTI**5)
    DO 1 M=1,NFP
 1  B(M)=B(M)+SR(M,I)*FL(I)
    CALL EQUA(XF,YF,B,AM1)
    XF=XF+H/2.0
    DO 20 K=1,N
20  YI(K) =YF(K)+AM1(K)*H/2.0
    CALL EQUA(XF,YI,B,AM2)
    DO 30 K=1,N
30  YI(K)=YF(K)+AM2(K)*H/2.0
    CALL EQUA(XF,YI,B,AM3)
    XF=XF+H/2.0
    DO 40 K=1,N
40  YI(K)=YF(K)+AM3(K)*H
    CALL EQUA(XF,YI,B,AM4)
    DO 50 K=1,N
50  YF(K)= H/6.0*(AM1(K)+AM4(K)+2.0*(AM2(K)+AM3(K)))+YF(K)
    DO 60 K=1,N
60  Y(K)=YF(K)
    RETURN
    END
    SUBROUTINE PTLTM(G,R2,R1,T11,T22,TP,DIA,PNO,L3)
    IMPLICIT REAL*8(A-H,O-Z)
    REAL*8 KG,K1,K2
    DIMENSION Z(6,9)
    DATA (Z(4,J),J=1,9)/1.7838E-3,7.985E-3,1.924E-5,-3.607E-9,-2.792E-
   112,1.288E-15,0.0,0.0,0.0,0.0/
```

```
      DATA(Z(5,J),J=1,9)/0.0,.026,.327E-4,-.484E-8,.782E-12,-.536E-16,0.
     .0,0.0,0.0/
      DATA (Z(6,J),J=1,9)/0.0,.083,.91E-4,0.0,0.0,0.0,0.0,0.0,0.0,0.0/
C     THIS SUBROUTINE CALCULATES PARTICLE SURFACE MEAN TEMPERATURE
C     BASED UPON SIMPLE MODEL USING EQUIVALENT AREAS.
      D=1.E-4*DIA
      TVOL=(3.14159*(R2**2-R1**2)*.125*16.38706)/PNO
      RAR=(3./(4.*3.14159)*TVOL)**(1./3.)
      T1=T22+273.15
      A1=3.14159*(D**2)
      A2=2.*3.14159*D*RAR/(RAR-D/2.)
      F=1./(1./.9+(D/(2.*RAR))**2*(1./.9-1.))
      SIG=5.6686E-12
      C1=SIG*A1*F
      T2=T1
      N=1
      X=35.
 10   T2=T2+X
      TF=9./5.*(T2-273.15)+32.
 20   KG=.0173*(Z(L3,2)+Z(L3,3)*TF+Z(L3,4)*TF**2+Z(L3,5)*TF**3+Z(L3,6)*T
     .F**4)
      C2=KG*A2
      K1=Q+T1*(C1*T1**3+C2)
      K2=T2*(C1*T2**3+C2)
      DK=(K1-K2)
      IF(DK)40,50,30
 30   IF(N-1)10,10,50
 40   N=2
      X=-5.
      GO TO 10
 50   TP=T2-273.15
      RETURN
      END
      SUBROUTINE EQUA(X,Y,B,YP)
      IMPLICIT REAL*8 (A-H,C-Z)
      DIMENSION Y(18),B(40),YP(18)
      COMMON/BLCK1/JJJ,IDATA,AL,VOL,M7,L6(30),L9(30),FTC(6,2),SR(25,2),N
     1G,POWER,FLM(2),FL(2),TTI,TSTEP,IFP
      YP(1)=-Y(1)*(B(1)+B(9))
      YP(2)= B(9)*Y(1)-B(10)*Y(2)-2.971*Y(2)/10.**7
      YP(3)=B(10)*Y(2)*.50-Y(3)*(B(2)+B(11))-2.887*Y(3)/10.**5
      YP(4)= 2.971*Y(2)/10.**7-Y(4)*(B(3)+ B(12))
      YP(5)=2.887*Y(3)/10.**5+Y(4)*B(12)-Y(5)*B(13)+B(10)*Y(2)*.50
      YP(6)= Y(5)*B(13)-Y(6)*(B(14)+B(4))+Y(3)*B(11)
      YP(7)= Y(6)*B(14)-Y(7)*B(15)
      YP(8)= Y(7)*B(15)-Y(8)*B(16)-1.189*Y(8)/10.**6
      YP(9)= Y(8)*B(16)-Y(9)*(B(17)+B(5))
      YP(10)= 1.189*Y(8)/10.**6-Y(10)*B(18)
      YP(11)= Y(10)*B(18)-Y(11)*(B(6)+B(19))-3.784*Y(11)/10.**6
      YP(12)= Y(9)*B(17)+Y(11)*B(19)-Y(12)*B(20)-3.414*Y(12)/10.**6
      YP(13)= 3.784*Y(11)/10.**6-Y(13)*B(21)
      YP(14)=3.414*Y(12)/10.**6-Y(14)*(B(7)+B(22))+Y(13)*B(21)
      YP(15)=Y(14)*B(22)+Y(12)*B(20)-Y(15)*B(23)
      YP(16)=Y(15)*B(23)-Y(16)*(B(8)+B(24))
      YP(17)=Y(16)*B(24)-Y(17)*B(25)
      NTP=IFP+1
 10   YP(NTP)=B(1)*Y(1)+B(2)*Y(3)+B(3)*Y(4)+B(4)*Y(6)+B(5)*Y(9)+B(6)*
     1Y(11)+B(7)*Y(14)+B(8)*Y(16)
      RETURN
      END
```

APPENDIX B

Data Preparation Guide and Data Deck Arrangement for HTCAP-1

For easier use, this Appendix has been arranged in the following manner:

- Data Input Variables and Formats
- Data Deck Arrangement
- Formulas for Data Calculations

Data Preparation Guide for HTCAP-1

HTCAP-1 Data Input Variables and Formats

Card No.					
1	TITLE(I), Job Description (18A4)				
2	NHOLD (I4)	M7 (I4)	ND3 (I4)	IDATA (I4)	NG (I4)

NHOLD=Number of holders and/or rods plus end plugs to be analyzed
M7=Number of HFIR cycles to be considered
ND3=Starting day of cycle (0)
IDATA=Data output flag:
<0-Print power per particle holder and/or linear heat rate, temperature calculations, dimensional changes
=0-Punch temperature data only
>0-Print temperature calculations only
NG=Number of energy groups

3	L6(I) (I4)	L9(I) (I4)	Continue in pairs for I=1,M7 Format (18I4)

L6(I)=Number of days in HFIR Cycle I
L9(I)=Number of full power days in HFIR Cycle I

4	IPOL1 (I4)	IPOL2 (I4)	FLXI (E8.0)	FLXF (E8.0)

IPOL1=Order of fast flux polynomial
IPOL2=Order of thermal flux polynomial
FLXI=Minimum Z of flux, in.
FLXF=Maximum Z of flux, in.

5A	ZZ1(I) (E8.0)	Continue for I=1, IPOL1+1 Format (9E8.0)

ZZ1(I)=Coefficients for fast flux polynomial

NOTE: if NG equals 1, skip card number 5B

5B	ZZ2(I) (E8.0)	Continue for I=1, IPOL2 + 1 Format (9E8.0)

ZZ2(I)=Coefficients for thermal flux polynomial

6	FTC(I,J) (F10.0)	Continue for I=1,6 Format (6F10.0)

FTC(I,J)=Time dependence of flux polynomial

HTCAP-1 Data Input Variables and Formats

(Continued)

7	S(I,J) (F8.0)	Continue for I=1,25 [Use three cards] Format (9F8.0)

S(I,J)=Cross section data set for specific flux

8	N9 (I8)	T9 (F8.0)	R9 (F8.0)	H9 (F8.0)

N9=Input 0
T9=Ambient coolant temperature, ^{o}F
R9=Inside hole radius for hollow element; if solid use 0.0 in.
H9=Surface heat transfer coefficient, Btu/hr-ft^2-^{o}F

NOTE: Repeat card number 9 J=NHOLD times

9	DIA(J) (F10.0)	RF(J) (F10.0)	RBF(J) (F10.0)	RLTI(J) (F10.0)	ZDIM(J) (F10.0)	Z00(J) (F10.0)	Z10(J) (F10.0)	PNO(J) (F5.0)	ND9(J) (I5)

DIA(J)=Particle diameter, μm
RF(J)=Kernel radius, cm
RBF(J)=Buffer thickness, cm
RLTI(J)=LTI thickness, cm
ZDIM(J)=Distance of holder midpoint from reactor HMP, in.
Z00(J)=Position of top of fueled annulus relative to reactor HMP, in.
Z10(J)=Position of bottom of fueled annulus relative to reactor HMP, in.
PNO(J)=Number of particles
ND9(J)=Number of radial nodes in sample holder

10	B1NM(J) (A8)	B2NM(J) (A3)	Continue in pairs; 6 pairs per card; repeat for J=1,NHOLD Format (6(A8,A3))

B1NM(J),B2NM(J)=Batch name associated with each particle. If no batch name, leave blank.

NOTE: Repeat card numbers 11 through 17 for particle holders and/or rods and end plugs. Start with the end plug closest to the HMP and continue through holders until end plug farthest from the HMP.

11	ANAME(J) (I4)	CHAIN(J) (I4)	STEMP(J) (I4)	FUEL(J) (I4)

ANAME(J)=Particle holder number
CHAIN(J)=Leave blank
STEMP(J)=0 Low-temperature sleeve
=1 High-temperature sleeve
FUEL(J)=0 Loose particles in holder
=1 Fuel rod

HTCAP-1 Data Input Variables and Formats

(Continued)

ZYX(J,K) (E9.4)	Continue for K=1,8 Format (8E9.4)	

ZYX(J,K)=Material data for fuel of Holder J
K=1, Material density (g/cm^3)
K=2-6, Coefficients for material thermal conductivity(4th orde
K=7-8, Coefficients for dimensional change characteristics

RDIM(I,J) (E8.0)	Continue for I=1,ND9(J) Format (9E8.0)	

RDIM(I,J)=Initial radius of Ith node of Jth holder, in.

E(I,J) (E8.0)	Continue for I=1,ND9(J) Format (9E8.0)	

E(I,J)=Emissivity at material surface (denoted by I^{th} node of the Jth holder)

MX(I,J) (I4)	Continue for I=1, ND9(J) Format (18I4)	

MX(I,J)=0 Indicates material immediately inside Node I is a gas
=1 Indicates material immediately inside Node I is a solid

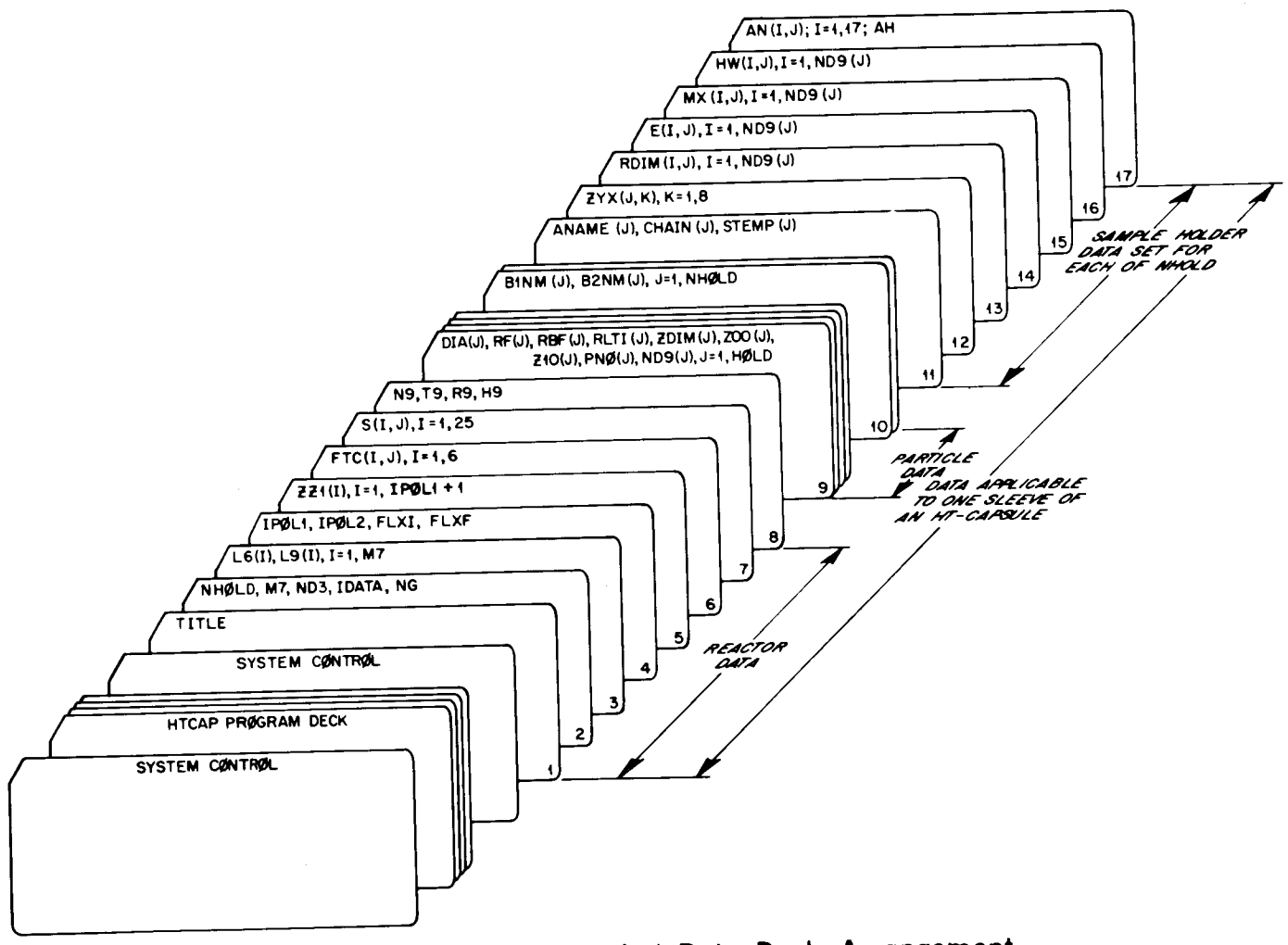
HW(I,J) (I4)	Continue for I=1, ND9(J) Format (18I4)	

HW(I,J)=Indicates type of material immediately inside Node I
=1 Poco graphite
=2 Fueled region
=3 Aluminum
=4 Argon gas
=5 Neon gas
=6 Helium gas

AN(I,J) (E9.3)	Continue for I=1,17 [Use three cards] Format (8E9.3)	AH (leave blank) (E9.3)

AN(I,J)=Number density of isotope
I=1 Th-232 (card 1, columns 1-9)
I=6 U-235 (card 1, columns 46-54)
I=9 U-238 (card 2, columns 1-9)
AH=Heavy metal content at day zero (usually 0)

ORNL-DWG 75-13475R2



HTCAP-1 Data Deck Arrangement

Data Preparation Guide for HTCAP-1
Formulas for Data

MATERIAL DENSITY

For rods: $\rho = \dfrac{\text{mass (g)}}{\text{volume (cm}^3)}$

For particles: $\rho = \dfrac{\rho_{graphite} V_{graphite} + \rho_{fuel} V_{fuel} + \rho_{gas} V_{gas}}{V_{annulus}}$

MATERIAL THERMAL CONDUCTIVITY

For rods: Warm-molded rods $k = .12$ W/cm-°C

Slug injected rods $k = .045$ W/cm-°C

For particles: $k = \dfrac{V_{annulus} / V_{region}}{\dfrac{V_{LTI}}{k_{LTI} V_{ann.}} + \dfrac{V_{SiC}}{k_{SiC} V_{ann.}} + \dfrac{V_{gas}}{k_{gas} V_{ann.}}} + \dfrac{V_{graphite} k_{graphite}}{V_{region}}$

$\rho_{graphite} = 1.79$ g/cm^3
$\rho_{Argon} = 1.7838E-3$ g/cm^3
$k_{graphite} = .300$ W/cm-°C
$k_{SiC} = .125$ W/cm-°C
$k_{Argon} = 6.3733E-4$ W/cm-°C
$k_{LTI} = .05$ W/cm-°C

$V_{LTI} = PNO \cdot \frac{4}{3} \cdot \pi \cdot (radius^3_{outer} - radius^3_{inn}$

V_{SiC} = same formula as above

Formulas for Data(cont.)

RADIAL NODES

For rods:

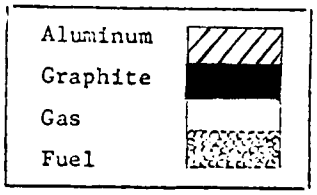
X 1 2 3 4 5

Center

For particles:

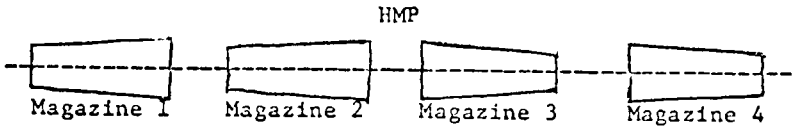
X 1 2 3 4 5 6 7

Center



RADII OF NODES

The outer diameter of the graphite magazine varies with the distance from the HMP.



Check design drawings to insure dimensions are correct for each experiment. They may vary from experiment to experiment.

NODE	RADIUS (in.)	
	Rod	Particles
1	varies	.116
2	.1935	varies
3	varies	.1925
4	.2655	.1935
5	.3275	varies
6	-----	.2655
7	-----	.3275

NUMBER DENSITY

$$\frac{\text{atoms}}{\text{barn-cm}} = \frac{\text{fuel (g)}}{\text{volume (cm}^3)} \cdot \frac{\text{6.025E23 atoms/mole}}{\text{molecular wt. (g/mole)}} \cdot \frac{\text{E-24 cm}^2}{\text{barn}}$$

fuel = U^{235}, U^{238}, or Th^{232}

Volume:

For rods: volume of rod

For particles: volume of annulus

Molecular Wt:

of U^{238} = 238.05 g/mole

of U^{235} = 235.04 g/mole

of Th^{232} = 232.038 g/mole

APPENDIX C

Input Data Listing and Tabular Output from Thermal Analysis of ORNL High-Temperature Magazine in Capsule HT-34

Table C-1. Data input of ORNL high-temperature magazine in HT-34

