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HTCAP—A FORTRAN IV Program for Calculating Coated-Particle Operating Temperatures in HFIR Target Irradiation Experiments

M. J. Kania

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HTCAP — A FORTRAN IV PROGRAM FOR CALCULATING COATED-PARTICLE OPERATING TEMPERATURES IN HFIR TARGET IRRADIATION EXPERIMENTS

M. J. Kania

MAY 1976

OAK RIDGE NATIONAL LABORATORY
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M. J. Kania

ABSTRACT

This report describes HTCAP, a computer code that calculates in-reactor operating temperatures of loose coated ThO_2 particles in the HFIR target series of irradiation tests. Three computational models are employed to determine

1. fission heat generation rates,
2. capsule heat transfer analysis,
3. maximum particle surface temperature,

within the design of an HT capsule. Maximum particle operating temperatures are calculated at daily intervals during each irradiation cycle. The application of HTCAP to sleeve CP-62 of HT-15 is discussed, and the results are compared with those obtained in an earlier thermal analysis on the same capsule. Agreement is generally within ±5%, while decreasing the computational time by more than an order of magnitude. A complete FORTRAN listing and summary of required input data are presented in Appendices A and B respectively. Appendix C contains a listing of the input data and a tabular output from the thermal analysis of sleeve CP-62 of HT-15.

INTRODUCTION

Accelerated irradiation experiments conducted at Oak Ridge National Laboratory are used to screen the performance of candidate HTGR fuels.[1] An initial phase in this program is the loose-coated-particle experiments irradiated in the target region[2,3] of the High Flux Isotope

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[1] J. A. Conlin et al., "HTGR Fuel Irradiations and Post-Irradiation Evaluations," *GCR Programs Annu. Prog. Rep. Dec. 31, 1972*, ORNL-4911, chap. 7.

[2] B. H. Montgomery, "Target Irradiation Tests," *GCR-TU Programs Annu. Prog. Rep. Sept. 30, 1971*, ORNL-4760, pp. 134–36.

[3] B. H. Montgomery, "Irradiation Tests in the HFIR Target Facility," *GCR Programs Annu. Prog. Rep. Dec. 31, 1972*, ORNL-4911, pp. 113–15.

Reactor.[4] These experiments, commonly known as the HT series,[5,6] test various coated-particle and fuel-rod matrix designs at or in excess of temperatures and fast neutron fluences encountered in a commercial HTGR. Full fluences of 8×10^{21} neutrons/cm^2 ($E > 0.18$ MeV) can be achieved in three to four months compared with six years required in an HTGR.

An important parameter in evaluating the performance of a candidate fuel design is its operating temperature during irradiation. In loose-coated-particle experiments, such as the HT series, the kernel temperature influences fission-gas release from the fuel and subsequently controls the gas pressure within the particle coatings. Excessive pressures can result in mechanical failure of the particles.[7] The mass transport of fission products and kernel thermal migration[8,9] (the amoeba effect) are also dependent on temperature and temperature gradients.

There are no provisions for direct temperature monitoring in the HT capsules. Therefore, thermal modeling is used to predict operating temperature histories. Initial modeling of the HT capsules was performed with the GENGTC code,[10] which computed one-dimensional radial thermal gradients in the capsule. Maximum particle operating temperatures were then assumed to be the same as those calculated for the graphite sample holders. A more sophisticated analysis was performed

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[4]R. D. Cheverton and T. M. Sims, *HFIR Core Nuclear Design*, ORNL-4621 (July 1971).

[5]M. J. Kania et al., *Irradiation Performance of HTGR Fertile Fuel in HFIR Target Capsules HT-12 through HT-15, Part I — Experimental Description and Fission Product Behavior*, ORNL/TM-5305 (in preparation).

[6]R. L. Beatty et al., *Irradiation Performance of HTGR Fertile Fuel in HFIR Target Capsules HT-17, HT-18, and HT-19*, report in preparation.

[7]C. L. Smith, *Fuel Particle Behavior Under Normal and Transient Conditions*, GA-A12971 (October 1, 1974).

[8]C. B. Scott and O. M. Stansfield, *Stability of Irradiated Coated-Particle Fuels in a Temperature Gradient*, Gulf-GA-A12081 (September 18, 1972).

[9]T. B. Lindemer and R. A. Olstad, *HTGR Fuel Kernel Migration Data for the Th-U-C-O System as of April 1, 1974*, ORNL-TM-4493 (April 1974).

[10]Hall C. Roland, *GENGTC, a One-Dimensional CEIR Computer Program for Capsule Temperature Calculations in Cylindrical Geometry*, ORNL-TM-1942 (December 1967).

using the HTTEMP code[11] in conjunction with the HEATING3 heat conduction code.[12] HTTEMP, a modified version of GENGTC, was used to calculate approximate temperatures and hot dimensions of the sleeves and particle holders at particular times during the irradiation. At these selected times, more accurate temperatures for the particle holders were calculated using the HEATING3 program. Particle holder temperatures were determined by a two-dimensional (r,θ) heat transfer calculation based upon the hot dimensions from the HTTEMP calculations and the approximate HTTEMP temperatures as first-guess temperatures. Maximum particle operating temperatures were then determined by a parametric relationship between particle surface temperature and power generated per particle at a defined holder temperature.[13] This procedure, although extremely time consuming, yielded realistic peak particle operating temperatures.

This report describes the third-generation thermal modeling code HTCAP, which incorporates modified versions of GENGTC and isotope depletion code,[14] FABGEN. HTCAP is being used for the postirradiation thermal analysis on loose-coated-particle experiments. HTCAP is a self-contained code that calculates total heat generation within the capsule, performs a modified one-dimensional heat transfer analysis of the HT capsule, and then predicts the maximum particle surface operating temperature at one-day intervals for each irradiation cycle.

HTCAP is written in FORTRAN IV language for the ORNL Compiler and requires less than 270K of core storage. A complete HT capsule thermal analysis, using HTCAP, requires less than 3 min total CPU time on the IBM 360/91. A complete FORTRAN listing is presented in Appendix A; a description of the input data deck and a data preparation guide for HTCAP are presented in Appendix B. This report also serves as a user's manual to HTCAP.

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[11]Unpublished work of R. A. Olstad.

[12]W. D. Turner and M. Siman-Tov, *HEATING3 — An IBM/360 Heat Conduction Program*, ORNL-TM-3208 (February 1971).

[13]J. A. Conlin, *Temperature of Loose Coated Particles in Irradiation Tests*, ORNL-TM-4542 (April 1975).

[14]Hall C. Roland, *FABGEN, a Transient Power-Generation and Isotope Birth Rate Calculator*, ORNL-TM-4750 (April 1975).

GENERAL DESCRIPTION

Meaningful operating temperature histories require consideration of the following:

1. heat generation rates, both fission and gamma, within each sample holder as a function of time, axial position, and isotope density;

2. heat flow in the radial and axial directions;

3. changing material thermal conductivities and dimensions as a function of fast neutron fluence and temperature.

HTCAP incorporates three computational models integrated into the basic design of an HT capsule. The primary purposes of these models are to determine:

1. fission heat generation rates for each sample holder,

2. temperatures at nodal material boundaries across the sample holder,

3. maximum surface temperature of the test particle within each sample holder.

HT CAPSULE DESIGN

A typical HT capsule used in the loose-coated-particle experiments is described in Fig. 1. Each capsule contains 32 Poco* Graphite sample holders of Biso-coated fertile (ThO_2) particles and 20 sample holders containing uranium particles (7% enriched). The uranium particles are included to provide the initial source of heat and to flatten the axial temperature distribution. They are not considered test particles. Sixteen fertile-particle sample holders are irradiated in the low-temperature, low-flux regions located near the ends of the capsule. The remaining 16 are irradiated in the high-temperature, high-flux regions nearest the reactor horizontal midplane (HMP). Thirteen sample holders are loaded into each of four tapered Poco Graphite sleeves, eight contain coated ThO_2 particles and five contain uranium particles. End plugs are placed in the top and bottom of each sleeve, those plugs nearest the HMP being loaded with uranium particles. Each of the four completed sleeves is then loaded into an aluminum containment vessel, backfilled with argon, and sealed.

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*Grade AFX-5Q manufactured by Poco Graphic, Inc., a subsidiary of Union Oil Company, P.O. Box 2121, Decature, Texas 76234.

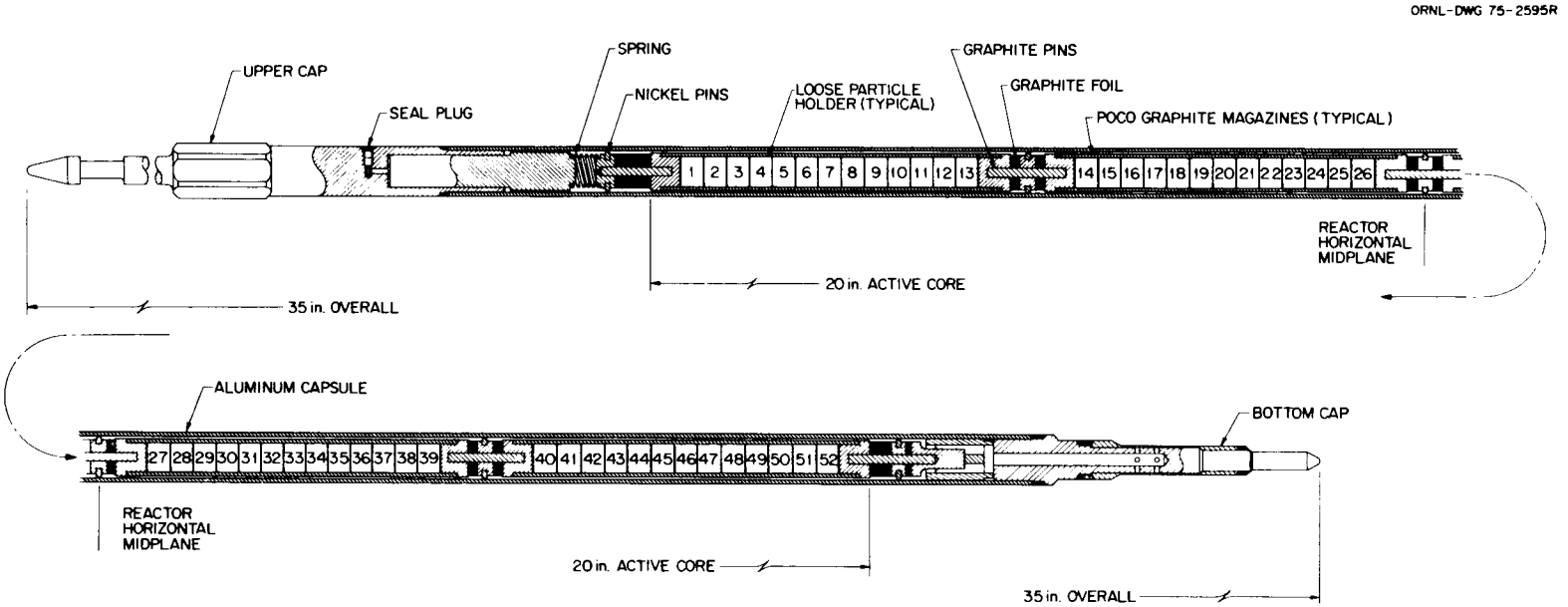


Fig. 1. Target Capsule Typical of HT-12, -13, -14, -15, -17, -18, -19.

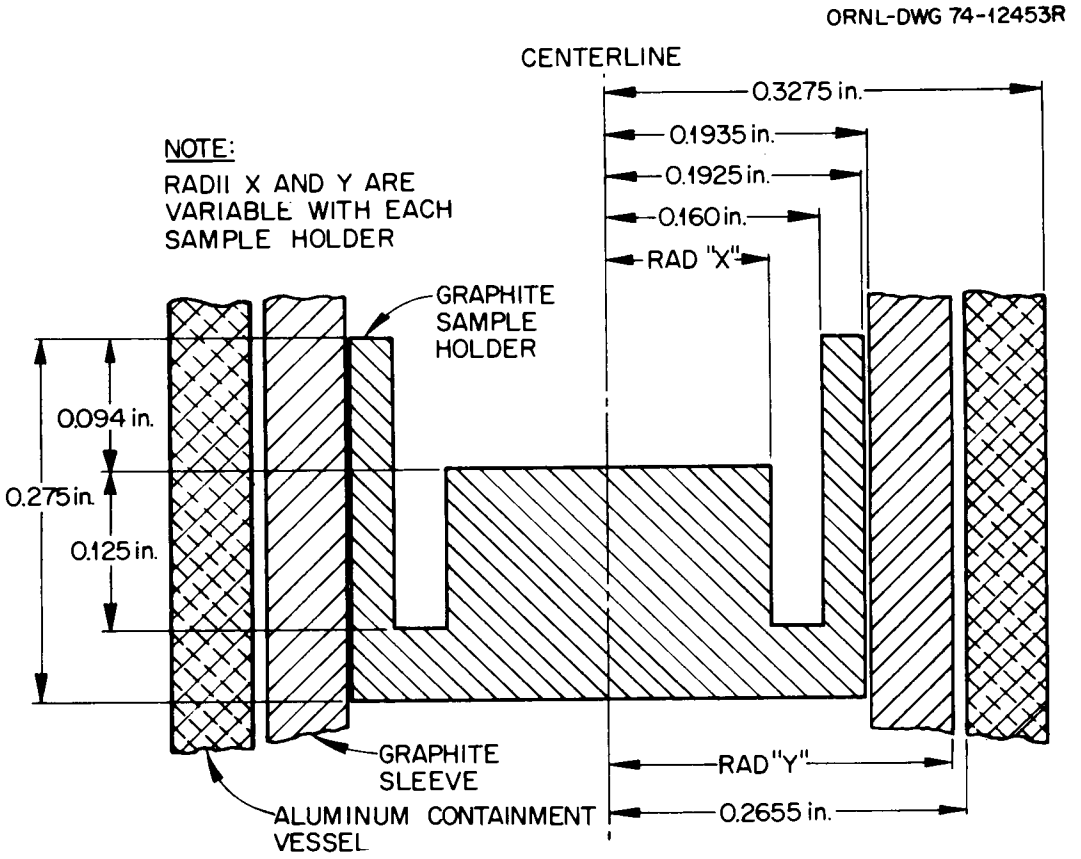


Fig. 2. Sample Holder for HFIR Target Experiments.

Figure 2 illustrates an axial cross section of a portion of an HT capsule with the sample holder sitting within the graphite sleeve surrounded by the aluminum containment vessel. The sample holder is approximately 3/8 in. in diameter by 0.275 in. long. Loose coated particles are individually selected, well characterized, and placed inside an annular region cut from the sample holder. Individual sample holders contain a specified number of particles determined by the particular temperature region. The variable radius *X* in Fig. 2 is determined by the diameter of the coated particles within the sample holder. The radius *Y* is determined by the relative position of the sample holder along the tapered graphite sleeve.

The HT capsules contain no instrumentation for direct temperature monitoring and no provisions for a sweep gas. Irradiation periods are typically from 2 to 8 HFIR cycles (one HFIR cycle equals 23 days at 100 MW full power).

COMPUTATIONAL MODELS

Fission heat generation rates are calculated with the use of a modified version of the FABGEN computer code. In its original form, FABGEN was a fast-running program for calculating fuel power generation rates and selected fission product production rates in a known neutron flux as a function of time. The modified version deletes the provisions for fission product production rates and incorporates two group fluxes and cross-section data applicable to the target region[15] of the HFIR. Figure 3 describes the time variation of the thermal (E < 1.86 eV) and the nonthermal (E > 1.86 eV) group fluxes during a typical HFIR cycle. Peak thermal flux at day zero at the reactor HMP is 2.81×10^{15} neutrons cm^{-2} sec^{-1} and peak nonthermal flux is 3.09×10^{15} neutrons cm^{-2} sec^{-1}. Because of the relatively small time variation (<4%) these values are assumed to remain constant during each cycle. Table 1 describes the axial variation of the two-group fluxes, and Table 2 describes the two-group cross sections incorporated in the modified version of FABGEN.

[15]Unpublished work of J. D. Jenkins.

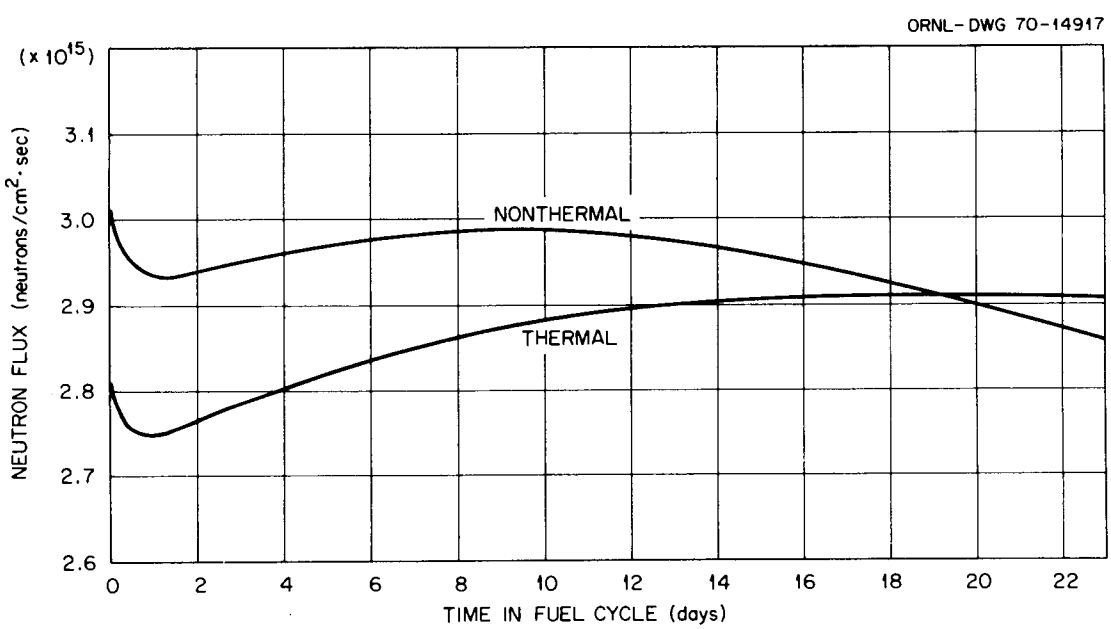


Fig. 3. Peak Neutron Fluxes in HFIR Target vs Time in Fuel Cycle.

Table 1. Flux Levels Applicable to HFIR Target Region

Axial Position (in.)	Target Fluxes ($\times 10^{15}$ neutrons cm^{-2} sec^{-1})	
	Nonthermal (E > 1.86 eV)	Thermal (E < 1.86 eV)
Midplane	2.81	3.09
+5	2.47	2.71
+10	1.40	1.54

Table 2. Cross-Section Data Base (barns)

Isotope	Nonthermal (E > 1.86 eV)		Thermal (E < 1.86 eV)	
	σ_c	σ_f	σ_c	σ_f
^{235}U	6.19 + 0	9.21 + 0	7.10 + 1	4.02 + 2
^{238}U	9.23 + 0	1.01 − 1	1.97 + 0	0.00 + 0
^{239}Np	2.10 + 1	5.14 − 1	3.92 + 1	0.00 + 0
^{239}Pu	6.20 + 0	1.01 + 1	3.01 + 2	6.60 + 2
^{240}Pu	7.07 + 1	5.48 − 1	6.74 + 2	0.00 + 0
^{241}Pu	6.90 + 1	2.33 + 1	2.67 + 2	8.23 + 2
^{232}Th	3.14 + 0	2.53 − 2	5.39 + 0	0.00 + 0
^{233}Pa	1.72 + 1	3.13 − 1	5.44 + 1	0.00 + 0
^{233}U	4.60 + 0	2.12 + 1	3.70 + 1	3.91 + 2
^{234}U	2.74 + 1	4.68 − 1	6.67 + 1	0.00 + 0

Second-order polynominals were fitted to the data in Table 1. Both the fast and thermal flux are considered symmetric about the HFIR HMP. Equations (1) and (2) describe the nonthermal and thermal flux, respectively, as a function of axial distance from the HMP:

$$\phi(z)(E > 1.86 \text{ eV}) = (2.81 + 5.00 \times 10^{-3}Z - 1.46 \times 10^{-2}Z^2) \times 10^{15} \text{ neutrons cm}^{-2} \text{ sec}^{-1} , \quad (1)$$

$$\phi(z)(E < 1.86 \text{ eV}) = (3.09 + 3.00 \times 10^{-3}Z - 1.58 \times 10^{-2}Z^2) \times 10^{15} \text{ neutrons cm}^{-2} \text{ sec}^{-1} , \quad (2)$$

where

Z = distance (in.) from the HFIR HMP.

Fission heat generation rates calculated for each sample holder and end plug are based upon the average fluxes (nonthermal and thermal) over the length of the fueled annulus (typically 0.125 in.) and the fissile isotope concentration. The average flux is described by

$$< \phi > = \int_a^b \phi(Z)\, dZ \Big/ \int_a^b dZ , \quad (3)$$

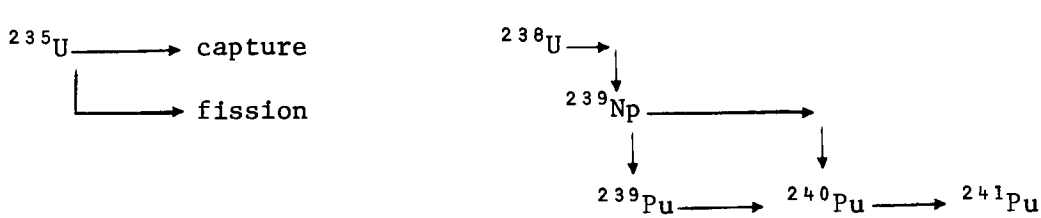
where

$< \phi >$ = average flux (nonthermal or thermal) ,

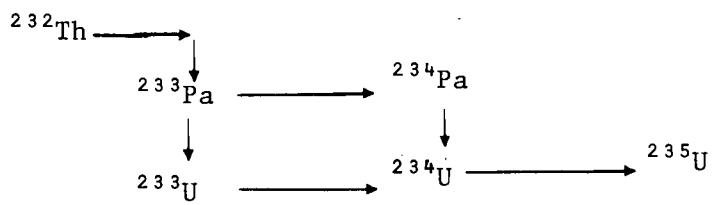
$\phi(Z)$ = either Eq. (1) or (2) ,

a (b) = distance from the top (bottom) of fueled annulus region to the reactor HMP.

Fissile isotope concentration is determined by either the thorium or uranium fuel chains. The uranium fuel chain has not been altered from the original FABGEN code; that is:



The thorium fuel chain has been modified and is represented by:



A forward differencing calculation is used for each fuel chain to determine isotope inventory at the end of each time step. The uranium chain time step is one day and the thorium chain time step is 6 hr. In the latter case, fission heats generated in four consecutive time steps are summed to store fission-heat generation rates on a day-to-day basis.

The heat transfer model employed in HTCAP is basically the same as that used in the existing GENGTC code. The GENGTC program performs a one-dimensional radial heat transfer analysis in cylindrical coordinates. HTCAP modifications include: (1) gamma heating as a function of axial position with reference to the HFIR HMP, and (2) dimensional change calculations as a function of fast-neutron exposure and temperature. Within this model each fueled graphite sleeve is divided into 15 longitudinal sections containing a particle holder or sleeve end plug, along with its surrounding material. Figure 4 illustrates a longitudinal section. Each section is further subdivided into cylindrical regions specified by the inner and outer radii of each material.

During the initial irradiation period of an HT capsule, the primary source of fission heat is from the ^{235}U located in the uranium particle holders positioned along the length of each graphite sleeve. As ^{233}U is bred into the ThO_2 particles and the ^{235}U is consumed, this reverses and the major source of fission heat becomes the ThO_2 particles. This situation where a particle holder is generating more heat than its adjacent holders sets up an axial flow of heat. To account for this axial flow of fission heat the heat generation rates calculated with the FABGEN routine are used to determine a linear heat rate for each longitudinal section as illustrated in Fig. 5. This calculation is accomplished by adding to the heat produced in each holder, Q_n^f, one-half of the heat generated in the two holders 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, $ZDIM_{n+1} - ZDIM_{n-1}$. The linear heat rate (LHR) in kW/ft for holder n is described by Eq. (4):

$$LHR_n = \left[Q_n^f + 1/2(Q_{n-1}^f + Q_{n+1}^f\right] \Big/ \left(ZDIM_{n+1} - ZDIM_{n-1}\right) . \qquad (4)$$

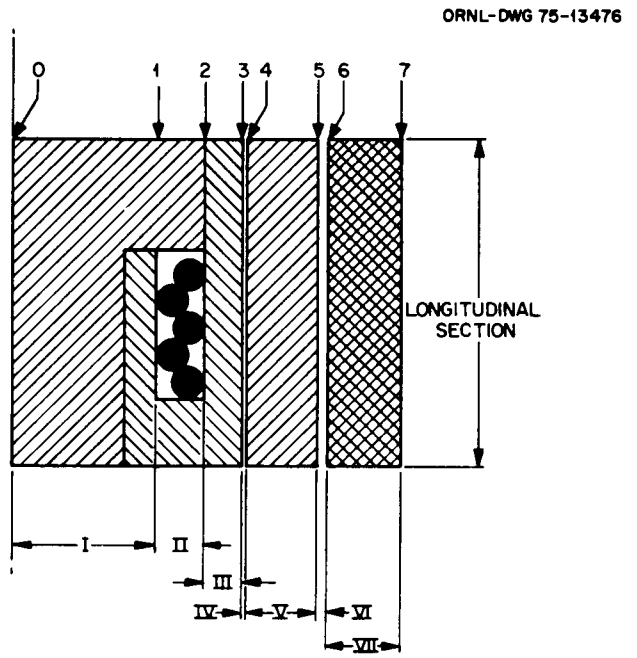


Fig. 4. Region Description of HT Capsule Longitudinal Section.

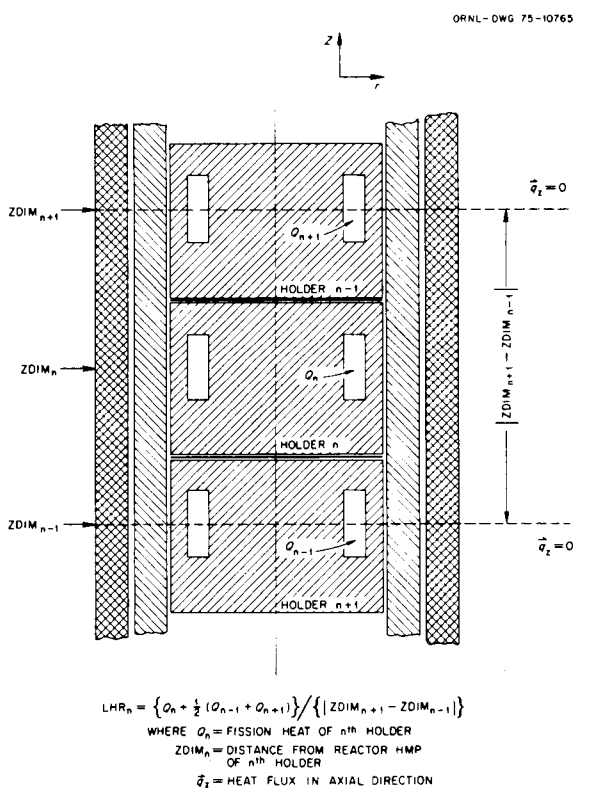


Fig. 5. Linear Heat Rate Determination.

Eighty percent of the heat generated within an HT capsule is due to gamma heating. Figure 6 describes the experimentally determined gamma heating rate[16] as a function of distance from the reactor HMP. Data for the high- and low-temperature regions for one-half of the capsule are shown along with a least-squares polynominal fit to the data, Eq. (5):

$$PGAM_n(Z) = 34.554 - 0.650*ZDIM_n - 0.214*(ZDIM_n)^2 + 1.295E-2*(ZDIM_n)^3 \ , \quad (5)$$

where $ZDIM_n$ = axial distance of the midpoint of holder n to the the reactor HMP. The heat generated in the ith region due to gamma heating is

$$Q_i^\gamma = PGAM_n(Z)V_i\rho_i \quad \text{watts} \ , \quad (6)$$

where

V_i = volume of ith region,

ρ_i = density of material in ith region,

[16]Personal communication, B. H. Montgomery to M. J. Kania, August 1974.

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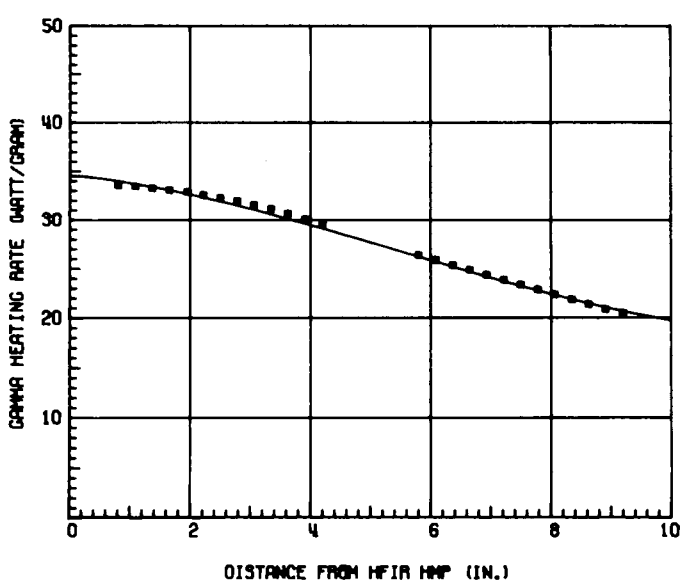

Fig. 6. Gamma Heating Rate in the HFIR Target Region.

and the total heat generated in a longitudinal section is

$$Q_n^t = \mathrm{LHR}_n{*}(1\ \mathrm{ft}) + \mathrm{PGAM}_n \sum_{i=1}^{J} V_i \rho_i \ \mathrm{watts}\ , \tag{7}$$

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 GENGTC program. The initial step in these calculations is to determine the outer surface temperature of the aluminum containment vessel. Knowing the average coolant temperature and the heat transfer coefficient at the surface, the surface temperature can be determined from Eq. (8):

$$T_s = T_\infty + Q_t/hA_n\ , \tag{8}$$

where

T_∞ = average coolant temperature,

Q_t = total heat generated within nth longitudinal section as determined from Eq. (7),

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. (9):

$$T_{i-1} = T_i + G_i(R_i^2 - R_{i-1}^2)/4k_i + q_{i-1}R_{i-1}/k_i - G_i R_{i-1}^2/2k_i \ \ln(R_i/R_{i-1})\ , \tag{9}$$

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

$$G_i = Q_i^{\gamma}/V_i \tag{10}$$

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

$$G_2 = \mathrm{LHR}_n{*}(1\ \mathrm{ft}) + Q_2^{\gamma}\ . \tag{10a}$$

The incident heat flux on the inside surface is described by

$$q_{i-1} = \left[\mathrm{LHR}_n{*}(1\ \mathrm{ft}) + \sum_{k=1}^{i-1} Q_k^{\gamma}\right] / \left[2\pi R_{i=1}(1\ \mathrm{ft})\right] \tag{11}$$

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

$$q_1 = Q_1^{\gamma} / \left[2\pi R_1(1\ \mathrm{ft})\right]\ . \tag{11a}$$

HTCAP 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 (regions IV and VI in Fig. 4) 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

$$Q_i = \sigma \mathcal{F}_{\varepsilon}\ (T_{i-1}^4 - T_i^4)\ 2\pi R_i(1\ \mathrm{ft}) - \frac{k_i(T_{i-1} - T_i)2\pi\ (1\ \mathrm{ft})}{\ln\ (R_{i-1}/R_i)}\ , \tag{12}$$

where

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

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

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

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

$\mathcal{F}_{\varepsilon}$ = emissivity factor[17] $\left[= \dfrac{1}{1(\varepsilon_{i-1} + (R_{i-1}/R_i){*}(1/\varepsilon_i - 1)}\right]$.

[17] S. T. Hsu, *Engineering Heat Transfer*, Van Nostrand, New York, 1963.

The gas gap inside surface temperature is calculated by initially equating T_{i-1} to T_i and incrementing T_{i-1} by +35°C until the sum of the radiation and conduction terms exceeds Q_i. At this point the increment is changed to −5°C. 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, $\langle T \rangle$.

After the initial set of temperature calculations, the dimensions of each region are recalculated as a function of temperature and fast neutron fluence ($E > 0.18$ MeV). Dimensional changes due to thermal expansion are calculated as described in the GENGTC program. Dimensional changes due to accumulated fast fluence are based on results obtained from experiments HT-14, -15, and -19. These data are summarized in Figs. 7 and 8 for the low-temperature, low-flux sleeves and the high-temperature, high-flux sleeves respectively. Also shown in each figure is the least-squares polynominal fit to the experimental data. Equations (13) and (14) describe the dimensional changes as a function of accumulated fast neutron fluence for the low- and high-temperature regions respectively:

$$\left(D/D_o\right)_L = \exp\left[8.351\text{E}{-4} + 2.037\text{E}{-2}*(F_3) - 8.924\text{E}{-3}*(F_3)^2\right], \qquad (13)$$

$$\left(D/D_o\right)_H = \exp\left[-4.993\text{E}{-2}*(F_3) + 8.575\text{E}{-2}*(F_3)^2\right], \qquad (14)$$

where

D/D_o = ratio of postirradiation diameter/preirradiation diameter,

F_3 = ratio of fast neutron fluence/11.84×10^{21} neutrons/cm^2 .

Accumulated fast neutron fluence is determined by multiplying the analytic expression for fast damage flux, evaluated at a particular axial position, by the number of accrued full power days. In each iteration, the radii are corrected and the temperature calculations are repeated until the difference between two successive iterations is ≤5°C.

For those particle holders containing ThO_2-coated particles, the computational model PARTMP[18] is employed to determine particle

[18]Personal communication, S. H. Jury to M. J. Kania, February 1975.

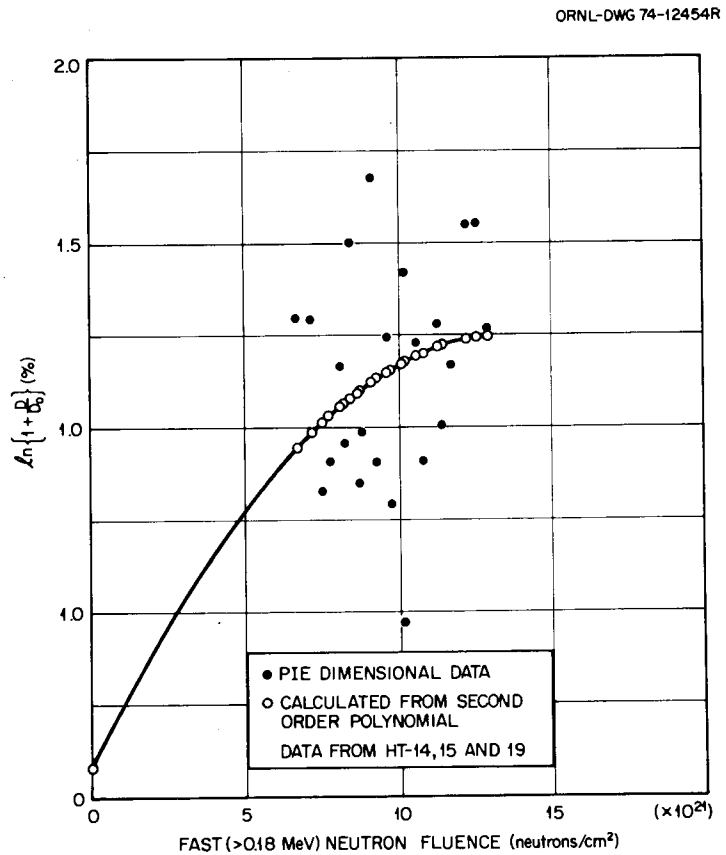

Fig. 7. Dimensional Changes vs Fluence for the Low-Temperature Particle Holders and Sleeves.