```
HT-34 MAGAZINE 3 HIGH TEMPERATURE
 15   5   0   0   1
 25  23  23  23  25  23  25  22  23  21
  4   0  0.0E00  1.0E01
5.27836  0.0    -.0412   0.0  1.389E-4
     1.0       0.0       0.0       0.0       0.0       0.0
   .012   2000.    215.    215.    .047   700.    351.    442.    4.32
   36.6    200.    22.0    48.1    39.3   10.0    140.    5.42    60.0
   18.0    11.0    160.    153.    356.   142.    35.0
      0   140.0     0.0  1510.0    .500    1.0
   803.43   .024385   .007927   .007860   .4688   .5938   .343   10.   5
   735.1    .02054    .005414   .004033   .8108   .8928   .7678  42.   7
   806.27   .02486    .007631   .007823   1.086   .9485   1.224  34.   5
   816.45   .024799   .008391   .007633   1.361   1.404   1.279  41.   7
   743.1    .02054    .005414   .004033   1.653   1.735   1.610  42.   7
   789.51   .024572   .007863   .007057   1.928   1.791   2.066  33.   5
   770.29   .024408   .006967   .007140   2.203   2.246   2.121  43.   7
   743.4    .02054    .005414   .004310   2.496   2.578   2.453  42.   7
   825.95   .024585   .007874   .008839   2.771   2.634   2.909  34.   5
   825.88   .024723   .007771   .00880    3.046   3.089   2.964  41.   7
   739.8    .02054    .005414   .004188   3.338   3.420   3.295  43.   7
   813.37   .024589   .008035   .008045   3.613   3.476   3.751  34.   5
   817.8    .025085   .007550   .00832    3.888   3.931   3.806  42.   7
                                          4.181   4.263   4.138  42    7
                                          4.529   4.654   4.404  10.   5
            A-765   A8340R2576H   A-780    A-785   A8350R2576H
  A-806     A-762   A8370R2576H   A-782    A-786   A8360R2576H
  A-787   OR19252013T
261       1   1
   .2843   1.696
 .08725  .16825   .2265   .2655   .3275
    0.9     0.9     0.9   0.825   0.750
  1   1   1   0   1
  1   2   1   4   3
```

Title

Description of reactor operation over life of irradiation exp't.

Description of Coated-Particles in irradiation positions.

Regional description of unfueled end-plug No. 26-1 longitudinal section.

Table C-1. (continued)

```
27        1   0
  1.212   .1637
  .116    .160    .1925   .1935  .24830   .2655   .3275
   0.9     0.9     0.9     0.9     0.9    0.825   0.750
 1   1   1   0   1   0   1
 1   2   1   4   1   4   3
7.573E-4
```

Regional description of holder No. 27 longitudinal section.

```
28        1   1
  1.698       .12
 .19205   .1935  .24788   .2655   .3275
   0.9     0.9     0.9   0.825   0.750
 1   0   1   0   1
 2   4   1   4   3
7.044E-5                                  4.316E-6
5.683E-5
```

Regional description of fuel rod No. 28 longitudinal section.

```
29        1   0
  1.207   .1637
  .116    .160    .1925   .1935  .24747   .2655   .327
   0.9     0.9     0.9     0.9     0.9    0.825   0.750
 1   1   1   0   1   0   1
 1   2   1   4   1   4   3
7.573E-4
```

Regional description of holder No. 29 longitudinal section.

```
30        1   0
  1.223   .1637
  .116    .160    .1925   .1935  .24703   .2655   .3275
   0.9     0.9     0.9     0.9     0.9    0.825   0.750
 1   1   1   0   1   0   1
 1   2   1   4   1   4   3
7.573E-4
```

Regional description of holder No. 30 longitudinal section.

```
31        1   1
  1.657       .12
 .1924   .1935  .24661   .2655   .3275
   0.9     0.9     0.9   0.825   0.750
 1   0   1   0   1
 2   4   1   4   3
```

Regional description of fuel rod No. 31 longitudinal section.

Table C-1. (continued)

```
7.380E-5                                    4.522E-6
5.953E-5
```

```
 32        1   0
   1.211    .1637
   .116     .160    .1925    .1935   .24620    .2655    .3275
    0.9      0.9      0.9      0.9      0.9    0.825    0.750
  1   1   1   0   1   0   1
  1   2   1   4   1   4   3
7.573E-4
```

Regional description of holder No. 32 longitudinal section.

```
 33        1   0
   1.201    .1637
   .116     .160    .1925    .1935   .24575    .2655    .3275
    0.9      0.9      0.9      0.9      0.9    0.825    0.750
  1   1   1   0   1   0   1
  1   2   1   4   1   4   3
7.573E-4
```

Regional description of holder No. 33 longitudinal section.

```
 34        1   1
   1.674      .12
 .1922    .1935   .24534    .2655    .3275
    0.9      0.9      0.9    0.825    0.750
  1   0   1   0   1
  2   4   1   4   3
7.449E-5                                    4.564E-6
6.009E-5
```

Regional description of fuel rod No. 34 longitudinal section.

```
 35        1   0
   1.220    .1 37
   .116     .160    .1925    .1935   .24493    .2655    .3275
    0.9      0.9      0.9      0.9      0.9    0.825    0.750
  1   1   1   0   1   0   1
  1   2   1   4   1   4   3
7.573E-4
```

Regional description of holder No. 35 longitudinal section.

Table C-1. (continued)

```
36        1   0
  1.220   .1637
  .116    .160    .1925   .1935  .24448   .2655   .3275
   0.9     0.9     0.9     0.9     0.9    0.825   0.750
 1   1   1   0   1   0   1
 1   2   1   4   1   4   3
7.573E-4
```

Regional description of holder No. 36 longitudinal section.

```
37        1   1
  1.703       .12
 .1918   .1935  .24407   .2655   .3275
   0.9     0.9     0.9   0.825   0.750
 1   0   1   0   1
 2   4   1   4   2
6.975E-5                              4.274E-6
5.627E-5
```

Regional description of fuel rod No. 37 longitudinal section.

```
38        1   0
  1.206   .1637
  .116    .160    .1925   .1935  .24365   .2655   .3275
   0.9     0.9     0.9     0.9     0.9    0.825   0.750
 1   1   1   0   1   0   1
 1   2   1   4   1   4   3
7.573E-4
```

Regional description of holder No. 38 longitudinal section.

```
39        1   0
  1.223   .1637
  .116    .160    .1925   .1935  .24321   .2655   .3275
   0.9     0.9     0.9     0.9     0.9    0.825   0.750
 1   1   1   0   1   0   1
 1   2   1   4   1   4   3
7.573E-4
```

Regional description of holder No. 39 longitudinal section.

Table C-1. (continued)

```
263        1   1
   .2843     1.696
 .02725  .16825   .2335   .2655   .3275
   0.9     0.9     0.9   0.825   0.750
  1   1   1   0   1
  1   2   1   4   3
```

Regional description of unfueled end-plug No. 26-3 longitudinal section.

HT-34 MAGAZINE 3 HIGH TEMPERATURE

NUMBER OF PARTICLE HOLDERS = 15

TOTAL NUMBER OF CYCLES = 5 STARTING DAY = 0
CYCLE 1 HAS 25 TOTAL DAYS WITH 23 FULL POWER DAYS
CYCLE 2 HAS 23 TOTAL DAYS WITH 23 FULL POWER DAYS
CYCLE 3 HAS 25 TOTAL DAYS WITH 23 FULL POWER DAYS
CYCLE 4 HAS 25 TOTAL DAYS WITH 22 FULL POWER DAYS
CYCLE 5 HAS 23 TOTAL DAYS WITH 21 FULL POWER DAYS

PARTICLE GEOMETRY

FUEL ROD #	BATCH #	PARTICLE DIA. (MICRON)	KERNEL RAD. (CM)	BUFFER THICK. (CM)	LTI THICK. (CM)
28	A8340R2576H	735.1	0.02054	0.00541	0.00403
31	A8350R2576H	743.1	0.02054	0.00541	0.00403
34	A8370R2576H	743.4	0.02054	0.00541	0.00431
37	A8360R2576H	739.8	0.02054	0.00541	0.00419

HOLDER #	BATCH #	PARTICLE DIA. (MICRON)	KERNEL RAD. (CM)	BUFFER THICK. (CM)	LTI THICK. (CM)
27	A-765	803.4	0.02439	0.00793	0.00786
29	A-780	806.3	0.02486	0.00763	0.00782
30	A-785	816.5	0.02480	0.00839	0.00763
32	A-806	789.5	0.02457	0.00786	0.00706
33	A-762	770.3	0.02441	0.00697	0.00714
35	A-782	826.0	0.02459	0.00787	0.00884
36	A-786	825.9	0.02472	0.00777	0.00880
38	A-787	813.4	0.02459	0.00803	0.00804
39	OR192520 13T	817.8	0.02509	0.00755	0.00832

TIME-TEMPERATURE HISTORY OF FUEL ROD CENTERLINE TEMPERATURE

CYCLE	DAY	CENTERLINE TEMPERATURE (C) FOR SPECIFIC FUEL RODS 28	31	34	37
1	1	1432.	1415.	1419.	1402.
1	3	1389.	1368.	1373.	1363.
1	5	1361.	1341.	1345.	1337.
1	7	1342.	1321.	1326.	1321.
1	9	1329.	1308.	1313.	1309.
1	11	1324.	1303.	1305.	1298.
1	13	1316.	1298.	1300.	1296.
1	15	1315.	1293.	1296.	1292.
1	17	1314.	1292.	1295.	1291.
1	19	1316.	1295.	1297.	1293.
1	21	1321.	1297.	1297.	1292.
1	23	1321.	1300.	1299.	1295.
1	25	60.	60.	60.	60.
AVERAGE		1340.	1319.	1322.	1316.

TIME-TEMPERATURE HISTORY OF ANNULUS C.D. TEMPERATURE

CYCLE	DAY	TEMPERATURE(C) FOR ANNULUS OF SPECIFIC HOLDERS 27	29	30	32	33	35	36	38	39
1	1	1114.	1171.	1177.	1170.	1166.	1162.	1146.	1137.	990.
1	3	1096.	1153.	1158.	1152.	1148.	1144.	1128.	1121.	990.
1	5	1087.	1144.	1147.	1142.	1139.	1132.	1119.	1112.	996.
1	7	1081.	1138.	1141.	1139.	1133.	1129.	1116.	1107.	999.
1	9	1075.	1138.	1141.	1134.	1130.	1126.	1114.	1106.	1008.
1	11	1075.	1138.	1141.	1137.	1133.	1129.	1116.	1107.	1014.
1	13	1078.	1141.	1144.	1139.	1136.	1129.	1117.	1109.	1017.
1	15	1081.	1147.	1147.	1143.	1142.	1132.	1122.	1112.	1026.
1	17	1081.	1153.	1155.	1149.	1145.	1138.	1128.	1116.	1032.
1	19	1084.	1159.	1159.	1152.	1148.	1144.	1132.	1121.	1038.
1	21	1090.	1162.	1165.	1160.	1154.	1150.	1138.	1127.	1046.
1	23	1093.	1168.	1171.	1167.	1163.	1153.	1143.	1133.	1052.
1	25	60.	60.	60.	60.	60.	60.	60.	60.	60.
AVERAGE		1086.	1151.	1154.	1149.	1145.	1139.	1127.	1117.	1017.

TIME-TEMPERATURE HISTORY OF FUEL ROD SURFACE TEMPERATURE

CYCLE	DAY	FUEL-ROD SURFACE TEMPERATURE (C) FOR SPECIFIC FUEL RODS 28	31	34	37
1	1	1338.	1320.	1326.	1317.
1	3	1305.	1284.	1290.	1287.
1	5	1284.	1263.	1269.	1266.
1	7	1269.	1248.	1254.	1254.
1	9	1260.	1239.	1245.	1245.
1	11	1257.	1236.	1239.	1236.
1	13	1251.	1233.	1236.	1236.
1	15	1251.	1230.	1233.	1233.
1	17	1251.	1230.	1233.	1233.
1	19	1254.	1233.	1236.	1236.
1	21	1260.	1236.	1236.	1236.
1	23	1260.	1239.	1239.	1239.
1	25	60.	60.	60.	60.
AVERAGE		1270.	1249.	1253.	1252.

TIME-TEMPERATURE HISTORY OF MAXIMUM PARTICLE SURFACE TEMPERATURE

		PARTICLE SURFACE TEMPERATURE(C) FOR SPECIFIC HOLDERS								
CYCLE	DAY	27	29	30	32	33	35	36	38	39
1	1	1114.	1171.	1177.	1170.	1166.	1162.	1137.	990.	
1	3	1106.	1158.	1163.	1157.	1153.	1149.	1133.	1126.	995.
1	5	1107.	1159.	1162.	1157.	1154.	1147.	1134.	1127.	1011.
1	7	1111.	1168.	1166.	1164.	1163.	1154.	1141.	1132.	1024.
1	9	1120.	1178.	1181.	1174.	1175.	1161.	1149.	1141.	1048.
1	11	1135.	1193.	1196.	1192.	1188.	1179.	1161.	1152.	1064.
1	13	1153.	1211.	1209.	1204.	1206.	1189.	1177.	1169.	1082.
1	15	1171.	1232.	1227.	1223.	1227.	1207.	1192.	1182.	1106.
1	17	1186.	1248.	1245.	1239.	1240.	1223.	1208.	1201.	1122.
1	19	1204.	1269.	1259.	1257.	1258.	1239.	1222.	1216.	1138.
1	21	1220.	1282.	1275.	1275.	1274.	1255.	1238.	1232.	1161.
1	23	1238.	1298.	1291.	1292.	1293.	1268.	1253.	1248.	1177.
1	25	60.	60.	60.	60.	60.	60.	60.	60.	60.
AVERAGE		1155.	1214.	1212.	1209.	1208.	1194.	1180.	1172.	1077.

		LINEAR HEAT RATE (KW/FT) FOR FUEL RODS			
CYCLE	DAY	28	31	34	37
1	1	2.954	3.046	2.984	2.678
1	3	2.486	2.572	2.531	2.287
1	5	2.177	2.257	2.229	2.022
1	7	1.961	2.036	2.015	1.833
1	9	1.807	1.876	1.858	1.693
1	11	1.694	1.759	1.742	1.587
1	13	1.612	1.673	1.656	1.508
1	15	1.553	1.610	1.592	1.448
1	17	1.511	1.565	1.546	1.403
1	19	1.482	1.534	1.513	1.371
1	21	1.464	1.514	1.491	1.349
1	23	1.454	1.502	1.477	1.334
1	25	0.0	0.0	0.0	0.0

TIME-POWER GENERATION HISTORY FOR THO2 PARTICLES

		POWER GENERATION(WATTS) PER PARTICLE FOR HOLDERS								
CYCLE	DAY	27	29	30	32	33	35	36	38	39
1	1	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004
1	3	0.017	0.017	0.016	0.015	0.015	0.015	0.014	0.013	0.013
1	5	0.034	0.034	0.033	0.031	0.031	0.031	0.028	0.027	0.026
1	7	0.056	0.056	0.054	0.051	0.051	0.050	0.046	0.045	0.043
1	9	0.080	0.081	0.078	0.074	0.074	0.072	0.067	0.065	0.062
1	11	0.106	0.107	0.103	0.098	0.098	0.096	0.089	0.087	0.083
1	13	0.134	0.135	0.130	0.123	0.124	0.122	0.113	0.109	0.105
1	15	0.161	0.163	0.157	0.149	0.150	0.147	0.137	0.133	0.128
1	17	0.189	0.191	0.184	0.175	0.176	0.173	0.161	0.157	0.151
1	19	0.217	0.219	0.211	0.201	0.202	0.199	0.185	0.180	0.174
1	21	0.244	0.247	0.238	0.227	0.227	0.225	0.209	0.204	0.197
1	23	0.270	0.273	0.264	0.251	0.252	0.250	0.232	0.227	0.219
1	25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TIME-TEMPERATURE HISTORY OF FUEL ROD CENTERLINE TEMPERATURE

CYCLE	DAY	CENTERLINE TEMPERATURE (C) FOR SPECIFIC FUEL RODS 28	31	34	37
2	1	1353.	1328.	1330.	1325.
2	3	1341.	1317.	1319.	1314.
2	5	1340.	1315.	1315.	1310.
2	7	1339.	1315.	1317.	1310.
2	9	1342.	1318.	1317.	1313.
2	11	1343.	1318.	1323.	1316.
2	13	1346.	1321.	1326.	1319.
2	15	1349.	1325.	1326.	1322.
2	17	1355.	1328.	1330.	1325.
2	19	1358.	1331.	1333.	1328.
2	21	1362.	1337.	1336.	1328.
2	23	1103.	1078.	1078.	1081.
AVERAGE		1328.	1303.	1304.	1299.

TIME-TEMPERATURE HISTORY OF ANNULUS C.D. TEMPERATURE

CYCLE	DAY	TEMPERATURE(C) FOR ANNULUS OF SPECIFIC HOLDERS 27	29	30	32	33	35	36	38	39
2	1	1114.	1195.	1198.	1188.	1187.	1177.	1167.	1155.	1067.
2	3	1111.	1192.	1195.	1186.	1184.	1174.	1167.	1152.	1070.
2	5	1111.	1193.	1195.	1188.	1184.	1177.	1167.	1154.	1073.
2	7	1111.	1196.	1198.	1191.	1187.	1180.	1170.	1157.	1076.
2	9	1114.	1199.	1201.	1194.	1190.	1183.	1173.	1161.	1082.
2	11	1120.	1202.	1204.	1200.	1193.	1186.	1177.	1166.	1085.
2	13	1120.	1205.	1207.	1203.	1199.	1189.	1182.	1169.	1088.
2	15	1123.	1214.	1213.	1206.	1202.	1195.	1186.	1173.	1091.
2	17	1126.	1217.	1216.	1209.	1205.	1198.	1189.	1176.	1094.
2	19	1129.	1220.	1219.	1212.	1209.	1204.	1192.	1179.	1097.
2	21	1132.	1223.	1222.	1218.	1212.	1207.	1195.	1185.	1103.
2	23	979.	1024.	1024.	1017.	1014.	1007.	1001.	994.	987.
AVERAGE		1107.	1190.	1191.	1184.	1181.	1173.	1164.	1152.	1076.

TIME-TEMPERATURE HISTORY OF FUEL ROD SURFACE TEMPERATURE

CYCLE	DAY	FUEL-ROD SURFACE TEMPERATURE (C) FOR SPECIFIC FUEL RODS 28	31	34	37
2	1	1287.	1263.	1266.	1266.
2	3	1278.	1254.	1257.	1257.
2	5	1278.	1254.	1254.	1254.
2	7	1278.	1254.	1257.	1254.
2	9	1281.	1257.	1257.	1257.
2	11	1281.	1257.	1263.	1260.
2	13	1284.	1260.	1266.	1263.
2	15	1287.	1263.	1266.	1266.
2	17	1293.	1266.	1269.	1269.
2	19	1296.	1269.	1272.	1272.
2	21	1299.	1275.	1275.	1272.
2	23	1073.	1049.	1050.	1054.
AVERAGE		1268.	1243.	1246.	1245.

TIME-TEMPERATURE HISTORY OF MAXIMUM PARTICLE SURFACE TEMPERATURE

PARTICLE SURFACE TEMPERATURE(C) FOR SPECIFIC HOLDERS

CYCLE	DAY	27	29	30	32	33	35	36	38	39
2	1	1284.	1345.	1338.	1333.	1342.	1312.	1297.	1290.	1212.
2	3	1286.	1347.	1345.	1338.	1344.	1319.	1302.	1292.	1220.
2	5	1291.	1353.	1350.	1343.	1349.	1322.	1307.	1299.	1228.
2	7	1296.	1361.	1353.	1351.	1357.	1330.	1315.	1307.	1236.
2	9	1309.	1369.	1361.	1359.	1365.	1338.	1323.	1316.	1247.
2	11	1320.	1377.	1369.	1370.	1373.	1346.	1332.	1326.	1260.
2	13	1325.	1385.	1377.	1378.	1384.	1354.	1342.	1334.	1268.
2	15	1333.	1399.	1388.	1386.	1392.	1365.	1346.	1343.	1276.
2	17	1341.	1407.	1396.	1394.	1400.	1373.	1354.	1351.	1284.
2	19	1349.	1415.	1404.	1402.	1409.	1384.	1362.	1354.	1292.
2	21	1357.	1423.	1412.	1413.	1417.	1392.	1370.	1365.	1298.
2	23	979.	1024.	1024.	1017.	1014.	1007.	1001.	994.	987.
AVERAGE		1289.	1350.	1343.	1340.	1346.	1320.	1304.	1297.	1234.

LINEAR HEAT RATE (KW/FT) FOR FUEL RODS

CYCLE	DAY	28	31	34	37
2	1	1.654	1.704	1.669	1.499
2	3	1.528	1.577	1.547	1.392
2	5	1.476	1.523	1.494	1.344
2	7	1.458	1.503	1.474	1.325
2	9	1.456	1.500	1.470	1.320
2	11	1.460	1.505	1.473	1.322
2	13	1.469	1.513	1.480	1.327
2	15	1.479	1.522	1.489	1.334
2	17	1.489	1.533	1.498	1.341
2	19	1.500	1.543	1.508	1.350
2	21	1.510	1.554	1.518	1.358
2	23	0.0	0.0	0.0	0.0

TIME-POWER GENERATION HISTORY FOR THO2 PARTICLES