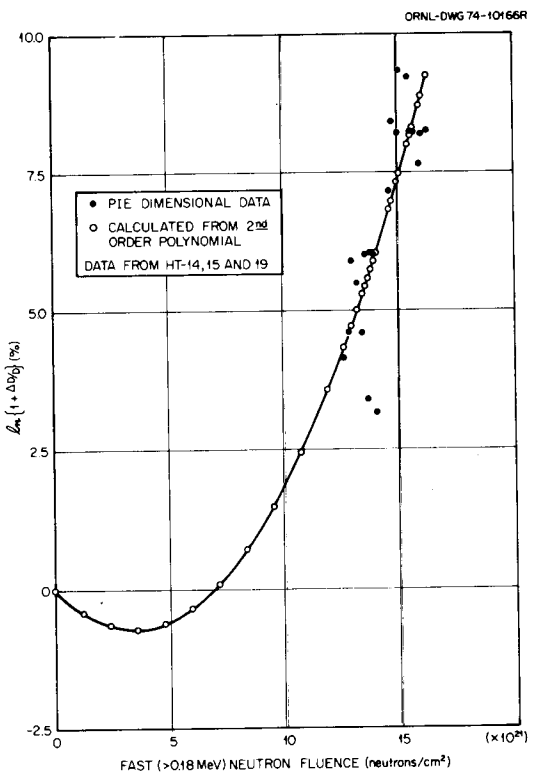

Fig. 8. Dimensional Changes vs Fluence for the High-Temperature Particle Holders and Sleeves.

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 OD within each particle holder. The exact arrangement of the particles within the fueled annulus is not known. However, previous results indicate that the average temperature difference between annulus walls, when a particle is in contact with one of the walls, is on the order of 20°C or less. Typical thicknesses for the annulus are from 0.023 to 0.053 in., depending on the particle diameter.

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 more 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 (15) describes an energy balance for this process:

$$Q_p = \sigma \mathcal{F}_\varepsilon (T_1^4 - T_2^4) A_1 + \frac{k_{Ar}(T_1 - T_2) A_{gm}}{(r_2 - r_1)} , \tag{15}$$

where

Q_p = heat transfer rate per particle,

$\mathcal{F}_\varepsilon$ = emissivity factor $\left[= \dfrac{1}{1/\varepsilon + (r_1^2/r_2^2)*(1/\varepsilon - 1)} \right]$,

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_{Ar} = argon gas thermal conductivity,

A_1 = surface area of particle ($4\pi r_1^2$),

A_{gm} = geometric mean surface area[19] ($4\pi r_1 r_2$, r_2 = radius associated with volume of particle plus gas shell).

[19] R. A. Greenkorn and D. P. Kessler, *Transfer Operations*, McGraw-Hill, New York, 1972.

The maximum particle surface temperature T_1 is calculated by the same iterative procedure used for the inside surface temperature of gas gaps within the sample holder.

INPUT AND CALCULATIONAL PROCEDURE

A flow chart describing the HTCAP program is shown in Fig. 9. A full listing of the HTCAP 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.

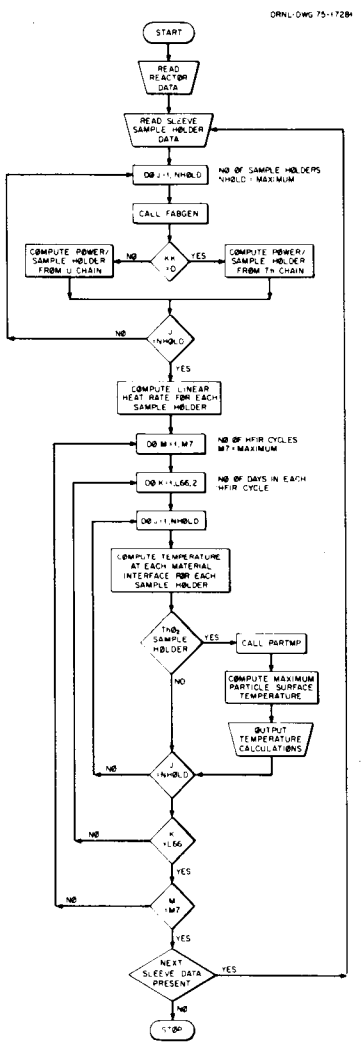

Fig. 9. Flow Chart for the HTCAP Program.

Data input into the HTCAP program has been arranged to describe a complete high-temperature or low-temperature sleeve of the experiment as follows:

1. reactor operation over the life of the irradiation experiment (card types 1–8);

2. ThO_2-coated particles in their respective holders (card types 9–10);

3. one-fourth of the HT capsule including sample holders, end plugs, graphite sleeve, and aluminum containment vessel (card types 11–18).

All dimensional data (r and z) are input as design dimensions. Card type 12 requires that the user provide a smeared density and thermal conductivity for the fueled region of each sample holder. Card type 18 also requires the user to calculate the initial fissile or fertile isotope number density (nuclei/cm^3) in the fueled region of each sample holder.

The calculational procedure is as follows:

1. Call FABGEN subroutine to compute fission heat generation rates for each sample holder on a day-to-day basis for each irradiation cycle considered.

2. Compute linear heat generation rates applicable to each sample holder and end plug on a day-to-day basis for each irradiation cycle.

3. Compute temperatures at each material interface (radial node) for each sample holder:

   (a) initially based on cold dimensions;

   (b) recalculate considering fast neutron fluence (E > 0.18 MeV) and temperature-dependent dimensional changes;

   (c) continue until solution converges;

   (d) for ThO_2 particle holders, call PARTMP subroutine to compute maximum particle surface temperatures;

   (e) output maximum operating temperatures for each ThO_2 particle on a day-to-day basis for each HFIR cycle.

THERMAL ANALYSIS OF SLEEVE CP-62 OF HT-15

As an illustrative example of the use of the HTCAP computer code, consider HFIR irradiation experiment HT-15. Only one sleeve (CP-62) is considered. This is the high-temperature, high-fluence region containing particle holders 27 through 39. Particle holders 27, 29, 30, 32, 33, 35, 36, and 38 each contain separate batches of Biso-coated ThO_2 particles. The remaining five sample holders contain uranium (7% enriched) particles. Table 3 describes the contents and configuration of this sleeve. Table 4 describes the irradiation history for HT-15 and how it is represented in the HTCAP input data.

In Appendix C, Table C-1 describes the input data for this sleeve, and Table C-2 describes the tabular output for this thermal analysis. Results are printed at two-day intervals beginning with day 1 of each irradiation cycle and for each ThO_2 test particle.

Table 3. HT-15 Irradiation Experiment: High-Temperature High-Fluence Sleeve CP-62

Sample Holder	Batch[a,b]	Particle Type	Design Dimensions[c]	Sample Holder[d] Location (in.)	Accumulated Damage Fluence $\times 10^{21}$ neutrons/cm^2 ($E > 0.18$ MeV)
Top End Plug	—	U	—	0.437	—
27	GGA 4252-02	ThO_2	508-83-75	0.801	16.2
28	—	U	—	1.084	16.2
29	ORNL OR-1838	ThO_2	402-32-64	1.366	16.1
30	GGA 4252-03	ThO_2	501-92-67	1.649	16.0
31	—	U	—	1.931	15.9
32	ORNL OR-1826	ThO_2	402-21-31	3.214	15.7
33	GGA 4252-01	ThO_2	487-61-76	2.496	15.6
34	—	U	—	2.779	15.5
35	ORNL OR-1830	ThO_2	402-1-38	3.061	15.3
36	GGA 4252-07	ThO_2	485-46-50	3.344	15.1
37	—	U	—	3.626	14.9
38	ORNL OR-1837	ThO_2	402-1-24	3.909	14.6
39	—	U	—	4.199	14.5
Bottom End Plug	—	None	—	4.563	—

[a]Batch numbers are listed for ThO_2 test particles only.

[b]GGA denotes Gulf General Atomic, presently General Atomic Company.

[c]Design given as kernel diameter, buffer thickness, outer pyrocarbon thickness, all in micrometers.

[d]Distance measured with respect to HMP.

Table 4. Irradiation History for HT-15

Capsule	HFIR Cycle	Begin	End	Accumulated Irradiation (100-MW Power Days)	HTCAP Cycle	Total Days in Cycle	Full Power Days (100-MW Power Days)
HT-15	85	11-20-72	12-13-72	23.09	1	24	23
	86[a]	12-13-72	1-7-73	46.35	2	26	23
	87A	1-9-73	1-10-73		3	3	1
	87B	1-12-73	2-3-73	68.86	4	22	21
	88	2-3-73	2-26-73	91.41	5	24	23
	89	2-27-73	3-22-73	114.14	6	24	23
	90	3-23-73	4-15-73	137.00	7	26	23
	91	4-18-73	5-11-73	159.96 (total)	8	23 (total = 172)	23 (total = 160)

[a]Includes two days at 50 MW reactor power.

The temperatures calculated with the HTCAP program have been compared with those calculated with the HTTEMP and HEATING3 codes for HT-15. As described earlier, that analysis used a two-dimensional (r,z) heat transfer analysis with the HEATING3 code, to determine the annulus OD temperature. Particle surface temperatures were determined by a parametric relationship between the annulus surface temperature and the heat generated per particle. This comparison, Table 5, shows good agreement between the two computational procedures; the largest variation is 6.5%. If one considers the uncertainties[20] in the calculated fluxes of ±15% and in the calculated ^{232}Th capture cross section of ±25%, HTCAP calculates particle surface temperatures within ±9% of those in Table 5. Therefore, the differences in surface temperatures calculated by the two methods are within the uncertainty of the experiment.

The computational time required for the HTCAP thermal analysis of sleeve CP-62 was on the order of 30 sec on the IBM 360/91, whereas the previous analysis (HTTEMP and HEATING3 thermal analysis) required 25 min for a limited amount of particle operating history data.

[20]Personal communication, H. T. Kerr to M. J. Kania, August 1974.

Table 5. Comparison of Temperature Calculations

Particle Holder (diam)[a]	Two-Dimensional Heat Transfer Analysis				One-Dimensional HTCAP Analysis				Percent Difference between Two Methods of Particle Surface Temperature
	Exposure Time (cycle, day)	Annulus Temp HEATING3 (°C)	W/Particle	Particle Surface Temp T1 (°C)	Corresponding Exposure Time (cycle, day)	Annulus OD Temp (°C)	W/Particle	Particle Surface Temp T2 (°C)	$\left[(T_2 - T_1)/T_1\right]$
27 (834 μm)	1, 0	1420	0.04	1425	1, 1	1481	0.007	1481	3.93
	1, 23	1227	0.40	1374	1, 23	1308	0.415	1438	4.66
	3, 9	1316	0.82	1595	4, 7	1364	0.839	1584	−0.69
	6, 9	1276	0.97	1630	7, 9	1361	0.888	1591	−2.39
29 (593 μm)	1, 0	1360	0.02	1370	1, 1	1322	0.004	1322	−3.50
	1, 23	1193	0.20	1330	1, 23	1254	0.204	1389	4.44
	3, 9	1285	0.40	1525	4, 7	1335	0.414	1555	1.97
	6, 9	1266	0.48	1520	7, 9	1356	0.438	1568	3.16
30 (819 μm)	1, 0	1372	0.04	1385	1, 1	1324	0.007	1324	−4.40
	1, 23	1205	0.38	1365	1, 23	1281	0.391	1330	−2.56
	3, 9	1319	0.77	1585	4, 7	1383	0.795	1593	0.50
	6, 9	1322	0.93	1635	7, 9	1387	0.838	1602	−2.02
32 (506 μm)	1, 0	1349	0.02	1350	1, 1	1317	0.004	1317	−2.44
	1, 23	1184	0.19	1345	4, 23	1243	0.199	1330	−1.12
	3, 9	1282	0.39	1555	4, 7	1320	0.406	1600	2.89
	6, 9	1288	0.47	1610	7, 9	1323	0.429	1618	0.50
33 (761 μm)	1, 0	1365	0.03	1370	1, 1	1313	0.006	1313	−4.16
	1, 23	1194	0.34	1360	1, 23	1261	0.350	1321	−2.87
	3, 9	1305	0.69	1585	4, 7	1359	0.716	1584	−0.06
	6, 9	1327	0.84	1648	7, 9	1365	0.758	1600	−2.91
35 (480 μm)	1, 0	1352	0.02	1355	1, 1	1318	0.003	1318	−2.73
	1, 23	1175	0.19	1355	1, 23	1238	0.192	1333	−1.62
	3, 9	1268	0.38	1510	4, 7	1321	0.395	1608	6.49
	6, 9	1289	0.46	1610	7, 9	1324	0.421	1629	1.18
36 (677 μm)	1, 0	1375	0.03	1380	1, 1	1305	0.006	1305	−5.43
	1, 23	1180	0.32	1370	1, 23	1256	0.331	1327	−3.14
	3, 9	1282	0.67	1585	4, 7	1351	0.686	1608	1.45
	6, 9	1314	0.81	1650	7, 9	1357	0.732	1632	−1.09
38 (452 μm)	1, 0	1400	0.02	1405	1, 1	1497	0.003	1497	6.55
	1, 23	1141	0.18	1350	1, 23	1264	0.182	1416	4.89
	3, 9	1193	0.37	1505	4, 7	1279	0.381	1601	6.38
	6, 9	1203	0.45	1600	7, 9	1267	0.409	1617	1.06

[a]Diameter of ThO_2 particles contained within particle holder.

CONCLUSION

The HTCAP computer code presented in this report has been shown to be a valuable analytical tool for calculating the extremes in coated-particle operating temperature in accelerated irradiation tests of the HT series. Detailed time-temperature and power-particle histories for each particle during its entire irradiation life can be calculated with a small amount of computation time. Typical running times on the IBM 360/91 for an entire HT capsule (32 test particle holders) require less than 3 min total CPU time with a core storage requirement of <270K. Results are quite consistent with previous results, using a more complex analysis, and can be obtained in a fraction of the time. HTCAP is flexible enough to incorporate more accurate data on the capsule nuclear environment, material thermal properties, and materials dimensional stability as they become available.

In addition to its use for postirradiation thermal analysis, HTCAP can be an effective design tool for future loose-coated-particle experiments in the HT series: in particular, it can be used to determine fuel loadings required to maintain isothermal conditions within each temperature region, the graphite sleeve dimensions, and to calculate prospective changes in the capsule design that would allow greater numbers of particles to be tested.