POWER GENERATION(WATTS) PER PARTICLE FOR HOLDERS

CYCLE	DAY	27	29	30	32	33	35	36	38	39
2	1	0.337	0.341	0.329	0.313	0.315	0.311	0.289	0.283	0.273
2	3	0.350	0.354	0.341	0.325	0.327	0.324	0.301	0.295	0.285
2	5	0.363	0.367	0.354	0.338	0.340	0.337	0.314	0.308	0.298
2	7	0.378	0.382	0.369	0.352	0.354	0.352	0.327	0.321	0.312
2	9	0.393	0.398	0.384	0.367	0.369	0.367	0.341	0.335	0.326
2	11	0.409	0.414	0.399	0.382	0.384	0.382	0.356	0.350	0.340
2	13	0.424	0.430	0.415	0.397	0.400	0.397	0.370	0.364	0.354
2	15	0.440	0.445	0.430	0.412	0.415	0.412	0.384	0.378	0.368
2	17	0.455	0.461	0.446	0.426	0.429	0.427	0.398	0.392	0.381
2	19	0.470	0.476	0.460	0.441	0.444	0.442	0.412	0.406	0.395
2	21	0.485	0.491	0.475	0.454	0.458	0.456	0.425	0.419	0.408
2	23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TIME-TEMPERATURE HISTORY OF FUEL ROD CENTERLINE TEMPERATURE

CYCLE	DAY	CENTERLINE TEMPERATURE (C) FOR SPECIFIC FUEL RODS 28	31	34	37
3	1	1365.	1340.	1342.	1334.
3	3	1365.	1341.	1345.	1338.
3	5	1369.	1344.	1349.	1341.
3	7	1374.	1347.	1349.	1344.
3	9	1375.	1348.	1352.	1344.
3	11	1378.	1351.	1352.	1347.
3	13	1381.	1354.	1355.	1348.
3	15	1381.	1357.	1358.	1351.
3	17	1384.	1360.	1359.	1354.
3	19	1385.	1360.	1362.	1357.
3	21	1385.	1360.	1365.	1357.
3	23	1388.	1363.	1365.	1360.
3	25	60.	60.	60.	60.
AVERAGE		1378.	1352.	1354.	1348.

TIME-TEMPERATURE HISTORY OF ANNULUS C.D. TEMPERATURE

CYCLE	DAY	TEMPERATURE(C) FOR ANNULUS OF SPECIFIC HOLDERS 27	29	30	32	33	35	36	38	39
3	1	1135.	1226.	1229.	1224.	1220.	1211.	1201.	1191.	1106.
3	3	1138.	1232.	1232.	1227.	1224.	1214.	1207.	1191.	1109.
3	5	1144.	1235.	1237.	1230.	1227.	1217.	1207.	1194.	1112.
3	7	1144.	1238.	1240.	1233.	1230.	1222.	1210.	1197.	1115.
3	9	1147.	1241.	1241.	1234.	1230.	1225.	1213.	1200.	1118.
3	11	1147.	1241.	1244.	1239.	1233.	1228.	1216.	1206.	1121.
3	13	1150.	1244.	1247.	1242.	1236.	1229.	1219.	1209.	1124.
3	15	1150.	1247.	1250.	1243.	1239.	1232.	1222.	1209.	1127.
3	17	1153.	1248.	1250.	1246.	1242.	1235.	1225.	1212.	1127.
3	19	1153.	1253.	1253.	1249.	1245.	1235.	1228.	1212.	1130.
3	21	1156.	1254.	1256.	1249.	1245.	1238.	1228.	1215.	1130.
3	23	1156.	1256.	1259.	1252.	1248.	1238.	1231.	1218.	1133.
3	25	60.	60.	60.	60.	60.	60.	60.	60.	60.
AVERAGE		1148.	1243.	1245.	1239.	1235.	1227.	1217.	1204.	1121.

TIME-TEMPERATURE HISTORY OF FUEL ROD SURFACE TEMPERATURE

CYCLE	DAY	FUEL-ROD SURFACE TEMPERATURE (C) FOR SPECIFIC FUEL RODS 28	31	34	37
3	1	1302.	1278.	1281.	1278.
3	3	1302.	1278.	1284.	1281.
3	5	1305.	1281.	1287.	1284.
3	7	1311.	1284.	1287.	1287.
3	9	1311.	1284.	1290.	1287.
3	11	1314.	1287.	1290.	1290.
3	13	1317.	1290.	1293.	1290.
3	15	1317.	1293.	1296.	1293.
3	17	1320.	1296.	1296.	1296.
3	19	1320.	1296.	1299.	1299.
3	21	1320.	1296.	1302.	1299.
3	23	1323.	1299.	1302.	1302.
3	25	60.	60.	60.	60.
AVERAGE		1313.	1288.	1292.	1290.

TIME-TEMPERATURE HISTORY OF MAXIMUM PARTICLE SURFACE TEMPERATURE

PARTICLE SURFACE TEMPERATURE(C) FOR SPECIFIC HOLDERS

CYCLE	DAY	27	29	30	32	33	35	36	38	39
3	1	1365.	1431.	1424.	1424.	1430.	1401.	1381.	1376.	1311.
3	3	1373.	1437.	1427.	1427.	1434.	1404.	1387.	1381.	1314.
3	5	1379.	1445.	1437.	1435.	1442.	1412.	1392.	1389.	1322.
3	7	1384.	1453.	1440.	1438.	1450.	1417.	1400.	1392.	1330.
3	9	1392.	1456.	1446.	1444.	1450.	1425.	1403.	1400.	1333.
3	11	1392.	1461.	1449.	1449.	1458.	1428.	1411.	1406.	1341.
3	13	1400.	1464.	1457.	1457.	1461.	1434.	1414.	1409.	1344.
3	15	1405.	1472.	1460.	1458.	1469.	1437.	1422.	1414.	1352.
3	17	1408.	1473.	1465.	1466.	1472.	1445.	1425.	1417.	1352.
3	19	1408.	1478.	1468.	1469.	1480.	1445.	1428.	1422.	1360.
3	21	1416.	1484.	1471.	1474.	1480.	1453.	1433.	1425.	1360.
3	23	1416.	1486.	1479.	1477.	1483.	1453.	1436.	1428.	1363.
3	25	60.	60.	60.	60.	60.	60.	60.	60.	60.
AVERAGE		1395.	1462.	1452.	1451.	1459.	1429.	1411.	1405.	1340.

LINEAR HEAT RATE (KW/FT) FOR FUEL RODS

CYCLE	DAY	28	31	34	37
3	1	1.526	1.570	1.533	1.371
3	3	1.535	1.580	1.543	1.379
3	5	1.545	1.589	1.552	1.387
3	7	1.554	1.598	1.561	1.395
3	9	1.562	1.607	1.569	1.402
3	11	1.569	1.615	1.577	1.409
3	13	1.576	1.622	1.584	1.416
3	15	1.583	1.629	1.591	1.422
3	17	1.589	1.635	1.597	1.428
3	19	1.594	1.640	1.602	1.433
3	21	1.599	1.646	1.608	1.438
3	23	1.603	1.650	1.612	1.442
3	25	0.0	0.0	0.0	0.0

TIME-POWER GENERATION HISTORY FOR THC2 PARTICLES

POWER GENERATION(WATTS) PER PARTICLE FOR HOLDERS

CYCLE	DAY	27	29	30	32	33	35	36	38	39
3	1	0.506	0.512	0.495	0.474	0.478	0.476	0.444	0.438	0.426
3	3	0.519	0.525	0.508	0.487	0.490	0.488	0.456	0.450	0.438
3	5	0.531	0.538	0.520	0.498	0.503	0.501	0.467	0.461	0.449
3	7	0.543	0.550	0.532	0.510	0.514	0.512	0.478	0.472	0.460
3	9	0.554	0.562	0.543	0.520	0.525	0.523	0.489	0.483	0.470
3	11	0.565	0.572	0.554	0.531	0.535	0.534	0.499	0.493	0.480
3	13	0.575	0.583	0.563	0.540	0.545	0.543	0.508	0.502	0.489
3	15	0.584	0.592	0.573	0.549	0.554	0.553	0.517	0.511	0.498
3	17	0.593	0.601	0.582	0.558	0.563	0.562	0.525	0.519	0.506
3	19	0.601	0.610	0.590	0.566	0.571	0.570	0.533	0.527	0.514
3	21	0.609	0.618	0.598	0.573	0.579	0.578	0.540	0.535	0.521
3	23	0.617	0.625	0.605	0.580	0.586	0.585	0.547	0.542	0.528
3	25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TIME-TEMPERATURE HISTORY OF FUEL ROD CENTERLINE TEMPERATURE

CYCLE	DAY	CENTERLINE TEMPERATURE (C) FOR SPECIFIC FUEL RODS 28	31	34	37
4	1	1420.	1392.	1397.	1386.
4	3	1405.	1384.	1382.	1377.
4	5	1401.	1374.	1378.	1373.
4	7	1397.	1373.	1375.	1370.
4	9	1397.	1370.	1374.	1366.
4	11	1397.	1370.	1374.	1366.
4	13	1397.	1370.	1371.	1366.
4	15	1397.	1370.	1371.	1366.
4	17	1397.	1370.	1371.	1366.
4	19	1397.	1370.	1374.	1366.
4	21	1397.	1370.	1374.	1366.
4	23	60.	60.	60.	60.
4	25	60.	60.	60.	60.
AVERAGE		1400.	1374.	1377.	1370.

TIME-TEMPERATURE HISTORY OF ANNULUS C.D. TEMPERATURE

CYCLE	DAY	TEMPERATURE(C) FOR ANNULUS OF SPECIFIC HOLDERS 27	29	30	32	33	35	36	38	39
4	1	1177.	1281.	1283.	1276.	1272.	1265.	1253.	1239.	1148.
4	3	1171.	1275.	1274.	1270.	1266.	1256.	1249.	1236.	1148.
4	5	1168.	1269.	1271.	1267.	1263.	1253.	1246.	1233.	1145.
4	7	1165.	1266.	1268.	1264.	1257.	1253.	1240.	1230.	1145.
4	9	1162.	1266.	1268.	1264.	1257.	1253.	1240.	1230.	1145.
4	11	1162.	1266.	1268.	1264.	1257.	1250.	1240.	1230.	1145.
4	13	1162.	1266.	1268.	1264.	1257.	1250.	1240.	1230.	1145.
4	15	1162.	1266.	1268.	1264.	1257.	1250.	1240.	1230.	1145.
4	17	1162.	1266.	1268.	1264.	1257.	1250.	1240.	1230.	1145.
4	19	1162.	1266.	1268.	1264.	1257.	1250.	1240.	1230.	1145.
4	21	1162.	1266.	1268.	1264.	1257.	1253.	1240.	1230.	1145.
4	23	60.	60.	60.	60.	60.	60.	60.	60.	60.
4	25	60.	60.	60.	60.	60.	60.	60.	60.	60.
AVERAGE		1165.	1268.	1270.	1266.	1260.	1253.	1243.	1232.	1145.

TIME-TEMPERATURE HISTORY OF FUEL ROD SURFACE TEMPERATURE

CYCLE	DAY	FUEL-ROD SURFACE TEMPERATURE (C) FOR SPECIFIC FUEL RODS 28	31	34	37
4	1	1350.	1323.	1329.	1326.
4	3	1338.	1317.	1317.	1317.
4	5	1335.	1308.	1314.	1314.
4	7	1332.	1308.	1311.	1311.
4	9	1332.	1305.	1311.	1308.
4	11	1332.	1305.	1311.	1308.
4	13	1332.	1305.	1308.	1308.
4	15	1332.	1305.	1308.	1308.
4	17	1332.	1305.	1308.	1308.
4	19	1332.	1305.	1311.	1308.
4	21	1332.	1305.	1311.	1308.
4	23	60.	60.	60.	60.
4	25	60.	60.	60.	60.
AVERAGE		1334.	1308.	1313.	1311.

TIME-TEMPERATURE HISTORY OF MAXIMUM PARTICLE SURFACE TEMPERATURE

		PARTICLE SURFACE TEMPERATURE(C) FOR SPECIFIC HOLDERS								
CYCLE	DAY	27	29	30	32	33	35	36	38	39
4	1	1457.	1526.	1513.	1516.	1522.	1495.	1473.	1464.	1398.
4	3	1451.	1520.	1504.	1510.	1516.	1486.	1464.	1461.	1398.
4	5	1443.	1514.	1501.	1502.	1513.	1478.	1461.	1458.	1390.
4	7	1440.	1506.	1498.	1499.	1507.	1478.	1455.	1455.	1390.
4	9	1437.	1506.	1498.	1499.	1507.	1478.	1455.	1455.	1390.
4	11	1437.	1506.	1498.	1499.	1507.	1475.	1455.	1455.	1390.
4	13	1437.	1506.	1498.	1499.	1507.	1475.	1455.	1455.	1390.
4	15	1437.	1506.	1498.	1499.	1507.	1475.	1455.	1455.	1390.
4	17	1437.	1506.	1498.	1499.	1507.	1475.	1455.	1455.	1390.
4	19	1437.	1506.	1498.	1499.	1507.	1475.	1455.	1455.	1390.
4	21	1437.	1506.	1498.	1499.	1507.	1478.	1455.	1455.	1390.
4	23	60.	60.	60.	60.	60.	60.	60.	60.	60.
4	25	60.	60.	60.	60.	60.	60.	60.	60.	60.
AVERAGE		1441.	1510.	1500.	1502.	1510.	1479.	1458.	1457.	1391.

		LINEAR HEAT RATE (KW/FT) FOR FUEL RODS			
CYCLE	DAY	28	31	34	37
4	1	1.818	1.869	1.823	1.626
4	3	1.704	1.754	1.714	1.533
4	5	1.652	1.701	1.664	1.490
4	7	1.629	1.678	1.642	1.471
4	9	1.619	1.668	1.632	1.463
4	11	1.614	1.663	1.628	1.459
4	13	1.612	1.661	1.626	1.458
4	15	1.611	1.660	1.625	1.457
4	17	1.610	1.660	1.625	1.457
4	19	1.610	1.659	1.624	1.457
4	21	1.609	1.659	1.624	1.457
4	23	0.0	0.0	0.0	0.0
4	25	0.0	0.0	0.0	0.0

TIME-POWER GENERATION HISTORY FOR THC2 PARTICLES

		POWER GENERATION(WATTS) PER PARTICLE FOR HOLDERS								
CYCLE	DAY	27	29	30	32	33	35	36	38	39
4	1	0.696	0.706	0.683	0.655	0.661	0.659	0.616	0.610	0.594
4	3	0.685	0.695	0.672	0.645	0.651	0.650	0.608	0.602	0.588
4	5	0.676	0.686	0.664	0.637	0.644	0.643	0.602	0.596	0.582
4	7	0.670	0.680	0.658	0.632	0.638	0.638	0.597	0.592	0.578
4	9	0.666	0.676	0.654	0.628	0.635	0.635	0.594	0.589	0.576
4	11	0.664	0.673	0.652	0.626	0.633	0.633	0.593	0.588	0.575