ACKNOWLEDGMENTS

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APPENDIX A

FORTRAN Listing of HTCAP

```
**FTN,M,L,E,G,P.
      PROGRAM HTCAP                                                     HTCAP 10
      IMPLICIT REAL*8(A-H,O-Z)                                          HTCAP 20
      INTEGER*4 HW,CHAIN,ANAME,STEMP                                    HTCAP 30
      COMMON/BLOK1/M7,ND3,L6(30),L9(30),D1,D6,R0,R1,Z0,Z1,NCYC(10),     HTCAP 40
     1       AH,F(2),NPOL1,NPOL2,ZZ1(3),ZZ2(3),FLXI,FLXF,STKP(15,30,8),  HTCAP 41
     2NHOLD,JJJ,AI(9),TS(9),KKK,IDATA                                   HTCAP 42
      DIMENSION TITLE(18),ZDIM(15),ND9(15),RDIM(9,15),E(9,15),MX(9,15),HHTCAP 50
     1W(9,15),F9(15,30,8),R(9,15),PGAM(15),V(9,15),G(9,15),P(9,15),A(9,1HTCAP 51
     25),Q(9,15),Q9(15),T(10,15),Y(9,15),Z(4,9),ANAME(15),TISO(9,15),   HTCAP 52
     3AN(9,15),CHAIN(15),R00(15),R10(15),Z00(15),Z10(15),DIA(15),STEMP(1HTCAP 53
     45),RF(15),RBF(15),RLTI(15),PNO(15),ZYX(15,9),PW(28,15),TOD(28,15),HTCAP 54
     5TPI(28,15),B1NM(15),B2NM(15),AVER(15)                             HTCAP 55
C*********************************************************************
C                                                                     *
C     THE HTCAP PROGRAM CALCULATES TEMPERATURES FOR HFIR TARGET CAPSULES.  *
C     IN PARTICULAR, FOR THE DESIGN OF HT-12 THROUGH -15, AND HT-17 THROUGH *
C     -19. ONLY THOSE PARTICLE HOLDERS CONTAINING THO2 HAVE TEMPERATURE   *
C     PRINTOUTS. THIS PROGRAM UTALIZES TWO PROGRAMS AUTHORED BY HALL C.   *
C     ROLAND. THEY ARE 'GENGTC' AND 'FABGEN'. BOTH PROGRAMS HAVE BEEN     *
C     MODIFIED TO MEET THE NEEDS OF HTCAP.                                *
C                                                                         *
C                                                                         *
C     'HT' CONSISTS OF A MAIN PROGRAM AND TWO SUBROUTINES. 'FABGEN' AND   *
C     'PTLTM'. RESPECTIVELY THEY CALCULATE POWER GENERATED/PARTICLE HOLD  *
C     AND MAXIMUM PARTICLE SURFACE TEMPERATURE WITHIN EACH HOLDER.        *
C     CALCULATIONS ARE MADE FOR EACH DAY DURING A HFIR CYCLE. BOTH FULL   *
C     POWER DAYS AND DOWN DAYS ARE CONSIDERED IN THE ANALYSIS.            *
C                                                                         *
C*********************************************************************
C*                                                                     HTCA 230
C*                    DATA FOR MATERIAL Z(I,J)                         HTCA 240
C*        I=1   POCO GRAPHITE                                          HTCA 250
C*         =2   U OR TH FUELED REGION                                  HTCA 260
C*         =3   ALUMINUM CONTAINMENT VESSEL                            HTCA 270
C*         =4   ARGON BACKFILL GAS                                     HTCA 280
C*                                                                     HTCA 290
C*        J=1     MATERIAL DENSITY (GM/CC)                             HTCA 300
C*         =2-6   COEFFICIENTS FOR MATERIAL THERMO CONDUCTIVITY (4TH ORDER)  310
C*         =7-9   COEFFICIENTS FOR MATERIAL DIMENSIONAL CHANGE CHARACTERISTS  320
C*                                                                     HTCA 330
      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,-HTCA 340
     12.808E-6/                                                         HTCA 341
      DATA (Z(3,J),J=1,9)/2.6989,117.0,0.0039,0.163E-4,0.813E-7,0.596E-1HTCA 350
     10,12.16,.00302,0.0/                                               HTCA 351
      DATA (Z(4,J),J=1,9)/1.7838E-3,7.985E-3,1.924E-5,-3.607E-9,-2.792E-HTCA 360
     112,1.288E-15,0.0,0.0,0.0,0.0/                                     HTCA 361
 10   READ 6225,(TITLE(I),I=1,18)                                       HTCA 370
      READ 6235,NHOLD,M7,ND3,IDATA                                      HTCA 380
      READ 6235,(L6(I),L9(I),I=1,M7)                                    HTCA 390
      F(1)=1.0E+15                                                      HTCA 400
      F(2)=1.0E+15                                                      HTCA 410
      READ 6435,IPOL1,IPOL2,FLXI,FLXF                                   HTCA 420
      NPOL1=IPOL1+1                                                     HTCA 430
      NPOL2=IPOL2+1                                                     HTCA 440
      READ 6375,(ZZ1(I),I=1,NPOL1)                                      HTCA 450
      READ 6375,(ZZ2(I),I=1,NPOL2)                                      HTCA 460
```

```
      READ 6415,N9,T9,R9,H9,D1,D6                                       HTCA 470
      READ 6235,(NCYC(I),I=1,M7)                                        HTCA 480
      READ 6445,(DIA(J),RF(J),RBF(J),RLTI(J),ZDIM(J),Z00(J),Z10(J),PND(JHTCA 490
     1),ND9(J),J=1,15)                                                  HTCA 491
      READ 6005,(B1NM(J),B2NM(J),J=1,NHOLD)                             HTCA 500
 6005 FORMAT(6(A8,A3))                                                  HTCA 510
      T9=T9+460.0                                                       HTCA 520
      PRINT 6305                                                        HTCA 530
C     READ DATA FOR EACH THO2 PARTICLE HOLDER (I.E. EACH HOLDER)        HTCA 540
      DO 20 J=1,NHOLD                                                   HTCA 550
      READ 6455,ANAME(J),CHAIN(J),STEMP(J)                              HTCA 560
      READ 6425,(ZYX(J,K),K=1,8)                                        HTCA 570
      ZYX(J,9)=0.0                                                      HTCA 580
      READ 6335,(TISO(I,J),I=1,6)                                       HTCA 590
      N9D=ND9(J)                                                        HTCA 600
      READ 6295,(RDIM(I,J),I=1,N9D)                                     HTCA 610
      READ 6295,(E(I,J),I=1,N9D)                                        HTCA 620
      READ 6235,(MX(I,J),I=1,N9D)                                       HTCA 630
      READ 6235,(HW(I,J),I=1,N9D)                                       HTCA 640
      READ 6365,(AN(I,J),I=1,7),AH                                      HTCA 650
 20   CONTINUE                                                          HTCA 660
C      M=CYCLE NUMBER AND K=DAY NUMBER                                  HTCA 670
      DO 40 J=1,NHOLD                                                   HTCA 680
      KKK=CHAIN(J)                                                      HTCA 690
      JJJ=J                                                             HTCA 700
      R0=RDIM(1,J)                                                      HTCA 710
      R1=RDIM(2,J)                                                      HTCA 720
      Z0=Z00(J)                                                         HTCA 730
      Z1=Z10(J)                                                         HTCA 740
      DO 30 I=1,9                                                       HTCA 750
      AI(I)=AN(I,J)                                                     HTCA 760
      TS(I)=TISO(I,J)                                                   HTCA 770
 30   CONTINUE                                                          HTCA 780
      CALL FABGEN                                                       HTCA 790
 40   CONTINUE                                                          HTCA 800
      DO 90 M=1,M7                                                      HTCA 810
      N6=L6(M)                                                          HTCA 820
      N9=L9(M)                                                          HTCA 830
      DO 80 K=1,N6                                                      HTCA 840
      DO 70 J=1,NHOLD                                                   HTCA 850
      IF(J.GT.1) GO TO 50                                               HTCA 860
      F98=STKP(1,K,M)+.5*STKP(2,K,M)                                    HTCA 870
      F99=F98/(ZDIM(2)-.2188)                                           HTCA 880
      F9(1,K,M)=F99*12.0                                                HTCA 890
      GO TO 70                                                          HTCA 900
 50   IF(J.EQ.15) GO TO 60                                              HTCA 910
      F98=STKP(J,K,M)+.5*STKP(J-1,K,M)+.5*STKP(J+1,K,M)                 HTCA 920
      F99=F98/(ZDIM(J+1)-ZDIM(J-1))                                     HTCA 930
      F9(J,K,M)=F99*12.0                                                HTCA 940
      GO TO 70                                                          HTCA 950
 60   F98=STKP(15,K,M)+.5*STKP(14,K,M)                                  HTCA 960
      F99=F98/(ZDIM(2)-.2188)                                           HTCA 970
      F9(15,K,M)=F99*12.0                                               HTCA 980
 70   CONTINUE                                                          HTCA 990
 80   CONTINUE                                                          HTC 1000
 90   CONTINUE                                                          HTC 1010
      DO 900 M=1,M7                                                     HTC 1020
```

```
      IF(IDATA)100,110,110                                              HTC 1030
100   PRINT 6015,M                                                      HTC 1040
6015  FORMAT(1H1,' DIMENSIONAL CHANGES FOR HOLDERS DURING CYCLE ',I2)   HTC 1050
      PRINT 6025                                                        HTC 1060
6025  FORMAT(1H0,10X,'INITIAL RADIUS   FINAL RADIUS  DAMAGE FLUENCE')   HTC 1070
      PRINT 6035                                                        HTC 1080
6035  FORMAT('  HOLDER        (IN)            (IN)          (N/CM**2)')  HTC 1090
110   L66=L6(M)                                                         HTC 1100
      L99=L9(M)                                                         HTC 1110
      DO 730 K=1,L66,2                                                  HTC 1120
      DO 130 J=1,NHOLD                                                  HTC 1130
      DO 120 I=1,9                                                      HTC 1140
      R(I,J)=RDIM(I,J)                                                  HTC 1150
120   CONTINUE                                                          HTC 1160
130   CONTINUE                                                          HTC 1170
      C9=0.                                                             HTC 1180
      NIN=1                                                             HTC 1190
      AL=12.                                                            HTC 1200
      DO 720 J=1,NHOLD                                                  HTC 1210
      DO 140 L=1,9                                                      HTC 1220
      Z(2,L)=ZYX(J,L)                                                   HTC 1230
140   CONTINUE                                                          HTC 1240
150   N9D=ND9(J)                                                        HTC 1250
      IF(K-L9(M))160,160,170                                            HTC 1260
160   PGAM(J)=34.5540116-.6498723*ZDIM(J)-.21359252*(ZDIM(J)**2)+1.29554HTC 1270
     12E-2*(ZDIM(J)**3)                                                 HTC 1271
      GO TO 180                                                         HTC 1280
170   PGAM(J)=0.                                                        HTC 1290
180   DO 290 I=1,N9D                                                    HTC 1300
190   IF(I-1)200,200,210                                                HTC 1310
200   V(I,J)=(R(I,J)**2)*AL*0.0018181                                   HTC 1320
      GO TO 220                                                         HTC 1330
210   V(I,J)=(R(I,J)**2-R(I-1,J)**2)*AL*0.0018181                       HTC 1340
220   NT=HW(I,J)                                                        HTC 1350
      G(I,J)=PGAM(J)*Z(NT,1)*96646.                                     HTC 1360
      IF(NT-2)240,230,240                                               HTC 1370
230   P(I,J)=V(I,J)*G(I,J)+F9(J,K,M)*3413.                              HTC 1380
      GO TO 250                                                         HTC 1390
240   P(I,J)=V(I,J)*G(I,J)                                              HTC 1400
250   A(I,J)=0.043633*R(I,J)*AL                                         HTC 1410
260   IF(I-1)280,280,270                                                HTC 1420
270   P(I,J)=P(I,J)+P(I-1,J)                                            HTC 1430
280   Q(I,J)=P(I,J)/A(I,J)                                              HTC 1440
290   CONTINUE                                                          HTC 1450
      Q9(J)=P(ND9(J),J)/A(ND9(J),J)                                     HTC 1460
300   T5=Q9(J)/H9                                                       HTC 1470
310   T(N9D,J)=T5+T9                                                    HTC 1480
      FFLUX=1.178517-2.95535E-3*ZDIM(J)-6.10752E-3*ZDIM(J)**2-1.9206E-4*HTC 1490
     1ZDIM(J)**3+1.003E-5*ZDIM(J)**4                                    HTC 1491
      F1=137.*1.E+15                                                    HTC 1500
      IF(M.NE.1) GO TO 340                                              HTC 1510
      IF(K-L99)320,320,330                                              HTC 1520
320   F2=FFLUX*K*1.E+15                                                 HTC 1530
      GO TO 390                                                         HTC 1540
330   F2=FFLUX*L99*1.E+15                                               HTC 1550
      GO TO 390                                                         HTC 1560
340   K25=0                                                             HTC 1570
```

```
      M25=M-1                                                           HTC 1580
      DO 350 M2=1,M25                                                   HTC 1590
      K25=K25+L9(M2)                                                    HTC 1600
  350 CONTINUE                                                          HTC 1610
      IF(K-L99)360,360,370                                              HTC 1620
  360 K2=K25+K                                                          HTC 1630
      GO TO 380                                                         HTC 1640
  370 K2=K25+L99                                                        HTC 1650
  380 F2=FFLUX*K2*1.0E+15                                               HTC 1660
  390 F3=F2/F1                                                          HTC 1670
      IF(STEMP(J))400,400,410                                           HTC 1680
  400 F4=EXP(8.3511E-4+2.036887E-2*F3-8.92418E-3*F3**2)                 HTC 1690
      GO TO 420                                                         HTC 1700
  410 F4=EXP(-4.992735E-2*F3+8.574773E-2*F3**2)                         HTC 1710
  420 N9D=ND9(J)                                                        HTC 1720
      N8D=N9D+2                                                         HTC 1730
  430 DO 530 I3=2,N9D                                                   HTC 1740
      I2=N8D-I3                                                         HTC 1750
      I1=I2-1                                                           HTC 1760
      NT=HW(I2,J)                                                       HTC 1770
      T(I1,J)=T(I2,J)                                                   HTC 1780
      RLG=R(I1,J)*DLOG(R(I2,J)/R(I1,J))                                 HTC 1790
      IF(MX(I2,J))460,460,440                                           HTC 1800
  440 DO 450 L=1,5                                                      HTC 1810
      B=(T(I1,J)+T(I2,J))/2.-460.                                       HTC 1820
      AK=Z(NT,2)+Z(NT,3)*B+Z(NT,4)*B**2+Z(NT,5)*B**3+Z(NT,6)*B**4       HTC 1830
      T(I1,J)=T(I2,J)+G(I2,J)*(R(I2,J)**2-R(I1,J)**2)/(576.*AK)         HTC 1840
      T(I1,J)=T(I1,J)+P(I1,J)*RLG/(12.*A(I1,J)*AK)                      HTC 1850
      T(I1,J)=T(I1,J)-G(I2,J)*R(I1,J)*RLG/(288.*AK)                     HTC 1860
  450 CONTINUE                                                          HTC 1870
      Y(I2,J)=AK                                                        HTC 1880
      GO TO 530                                                         HTC 1890
  460 N=1                                                               HTC 1900
      X=35.                                                             HTC 1910
      F0=1./(1./(E(I1,J)+1.E-8)+R(I1,J)/R(I2,J)*(1./(E(I2,J)+1.E-8)-1.))HTC 1920
  470 T(I1,J)=T(I1,J)+X                                                 HTC 1930
      Q1=0.1714*F0*A(I1,J)*((T(I1,J)/100.)**4-(T(I2,J)/100.)**4)        HTC 1940
      B=(T(I1,J)+T(I2,J))/2.-460.                                       HTC 1950
      AK=Z(NT,2)+Z(NT,3)*B+Z(NT,4)*B**2+Z(NT,5)*B**3+Z(NT,6)*B**4       HTC 1960
      Y(I2,J)=AK                                                        HTC 1970
      Q2=A(I1,J)*AK*12.*(T(I1,J)-T(I2,J))/RLG                           HTC 1980
      Q3=Q1+Q2                                                          HTC 1990
      IF(Q3-P(I2,J))480,530,500                                         HTC 2000
  480 IF(N-1)470,470,490                                                HTC 2010
  490 GO TO 530                                                         HTC 2020
  500 IF(N-1)520,520,510                                                HTC 2030
  510 GO TO 470                                                         HTC 2040
  520 N=2                                                               HTC 2050
      X=-5.                                                             HTC 2060
      GO TO 470                                                         HTC 2070
  530 CONTINUE                                                          HTC 2080
C     CALCULATE DIMENSIONAL CHANGES DUE TO FAST NEUTRON DAMAGE          HTC 2090
      N9D=ND9(J)                                                        HTC 2100
      N7D=N9D+1                                                         HTC 2110
      DO 650 I4=1,N9D,2                                                 HTC 2120
      I5=N7D-I4                                                         HTC 2130
      NT=HW(I5,J)                                                       HTC 2140
```

```
      IF(I5-1)610,610,540                                               HTC 2150
540   IF(NT-1)550,550,570                                               HTC 2160
550   IF(NIN-1)560,560,570                                              HTC 2170
560   R(I5,J)=R(I5,J)*F4                                                HTC 2180
      R(I5-1,J)=R(I5-1,J)*F4                                            HTC 2190
570   B=(T(I5,J)+T(I5-1,J))/2.-460.                                     HTC 2200
      B=B-70.                                                           HTC 2210
      A7=(Z(NT,7)+Z(NT,8)*B+Z(NT,9)*B**2)*1.0E-6                        HTC 2220
      R(I5,J)=R(I5,J)+(RDIM(I5,J)*(1.+A7*B)-R(I5,J))/3.                 HTC 2230
      IF(I5-3)580,580,600                                               HTC 2240
580   IF(N9D-7)600,590,600                                              HTC 2250
590   B2=(T(1,J)+T(2,J))/2.-460.                                        HTC 2260
      B2=B2-70.                                                         HTC 2270
      R(2,J)=R(2,J)+(RDIM(2,J)*(1.+A7*B)-R(2,J))/3.                     HTC 2280
      GO TO 650                                                         HTC 2290
600   R(I5-1,J)=R(I5-1,J)+(RDIM(I5-1,J)*(1.+A7*B)-R(I5-1,J))/3.         HTC 2300
      GO TO 650                                                         HTC 2310
610   IF(NT-1)620,620,640                                               HTC 2320
620   IF(NIN-1)630,630,640                                              HTC 2330
630   R(I5,J)=R(I5,J)*F4                                                HTC 2340
640   B=T(I5,J)-400.                                                    HTC 2350
      B=B-70.                                                           HTC 2360
      A7=(Z(NT,7)+Z(NT,8)*B+Z(NT,9)*B**2)*1.0E-6                        HTC 2370
      R(I5,J)=R(I5,J)+(RDIM(I5,J)*(1.+A7*B)-R(I5,J))/3.                 HTC 2380
650   CONTINUE                                                          HTC 2390
      N9D=ND9(J)                                                        HTC 2400
      N8D=N9D+2                                                         HTC 2410
      DO 670 I6=2,N9D                                                   HTC 2420
      I8=N8D-I6                                                         HTC 2430
      I7=I8-1                                                           HTC 2440
      DELTR=R(I8,J)-R(I7,J)                                             HTC 2450
      IF(DELTR-0.0005)660,660,670                                       HTC 2460
660   R(I7,J)=R(I8,J)-0.0005                                            HTC 2470
670   CONTINUE                                                          HTC 2480
      NIN=NIN+1                                                         HTC 2490
      C9=C9+1.                                                          HTC 2500
      IF(C9-8.)150,150,680                                              HTC 2510
680   GO TO (720,690,720,690,690,720,690,690,720,690,690,720,690,720,720HTC 2520
     1),J                                                               HTC 2521
690   N9D=ND9(J)                                                        HTC 2530
      DO 700 I222=1,3                                                   HTC 2540
      T(I222,J)=T(I222,J)-460.                                          HTC 2550
700   T(I222,J)=5./9.*(T(I222,J)-32.)                                   HTC 2560
      DP=DIA(J)                                                         HTC 2570
      PP=STKP(J,K,M)                                                    HTC 2580
      POWER=PP*1000./PNO(J)                                             HTC 2590
      CALL PTLTM(POWER,RDIM(2,J),RDIM(1,J),T(1,J),T(2,J),TP,DP,PNO(J))  HTC 2600
      TOD(K,J)=T(2,J)                                                   HTC 2610
      PW(K,J)=POWER                                                     HTC 2620
      TPI(K,J)=TP                                                       HTC 2630
      IF(K.EQ.L99.OR.K.EQ.L99-1) GO TO 710                              HTC 2640
      GO TO 720                                                         HTC 2650
710   IF(IDATA.GE.0) GO TO 720                                          HTC 2651
      F27=F2*8.64E+4                                                    HTC 2660
      PRINT 6045,(ANAME(J),RDIM(I,J),R(I,J),F27,I=1,N9D)                HTC 2670
6045  FORMAT(I8,4X,F10.5,5X,F10.5,5X,E11.4)                             HTC 2680
      PRINT 6275                                                        HTC 2690
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720   CONTINUE                                                          HTC 2700
730   CONTINUE                                                          HTC 2710
      IF(IDATA.EQ.0) GO TO 870                                          HTC 2720
      IF(M.GT.1) GO TO 770                                              HTC 2730
      PRINT 6305                                                        HTC 2740
      PRINT 6225,(TITLE(I),I=1,18)                                      HTC 2750
      PRINT 6275                                                        HTC 2760
      PRINT 6255,NHOLD                                                  HTC 2770
      PRINT 6265,N7,ND3                                                 HTC 2780
      DO 740 I=1,N7                                                     HTC 2790
      PRINT 6285,I,L6(I),L9(I)                                          HTC 2800
740   CONTINUE                                                          HTC 2810
      PRINT 6275                                                        HTC 2820
      PRINT 6275                                                        HTC 2830
      PRINT 6275                                                        HTC 2840
      PRINT 6275                                                        HTC 2850
      PRINT 6055                                                        HTC 2860
6055  FORMAT(35X,' PARTICLE GEOMETRY')                                  HTC 2870
      PRINT 6065                                                        HTC 2880
6065  FORMAT(19X,' PARTICLE DIA.  KERNEL RAD. BUFFER THICK. LTI THICK.')HTC 2890
      PRINT 6075                                                        HTC 2900
6075  FORMAT(1X,' HOLDER#   BATCH#      (MICRON)        (CM)          (CM)HTC 2910
     1          (CM)')                                                  HTC 2911
      DO 760 J=1,NHOLD                                                  HTC 2920
      GO TO (760,750,760,750,750,760,750,750,760,750,750,760,750,760,760HTC 2930
     1),J                                                               HTC 2931
750   PRINT 6085,ANAME(J),B1NM(J),B2NM(J),DIA(J),RF(J),RBF(J),RLTI(J)   HTC 2940
6085  FORMAT(I6,4X,A8,A3,2X,F7.1,6X,F8.5,4X,F8.5,5X,F8.5)               HTC 2950
760   CONTINUE                                                          HTC 2960
770   PRINT 6095                                                        HTC 2970
6095  FORMAT(1H1,' TIME-TEMPERATURE HISTORY OF ANNULUS O.D. TEMPERATURE'HTC 2980
     1)                                                                 HTC 2981
      PRINT 6105                                                        HTC 2990
6105  FORMAT(1H0,22X,' TEMPERATURE(C) FOR ANNULUS OF SPEFIC HOLDERS')   HTC 3000
      PRINT 6115,ANAME(2),ANAME(4),ANAME(5),ANAME(7),ANAME(8),ANAME(10),HTC 3010
     1ANAME(11),ANAME(13)                                               HTC 3011
6115  FORMAT(' CYCLE DAY',8I7)                                          HTC 3020
      DO 780 K=1,L66,2                                                  HTC 3030
      PRINT 6125,M,K,TOD(K,2),TOD(K,4),TOD(K,5),TOD(K,7),TOD(K,8),TOD(K,HTC 3040
     110),TOD(K,11),TOD(K,13)                                           HTC 3041
6125  FORMAT(I4,I5,3X,8F7.0)                                            HTC 3050
780   CONTINUE                                                          HTC 3060
      DO 800 J=1,15                                                     HTC 3080
      AVER(J)=0.0                                                       HTC 3090
      DO 790 K=1,L66,2                                                  HTC 3100
      IF(K.GT.L99) GO TO 790                                            HTC 3110
      AVER(J)=AVER(J)+TOD(K,J)                                          HTC 3120
790   CONTINUE                                                          HTC 3130
      AVER(J)=AVER(J)/(DFLOAT((L99+1)/2))                               HTC 3140
800   CONTINUE                                                          HTC 3150
      PRINT 6155,AVER(2),AVER(4),AVER(5),AVER(7),AVER(8),AVER(10),AVER(1HTC 3160
     11),AVER(13)                                                       HTC 3161
810   PRINT 6135                                                        HTC 3170
6135  FORMAT(1H0,' TIME-TEMPERATURE HISTORY OF MAXIMUM PARTICLE SURFACE HTC 3180
     1TEMPERATURE',/)                                                   HTC 3181
      PRINT 6145                                                        HTC 3190
6145  FORMAT(15X,' PARTICLE SURFACE TEMPERATURE(C) FOR SPEFIC HOLDERS') HTC 3200
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      PRINT 6115,ANAME(2),ANAME(4),ANAME(5),ANAME(7),ANAME(8),ANAME(10),HTC 3210
     1ANAME(11),ANAME(13)                                               HTC 3211
      DO 820 K=1,L66,2                                                  HTC 3220
      PRINT 6125,M,K,TPI(K,2),TPI(K,4),TPI(K,5),TPI(K,7),TPI(K,8),TPI(K,HTC 3230
     110),TPI(K,11),TPI(K,13)                                           HTC 3231
820   CONTINUE                                                          HTC 3240
      DO 840 J=1,15                                                     HTC 3260
      AVER(J)=0.0                                                       HTC 3270
      DO 830 K=1,L66,2                                                  HTC 3280
      IF(K.GT.L99) GO TO 830                                            HTC 3290
      AVER(J)=AVER(J)+TPI(K,J)                                          HTC 3300
830   CONTINUE                                                          HTC 3310
      AVER(J)=AVER(J)/(DFLOAT((L99+1)/2))                               HTC 3320
840   CONTINUE                                                          HTC 3330
      PRINT 6155,AVER(2),AVER(4),AVER(5),AVER(7),AVER(8),AVER(10),AVER(1HTC 3340
     11),AVER(13)                                                       HTC 3341
6155  FORMAT(' AVERAGE     ',8F7.0)                                     HTC 3350
850   PRINT 6165                                                        HTC 3360
6165  FORMAT(1H0,' TIME-POWER GENERATION HISTORY FOR THO2 PARTICLES',/) HTC 3370
      PRINT 6175                                                        HTC 3380
6175  FORMAT(17X,' POWER GENERATION(WATTS) PER PARTICLE FOR HOLDERS')   HTC 3390
      PRINT 6115,ANAME(2),ANAME(4),ANAME(5),ANAME(7),ANAME(8),ANAME(10),HTC 3400
     1ANAME(11),ANAME(13)                                               HTC 3401
      DO 860 K=1,L66,2                                                  HTC 3410
      PRINT 6185,M,K,PW(K,2),PW(K,4),PW(K,5),PW(K,7),PW(K,8),PW(K,10),PWHTC 3420
     1(K,11),PW(K,13)                                                   HTC 3421
6185  FORMAT(I4,I5,2X,8F7.3)                                            HTC 3430
860   CONTINUE                                                          HTC 3440
      IF(IDATA)900,870,900                                              HTC 3450
870   PUNCH 6195,(TITLE(I),I=1,17)                                      HTC 3460
6195  FORMAT(17A4)                                                      HTC 3470
      DO 890 J=1,NHOLD                                                  HTC 3480
      GO TO (890,880,890,880,880,890,880,880,890,880,880,890,880,890,890HTC 3490
     1),J                                                               HTC 3491
880   PUNCH 6205,ANAME(J),M                                             HTC 3500
6205  FORMAT(2I4)                                                       HTC 3510
      PUNCH 6215,(K,TOD(K,J),TPI(K,J),PW(K,J),K=1,L66,2)                HTC 3520
6215  FORMAT(4(I2,1X,F5.0,1X,F5.0,1X,F5.3))                             HTC 3530
890   CONTINUE                                                          HTC 3540
900   CONTINUE                                                          HTC 3550
      GO TO 10                                                          HTC 3560
6225  FORMAT(17A4,I1)                                                   HTC 3570
6235  FORMAT(18I4)                                                      HTC 3580
6245  FORMAT(4F8.0)                                                     HTC 3590
6255  FORMAT(' NUMBER OF PARTICLE HOLDERS = ',I2)                       HTC 3600
6265  FORMAT(1H0,' TOTAL NUMBER OF CYCLES = ',I2,'   STARTING DAY = ',I2HTC 3610
     1)                                                                 HTC 3611
6275  FORMAT(1H0)                                                       HTC 3620
6285  FORMAT(' CYCLE ',I2,' HAS ',I2,' TOTAL DAYS WITH ',I2,' FULL POWERHTC 3630
     1 DAYS')                                                           HTC 3631
6295  FORMAT(9F8.0)                                                     HTC 3640
6305  FORMAT(1H1)                                                       HTC 3650
6315  FORMAT(2X,'NODE#  RADIUS(IN)  EMISSIVITY  MATL TYPE  MATL-SELECT#'HTC 3660
     1)                                                                 HTC 3661
6325  FORMAT(2X,I3,5X,F8.5,4X,F6.4,9X,I1,10X,I2)                        HTC 3670
6335  FORMAT(9A8)                                                       HTC 3680
6345  FORMAT(2X,'DISTANCE FROM HMP = ',F8.5)                            HTC 3690
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6355 FORMAT(2X,'HOLDER# ',I2,' HAS ',I2,' RADIAL NODES')                HTC 3700
6365 FORMAT(8E9.3)                                                      HTC 3710
6375 FORMAT(9E8.0)                                                      HTC 3720
6385 FORMAT(34X,'TEMPERATURES(C)',16X,'POWER/PARTICLE  PART DIA  PART SHTC 3730
    1URF. TEMP')                                                        HTC 3731
6395 FORMAT(1X,'HOLDER#  CYCLE  DAY  ANNULUS I.D.  ANNULUS O.D.  HOLDERHTC 3740
    1 SURFACE      (WATTS)       (MICRON)        (C)')                  HTC 3741
6405 FORMAT(I5,I7,I6,5X,F8.2,6X,F8.2,5X,F8.2,10X,F8.5,5X,F6.1,6X,F8.2) HTC 3750
6415 FORMAT(I8,5F8.0)                                                   HTC 3760
6425 FORMAT(8E9.4)                                                      HTC 3770
6435 FORMAT(2I4,2E8.0)                                                  HTC 3780
6445 FORMAT(7F10.0,F5.0,I5)                                             HTC 3790
6455 FORMAT(I4,I4,I4)                                                   HTC 3800
6465 FORMAT(3I10,2F10.0,3F10.3)                                         HTC 3810
     STOP                                                               HTC 3820
     END                                                                HTC 3830
```

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C     ***********************************************************************
C     ***********************************************************************
C     ***********************************************************************
C     ***********************************************************************
      SUBROUTINE FABGEN
      IMPLICIT REAL*8(A-H,O-Z)
      INTEGER*4 CHAIN
      COMMON/BLOK1/M7,ND3,L6(30),L9(30),D1,D6,R0,R1,Z0,Z1,NCYC(10),
     1       AH,F(2),NPOL1,NPOL2,ZZ1(3),ZZ2(3),FLXI,FLXF,STKP(15,30,8),
     2NHOLD,JJJ,AI(9),TS(9),KKK,IDATA
      DIMENSION Q(6),S(6,2),C(6,2)T(6,2),A1(4),A2(4),FNCYC(112),H(6),R(6
     1),P(6),AL(6),O(6),G(6),X(6),B(7),POW(15,112,8),Z(6),Y(6),W(6),
     2 AN(9),TISO(9)
      EQUIVALENCE (NHOLD,NSTK),(AI(9),AN(9)),(KKK,CHAIN),(TS(9),TISO(9))
      IF(JJJ.EQ.15) GO TO 150
      DO 10 I=1,6
 10   Q(I)=185.0
      DO 20 I=1,6
 20   Q(I)=Q(I)*1.6E-16
      STKL=ABS(Z1-Z0)
      C0=.9994
      C1=-1.1967
      C2=.9635
      C3=-.4507
      C4=.10655
      C5=-9.79E-3
      V=3.1416*(R1**2-R0**2)*12.*(2.54**3)
      A8=6.2832*R1*12.*(2.54**2)
      NC=0
      ND4=ND3+1
      R9=2.*V/A8
      C7=.5*(R1*2.54/(.55*D1))
      IF(KKK.EQ.0) GO TO 50
      S(1,1)=.253E-25
      S(2,1)=.313E-24
      S(3,1)=50.0E-24
      S(4,1)=21.2E-24
      S(5,1)=.468E-24
      S(6,1)=9.21E-24
      S(1,2)=0.0
      S(2,2)=0.0
      S(3,2)=3500.E-24
      S(4,2)=391.E-24
      S(5,2)=0.0
      S(6,2)=402.E-24
      C(1,1)=3.145E-24
      C(2,1)=17.187E-24
      C(3,1)=0.0
      C(4,1)=4.6E-24
      C(5,1)=27.432E-24
      C(6,1)=6.19E-24
      C(1,2)=5.39E-24
      C(2,2)=54.4E-24
      C(3,2)=0.0
      C(4,2)=37.0E-24
      C(5,2)=66.7E-24
```

```
      C(6,2)=71.0E-24
      X(1)=0.0
      X(2)=2.928E-7
      X(3)=2.891E-5
      X(4)=0.0
      X(5)=0.0
      X(6)=0.0
      B(1)=12.5
      B(2)=10.0
      B(3)=10.0
      B(4)=8.3
      B(5)=8.3
      B(6)=8.3
      B(7)=4.2
      T5=6.*3600.
      DO 30 I=1,6
30    Y(I)=1.
      Y(1)=0.
      Y(4)=0.
      DO 40 I=1,6
40    W(I)=0.
      W(4)=1.
      W(5)=1.
      GO TO 90
50    T5=24.*3600.
      S(1,1)=9.21E-24
      S(2,1)=.101E-24
      S(3,1)=.514E-24
      S(4,1)=10.1E-24
      S(5,1)=.548E-24
      S(6,1)=23.3E-24
      S(1,2)=402.E-24
      S(2,2)=0.00E-24
      S(3,2)=0.00E-24
      S(4,2)=660.E-24
      S(5,2)=0.00E-24
      S(6,2)=823.E-24
      C(1,1)=6.19E-24
      C(2,1)=9.229E-24
      C(3,1)=20.986E-24
      C(4,1)=6.2E-24
      C(5,1)=7.072E-24
      C(6,1)=6.9E-24
      C(1,2)=71.0E-24
      C(2,2)=1.97E-24
      C(3,2)=39.2E-24
      C(4,2)=3.01E-22
      C(5,2)=674.E-24
      C(6,2)=2.67E-22
      X(1)=0.0
      X(2)=0.0
      X(3)=3.487E-6
      X(4)=0.0
      X(5)=0.0
      X(6)=0.0
      B(1)=8.3
      B(2)=12.5
```

```
      B(3)=10.0
      B(4)=8.3
      B(5)=8.3
      B(6)=8.3
      B(7)=4.2
      DO 60 I=1,5
 60   Z(I)=0.
      Z(3)=1.
      DO 70 I=1,5
 70   G(I)=1.
      G(1)=0.
      G(3)=0.
      DO 80 I=1,4
 80   O(I)=0.
      O(3)=1.
 90   DO 110 I=1,6
      DO 100 J=1,2
 100  T(I,J)=S(I,J)+C(I,J)
 110  CONTINUE
      ZF2=Z1
      ZI2=Z0
 120  A11=0.
      A21=0.
C*    CALCULATION FOR FAST AND THERMAL FLUX
      DO 130 I=1,NPOL1
      A1(I)=ZZ1(I)*(ZF2**I-ZI2**I)/DFLOAT(I)
      A11=A11+A1(I)
 130  CONTINUE
      DO 140 I=1,NPOL2
      A2(I)=ZZ2(I)*(ZF2**I-ZI2**I)/DFLOAT(I)
      A21=A21+A2(I)
 140  CONTINUE
      V1=V*STKL/12.0
      NT6=ND3+1
      IF(IDATA.GE.0) GO TO 150
      PRINT 6115
      PRINT 6125
 150  DO 460 M=1,M7
      NT7=NT6+1
      IF(KKK.EQ.0) GO TO 160
      N6=L6(M)*4
      N9=L9(M)*4
      GO TO 170
 160  N6=L6(M)
      N9=L9(M)
      IF(JJJ.EQ.15) GO TO 410
 170  DO 180 I=1,N6
 180  FNCYC(I)=1.
 190  DO 390 K1=1,N6
      F7=F(2)*A21
      F7=F7*D6
      IF(NCYC(M).EQ.0) GO TO 200
      F7=F7*FNCYC(K)
 200  B1=0.
      B5=0.
      DO 210 I=1,7
 210  B1=B1+AN(I)*B(I)*1.E-24
```

```
      DO 220 I=1,6
220   B5=B5+AN(I)*T(I,2)
      B5=B5+B1
      R5=B1/B5
      S5=R9*B5
      IF(S5-3.5) 230,230,370
230   S1=R9*(B5-B1)
      T3=C0+C1*S5+C2*S5**2+C3*S5**3+C4*S5**4+C5*S5**5
      T3=T3/(1.-(1.-T3)*R5-S1*T3)
      T2=1./(1.+T3*S1*C7)
      T2=T2*T3
      F2=F7*T2
      PHI1=F(1)*A11
      PHI2=F2
      P7=0.
      P8=0.
      PSTK=0.
      PDEN=0.
      IF(FNCYC(K1)-0.)240,240,250
240   PHI1=PHI1*FNCYC(K1)
      PHI2=PHI2*FNCYC(K1)
250   DO 290 I=1,6
      H(I)=0.
      R(I)=0.
      P(I)=0.
      AL(I)=0.
260   IF(K1-N9)270,270,290
270   H(I)=H(I)+PHI1*C(I,1)+PHI2*C(I,2)
      R(I)=R(I)+PHI1*T(I,1)+PHI2*T(I,2)
      AL(I)=AL(I)+PHI1*S(I,1)+PHI2*S(I,2)
      H(I)=H(I)/STKL
      R(I)=R(I)/STKL
      P(I)=(P(I)+AL(I))/STKL
      H(I)=H(I)*AN(I)
      R(I)=R(I)*AN(I)
280   P(I)=P(I)*AN(I)
      P8=P8+P(I)
      P(I)=P(I)*Q(I)
      PDEN=PDEN+P(I)
      P(I)=P(I)*V1
290   PSTK=PSTK+P(I)
      POW(JJJ,K1,M)=PSTK
300   AH=AH+T5*H(1)
      AH=AH+T5*H(6)
      DO 360 J=1,6
      IF(KKK.EQ.0) GO TO 330
      AN(J)=AN(J)-T5*R(J)-AN(J)*(1.-EXP(0.-T5*X(J)))
      IF(J-1)360,360,310
310   AN(J)=AN(J)+T5*Y(J)*H(J-1)
      IF(J-2)360,360,320
320   AN(J)=AN(J)+AN(J-2)*W(J)*(1.-EXP(0.-T5*X(J-2)))
      GO TO 360
330   I=6-J
      AN(I+1)=AN(I+1)-T5*R(I+1)-AN(I+1)*(1.-EXP(0.-T5*X(I+1)))
      IF(I-1) 360,340,340
340   AN(I+1)=AN(I+1)+T5*G(I)*H(I)+Z(I)*AN(I)*(1.-EXP(0.-T5*X(I)))
      IF(I-2) 360,350,350
```