4	13	0.662	0.672	0.651	0.625	0.632	0.632	0.592	0.588	0.574
4	15	0.662	0.672	0.651	0.625	0.632	0.632	0.592	0.588	0.575
4	17	0.663	0.673	0.651	0.626	0.633	0.633	0.593	0.589	0.576
4	19	0.664	0.674	0.652	0.627	0.634	0.634	0.594	0.590	0.577
4	21	0.665	0.675	0.654	0.628	0.635	0.636	0.596	0.592	0.579
4	23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TIME-TEMPERATURE HISTORY OF FUEL ROD CENTERLINE TEMPERATURE

		CENTERLINE TEMPERATURE (C) FOR SPECIFIC FUEL RODS			
CYCLE	DAY	28	31	34	37
5	1	1436.	1412.	1414.	1407.
5	3	1421.	1394.	1398.	1393.
5	5	1408.	1386.	1388.	1382.
5	7	1404.	1379.	1384.	1379.
5	9	1400.	1376.	1378.	1375.
5	11	1400.	1373.	1377.	1375.
5	13	1397.	1372.	1374.	1372.
5	15	1397.	1369.	1374.	1369.
5	17	1396.	1369.	1374.	1369.
5	19	1396.	1369.	1374.	1369.
5	21	1396.	1369.	1374.	1366.
5	23	60.	60.	60.	60.
AVERAGE		1405.	1379.	1382.	1378.

TIME-TEMPERATURE HISTORY OF ANNULUS C.D. TEMPERATURE

		TEMPERATURE(C) FOR ANNULUS OF SPECIFIC HOLDERS								
CYCLE	DAY	27	29	30	32	33	35	36	38	39
5	1	1195.	1300.	1302.	1295.	1291.	1284.	1274.	1261.	1166.
5	3	1183.	1288.	1290.	1285.	1282.	1274.	1265.	1251.	1163.
5	5	1177.	1284.	1284.	1276.	1276.	1268.	1259.	1248.	1157.
5	7	1174.	1278.	1280.	1273.	1270.	1262.	1255.	1242.	1154.
5	9	1171.	1275.	1277.	1270.	1269.	1259.	1252.	1239.	1154.
5	11	1168.	1272.	1274.	1270.	1266.	1259.	1249.	1236.	1151.
5	13	1171.	1269.	1271.	1267.	1266.	1256.	1249.	1236.	1151.
5	15	1168.	1269.	1271.	1267.	1263.	1256.	1246.	1233.	1151.
5	17	1168.	1269.	1271.	1267.	1263.	1253.	1246.	1233.	1148.
5	19	1168.	1269.	1268.	1264.	1260.	1253.	1246.	1233.	1148.
5	21	1168.	1266.	1268.	1264.	1260.	1253.	1246.	1233.	1148.
5	23	60.	60.	60.	60.	60.	60.	60.	60.	60.
AVERAGE		1174.	1276.	1278.	1273.	1270.	1262.	1253.	1241.	1154.

TIME-TEMPERATURE HISTORY OF FUEL ROD SURFACE TEMPERATURE

		FUEL-ROD SURFACE TEMPERATURE (C) FOR SPECIFIC FUEL RODS			
CYCLE	DAY	28	31	34	37
5	1	1365.	1341.	1344.	1344.
5	3	1353.	1326.	1332.	1332.
5	5	1341.	1320.	1323.	1323.
5	7	1338.	1314.	1320.	1320.
5	9	1335.	1311.	1314.	1317.
5	11	1335.	1308.	1314.	1317.
5	13	1332.	1308.	1311.	1314.
5	15	1332.	1305.	1311.	1311.
5	17	1332.	1305.	1311.	1311.
5	19	1332.	1305.	1311.	1311.
5	21	1332.	1305.	1311.	1308.
5	23	60.	60.	60.	60.
AVERAGE		1339.	1314.	1319.	1319.

TIME-TEMPERATURE HISTORY OF MAXIMUM PARTICLE SURFACE TEMPERATURE

PARTICLE SURFACE TEMPERATURE(C) FOR SPECIFIC HOLDERS

CYCLE	DAY	27	29	30	32	33	35	36	38	39
5	1	1490.	1560.	1547.	1550.	1561.	1529.	1509.	1501.	1436.
5	3	1478.	1548.	1535.	1535.	1547.	1514.	1495.	1491.	1428.
5	5	1467.	1539.	1524.	1526.	1536.	1508.	1489.	1483.	1417.
5	7	1459.	1528.	1520.	1518.	1530.	1497.	1480.	1477.	1414.
5	9	1456.	1525.	1512.	1515.	1524.	1494.	1477.	1474.	1409.
5	11	1448.	1522.	1509.	1510.	1521.	1489.	1474.	1466.	1406.
5	13	1451.	1514.	1506.	1507.	1521.	1486.	1469.	1466.	1406.
5	15	1448.	1514.	1506.	1507.	1518.	1486.	1466.	1463.	1401.
5	17	1448.	1514.	1506.	1507.	1513.	1483.	1466.	1463.	1398.
5	19	1443.	1514.	1503.	1504.	1515.	1483.	1466.	1463.	1398.
5	21	1443.	1511.	1503.	1504.	1510.	1483.	1466.	1463.	1398.
5	23	60.	60.	60.	60.	60.	60.	60.	60.	60.
AVERAGE		1458.	1526.	1516.	1517.	1527.	1496.	1478.	1474.	1410.

LINEAR HEAT RATE (KW/FT) FOR FUEL RODS

CYCLE	DAY	28	31	34	37
5	1	1.892	1.948	1.902	1.701
5	3	1.740	1.794	1.756	1.575
5	5	1.667	1.720	1.686	1.514
5	7	1.632	1.684	1.651	1.483
5	9	1.613	1.665	1.632	1.467
5	11	1.602	1.653	1.622	1.456
5	13	1.595	1.646	1.614	1.451
5	15	1.590	1.640	1.609	1.447
5	17	1.585	1.636	1.605	1.443
5	19	1.581	1.632	1.601	1.440
5	21	1.578	1.629	1.598	1.437
5	23	0.0	0.0	0.0	0.0

TIME-POWER GENERATION HISTORY FOR THC2 PARTICLES

POWER GENERATION(WATTS) PER PARTICLE FOR HOLDERS

CYCLE	DAY	27	29	30	32	33	35	36	38	39
5	1	0.778	0.789	0.764	0.734	0.741	0.741	0.694	0.688	0.672
5	3	0.753	0.764	0.740	0.711	0.719	0.720	0.674	0.669	0.654
5	5	0.733	0.744	0.721	0.693	0.701	0.702	0.658	0.654	0.639
5	7	0.717	0.729	0.706	0.679	0.687	0.688	0.645	0.641	0.628
5	9	0.706	0.717	0.694	0.668	0.676	0.677	0.635	0.632	0.619
5	11	0.697	0.708	0.686	0.660	0.667	0.669	0.628	0.624	0.611
5	13	0.690	0.701	0.679	0.653	0.661	0.663	0.622	0.619	0.606
5	15	0.685	0.696	0.674	0.649	0.657	0.658	0.618	0.615	0.602
5	17	0.681	0.692	0.671	0.645	0.653	0.655	0.615	0.612	0.599
5	19	0.679	0.690	0.668	0.643	0.651	0.653	0.612	0.610	0.597
5	21	0.677	0.688	0.666	0.641	0.649	0.651	0.611	0.608	0.596
5	23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX D

HTPLOT Program Listing, Data Deck Preparation Guide, Input Data Deck Listing and Time-Temperature History Graphs for the Thermal Analysis of HT-34, ORNL High-Temperature Magazine

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C       PROGRAM HTPLOT
        DIMENSION A(15),B(15),BUFF(7000),C(15),INAME(50),ISYMB(3),K(125),
       1L6(9),LNTHS(10),P(125),PT(125),TA(125),TTD(5),TTL(15),TTP(12),
       2X(125),XNUM(10),IPACK(40)
C
C       THIS PROGRAM USES PUNCHED OUTPUT DATA FROM THE HTCAP-1 THERMAL
C       MODELING CODE AND USES IT TO PRESENT THE DATA IN GRAPHIC FORM.
C
C
C       INPUT VARIABLES: A DESCRIPTION OF EACH
C
C       NP       =NO. OF PLOTS REQUIRED (MAXIMUM OF 16 PER COMPUTER RUN)
C       IFT      =FUEL SPECIMEN TYPE     0=LOOSE PARTICLES IN GRAPHITE HOLDERS
C                                        1=BONDED FUEL RODS
C       TTD(IK) =ALPHAMERIC TITLE DESCRIBING "ORNL DWG NUMBER" FOR GRAPH
C       TTL(IK) =ALPHAMERIC TITLE TELLING WHAT THE GRAPH IS FOR
C       TTP(IK) =ALPHAMERIC TITLE DESCRIBING PARTICLE SIZE
C       NCYC     =NUMBER OF HFIR IRRADIATION CYCLES FOR EXPERIMENT
C       L6(I)    =NUMBER OF TOTAL DAYS IN CYCLE I
C       K(J)     =DAY IN CYCLE FOR WHICH TEMPERATURE DATA IS FOR
C       A(J)     =MAXIMUM PARTICLE SURFACE TEMPERATURE IF VARIABLE IFT=0
C                 FUEL ROD CENTERLINE TEMPERATURE IF VARIABLE IFT=1
C       B(J)     =ANNULUS SURFACE (HOLDER) TEMPERATURE IF VARIABLE IFT=0
C                 FUEL ROD SURFACE TEMPERATURE IF VARIABLE IFT=1
C       C(J)     =FISSION POWER PER PARTICLE IF VARIABLE IFT=0
C                 FISSION LINEAR HEAT RATE FOR FUEL ROD IF VARIABLE IFT=1
C
C
        READ 510,NP
        CALL CALCMP
        DO 1050 KK=1,NP
        READ 520,NCYC,(L6(I),I=1,NCYC)
        READ 530,IFT,(TTD(IK),IK=1,5)
        READ 540,(TTL(IK),IK=1,15)
        READ 540,(TTP(IK),IK=1,12)
        N=0
        DO 1000 I=1,NCYC
        I1=(L6(I)+1)/2
        READ 550,(K(J),A(J),B(J),C(J),J=1,I1)
        DO 950 JJ=1,I1
        N=N+1
        GO TO (1,2,3,4,5,6,7,8),I
      1 X(N)=FLOAT(K(JJ))
        GO TO 100
      2 X(N)=FLOAT(K(JJ)+L6(1))
        GO TO 100
      3 X(N)=FLOAT(K(JJ)+L6(1)+L6(2))
        GO TO 100
      4 X(N)=FLOAT(K(JJ)+L6(1)+L6(2)+L6(3))
        GO TO 100
      5 X(N)=FLOAT(K(JJ)+L6(1)+L6(2)+L6(3)+L6(4))
        GO TO 100
      6 X(N)=FLOAT(K(JJ)+L6(1)+L6(2)+L6(3)+L6(4)+L6(5))
        GO TO 100
      7 X(N)=FLOAT(K(JJ)+L6(1)+L6(2)+L6(3)+L6(4)+L6(5)+L6(6))
        GO TO 100
      8 X(N)=FLOAT(K(JJ)+L6(1)+L6(2)+L6(3)+L6(4)+L6(5)+L6(6)+L6(7))
    100 CONTINUE
```

```
      IF(IFT.EQ.0)P(N)=1000.*C(JJ)
      IF(IFT.EQ.1)P(N)=500.*C(JJ)
      TA(N)=A(JJ)
      PT(N)=B(JJ)
  950 CONTINUE
 1000 CONTINUE
      CALL BGNPL(0)
      CALL INTAXS
      CALL YAXANG(0)
      CALL HEIGHT(0.08)
      CALL TITLE('  $',100,'  $',100,'  $',100,4.4,4.5)
      CALL FRAME
      CALL XTICKS(10)
      CALL YTICKS(5)
      CALL HEIGHT(0.12)
      CALL GRAF(0.,20.,140.,0.,500.,2000.)
      CALL BLNK1(0.0,2.2,3.8,4.5,2)
      CALL GRID(1,2)
      CALL SCLPIC(0.6)
      CALL CURVE(X,TA,N,-1)
      CALL MARKER(2)
      CALL CURVE(X,PT,N,-1)
      CALL MARKER(5)
      CALL CURVE(X,P,N,-1)
      CALL HEIGHT(0.08)
      MAXLIN=LINEST(IPACK,40,23)
      IF(IFT.EQ.0)CALL LINES(14HANNULUS TEMP.$,IPACK,1)
      IF(IFT.EQ.0)CALL LINES(23HPARTICLE SURFACE TEMP.$,IPACK,2)
      IF(IFT.EQ.0)CALL LINES(19HPOWER PER PARTICLE$,IPACK,3)
      IF(IFT.EQ.1)CALL LINES(17HCENTERLINE TEMP.$,IPACK,1)
      IF(IFT.EQ.1)CALL LINES(18HROD SURFACE TEMP.$,IPACK,2)
      IF(IFT.EQ.1)CALL LINES(17HLINEAR HEAT RATE$,IPACK,3)
      CALL RESET('BLNK1')
      CALL LEGEND(IPACK,3,0.2,3.9)
      CALL ANGLE(90.)
      IF(IFT.EQ.0)CALL MESSAG('POWER PER PARTICLE (WATTS)$',100,5.0,0.2)
      IF(IFT.EQ.1)CALL MESSAG('  LINEAR HEAT RATE (KW/FT)$',100,5.0,0.2)
      CALL MESSAG('TEMPERATURE (C)$',100,-0.5,1.7)
      CALL RESET('ANGLE')
      CALL MESSAG('TIME FROM BEGINNING OF IRRADIATION (DAYS)$',100,0.6,
     .-0.5)
      CALL HEIGHT(0.09)
      CALL MESSAG(TTD,100,3.4,4.6)
      CALL INTNO(0,4.5,0.0)
      IF(IFT.EQ.0)CALL REALNO(0.5,1.4,4.1,1)
      IF(IFT.EQ.0)CALL REALNO(1.0,1.4,4.2,2)
      IF(IFT.EQ.1)CALL REALNO(1.0,1.4,4.1,1)
      IF(IFT.EQ.1)CALL REALNO(2.0,1.4,4.2,2)
      CALL HEIGHT(.13)
      CALL MESSAG(TTL,100,-0.3,-0.9)
      CALL MESSAG(TTP,100,-0.3,-1.1)
      CALL ENDPL(0)
 1050 CONTINUE
      CALL DONEPL
   45 FORMAT(1H1)
  510 FORMAT(10I5)
  520 FORMAT(10I3)
  530 FORMAT(I5,5A4)
  540 FORMAT(15A4)
  550 FORMAT(4(I2,3F6.3))
      STOP
      END
```