```
350   AN(I+1)=AN(I+1)+T5*O(I-1)*H(I-1)
360   CONTINUE
      NT6=NT6+1
      NT7=NT6+1
      GO TO 390
370   PRINT 6075
380   PRINT 6085,S5
390   CONTINUE
      IF(KKK.EQ.0) GO TO 410
      DO 400 II=4,N6,4
      K=II/4
      STKP(JJJ,K,M)=POW(JJJ,II,M)
      IF(IDATA.GE.0) GO TO 400
      PRINT 6135,JJJ,K,M,STKP(JJJ,K,M)
400   CONTINUE
      GO TO 460
410   DO 450 K=1,N6
      IF(JJJ-15)430,420,420
420   POW(15,K,M)=0.
      STKP(15,K,M)=0.
      GO TO 440
430   STKP(JJJ,K,M)=POW(JJJ,K,M)
440   IF(IDATA.GE.0) GO TO 450
      PRINT 6135,JJJ,K,M,STKP(JJJ,K,M)
450   CONTINUE
460   CONTINUE
      RETURN
6005  FORMAT(1H0)
6015  FORMAT(I5,I7,2X,A8,E12.5,F11.5)
6025  FORMAT(2X,'CYCLE  DAY  ISOTOPE  NO.DENSITY  POWER(KWATT)')
6035  FORMAT(14X,3H HM,E17.5)
6045  FORMAT(16H0LINEAR POWER = ,F9.5,6H KW/FT)
6055  FORMAT(21H0TOTAL STICK POWER = ,F9.5,3H KW)
6065  FORMAT(19H0FISSION DENSITY = ,E12.3,16H FISSIONS/SEC/CC)
6075  FORMAT(40H FLUX DEPRESSION PARAMETER EXCEEDS LIMIT)
6085  FORMAT(29H0FLUX DEPRESSION PARAMETER = ,F10.3)
6095  FORMAT(6E12.5)
6105  FORMAT(' POWER DENSITY = ',E10.5,' KW/CC')
6115  FORMAT(1H1)
6125  FORMAT(2X,'HOLDER#  DAY  CYCLE  STICK POWER(KWATT)')
6135  FORMAT(2X,I4,I7,I6,7X,F8.5)
      END
```

```
      SUBROUTINE PTLTM(Q,R2,R1,T11,T22,TP,DIA,PNO)                      PTLTM 10
      IMPLICIT REAL*8(A-H,O-Z)                                          PTLTM 20
      REAL*8 KG,K1,K2                                                   PTLTM 30
      DIMENSION Z(4,9)                                                  PTLTM 40
      DATA (Z(4,J),J=1,9)/1.7838E-3,7.985E-3,1.924E-5,-3.607E-9,-2.792E-PTLTM 50
     112,1.288E-15,0.0,0.0,0.0,0.0/                                     PTLTM 51
C     THIS SUBROUTINE CALCULATES PARTICLE SURFACE MEAN TEMPERATURE      PTLTM 60
C     BASED UPON SIMPLE MODEL USING EQUIVALENT AREAS.                   PTLTM 70
      D=1.E-4*DIA                                                       PTLTM 80
      TVOL=(3.14159*(R2**2-R1**2)*.125*16.38706)/PNO                    PTLTM 90
      RAR=(3./(4.*3.14159)*TVOL)**(1./3.)                               PTLT 100
      T1=T22+273.15                                                     PTLT 110
      A1=3.14159*(D**2)                                                 PTLT 120
      A2=2.*3.14159*D*RAR/(RAR-D/2.)                                    PTLT 130
      F=1./(1./.9+(D/(2.*RAR))**2*(1./.9-1.))                           PTLT 140
      SIG=5.6686E-12                                                    PTLT 150
      C1=SIG*A1*F                                                       PTLT 160
      T2=T1                                                             PTLT 170
      N=1                                                               PTLT 180
      X=35.                                                             PTLT 190
 10   T2=T2+X                                                           PTLT 200
      TF=9./5.*(T2-273.15)+32.                                          PTLT 210
 20   KG=.0173*(Z(4,2)+Z(4,3)*TF+Z(4,4)*TF**2+Z(4,5)*TF**3+Z(4,6)*TF**4)PTLT 220
      C2=KG*A2                                                          PTLT 230
      K1=Q+T1*(C1*T1**3+C2)                                             PTLT 240
      K2=T2*(C1*T2**3+C2)                                               PTLT 250
      DK=(K1-K2)                                                        PTLT 260
      IF(DK)40,50,30                                                    PTLT 270
 30   IF(N-1)10,10,50                                                   PTLT 280
 40   N=2                                                               PTLT 290
      X=-5.                                                             PTLT 300
      GO TO 10                                                          PTLT 310
 50   TP=T2-273.15                                                      PTLT 320
      RETURN                                                            PTLT 330
      END                                                               PTLT 340
```

APPENDIX B

Data Preparation Guide and Data Deck Arrangement for HTCAP

Data Preparation Guide for HTCAP

HTCAP Data Input Variables and Formats

Card Type

1 (columns 1–72): TITLE(I), Job Description (18A4)

2

NHOLD (I4)	M7 (I4)	ND3 (I4)	IDATA (I4)

NHOLD = Number of particle holders 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/particle holder, temperature calculations, dimensional changes
= 0 – Punch temperature data only
> 0 – Print temperature calculations only

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)

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

5

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

ZZ1(I) = Coefficients for fast flux polynomial

6

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

ZZ2(I) = Coefficients for thermal flux polynomial

7

N9 (I8)	T9 (F8.0)	R9 (F8.0)	H9 (F5.0)	D1 (F5.0)	D6 (F5.0)

N9 = Input 0
T9 = Ambient coolant temperature, °F
R9 = Inside hole radius for hollow element; if solid use 0.0, in.
H9 = Surface heat transfer coefficient, Btu/hr-ft^2-°F
D1 = Diffusion coefficient for thermal neutrons for material surrounding capsule
D6 = Capsule flux depression factor

8

NCYC(J) (I4)	Continue for I=1,M7 Format (18I4)

NCYC(I) = Input 0 for each cycle considered.

9

DIA(J) (F10.0)	RF(J) (F10.0)	RBF(J) (F10.0)	RLTI(J) (F10.0)	ZDIM(J) (F10.0)	ZOO(J) (F10.0)	ZIO(J) (F10.0)	PNO(J) (F5.0)	ND9(J) (I5)

Repeat Card 9 J = NHOLD times

DIA(J) = Particle diameter, μm
RF(J) = Kernel radius, cm
RBF(J) = Buffer thickness, cm
ZOO(J) = Position of top of fueled annulus relative to reactor HMP, in.
ZIO(J) = Position of bottom of fueled annulus relative to reactor HMP, in.
RLTI(J) = LTI thickness, cm
ZDIM(J) = Distance of holder midpoint from reactor HMP, in.
PNO(J) = Number of ThO_2 particles/sample holder
ND9(J) = Number of radial nodes in sample holder

HTCAP Data Input Variables and Formats (Continued)

1 — 72

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 ThO_2 particle. If no batch name, leave blank.

Example → GGA-4252-06

B1NM B2NM

NOTE: Repeat Cards 11 through 18 for each end plug and particle holder. Start with end plug closest to HMP and continue through particle holders (including U holders) until end plug farthest from HMP.

1 — 12

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

ANAME(J) = Particle holder number
CHAIN(J) = FLAG = 0 Uranium particle holder
= 1 Thorium Particle holder
STEMP(J) = FLAG = 0 Low-temperature sleeve
= 1 High-temperature sleeve

1 — 72

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

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

2 — 48

13	TISO(I,J) (A8)	Continue for I=1,6 Format (6A8)

TISO(I,J) = Isotope names for the initial fissionable isotope and five other chain isotopes.
If CHAIN(J) = 0, TISO(I,J) = ^{235}U, ^{238}U, ^{239}Np, ^{239}Pu, ^{240}Pu, ^{241}Pu.
If CHAIN(J) = 1, TISO(I,J) = ^{232}Th, ^{233}Pa, ^{234}Pa, ^{233}U, ^{234}U, ^{235}U.

1 — 72

14	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.

1 — 72

15	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)

1 — 72

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

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

1 — 72

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

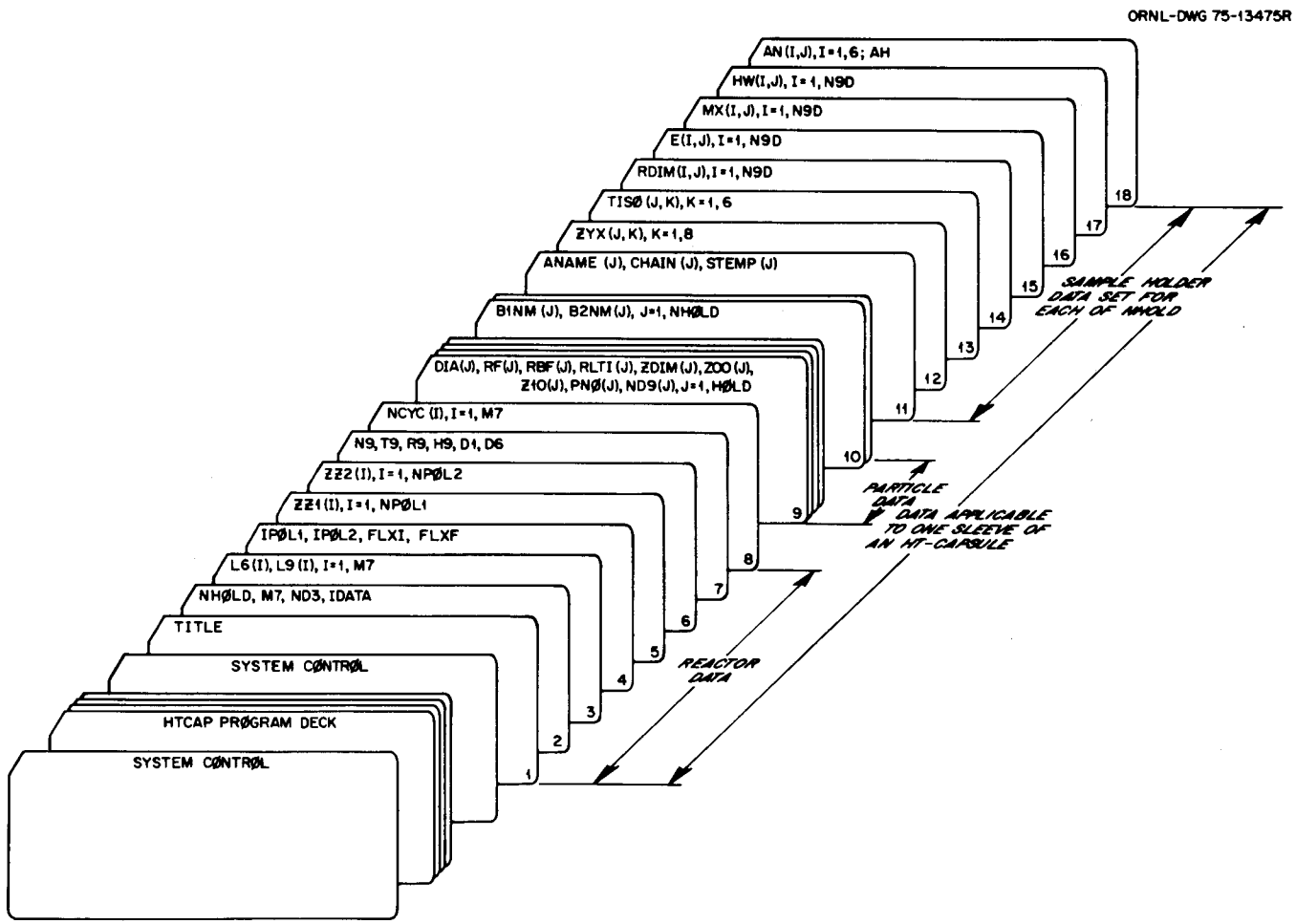
HW(I,J) = Indicates type of material immediately inside Node I
= 1, Poco graphite; = 2, Fueled region; = 3, Type 304 stainless steel;
= 4, Argon gas

1 — 72

18	AN(I,J) (E9.3)	Continue for I=1,7 Format (7E9.3)	AH (E9.3)

AN(I,J) for I=1–6 = Number density of Ith isotope in TISO(I,J) (nuclei/cm^3)
I=7 = Number density of O, C, or N contained in fuel (atoms/cm^3)
AH = Heavy metal content at day zero (usually 0)

HTCAP Data Deck Arrangement



APPENDIX C

Input Data Listing and Tabular Output from Thermal Analysis of Sleeve CP-62 of Capsule HT-15

Table C-1. Data Input for HT-15 Sample Problem

```
HIGH TEMPERATURE SLEEVE APPLICABLE TO HT-14 AND -15 HOLDERS 27--38
 15   8   0  -1
 24  23  26  23   3   1  22  21  24  23  24  23  26  23  23  23
  2   2    0.0E0  1.0E01
 2.81E0 5.00E-3-1.46E-2
 3.09E0 3.00E-3-1.58E-2
      0   140.0      0.0  1510.0     .500      1.0
  0   0   0   0   0   0   0   0
   824.00     .02540     .00830     .00750   0.43730     .24980     .6248   75.     7
   824.00     .02540     .00830     .00750   0.80100     .75780     .88280  75.     7
    594.0     .02010     .00320     .00640    1.0840    1.04025    1.16525  75.     7
    594.0     .02010     .00320     .00640    1.3660    1.32275    1.44775  75.     7
    819.0     .02505     .00920     .00670    1.6490    1.60575    1.73075  75.     7
    506.0     .02010     .00210     .00310    1.9310    1.88825    2.01325  75.     7
    506.0     .02010     .00210     .00310    2.2140    2.17075    2.29575  75.     7
    761.0     .02435     .00610     .00760    2.4960    2.45275    2.57775  75.     7
    761.0     .02435     .00610     .00760    2.7790    2.73525    2.86025  75.     7
    480.0     .02010     .00010     .00380    3.0610    3.01775    3.14275  75.     7
    677.0     .02425     .00460     .00500    3.3440    3.30075    3.42575  75.     7
    677.0     .02425     .00460     .00500    3.6260    3.58325    3.70825  75.     7
    452.0     .02010     .00010     .00240    3.9090    3.86575    3.99075  75.     7
    452.0     .02010     .00010     .00240    4.1990    4.14825    4.27325  75.     7
    452.0     .02010     .00010     .00240   4.56275        0.0        0.0  75.     5
          GGA-4252-02            ORNL-1838  GGA-4252-03
ORNL-1826 GGA-4252-01            ORNL-1830  GGA-4252-07
ORNL-1837
   1   0   1
 1.0725E0 .57225E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0
U235    U238    N239    P239    P240    P241
   0.103 .113027  0.1925  0.1935 0.24800  0.2655  0.3275
     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
9.5611E191.2575E21 .0000E00 .0000E00 .0000E00 .0000E002.7063E21 .0000E00
  27   1   1
 1.0725E0 .57225E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0
TH-232  PA-233  PA-234  U-233   U-234   U-235
  0.1200  0.1600  0.1925  0.1935 0.24668  0.2655  0.3275
     0.9     0.9     0.9     0.9     0.9   0.825    0.75
   1   1   1   0   1   0   1
   1   2   1   4   1   4   3
1.630E+21  .0000E0  .0000E0  .0000E0  .0000E0  .0000E03.260E+21 .0000E00
  28   0   1
 1.0725E0 .57225E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0
U235    U238    N239    P239    P240    P241
   0.120   0.160  0.1925  0.1935 0.24607  0.2655  0.3275
      .9      .9      .9      .9      .9    .825     .75
   1   1   1   0   1   0   1
   1   2   1   4   1   4   3
5.5474E197.2963E20 .0000E00 .0000E00 .0000E00 .0000E001.5702E21 .0000E00
  29   1   1
6.3571E-1 .36865E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0
TH-232  PA-233  PA-234  U-233   U-234   U-235
  0.1310  0.1600  0.1925  0.1935 0.24545  0.2655  0.3275
      .9      .9      .9      .9      .9    .825     .75
```

Title

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

Description of ThO_2 Coated Particles

Regional description of fueled end cap longitudinal section.

Regional description of holder No. 27 longitudinal section.

Regional description of holder No. 28 longitudinal section.

Regional description of holder No. 29 longitudinal section

Table C-1. (Continued)

```
   1   1   1   0   1   0   1
   1   2   1   4   1   4   3
1.0719E21  .0000E0  .0000E0  .0000E0  .0000E0  .0000E02.1439E21  .0000E0
  30   1   1
 1.0414E0 .55239E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0
TH-232  PA-233  PA-234  U-233  U-234  U-235
   0.120   0.160  0.1925  0.1935 0.24484  0.2655  0.3275
     .9      .9      .9      .9      .9    .825     .75
   1   1   1   0   1   0   1
   1   2   1   4   1   4   3
1.563E+21  .0000E0  .0000E0  .0000E0  .0000E0  .0000E03.127E+21  .0000E0
  31   0   1
 1.0725E0 .57225E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0
U235    U238    N239    P239    P240    P241
   0.120   0.160  0.1925  0.1935 0.24423  0.2655  0.3275
     .9      .9      .9      .9      .9    .825     .75
   1   1   1   0   1   0   1
   1   2   1   4   1   4   3
5.5474E197.2963E20 .0000E00 .0000E00 .0000E00 .0000E001.5702E21 .0000E00
  32   1   1
5.5040E-1 .23124E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0
TH-232  PA-233  PA-234  U-233  U-234  U-235
   0.131   0.160  0.1925  0.1935 0.24361  0.2655  0.3275
     .9      .9      .9      .9      .9    .825     .75
   1   1   1   0   1   0   1
   1   2   1   4   1   4   3
1.072E+21  .0000E0  .0000E0  .0000E0  .0000E0  .0000E02.144E+21  .0000E0
  33   1   1
9.3512E-1 .51705E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0
TH-232  PA-233  PA-234  U-233  U-234  U-235
   0.120   0.160  0.1925  0.1935 0.24300  0.2655  0.3275
     .9      .9      .9      .9      .9    .825     .75
   1   1   1   0   1   0   1
   1   2   1   4   1   4   3
1.436E+21  .0000E0  .0000E0  .0000E0  .0000E0  .0000E02.872E+21  .0000E0
  34   0   1
 1.0725E0 .57225E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0
U235    U238    N239    P239    P240    P241
  0.1200  0.1600  0.1925  0.1935 0.24239  0.2655  0.3275
    0.9     0.9     0.9     0.9     0.9   0.825    0.75
   1   1   1   0   1   0   1
   1   2   1   4   1   4   3
5.5474E197.2963E20 .0000E00 .0000E00 .0000E00 .0000E001.5702E21 .0000E00
  35   1   1
6.6308E-1 .28273E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0
TH-232  PA-233  PA-234  U-233  U-234  U-235
   0.137   0.160  0.1925  0.1935 0.24177  0.2655  0.3275
     .9      .9      .9      .9      .9    .825     .75
   1   1   1   0   1   0   1
   1   2   1   4   1   4   3
1.324E+21  .0000E0  .0000E0  .0000E0  .0000E0  .0000E02.648E+21  .0000E0
  36   1   1
9.3753E-1 .42385E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0
TH-232  PA-233  PA-234  U-233  U-234  U-235
   0.127   0.160  0.1925  0.1935 0.24116  0.2655  0.3275
```

Regional description of holder No. 30 longitudinal section.

Regional description of holder No. 31 longitudinal section.

Regional description of holder No. 32 longitudinal section.

Regional description of holder No. 33 longitudinal section

Regional description of holder No.34 longitudinal section.

Regional description of holder No.35 longitudinal section.

Regional description of holder No.36 longitudinal section.

Table C-1. (Continued)

```
     .9       .9       .9       .9       .9     .825      .75
   1   1    1   0    1   0    1
   1   2    1   4    1   4    3
1.677E+21   .0000E0  .0000E0  .0000E0  .0000E0  .0000E03.355E+21  .0000E0
  37   0    1
  1.C725E0 .57225E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0
U235     U238     N239     P239     P240     P241
  0.1200   0.1600  0.1925  0.1935 0.24055  0.2655  0.3275
     0.9      0.9      0.9      0.9      0.9    0.825     0.75
   1   1    1   0    1   0    1
   1   2    1   4    1   4    3
5.5474E197.2963E20 .0000E00 .0000E00 .0000E00 .0000E001.5702E21 .0000E00
  38   1    1
6.3058E-1 .23622E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0
TH-232  PA-233  PA-234  U-233   U-234   U-235
   C.137    0.160  0.1925  0.1935 0.23993  0.2655  0.3275
     .9       .9       .9       .9       .9     .825      .75
   1   1    1   0    1   0    1
   1   2    1   4    1   4    3
1.324E+21   .0000E0  .0000E0  .0000E0  .0000E0  .0000E02.648E+21  .0000E0
  39   0    1
  1.0725E0 .57225E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0  .0000E0
U235     U238     N239     P239     P240     P241
  0.1200   0.1600  0.1925  0.1935 0.23897  0.2655  0.3275
     0.9      0.9      0.9      0.9      0.9    0.825     0.75
   1   1    1   0    1   0    1
   1   2    1   4    1   4    3
5.5474E197.2963E20 .0000E00 .0000E00 .0000E00 .0000E001.5702E21 .0000E00
   2   0    1
   1.79E0   17.34E0    0.00E0     0.0E0     0.0E0    0.00E0 3.5896E01.5342E-3
U235     U238     N239     P239     P240     P241
  0.1925   0.1935 0.23800  0.2655   0.3275
     0.9      0.9      0.9    0.825    0.750
   1   0    1   0    1
   2   4    1   4    3
 .0C00E00 .0000E00 .0000E00 .0000E00 .0000E00 .0000E00 .0000E00 .0000E00
```

Regional description of holder No. 37 longitudinal section.

Regional description of holder No. 38 longitudinal section.

Regional description of holder No. 39 longitudinal section.

Regional description of unfueled end cap longitudinal section.

Table C-2. Computer Output for Thermal Analysis of High-Temperature Sleeve CP-62 of Capsule HT-15

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HIGH TEMPERATURE SLEEVE APPLICABLE TO HT-14 AND -15 HOLDERS 27--38 0

NUMBER OF PARTICLE HOLDERS = 15

 TOTAL NUMBER OF CYCLES =   8   STARTING DAY =   0
CYCLE  1 HAS 24 TOTAL DAYS WITH 23 FULL POWER DAYS
CYCLE  2 HAS 26 TOTAL DAYS WITH 23 FULL POWER DAYS
CYCLE  3 HAS  3 TOTAL DAYS WITH  1 FULL POWER DAYS
CYCLE  4 HAS 22 TOTAL DAYS WITH 21 FULL POWER DAYS
CYCLE  5 HAS 24 TOTAL DAYS WITH 23 FULL POWER DAYS
CYCLE  6 HAS 24 TOTAL DAYS WITH 23 FULL POWER DAYS
CYCLE  7 HAS 26 TOTAL DAYS WITH 23 FULL POWER DAYS
CYCLE  8 HAS 23 TOTAL DAYS WITH 23 FULL POWER DAYS
```

			PARTICLE GEOMETRY		
HOLDER#	BATCH#	PARTICLE DIA. (MICRON)	KERNEL RAD. (CM)	BUFFER THICK. (CM)	LTI THICK. (CM)
27	GGA-4252-02	824.0	0.02540	0.00830	0.00750
29	ORNL-1838	594.0	0.02010	0.00320	0.00640
30	GGA-4252-03	819.0	0.02505	0.00920	0.00670
32	ORNL-1826	506.0	0.02010	0.00210	0.00310
33	GGA-4252-01	761.0	0.02435	0.00610	0.00760
35	ORNL-1830	480.0	0.02010	0.00010	0.00380
36	GGA-4252-07	677.0	0.02425	0.00460	0.00500
38	ORNL-1837	452.0	0.02010	0.00010	0.00240

Table C-2. (Continued)

TIME-TEMPERATURE HISTORY OF ANNULUS O.D. TEMPERATURE

CYCLE	DAY	TEMPERATURE(C) FOR ANNULUS OF SPEFIC HOLDERS 27	29	30	32	33	35	36	38
1	1	1481.	1322.	1324.	1317.	1313.	1318.	1305.	1497.
1	3	1408.	1270.	1278.	1268.	1267.	1269.	1262.	1421.
1	5	1364.	1245.	1251.	1237.	1243.	1239.	1238.	1374.
1	7	1336.	1230.	1242.	1225.	1230.	1226.	1226.	1338.
1	9	1318.	1224.	1238.	1216.	1224.	1217.	1220.	1316.
1	11	1308.	1221.	1238.	1213.	1224.	1214.	1217.	1300.
1	13	1302.	1224.	1242.	1213.	1227.	1214.	1220.	1285.
1	15	1299.	1227.	1248.	1219.	1233.	1217.	1228.	1279.
1	17	1299.	1233.	1257.	1225.	1237.	1223.	1232.	1273.
1	19	1302.	1239.	1263.	1228.	1246.	1229.	1238.	1267.
1	21	1305.	1245.	1272.	1234.	1255.	1232.	1247.	1264.
1	23	1308.	1254.	1281.	1243.	1261.	1238.	1256.	1264.
AVERAGE		1336.	1245.	1261.	1237.	1247.	1236.	1241.	1323.

TIME-TEMPERATURE HISTORY OF MAXIMUM PARTICAL SURFACE TEMPERATURE

CYCLE	DAY	PARTICLE SURFACE TEMPERATURE(C) FOR SPEFIC HOLDERS 27	29	30	32	33	35	36	38
1	1	1481.	1322.	1324.	1317.	1313.	1318.	1305.	1497.
1	3	1418.	1280.	1288.	1283.	1277.	1284.	1272.	1431.
1	5	1384.	1265.	1271.	1267.	1268.	1269.	1268.	1399.
1	7	1366.	1265.	1277.	1275.	1270.	1276.	1271.	1383.
1	9	1363.	1274.	1288.	1286.	1279.	1287.	1285.	1381.
1	11	1368.	1286.	1303.	1303.	1294.	1304.	1297.	1385.
1	13	1377.	1304.	1322.	1318.	1312.	1324.	1320.	1390.
1	15	1389.	1322.	1338.	1344.	1333.	1342.	1343.	1399.
1	17	1399.	1338.	1362.	1365.	1347.	1368.	1362.	1413.
1	19	1412.	1354.	1378.	1383.	1366.	1389.	1383.	1427.
1	21	1425.	1370.	1397.	1399.	1390.	1407.	1402.	1439.
1	23	1438.	1389.	1411.	1423.	1406.	1423.	1421.	1454.
AVERAGE		1402.	1314.	1330.	1330.	1321.	1333.	1327.	1416.

TIME-POWER GENERATION HISTORY FOR THO2 PARTICLES

CYCLE	DAY	POWER GENERATION(WATTS) PER PARTICLE FOR HOLDERS 27	29	30	32	33	35	36	38
1	1	0.007	0.004	0.007	0.004	0.006	0.003	0.006	0.003
1	3	0.032	0.016	0.030	0.015	0.027	0.014	0.025	0.013
1	5	0.064	0.031	0.060	0.030	0.053	0.029	0.049	0.027
1	7	0.100	0.049	0.094	0.048	0.083	0.045	0.078	0.042
1	9	0.139	0.068	0.131	0.066	0.116	0.063	0.109	0.059
1	11	0.180	0.088	0.169	0.086	0.150	0.082	0.141	0.077
1	13	0.221	0.109	0.208	0.106	0.185	0.101	0.174	0.095
1	15	0.262	0.129	0.247	0.125	0.220	0.120	0.207	0.113
1	17	0.302	0.148	0.285	0.145	0.254	0.139	0.239	0.131
1	19	0.341	0.168	0.322	0.163	0.287	0.157	0.271	0.149
1	21	0.379	0.186	0.357	0.182	0.319	0.175	0.302	0.166
1	23	0.415	0.204	0.391	0.199	0.350	0.192	0.331	0.182

Table C-2. (Continued)

TIME-TEMPERATURE HISTORY OF ANNULUS O.D. TEMPERATURE

		TEMPERATURE(C) FOR ANNULUS OF SPEFIC HOLDERS							
CYCLE	DAY	27	29	30	32	33	35	36	38
2	1	1339.	1279.	1309.	1268.	1288.	1263.	1280.	1291.
2	3	1324.	1270.	1306.	1259.	1282.	1257.	1277.	1273.
2	5	1321.	1273.	1306.	1259.	1285.	1260.	1277.	1264.
2	7	1324.	1276.	1312.	1265.	1291.	1263.	1280.	1264.
2	9	1324.	1282.	1315.	1268.	1295.	1266.	1287.	1264.
2	11	1327.	1285.	1322.	1274.	1301.	1272.	1293.	1264.
2	13	1333.	1291.	1328.	1277.	1307.	1275.	1299.	1267.
2	15	1336.	1295.	1334.	1283.	1313.	1281.	1305.	1267.
2	17	1339.	1300.	1340.	1289.	1319.	1284.	1308.	1267.
2	19	1342.	1304.	1343.	1292.	1322.	1287.	1311.	1270.
2	21	1346.	1307.	1349.	1295.	1325.	1293.	1320.	1273.
2	23	1349.	1310.	1352.	1298.	1329.	1296.	1323.	1276.
2	25	60.	60.	60.	60.	60.	60.	60.	60.
AVERAGE		1334.	1289.	1326.	1277.	1305.	1275.	1297.	1270.

TIME-TEMPERATURE HISTORY OF MAXIMUM PARTICAL SURFACE TEMPERATURE

		PARTICLE SURFACE TEMPERATURE(C) FOR SPEFIC HOLDERS							
CYCLE	DAY	27	29	30	32	33	35	36	38
2	1	1479.	1424.	1449.	1458.	1438.	1463.	1455.	1491.
2	3	1474.	1425.	1456.	1459.	1442.	1467.	1462.	1488.
2	5	1476.	1433.	1461.	1469.	1450.	1475.	1472.	1489.
2	7	1484.	1441.	1472.	1480.	1461.	1488.	1480.	1499.
2	9	1494.	1452.	1480.	1488.	1475.	1496.	1492.	1509.
2	11	1502.	1460.	1492.	1499.	1481.	1507.	1503.	1514.
2	13	1508.	1471.	1503.	1512.	1492.	1515.	1514.	1527.
2	15	1516.	1480.	1509.	1523.	1503.	1526.	1525.	1532.
2	17	1524.	1490.	1520.	1529.	1514.	1534.	1533.	1537.
2	19	1532.	1494.	1528.	1537.	1522.	1542.	1541.	1550.
2	21	1541.	1502.	1534.	1545.	1525.	1553.	1555.	1553.
2	23	1544.	1510.	1542.	1553.	1534.	1561.	1558.	1561.
2	25	60.	60.	60.	60.	60.	60.	60.	60.
AVERAGE		1506.	1465.	1495.	1504.	1487.	1511.	1507.	1521.

TIME-POWER GENERATION HISTORY FOR THO2 PARTICLES

		POWER GENERATION(WATTS) PER PARTICLE FOR HOLDERS							
CYCLE	DAY	27	29	30	32	33	35	36	38
2	1	0.467	0.230	0.441	0.224	0.394	0.216	0.373	0.205
2	3	0.493	0.243	0.466	0.237	0.416	0.228	0.395	0.217
2	5	0.517	0.254	0.488	0.249	0.437	0.240	0.415	0.229
2	7	0.541	0.266	0.511	0.260	0.458	0.251	0.435	0.240
2	9	0.565	0.278	0.534	0.272	0.478	0.263	0.454	0.251
2	11	0.588	0.289	0.556	0.283	0.498	0.274	0.474	0.262
2	13	0.610	0.300	0.577	0.294	0.517	0.284	0.492	0.272
2	15	0.631	0.311	0.597	0.304	0.535	0.295	0.510	0.282
2	17	0.652	0.321	0.617	0.314	0.553	0.305	0.527	0.292
2	19	0.671	0.330	0.635	0.324	0.570	0.314	0.543	0.301
2	21	0.689	0.339	0.652	0.333	0.586	0.323	0.559	0.309
2	23	0.706	0.348	0.669	0.341	0.601	0.331	0.573	0.318
2	25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table C-2. (Continued)

TIME-TEMPERATURE HISTORY OF ANNULUS O.D. TEMPERATURE

		TEMPERATURE(C) FOR ANNULUS OF SPEFIC HOLDERS							
CYCLE	DAY	27	29	30	32	33	35	36	38
3	1	1416.	1372.	1415.	1357.	1391.	1352.	1382.	1337.
3	3	60.	60.	60.	60.	60.	60.	60.	60.
AVERAGE		1416.	1372.	1415.	1357.	1391.	1352.	1382.	1337.

TIME-TEMPERATURE HISTORY OF MAXIMUM PARTICAL SURFACE TEMPERATURE

		PARTICLE SURFACE TEMPERATURE(C) FOR SPEFIC HOLDERS							
CYCLE	DAY	27	29	30	32	33	35	36	38
3	1	1628.	1582.	1615.	1627.	1611.	1637.	1637.	1642.
3	3	60.	60.	60.	60.	60.	60.	60.	60.
AVERAGE		1628.	1582.	1615.	1627.	1611.	1637.	1637.	1642.

TIME-POWER GENERATION HISTORY FOR THO2 PARTICLES

		POWER GENERATION(WATTS) PER PARTICLE FOR HOLDERS							
CYCLE	DAY	27	29	30	32	33	35	36	38
3	1	0.855	0.421	0.809	0.413	0.726	0.400	0.692	0.383
3	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table C-2. (Continued)

TIME-TEMPERATURE HISTORY OF ANNULUS O.D. TEMPERATURE

		TEMPERATURE(C) FOR ANNULUS OF SPEFIC HOLDERS							
CYCLE	DAY	27	29	30	32	33	35	36	38
4	1	1427.	1384.	1434.	1370.	1406.	1367.	1398.	1343.
4	3	1369.	1356.	1405.	1342.	1378.	1339.	1370.	1300.
4	5	1370.	1341.	1390.	1326.	1366.	1327.	1357.	1282.
4	7	1364.	1335.	1383.	1320.	1359.	1321.	1351.	1279.
4	9	1361.	1332.	1380.	1320.	1353.	1318.	1348.	1276.
4	11	1361.	1331.	1377.	1317.	1353.	1318.	1348.	1276.
4	13	1361.	1331.	1377.	1317.	1353.	1315.	1345.	1276.
4	15	1361.	1331.	1377.	1317.	1353.	1315.	1345.	1276.
4	17	1361.	1331.	1377.	1317.	1353.	1318.	1345.	1276.
4	19	1361.	1331.	1377.	1317.	1353.	1318.	1348.	1279.
4	21	1364.	1332.	1380.	1320.	1353.	1318.	1348.	1279.
AVERAGE		1371.	1340.	1387.	1326.	1362.	1325.	1355.	1286.

TIME-TEMPERATURE HISTORY OF MAXIMUM PARTICAL SURFACE TEMPERATURE

		PARTICLE SURFACE TEMPERATURE(C) FOR SPEFIC HOLDERS							
CYCLE	DAY	27	29	30	32	33	35	36	38
4	1	1647.	1609.	1644.	1655.	1636.	1662.	1663.	1663.
4	3	1614.	1561.	1615.	1627.	1608.	1639.	1635.	1630.
4	5	1595.	1566.	1600.	1611.	1596.	1622.	1622.	1612.
4	7	1584.	1555.	1593.	1600.	1584.	1616.	1611.	1604.
4	9	1581.	1552.	1585.	1600.	1578.	1608.	1608.	1601.
4	11	1576.	1546.	1582.	1597.	1578.	1608.	1608.	1596.
4	13	1576.	1546.	1582.	1592.	1573.	1605.	1605.	1596.
4	15	1576.	1546.	1582.	1592.	1573.	1605.	1605.	1596.
4	17	1576.	1546.	1582.	1592.	1573.	1603.	1605.	1596.
4	19	1576.	1546.	1582.	1592.	1578.	1608.	1608.	1599.
4	21	1579.	1547.	1585.	1595.	1578.	1608.	1608.	1599.
AVERAGE		1589.	1558.	1594.	1605.	1587.	1617.	1616.	1608.