Data Preparation Guide for HTPLOT

Card No.		
1	NP (I5)	
2	NCYC (I5)	L6(I) (I5) Continue for I=1, NCYC Format (9I5)
3	IFT (I5)	TTD(IK) (A4) Continue for IK=1, 5 Format (5A4)
4	TTL(IK) (A4)	Continue for IK=1, 15 Format (15A4)
5	TTP(IK) (A4)	Continue for IK=1, 12 Format (12A4)
6	Punched Data from HTCAP-1 Analysis for Cycle 1 through NCYC	

Note: **A description of each of the input variables is given in the comment section of the HTPLOT Program Listing.**

Card types 2 through 6 must be provided for each specimen for which a graph is requested (total of NP sets).

```
  13
 5 25 23 25 25 23
   0 CRNL-DWG 78-10715$
   HT-34 PARTICLE HOLDER 27 BATCH A-765$
      803.4 MICRON PARTICLE DIAMETERS$
 1 1114. 1114. 0.005 3 1096. 1106. 0.017 5 1087. 1107. 0.034 7 1081. 1111. 0.056
 9 1075. 1120. 0.08011 1075. 1135. 0.10613 1078. 1153. 0.13415 1081. 1171. 0.161
17 1081. 1186. 0.18919 1084. 1204. 0.21721 1090. 1220. 0.24423 1093. 1238. 0.270
25   60.   60. 0.0
 1 1114. 1284. 0.337 3 1111. 1286. 0.350 5 1111. 1291. 0.363 7 1111. 1296. 0.378
 9 1114. 1309. 0.39311 1120. 1320. 0.40913 1120. 1325. 0.42415 1123. 1333. 0.440
17 1126. 1341. 0.45519 1129. 1349. 0.47021 1132. 1357. 0.48523  979.  979. 0.0
 1 1135. 1365. 0.506 3 1138. 1373. 0.519 5 1144. 1379. 0.531 7 1144. 1384. 0.543
 9 1147. 1392. 0.55411 1147. 1392. 0.56513 1150. 1400. 0.57515 1150. 1405. 0.584
17 1153. 1408. 0.59319 1153. 1408. 0.60121 1156. 1416. 0.60923 1156. 1416. 0.617
25   60.   60. 0.0
 1 1177. 1457. 0.696 3 1171. 1451. 0.685 5 1168. 1443. 0.676 7 1165. 1440. 0.670
 9 1162. 1437. 0.66611 1162. 1437. 0.66413 1162. 1437. 0.66215 1162. 1437. 0.662
17 1162. 1437. 0.66319 1162. 1437. 0.66421 1162. 1437. 0.66523   60.   60. 0.0
25   60.   60. 0.0
 1 1195. 1490. 0.778 3 1183. 1478. 0.753 5 1177. 1467. 0.733 7 1174. 1459. 0.717
 9 1171. 1456. 0.70611 1168. 1448. 0.69713 1171. 1451. 0.69015 1168. 1448. 0.685
17 1168. 1448. 0.68119 1168. 1443. 0.67921 1168. 1443. 0.67723   60.   60. 0.0
  5 25 23 25 25 23
   1 CRNL-DWG 78-10716$
 HT-34 FUEL ROD NUMBER 28 BATCH A837+OR2576H$
      735.1 MICRON AVG. PARTICLE DIAMETERS$
 1 1432. 1338. 2.954 3 1389. 1305. 2.486 5 1361. 1284. 2.177 7 1342. 1269. 1.961
 9 1329. 1260. 1.80711 1324. 1257. 1.69413 1316. 1251. 1.61215 1315. 1251. 1.553
17 1314. 1251. 1.51119 1316. 1254. 1.48221 1321. 1260. 1.46423 1321. 1260. 1.454
25   60.   60. 0.0
 1 1353. 1287. 1.654 3 1341. 1278. 1.528 5 1340. 1278. 1.476 7 1339. 1278. 1.458
 9 1342. 1281. 1.45611 1343. 1281. 1.46013 1346. 1284. 1.46915 1349. 1287. 1.479
17 1358. 1293. 1.48919 1358. 1296. 1.50021 1362. 1299. 1.51023 1103. 1073. 0.0
 1 1365. 1302. 1.526 3 1365. 1302. 1.535 5 1369. 1305. 1.545 7 1374. 1311. 1.554
 9 1375. 1311. 1.56211 1378. 1314. 1.56913 1381. 1317. 1.57615 1381. 1317. 1.583
17 1384. 1320. 1.58919 1385. 1320. 1.59421 1385. 1320. 1.59923 1388. 1323. 1.603
25   60.   60. 0.0
 1 1420. 1350. 1.818 3 1405. 1338. 1.704 5 1401. 1335. 1.652 7 1397. 1332. 1.629
 9 1397. 1332. 1.61911 1397. 1332. 1.61413 1397. 1332. 1.61215 1397. 1332. 1.611
17 1397. 1332. 1.61019 1397. 1332. 1.61021 1397. 1332. 1.60923   60.   60. 0.0
25   60.   60. 0.0
 1 1436. 1365. 1.892 3 1421. 1353. 1.740 5 1408. 1341. 1.667 7 1404. 1338. 1.632
 9 1400. 1335. 1.61311 1400. 1335. 1.60213 1397. 1332. 1.59515 1397. 1332. 1.590
17 1396. 1332. 1.58519 1396. 1332. 1.58121 1396. 1332. 1.57823   60.   60. 0.0
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  5 25 23 25 25 23
    0 ORNL-DWG 78-10717$
    HT-34 PARTICLE HOLDER 29 BATCH A-780$
       806.3 MICRON PARTICLE DIAMETERS$
  1 1171. 1171. 0.005 3 1153. 1158. 0.017 5 1144. 1159. 0.034 7 1138. 1168. 0.056
  9 1138. 1178. 0.08111 1138. 1193. 0.10713 1141. 1211. 0.13515 1147. 1232. 0.163
 17 1153. 1248. 0.19119 1159. 1269. 0.21921 1162. 1282. 0.24723 1168. 1298. 0.273
 25   60.   60. 0.0
  1 1195. 1345. 0.341 3 1192. 1347. 0.354 5 1193. 1353. 0.367 7 1196. 1361. 0.382
  9 1199. 1369. 0.39811 1202. 1377. 0.41413 1205. 1385. 0.43015 1214. 1399. 0.445
 17 1217. 1407. 0.46119 1220. 1415. 0.47621 1223. 1423. 0.49123 1024. 1024. 0.0
  1 1226. 1431. 0.512 3 1232. 1437. 0.525 5 1235. 1445. 0.538 7 1238. 1453. 0.550
  9 1241. 1456. 0.56211 1241. 1461. 0.57213 1244. 1464. 0.58315 1247. 1472. 0.592
 17 1248. 1473. 0.60119 1253. 1478. 0.61021 1254. 1484. 0.61823 1256. 1486. 0.625
 25   60.   60. 0.0
  1 1281. 1526. 0.706 3 1275. 1520. 0.695 5 1269. 1514. 0.686 7 1266. 1506. 0.680
  9 1266. 1506. 0.67611 1266. 1506. 0.67313 1266. 1506. 0.67215 1266. 1506. 0.672
 17 1266. 1506. 0.67319 1266. 1506. 0.67421 1266. 1506. 0.67523   60.   60. 0.0
 25   60.   60. 0.0
  1 1300. 1560. 0.789 3 1288. 1548. 0.764 5 1284. 1539. 0.744 7 1278. 1528. 0.729
  9 1275. 1525. 0.71711 1272. 1522. 0.70813 1269. 1514. 0.70115 1269. 1514. 0.696
 17 1269. 1514. 0.69219 1269. 1514. 0.69021 1266. 1511. 0.68823   60.   60. 0.0
  5 25 23 25 25 23
    0 ORNL-DWG 78-10718$
    HT-34 PARTICLE HOLDER 30 BATCH A-785$
       816.5 MICRON PARTICLE DIAMETERS$
  1 1177. 1177. 0.005 3 1158. 1163. 0.016 5 1147. 1162. 0.033 7 1141. 1166. 0.054
  9 1141. 1181. 0.07811 1141. 1196. 0.10313 1144. 1209. 0.13015 1147. 1227. 0.157
 17 1155. 1245. 0.18419 1159. 1259. 0.21121 1165. 1275. 0.23823 1171. 1291. 0.264
 25   60.   60. 0.0
  1 1198. 1338. 0.329 3 1195. 1345. 0.341 5 1195. 1350. 0.354 7 1198. 1353. 0.369
  9 1201. 1361. 0.38411 1204. 1369. 0.39913 1207. 1377. 0.41515 1213. 1388. 0.430
 17 1216. 1396. 0.44619 1219. 1404. 0.46021 1222. 1412. 0.47523 1024. 1024. 0.0
  1 1229. 1424. 0.495 3 1232. 1427. 0.508 5 1237. 1437. 0.520 7 1240. 1440. 0.532
  9 1241. 1446. 0.54311 1244. 1449. 0.55413 1247. 1457. 0.56315 1250. 1460. 0.573
 17 1250. 1465. 0.58219 1253. 1468. 0.59021 1256. 1471. 0.59823 1259. 1479. 0.605
 25   60.   60. 0.0
  1 1283. 1513. 0.683 3 1274. 1504. 0.672 5 1271. 1501. 0.664 7 1268. 1498. 0.658
  9 1268. 1498. 0.65411 1268. 1498. 0.65213 1268. 1498. 0.65115 1268. 1498. 0.651
 17 1268. 1498. 0.65119 1268. 1498. 0.65221 1268. 1498. 0.65423   60.   60. 0.0
 25   60.   60. 0.0
  1 1302. 1547. 0.764 3 1290. 1535. 0.740 5 1284. 1524. 0.721 7 1280. 1520. 0.706
  9 1277. 1512. 0.69411 1274. 1509. 0.68613 1271. 1506. 0.67915 1271. 1506. 0.674
 17 1271. 1506. 0.67119 1268. 1503. 0.66821 1268. 1503. 0.66623   60.   60. 0.0
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  5 25 23 25 25 23
    1 ORNL-DWG 78-10719$
HT-34 FUEL ROD NUMBER 31 BATCH A835+OR2576H$
     743.1 MICRON AVG. PARTICLE DIAMETER$
 1 1415. 1320. 3.046 3 1368. 1284. 2.572 5 1341. 1263. 2.257 7 1321. 1248. 2.036
 9 1308. 1239. 1.87611 1303. 1236. 1.75913 1298. 1233. 1.67315 1293. 1230. 1.610
17 1292. 1230. 1.56519 1295. 1233. 1.53421 1297. 1236. 1.51423 1300. 1239. 1.502
25   60.   60. 0.0
 1 1328. 1263. 1.704 3 1317. 1254. 1.577 5 1315. 1254. 1.523 7 1315. 1254. 1.503