TIME-POWER GENERATION HISTORY FOR THO2 PARTICLES

		POWER GENERATION(WATTS) PER PARTICLE FOR HOLDERS							
CYCLE	DAY	27	29	30	32	33	35	36	38
4	1	0.932	0.459	0.882	0.450	0.792	0.437	0.756	0.419
4	3	0.892	0.439	0.844	0.431	0.759	0.419	0.726	0.402
4	5	0.860	0.424	0.815	0.417	0.734	0.405	0.702	0.390
4	7	0.839	0.414	0.795	0.406	0.716	0.395	0.686	0.381
4	9	0.825	0.407	0.782	0.400	0.704	0.389	0.675	0.375
4	11	0.817	0.403	0.774	0.396	0.697	0.385	0.669	0.372
4	13	0.812	0.400	0.770	0.394	0.694	0.384	0.666	0.370
4	15	0.811	0.400	0.769	0.393	0.693	0.383	0.665	0.370
4	17	0.812	0.400	0.770	0.394	0.694	0.383	0.666	0.370
4	19	0.814	0.401	0.772	0.395	0.696	0.385	0.668	0.371
4	21	0.818	0.403	0.776	0.396	0.699	0.386	0.671	0.373

Table C-2. (Continued)

TIME-TEMPERATURE HISTORY OF ANNULUS O.D. TEMPERATURE

		TEMPERATURE(C) FOR ANNULUS OF SPEFIC HOLDERS							
CYCLE	DAY	27	29	30	32	33	35	36	38
5	1	1389.	1353.	1402.	1341.	1375.	1336.	1369.	1304.
5	3	1373.	1344.	1390.	1329.	1369.	1327.	1357.	1285.
5	5	1367.	1338.	1387.	1326.	1365.	1324.	1354.	1279.
5	7	1367.	1338.	1387.	1323.	1362.	1324.	1354.	1279.
5	9	1364.	1338.	1386.	1323.	1362.	1324.	1354.	1279.
5	11	1364.	1338.	1384.	1323.	1362.	1324.	1354.	1279.
5	13	1364.	1338.	1387.	1323.	1362.	1324.	1354.	1279.
5	15	1364.	1338.	1387.	1323.	1363.	1324.	1354.	1279.
5	17	1364.	1338.	1387.	1323.	1363.	1324.	1354.	1279.
5	19	1367.	1338.	1387.	1323.	1365.	1324.	1354.	1279.
5	21	1367.	1338.	1387.	1326.	1365.	1324.	1354.	1279.
5	23	1367.	1338.	1387.	1326.	1365.	1324.	1357.	1279.
AVERAGE		1368.	1340.	1388.	1326.	1365.	1325.	1356.	1282.

TIME-TEMPERATURE HISTORY OF MAXIMUM PARTICAL SURFACE TEMPERATURE

		PARTICLE SURFACE TEMPERATURE(C) FOR SPEFIC HOLDERS							
CYCLE	DAY	27	29	30	32	33	35	36	38
5	1	1609.	1573.	1612.	1621.	1600.	1631.	1634.	1629.
5	3	1593.	1564.	1600.	1614.	1599.	1622.	1622.	1615.
5	5	1592.	1563.	1597.	1611.	1595.	1619.	1619.	1609.
5	7	1587.	1558.	1597.	1608.	1592.	1619.	1619.	1609.
5	9	1589.	1558.	1596.	1608.	1592.	1619.	1619.	1609.
5	11	1589.	1558.	1594.	1608.	1592.	1619.	1619.	1609.
5	13	1589.	1558.	1597.	1608.	1592.	1619.	1619.	1609.
5	15	1589.	1558.	1597.	1608.	1593.	1619.	1619.	1609.
5	17	1589.	1563.	1597.	1608.	1593.	1619.	1619.	1614.
5	19	1592.	1563.	1597.	1606.	1595.	1624.	1619.	1614.
5	21	1592.	1563.	1597.	1611.	1595.	1624.	1624.	1614.
5	23	1592.	1563.	1597.	1611.	1595.	1624.	1622.	1614.
AVERAGE		1592.	1562.	1598.	1610.	1595.	1621.	1621.	1613.

TIME-POWER GENERATION HISTORY FOR THO2 PARTICLES

		POWER GENERATION(WATTS) PER PARTICLE FOR HOLDERS							
CYCLE	DAY	27	29	30	32	33	35	36	38
5	1	0.866	0.427	0.821	0.420	0.740	0.409	0.709	0.394
5	3	0.860	0.424	0.816	0.417	0.735	0.407	0.706	0.393
5	5	0.855	0.421	0.811	0.415	0.731	0.404	0.702	0.390
5	7	0.852	0.420	0.808	0.413	0.728	0.403	0.700	0.389
5	9	0.850	0.419	0.807	0.413	0.728	0.402	0.699	0.389
5	11	0.850	0.419	0.807	0.413	0.728	0.403	0.699	0.389
5	13	0.851	0.420	0.808	0.413	0.729	0.403	0.700	0.390
5	15	0.853	0.421	0.810	0.414	0.730	0.404	0.702	0.391
5	17	0.855	0.422	0.812	0.415	0.732	0.405	0.704	0.392
5	19	0.857	0.423	0.814	0.416	0.734	0.406	0.706	0.393
5	21	0.860	0.424	0.816	0.418	0.736	0.408	0.708	0.395
5	23	0.862	0.425	0.818	0.419	0.739	0.409	0.710	0.396

Table C-2. (Continued)

TIME-TEMPERATURE HISTORY OF ANNULUS O.D. TEMPERATURE

CYCLE	DAY	TEMPERATURE(C) FOR ANNULUS OF SPEFIC HOLDERS 27	29	30	32	33	35	36	38
6	1	1392.	1359.	1409.	1345.	1387.	1345.	1376.	1303.
6	3	1374.	1350.	1399.	1335.	1375.	1333.	1369.	1285.
6	5	1370.	1347.	1393.	1332.	1372.	1330.	1361.	1279.
6	7	1367.	1344.	1390.	1329.	1369.	1327.	1360.	1276.
6	9	1367.	1341.	1390.	1326.	1369.	1327.	1360.	1276.
6	11	1364.	1341.	1390.	1326.	1366.	1327.	1357.	1276.
6	13	1364.	1338.	1390.	1326.	1366.	1324.	1357.	1276.
6	15	1364.	1338.	1387.	1326.	1366.	1324.	1357.	1276.
6	17	1364.	1338.	1387.	1326.	1366.	1324.	1357.	1276.
6	19	1364.	1338.	1387.	1326.	1366.	1324.	1357.	1276.
6	21	1364.	1338.	1387.	1323.	1365.	1324.	1357.	1273.
6	23	1364.	1338.	1387.	1323.	1365.	1324.	1357.	1273.
AVERAGE		1368.	1342.	1391.	1329.	1369.	1328.	1361.	1279.

TIME-TEMPERATURE HISTORY OF MAXIMUM PARTICAL SURFACE TEMPERATURE

CYCLE	DAY	PARTICLE SURFACE TEMPERATURE(C) FOR SPEFIC HOLDERS 27	29	30	32	33	35	36	38
6	1	1617.	1584.	1624.	1635.	1622.	1645.	1646.	1638.
6	3	1604.	1580.	1614.	1630.	1610.	1638.	1639.	1630.
6	5	1600.	1577.	1608.	1622.	1607.	1635.	1636.	1624.
6	7	1597.	1574.	1605.	1619.	1604.	1632.	1635.	1621.
6	9	1597.	1571.	1605.	1616.	1604.	1632.	1630.	1621.
6	11	1594.	1566.	1605.	1616.	1601.	1632.	1627.	1616.
6	13	1594.	1563.	1605.	1616.	1601.	1629.	1627.	1616.
6	15	1594.	1563.	1602.	1616.	1601.	1629.	1627.	1616.
6	17	1594.	1563.	1602.	1616.	1601.	1629.	1627.	1616.
6	19	1594.	1563.	1602.	1616.	1596.	1629.	1627.	1616.
6	21	1589.	1563.	1602.	1613.	1595.	1624.	1627.	1613.
6	23	1589.	1563.	1602.	1613.	1595.	1624.	1627.	1613.
AVERAGE		1597.	1569.	1606.	1619.	1603.	1632.	1631.	1620.

TIME-POWER GENERATION HISTORY FOR THO2 PARTICLES

CYCLE	DAY	POWER GENERATION(WATTS) PER PARTICLE FOR HOLDERS 27	29	30	32	33	35	36	38
6	1	0.910	0.449	0.863	0.442	0.779	0.431	0.749	0.417
6	3	0.902	0.445	0.856	0.438	0.773	0.428	0.743	0.414
6	5	0.893	0.441	0.848	0.434	0.766	0.424	0.737	0.411
6	7	0.887	0.438	0.843	0.431	0.761	0.422	0.733	0.409
6	9	0.883	0.436	0.838	0.429	0.757	0.420	0.729	0.407
6	11	0.880	0.434	0.835	0.428	0.755	0.418	0.727	0.406
6	13	0.877	0.433	0.833	0.427	0.753	0.417	0.725	0.405
6	15	0.876	0.432	0.832	0.426	0.752	0.417	0.724	0.404
6	17	0.874	0.432	0.831	0.425	0.751	0.416	0.724	0.404
6	19	0.874	0.431	0.830	0.425	0.750	0.416	0.723	0.404
6	21	0.873	0.431	0.830	0.425	0.750	0.416	0.723	0.404
6	23	0.872	0.430	0.829	0.425	0.750	0.416	0.723	0.404

Table C-2. (Continued)

TIME-TEMPERATURE HISTORY OF ANNULUS O.D. TEMPERATURE

		TEMPERATURE(C) FOR ANNULUS OF SPEFIC HOLDERS							
CYCLE	DAY	27	29	30	32	33	35	36	38
7	1	1366.	1356.	1408.	1345.	1384.	1342.	1376.	1297.
7	3	1370.	1350.	1396.	1335.	1375.	1333.	1367.	1279.
7	5	1364.	1344.	1393.	1329.	1369.	1327.	1360.	1276.
7	7	1361.	1338.	1390.	1326.	1366.	1327.	1357.	1270.
7	9	1361.	1338.	1387.	1323.	1365.	1324.	1357.	1267.
7	11	1361.	1338.	1387.	1323.	1363.	1324.	1354.	1267.
7	13	1358.	1335.	1384.	1323.	1362.	1321.	1354.	1267.
7	15	1358.	1335.	1384.	1320.	1362.	1321.	1354.	1267.
7	17	1355.	1335.	1383.	1320.	1362.	1321.	1354.	1267.
7	19	1355.	1334.	1383.	1320.	1359.	1321.	1351.	1267.
7	21	1352.	1332.	1381.	1320.	1359.	1321.	1351.	1264.
7	23	1352.	1332.	1380.	1320.	1359.	1318.	1351.	1264.
7	25	60.	60.	60.	60.	60.	60.	60.	60.
AVERAGE		1361.	1339.	1388.	1325.	1366.	1325.	1357.	1271.

TIME-TEMPERATURE HISTORY OF MAXIMUM PARTICAL SURFACE TEMPERATURE

		PARTICLE SURFACE TEMPERATURE(C) FOR SPEFIC HOLDERS							
CYCLE	DAY	27	29	30	32	33	35	36	38
7	1	1616.	1586.	1623.	1640.	1619.	1647.	1651.	1642.
7	3	1600.	1580.	1616.	1630.	1610.	1643.	1642.	1629.
7	5	1594.	1574.	1608.	1624.	1604.	1632.	1635.	1626.
7	7	1591.	1568.	1605.	1621.	1601.	1632.	1632.	1620.
7	9	1591.	1568.	1602.	1618.	1600.	1629.	1632.	1617.
7	11	1591.	1563.	1602.	1613.	1598.	1629.	1629.	1612.
7	13	1588.	1560.	1599.	1613.	1597.	1626.	1624.	1612.
7	15	1588.	1560.	1599.	1610.	1597.	1626.	1624.	1612.
7	17	1585.	1560.	1598.	1610.	1592.	1626.	1624.	1612.
7	19	1585.	1559.	1598.	1610.	1594.	1621.	1621.	1612.
7	21	1582.	1557.	1596.	1610.	1589.	1621.	1621.	1609.
7	23	1582.	1557.	1595.	1610.	1589.	1618.	1621.	1609.
7	25	60.	60.	60.	60.	60.	60.	60.	60.
AVERAGE		1591.	1566.	1603.	1617.	1599.	1629.	1630.	1618.

TIME-POWER GENERATION HISTORY FOR THO2 PARTICLES

		POWER GENERATION(WATTS) PER PARTICLE FOR HOLDERS							
CYCLE	DAY	27	29	30	32	33	35	36	38
7	1	0.917	0.453	0.871	0.446	0.788	0.437	0.759	0.424
7	3	0.907	0.448	0.862	0.441	0.779	0.432	0.752	0.420
7	5	0.896	0.442	0.852	0.436	0.771	0.427	0.743	0.415
7	7	0.888	0.438	0.844	0.432	0.764	0.424	0.737	0.412
7	9	0.881	0.435	0.838	0.429	0.758	0.421	0.732	0.409
7	11	0.876	0.432	0.833	0.427	0.754	0.418	0.728	0.407
7	13	0.872	0.430	0.829	0.425	0.750	0.416	0.725	0.405
7	15	0.868	0.429	0.826	0.423	0.747	0.415	0.722	0.404
7	17	0.865	0.427	0.823	0.422	0.745	0.413	0.720	0.402
7	19	0.863	0.426	0.820	0.421	0.743	0.412	0.718	0.401
7	21	0.860	0.425	0.818	0.419	0.741	0.411	0.716	0.400
7	23	0.858	0.424	0.816	0.419	0.739	0.410	0.714	0.400
7	25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table C-2. (Continued)

TIME-TEMPERATURE HISTORY OF ANNULUS O.D. TEMPERATURE

		TEMPERATURE(C) FOR ANNULUS OF SPEFIC HOLDERS							
CYCLE	DAY	27	29	30	32	33	35	36	38
8	1	1411.	1381.	1433.	1366.	1406.	1367.	1401.	1322.
8	3	1377.	1356.	1409.	1345.	1387.	1342.	1379.	1285.
8	5	1364.	1347.	1396.	1332.	1372.	1330.	1366.	1270.
8	7	1355.	1338.	1387.	1323.	1366.	1324.	1357.	1264.
8	9	1352.	1334.	1384.	1320.	1362.	1321.	1354.	1261.
8	11	1349.	1331.	1380.	1317.	1356.	1318.	1351.	1261.
8	13	1346.	1328.	1377.	1317.	1353.	1318.	1348.	1258.
8	15	1345.	1328.	1377.	1314.	1350.	1312.	1348.	1258.
8	17	1345.	1325.	1374.	1314.	1350.	1312.	1345.	1258.
8	19	1342.	1325.	1371.	1311.	1350.	1309.	1345.	1258.
8	21	1342.	1322.	1368.	1311.	1347.	1309.	1342.	1255.
8	23	1342.	1322.	1368.	1310.	1347.	1309.	1342.	1255.
AVERAGE		1356.	1337.	1385.	1323.	1362.	1322.	1356.	1267.

TIME-TEMPERATURE HISTORY OF MAXIMUM PARTICAL SURFACE TEMPERATURE

		PARTICLE SURFACE TEMPERATURE(C) FOR SPEFIC HOLDERS							
CYCLE	DAY	27	29	30	32	33	35	36	38
8	1	1646.	1616.	1653.	1666.	1651.	1682.	1681.	1677.
8	3	1617.	1591.	1634.	1645.	1627.	1657.	1664.	1645.
8	5	1604.	1582.	1616.	1632.	1612.	1645.	1646.	1630.
8	7	1590.	1568.	1607.	1623.	1606.	1634.	1637.	1619.
8	9	1587.	1564.	1599.	1615.	1597.	1626.	1629.	1611.
8	11	1579.	1556.	1595.	1607.	1591.	1623.	1626.	1611.
8	13	1576.	1553.	1592.	1607.	1588.	1618.	1618.	1603.
8	15	1575.	1553.	1587.	1604.	1580.	1612.	1618.	1603.
8	17	1570.	1550.	1584.	1599.	1580.	1612.	1615.	1598.
8	19	1567.	1545.	1581.	1596.	1580.	1609.	1615.	1598.
8	21	1567.	1542.	1578.	1596.	1577.	1609.	1612.	1595.
8	23	1567.	1542.	1578.	1595.	1577.	1609.	1607.	1595.
AVERAGE		1587.	1564.	1600.	1615.	1597.	1628.	1631.	1615.

TIME-POWER GENERATION HISTORY FOR THO2 PARTICLES

		POWER GENERATION(WATTS) PER PARTICLE FOR HOLDERS							
CYCLE	DAY	27	29	30	32	33	35	36	38
8	1	0.989	0.488	0.941	0.482	0.851	0.472	0.821	0.459
8	3	0.954	0.471	0.907	0.465	0.821	0.456	0.794	0.444
8	5	0.923	0.458	0.879	0.451	0.796	0.442	0.770	0.431
8	7	0.900	0.444	0.856	0.439	0.776	0.431	0.751	0.421
8	9	0.881	0.435	0.839	0.430	0.760	0.423	0.736	0.412
8	11	0.867	0.428	0.825	0.423	0.748	0.416	0.724	0.406
8	13	0.855	0.422	0.814	0.418	0.738	0.410	0.715	0.401
8	15	0.846	0.418	0.806	0.413	0.731	0.406	0.708	0.397
8	17	0.839	0.414	0.799	0.410	0.724	0.403	0.702	0.393
8	19	0.833	0.411	0.793	0.407	0.719	0.400	0.697	0.391
8	21	0.828	0.409	0.789	0.405	0.715	0.398	0.693	0.388
8	23	0.824	0.407	0.785	0.403	0.712	0.396	0.690	0.386

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