 9 1318. 1257. 1.50011 1318. 1257. 1.50513 1321. 1260. 1.51315 1325. 1263. 1.522
17 1328. 1266. 1.53319 1331. 1269. 1.54321 1337. 1275. 1.55423 1078. 1049. 0.0
 1 1340. 1278. 1.570 3 1341. 1278. 1.580 5 1344. 1281. 1.589 7 1347. 1284. 1.598
 9 1348. 1284. 1.60711 1351. 1287. 1.61513 1354. 1290. 1.62215 1357. 1293. 1.629
17 1360. 1296. 1.63519 1360. 1296. 1.64021 1360. 1296. 1.64623 1363. 1299. 1.650
25   60.   60. 0.0
 1 1392. 1323. 1.869 3 1384. 1317. 1.754 5 1374. 1308. 1.701 7 1373. 1308. 1.678
 9 1370. 1305. 1.66811 1370. 1305. 1.66313 1370. 1305. 1.66115 1370. 1305. 1.660
17 1370. 1305. 1.66019 1370. 1305. 1.65921 1370. 1305. 1.65923   60.   60. 0.0
25   60.   60. 0.0
 1 1412. 1341. 1.948 3 1394. 1326. 1.794 5 1386. 1320. 1.720 7 1379. 1314. 1.684
 9 1376. 1311. 1.66511 1373. 1308. 1.65313 1372. 1308. 1.64615 1369. 1305. 1.640
17 1369. 1305. 1.63619 1369. 1305. 1.63221 1369. 1305. 1.62923   60.   60. 0.0
  5 25 23 25 25 23
    0 ORNL-DWG 78-10720$
    HT-34 PARTICLE HOLDER 32 BATCH A-806$
       789.5 MICRON PARTICLE DIAMETER$
 1 1170. 1170. 0.005 3 1152. 1157. 0.015 5 1142. 1157. 0.031 7 1139. 1164. 0.051
 9 1134. 1174. 0.07411 1137. 1192. 0.09813 1139. 1204. 0.12315 1143. 1223. 0.149
17 1149. 1239. 0.17519 1152. 1257. 0.20121 1160. 1275. 0.22723 1167. 1292. 0.251
25   60.   60. 0.0
 1 1188. 1333. 0.313 3 1188. 1338. 0.325 5 1188. 1343. 0.338 7 1191. 1351. 0.352
 9 1194. 1359. 0.36711 1200. 1370. 0.38213 1203. 1378. 0.39715 1206. 1386. 0.412
17 1209. 1394. 0.42619 1212. 1402. 0.44121 1218. 1413. 0.45423 1017. 1017. 0.0
 1 1224. 1424. 0.474 3 1227. 1427. 0.487 5 1230. 1435. 0.498 7 1233. 1438. 0.510
 9 1234. 1444. 0.52011 1239. 1449. 0.53113 1242. 1457. 0.54015 1243. 1458. 0.549
17 1246. 1466. 0.55819 1249. 1469. 0.56621 1249. 1474. 0.57323 1252. 1477. 0.580
25   60.   60. 0.0
 1 1276. 1516. 0.655 3 1270. 1510. 0.645 5 1267. 1502. 0.637 7 1264. 1499. 0.632
 9 1264. 1499. 0.62811 1264. 1499. 0.62613 1264. 1499. 0.62515 1264. 1499. 0.625
17 1264. 1499. 0.62619 1264. 1499. 0.62721 1264. 1499. 0.62823   60.   60. 0.0
25   60.   60. 0.0
 1 1295. 1550. 0.734 3 1285. 1535. 0.711 5 1276. 1526. 0.693 7 1273. 1518. 0.679
 9 1270. 1515. 0.66811 1270. 1510. 0.66013 1267. 1507. 0.65315 1267. 1507. 0.649
17 1267. 1507. 0.64519 1264. 1504. 0.64321 1264. 1504. 0.64123   60.   60. 0.0
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  5 25 23 25 25 23
    0 ORNL-DWG 78-10721$
    HT-34 PARTICLE HOLDER 33 BATCH A-762$
       770.3 MICRON PARTICLE DIAMETERS
 1 1166. 1166. 0.005 3 1148. 1153. 0.015 5 1139. 1154. 0.031 7 1133. 1163. 0.051
 9 1130. 1175. 0.07411 1133. 1188. 0.09813 1136. 1206. 0.12415 1142. 1227. 0.150
17 1145. 1240. 0.17619 1148. 1258. 0.20221 1154. 1274. 0.22723 1163. 1293. 0.252
25   60.   60. 0.0
 1 1187. 1342. 0.315 3 1184. 1344. 0.327 5 1184. 1349. 0.340 7 1187. 1357. 0.354
 9 1190. 1365. 0.36911 1193. 1373. 0.38413 1199. 1384. 0.40015 1202. 1392. 0.415
17 1205. 1400. 0.42919 1209. 1409. 0.44421 1212. 1417. 0.45823 1014. 1014. 0.0
 1 1220. 1430. 0.478 3 1224. 1434. 0.490 5 1227. 1442. 0.503 7 1230. 1450. 0.514
 9 1230. 1450. 0.52511 1233. 1458. 0.53513 1236. 1461. 0.54515 1239. 1469. 0.554
17 1242. 1472. 0.56319 1245. 1480. 0.57121 1245. 1480. 0.57923 1248. 1483. 0.586
25   60.   60. 0.0
 1 1272. 1522. 0.661 3 1266. 1516. 0.651 5 1263. 1513. 0.644 7 1257. 1507. 0.638
 9 1257. 1507. 0.63511 1257. 1507. 0.63313 1257. 1507. 0.63215 1257. 1507. 0.632
17 1257. 1507. 0.63319 1257. 1507. 0.63421 1257. 1507. 0.63523   60.   60. 0.0
25   60.   60. 0.0
 1 1291. 1561. 0.741 3 1282. 1547. 0.719 5 1276. 1536. 0.701 7 1270. 1530. 0.687
 9 1269. 1524. 0.67611 1266. 1521. 0.66713 1266. 1521. 0.66115 1263. 1518. 0.657
17 1263. 1513. 0.65319 1260. 1515. 0.65121 1260. 1510. 0.64923   60.   60. 0.0
  5 25 23 25 25 23
    1 ORNL-DWG 78-10722$
 HT-34 FUEL RCD NUMBER 34 BATCH A837+OR2576H$
    743.4 MICRON AVG. PARTICLE DIAMETERS
 1 1419. 1326. 2.984 3 1373. 1290. 2.531 5 1345. 1269. 2.229 7 1326. 1254. 2.015
 9 1313. 1245. 1.85811 1305. 1239. 1.74213 1300. 1236. 1.65615 1296. 1233. 1.592
17 1295. 1233. 1.54619 1297. 1236. 1.51321 1297. 1236. 1.49123 1299. 1239. 1.477
25   60.   60. 0.0
 1 1330. 1266. 1.669 3 1319. 1257. 1.547 5 1315. 1254. 1.494 7 1317. 1257. 1.474
 9 1317. 1257. 1.47011 1323. 1263. 1.47313 1326. 1266. 1.48015 1326. 1266. 1.489
17 1330. 1269. 1.49819 1333. 1272. 1.50821 1336. 1275. 1.51823 1078. 1050. 0.0
 1 1342. 1281. 1.533 3 1345. 1284. 1.543 5 1349. 1287. 1.552 7 1349. 1287. 1.561
 9 1352. 1290. 1.56911 1352. 1290. 1.57713 1355. 1293. 1.58415 1358. 1296. 1.591
17 1359. 1296. 1.59719 1362. 1299. 1.60221 1365. 1302. 1.60823 1365. 1302. 1.612
25   60.   60. 0.0
 1 1397. 1329. 1.823 3 1382. 1317. 1.714 5 1378. 1314. 1.664 7 1375. 1311. 1.642
 9 1374. 1311. 1.63211 1374. 1311. 1.62813 1371. 1308. 1.62615 1371. 1308. 1.625
17 1371. 1308. 1.62519 1374. 1311. 1.62421 1374. 1311. 1.62423   60.   60. 0.0
25   60.   60. 0.0
 1 1414. 1344. 1.902 3 1398. 1332. 1.756 5 1388. 1323. 1.686 7 1384. 1320. 1.651
 9 1378. 1314. 1.63211 1377. 1314. 1.62213 1374. 1311. 1.61415 1374. 1311. 1.609
17 1374. 1311. 1.60519 1374. 1311. 1.60121 1374. 1311. 1.59823   60.   60. 0.0
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  5 25 23 25 25 23
    0 CRNL-DWG 78-10723S
    HT-34 PARTICLE HOLDER 35 BATCH A-782S
        826.0 MICRON PARTICLE DIAMETERS
 1 1162. 1162. 0.005 3 1144. 1149. 0.015 5 1132. 1147. 0.031 7 1129. 1154. 0.050
 9 1126. 1161. 0.07211 1129. 1179. 0.09613 1129. 1189. 0.12215 1132. 1207. 0.147
17 1138. 1223. 0.17319 1144. 1239. 0.19921 1150. 1255. 0.22523 1153. 1268. 0.250
25   60.   60. 0.0
 1 1177. 1312. 0.311 3 1174. 1319. 0.324 5 1177. 1322. 0.337 7 1180. 1330. 0.352
 9 1183. 1338. 0.36711 1186. 1346. 0.38213 1189. 1354. 0.39715 1195. 1365. 0.412
17 1198. 1373. 0.42719 1204. 1384. 0.44221 1207. 1392. 0.45623 1007. 1007. 0.0
 1 1211. 1401. 0.476 3 1214. 1404. 0.488 5 1217. 1412. 0.501 7 1222. 1417. 0.512
 9 1225. 1425. 0.52311 1228. 1428. 0.53413 1229. 1434. 0.54315 1232. 1437. 0.553
17 1235. 1445. 0.56219 1235. 1445. 0.57021 1238. 1453. 0.57823 1238. 1453. 0.585
25   60.   60. 0.0
 1 1265. 1495. 0.659 3 1256. 1486. 0.650 5 1253. 1478. 0.643 7 1253. 1478. 0.638
 9 1253. 1478. 0.63511 1250. 1475. 0.63313 1250. 1475. 0.63215 1250. 1475. 0.632
17 1250. 1475. 0.63319 1250. 1475. 0.63421 1253. 1478. 0.63623   60.   60. 0.0
25   60.   60. 0.0
 1 1284. 1529. 0.741 3 1274. 1514. 0.720 5 1268. 1508. 0.702 7 1262. 1497. 0.688
 9 1259. 1494. 0.67711 1259. 1489. 0.66913 1256. 1486. 0.66315 1256. 1486. 0.658
17 1253. 1483. 0.65519 1253. 1483. 0.65321 1253. 1483. 0.65123   60.   60. 0.0
  5 25 23 25 25 23
    0 CRNL-DWG 78-10724S
    HT-34 PARTICLE HOLDER 36 BATCH A-786S
        825.9 MICRON PARTICLE DIAMETERS
 1 1146. 1146. 0.004 3 1128. 1133. 0.014 5 1119. 1134. 0.028 7 1116. 1141. 0.046
 9 1114. 1149. 0.06711 1116. 1161. 0.08913 1117. 1177. 0.11315 1122. 1192. 0.137
17 1128. 1206. 0.16119 1132. 1222. 0.18521 1138. 1238. 0.20923 1143. 1253. 0.232
25   60.   60. 0.0
 1 1167. 1297. 0.289 3 1167. 1302. 0.301 5 1167. 1307. 0.314 7 1170. 1315. 0.327
 9 1173. 1323. 0.34111 1177. 1332. 0.35613 1182. 1342. 0.37015 1186. 1346. 0.384
17 1189. 1354. 0.39819 1192. 1362. 0.41221 1195. 1370. 0.42523 1001. 1001. 0.0
 1 1201. 1381. 0.444 3 1207. 1387. 0.456 5 1207. 1392. 0.467 7 1210. 1400. 0.478
 9 1213. 1403. 0.48911 1216. 1411. 0.49913 1219. 1414. 0.50815 1222. 1422. 0.517
17 1225. 1425. 0.52519 1228. 1428. 0.53321 1228. 1433. 0.54023 1231. 1436. 0.547
25   60.   60. 0.0
 1 1253. 1473. 0.616 3 1249. 1464. 0.608 5 1246. 1461. 0.602 7 1240. 1455. 0.597
 9 1240. 1455. 0.59411 1240. 1455. 0.59313 1240. 1455. 0.59215 1240. 1455. 0.592
17 1240. 1455. 0.59319 1240. 1455. 0.59421 1240. 1455. 0.59623   60.   60. 0.0
25   60.   60. 0.0
 1 1274. 1509. 0.694 3 1265. 1495. 0.674 5 1259. 1489. 0.658 7 1255. 1480. 0.645
 9 1252. 1477. 0.63511 1249. 1474. 0.62813 1249. 1469. 0.62215 1246. 1466. 0.618
17 1246. 1466. 0.61519 1246. 1466. 0.61221 1246. 1466. 0.61123   60.   60. 0.0
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  5 25 23 25 25 23
    1 CRNL-DWG 78-10725$
 HT-34 FUEL RCC NUMBER 37 BATCH A836+OR2576H$
     739.8 MICRON AVG. PARTICLE DIAMETER$
 1 1402. 1317. 2.678 3 1363. 1287. 2.287 5 1337. 1266. 2.022 7 1321. 1254. 1.833
 9 1309. 1245. 1.69311 1298. 1236. 1.58713 1296. 1236. 1.50815 1292. 1233. 1.448
17 1291. 1233. 1.40319 1293. 1236. 1.37121 1292. 1236. 1.34923 1295. 1239. 1.334
25   60.   60. 0.0
 1 1325. 1266. 1.499 3 1314. 1257. 1.392 5 1310. 1254. 1.344 7 1310. 1254. 1.325
 9 1313. 1257. 1.32011 1316. 1260. 1.32213 1319. 1263. 1.32715 1322. 1266. 1.334
17 1325. 1269. 1.34119 1328. 1272. 1.35021 1328. 1272. 1.35823 1081. 1054. 0.0
 1 1334. 1278. 1.371 3 1338. 1281. 1.379 5 1341. 1284. 1.387 7 1344. 1287. 1.395
 9 1344. 1287. 1.40211 1347. 1290. 1.40913 1348. 1290. 1.41615 1351. 1293. 1.422
17 1354. 1296. 1.42819 1357. 1299. 1.43321 1357. 1299. 1.43823 1360. 1302. 1.442
25   60.   60. 0.0
 1 1388. 1326. 1.626 3 1377. 1317. 1.533 5 1373. 1314. 1.490 7 1370. 1311. 1.471
 9 1366. 1308. 1.46311 1366. 1308. 1.45913 1366. 1308. 1.45815 1366. 1308. 1.457
17 1366. 1308. 1.45719 1366. 1308. 1.45721 1366. 1308. 1.45723   60.   60. 0.0
25   60.   60. 0.0
 1 1407. 1344. 1.701 3 1393. 1332. 1.575 5 1382. 1323. 1.514 7 1379. 1320. 1.483
 9 1375. 1317. 1.46711 1375. 1317. 1.45813 1372. 1314. 1.45115 1369. 1311. 1.447
17 1369. 1311. 1.44319 1369. 1311. 1.44021 1366. 1308. 1.43723   60.   60. 0.0
  5 25 23 25 25 23
    0 CRNL-DWG 78-10726$
    HT-34 PARTICLE HOLDER 38 BATCH A-787$
       813.4 MICRON PARTICLE DIAMETER$
 1 1137. 1137. 0.004 3 1121. 1126. 0.013 5 1112. 1127. 0.027 7 1107. 1132. 0.045
 9 1106. 1141. 0.06511 1107. 1152. 0.08713 1109. 1169. 0.10915 1112. 1182. 0.133
17 1116. 1201. 0.15719 1121. 1216. 0.18021 1127. 1232. 0.20423 1133. 1248. 0.227
25   60.   60. 0.0
 1 1155. 1290. 0.283 3 1152. 1292. 0.295 5 1154. 1299. 0.308 7 1157. 1307. 0.321
 9 1161. 1316. 0.33511 1166. 1326. 0.35013 1169. 1334. 0.36415 1173. 1343. 0.378
17 1176. 1351. 0.39219 1179. 1354. 0.40621 1185. 1365. 0.41923  994.  994. 0.0
 1 1191. 1376. 0.438 3 1191. 1381. 0.450 5 1194. 1389. 0.461 7 1197. 1392. 0.472
 9 1200. 1400. 0.48311 1206. 1406. 0.49313 1209. 1409. 0.50215 1209. 1414. 0.511
17 1212. 1417. 0.51919 1212. 1422. 0.52721 1215. 1425. 0.53523 1218. 1428. 0.542
25   60.   60. 0.0
 1 1239. 1464. 0.610 3 1236. 1461. 0.602 5 1233. 1458. 0.596 7 1230. 1455. 0.592
 9 1230. 1455. 0.58911 1230. 1455. 0.58813 1230. 1455. 0.58815 1230. 1455. 0.588
17 1230. 1455. 0.58919 1230. 1455. 0.59021 1230. 1455. 0.59223   60.   60. 0.0
25   60.   60. 0.0
 1 1261. 1501. 0.688 3 1251. 1491. 0.669 5 1248. 1483. 0.654 7 1242. 1477. 0.641
 9 1239. 1474. 0.63211 1236. 1466. 0.62413 1236. 1466. 0.61915 1233. 1463. 0.615
17 1233. 1463. 0.61219 1233. 1463. 0.61021 1233. 1463. 0.60823   60.   60. 0.0
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  5 25 23 25 25 23
    0 CRNL-DWG 78-10727S
HT-34 PARTICLE HOLDER 39 BATCH OR1975T+OR2013TS
     817.8 MICRON AVG. PARTICLE DIAMETERS
 1   990.  990. 0.004 3  990.  995. 0.013 5  996. 1011. 0.026 7  999. 1024. 0.043
 9  1008. 1048. 0.06211 1014. 1064. 0.08313 1017. 1082. 0.10515 1026. 1106. 0.128
17  1032. 1122. 0.15119 1038. 1138. 0.17421 1046. 1161. 0.19723 1052. 1177. 0.219
25    60.   60. 0.0
 1  1067. 1212. 0.273 3 1070. 1220. 0.285 5 1073. 1228. 0.298 7 1076. 1236. 0.312
 9  1082. 1247. 0.32611 1085. 1260. 0.34013 1088. 1268. 0.35415 1091. 1276. 0.368
17  1094. 1284. 0.38119 1097. 1292. 0.39521 1103. 1298. 0.40823  987.  987. 0.0
 1  1106. 1311. 0.426 3 1109. 1314. 0.438 5 1112. 1322. 0.449 7 1115. 1330. 0.460
 9  1118. 1333. 0.47011 1121. 1341. 0.48013 1124. 1344. 0.48915 1127. 1352. 0.498
17  1127. 1352. 0.50619 1130. 1360. 0.51421 1130. 1360. 0.52123 1133. 1363. 0.528
25    60.   60. 0.0
 1  1148. 1398. 0.594 3 1148. 1398. 0.588 5 1145. 1390. 0.582 7 1145. 1390. 0.578
 9  1145. 1390. 0.57611 1145. 1390. 0.57513 1145. 1390. 0.57415 1145. 1390. 0.575
17  1145. 1390. 0.57619 1145. 1390. 0.57721 1145. 1390. 0.57923   60.   60. 0.0
25    60.   60. 0.0
 1  1166. 1436. 0.672 3 1163. 1428. 0.654 5 1157. 1417. 0.639 7 1154. 1414. 0.628
 9  1154. 1409. 0.61911 1151. 1406. 0.61113 1151. 1406. 0.60615 1151. 1401. 0.602
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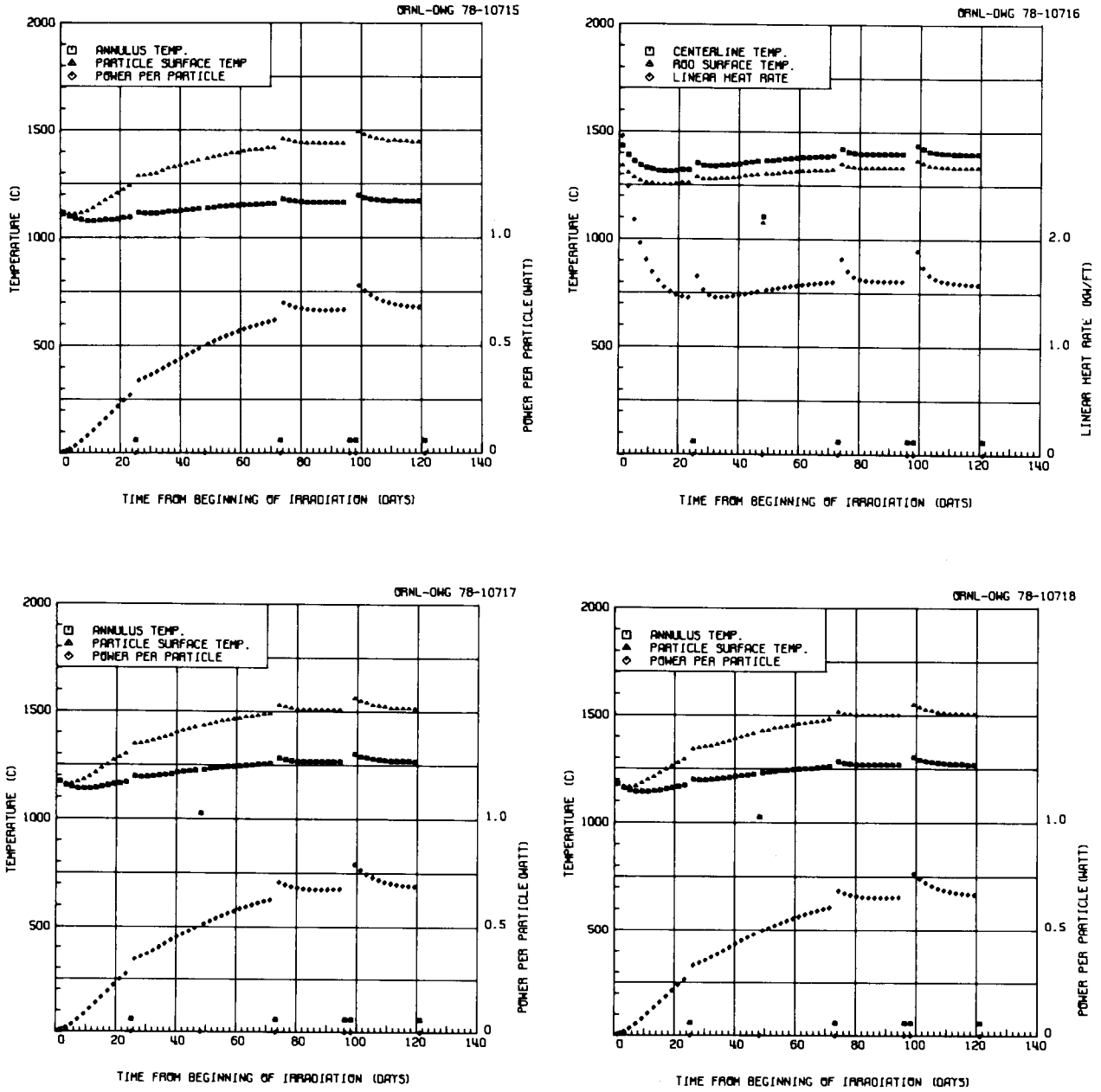
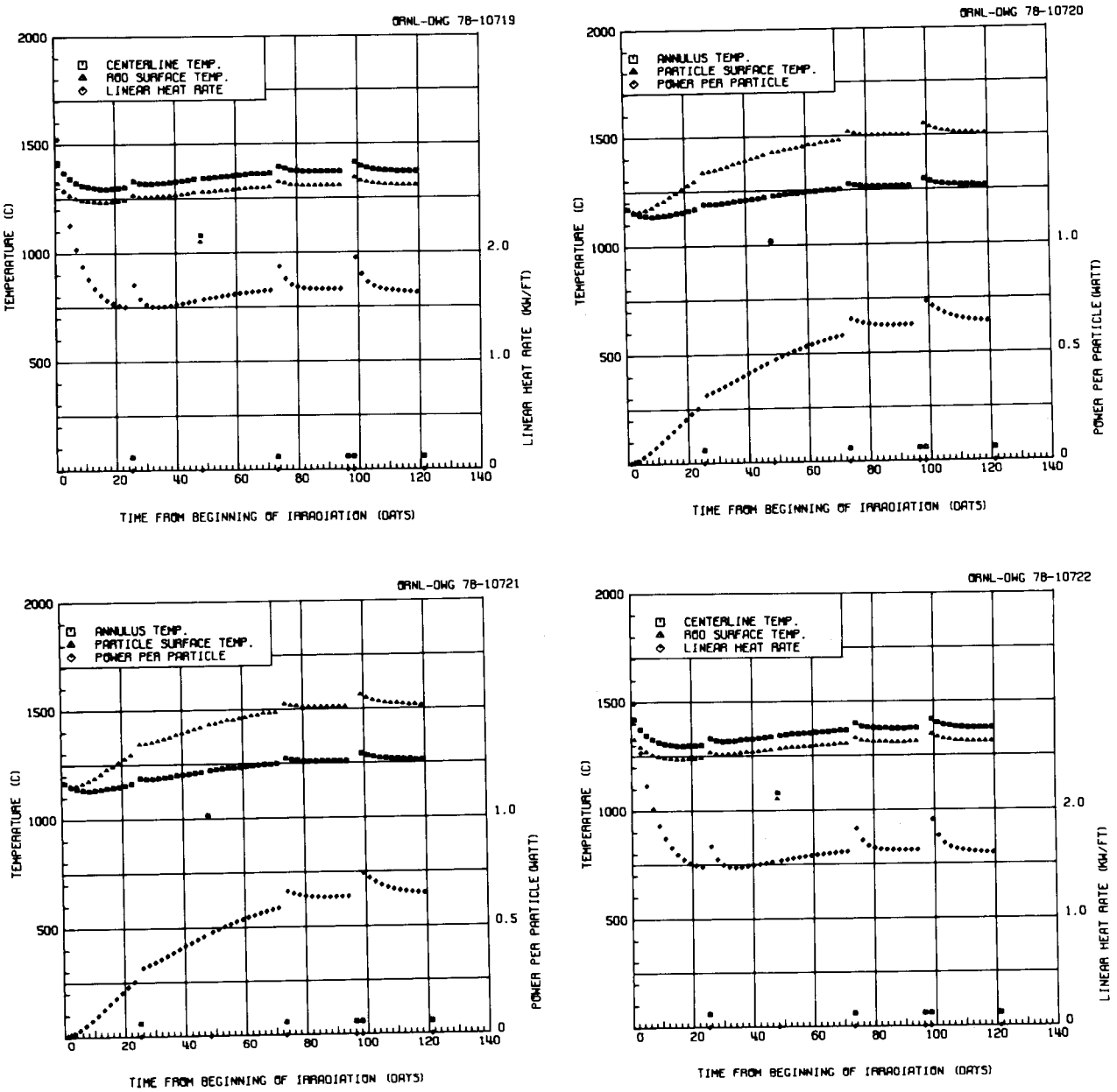
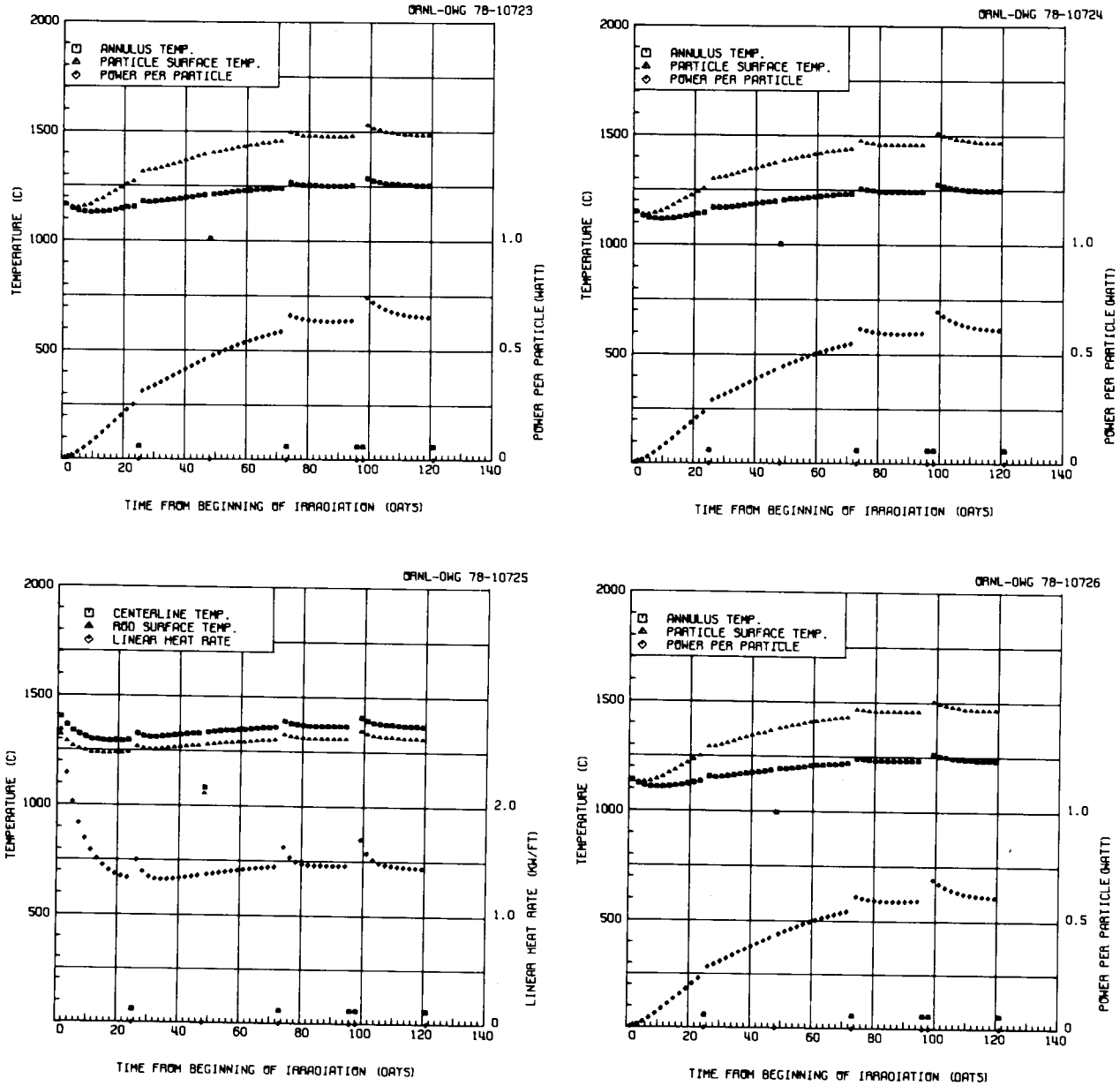


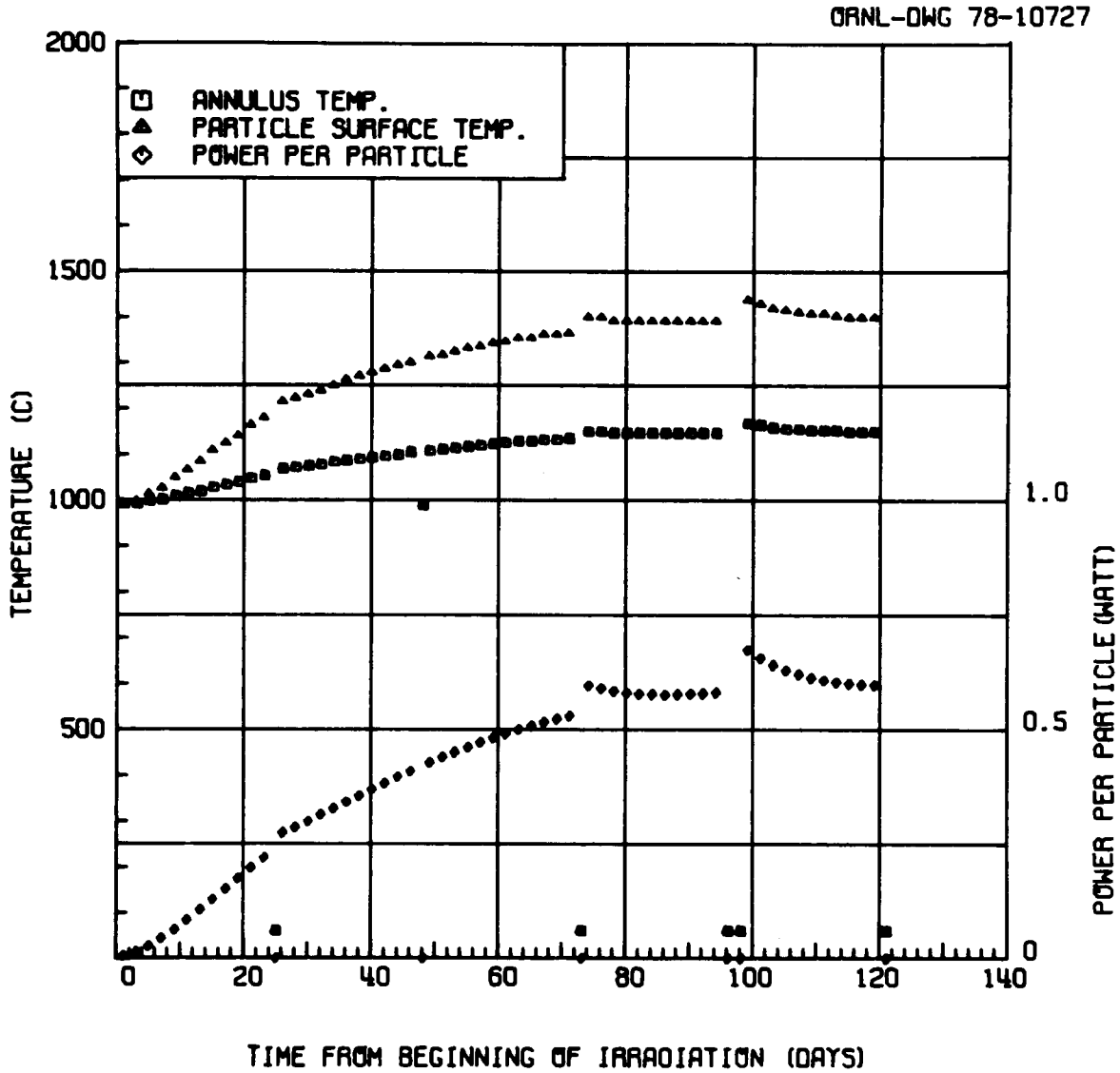
Calculated Temperature and Power Histories for Positions in Magazine 3 of HT-34 Capsule: (a) Loose Particle Holder 27, Batch A-765, 803.4-μm-diam Particle; (b) Fuel Rod 28, Batches A-834 and OR-2576H, 735.1-μm-avg. diam Particle; (c) Loose Particle Holder 29, Batch A-780, 806.3-μm-diam Particle; (d) Loose Particle Holder 30, Batch A-785, 816.5-μm-diam Particle.



Calculated Temperature and Power Histories for Positions in Magazine 3 of HT-34 Capsule: (a) Fuel Rod 31, Batches A-835 and OR-2576H, 734.1-μm-avg. diam Particle; (b) Loose Particle Holder 32, Batch A-806, 789.1-μm-diam Particle; (c) Loose Particle Holder 33, Batch A-762, 770.3-μm-diam Particle; (d) Fuel Rod 34, Batches A-837 and OR-2576H, 743.4-μm-avg. diam Particle.



Calculated Temperature and Power Histories for Positions in Magazine 3 of HT-34 Capsule: (a) Loose Particle Holder 35, Batch A-782, 826.0-μm-diam Particle; (b) Loose Particle Holder 36, Batch A-786, 825.9-μm-diam Particle; (c) Fuel Rod 37, Batches A-836 and OR-2576H, 739.8-μm-avg. diam Particle; (d) Loose Particle Holder 38, Batch A-787, 813.4-μm-diam Particle.



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