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

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METALS AND CERAMICS DIVISION

HTGR BASE TECHNOLOGY PROGRAM

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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

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ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

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CONTENTS

ABSTRACT	1
INTRODUCTION	1
GENERAL DESCRIPTION	4
HT CAPSULE DESIGN	4
COMPUTATIONAL MODELS	7
INPUT AND CALCULATIONAL PROCEDURE	18
THERMAL ANALYSIS OF SLEEVE CP-62 OF HT-15	20
CONCLUSION	23
ACKNOWLEDGMENTS	23
APPENDIX A	27
APPENDIX B	43
APPENDIX C	49

HTCAP — A FORTRAN IV PROGRAM FOR CALCULATING
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ABSTRACT

This report describes HTCAP, a computer code that calculates in-reactor operating temperatures of loose coated ThO₂ 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 $\pm 5\%$, 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

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

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

³B. 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/cm² ($E > 0.18$ 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 GENGTG 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

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

⁵M. 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).

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

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

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

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

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

using the HTTEMP code¹¹ 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.

¹¹Unpublished work of R. A. Olstad.

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

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

¹⁴Hall 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.

*Grade AFX-5Q manufactured by Poco Graphite, Inc., a subsidiary of Union Oil Company, P.O. Box 2121, Decatur, 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 region¹⁵ 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 $\text{cm}^{-2} \text{sec}^{-1}$ and peak nonthermal flux is 3.09×10^{15} neutrons $\text{cm}^{-2} \text{sec}^{-1}$. 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.

¹⁵Unpublished 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 $\text{cm}^{-2} \text{sec}^{-1}$)	
	Nonthermal ($E > 1.86 \text{ eV}$)	Thermal ($E < 1.86 \text{ eV}$)
Midplane	2.81	3.09
+5	2.47	2.71
+10	1.40	1.54

Table 2. Cross-Section Data Base (barns)

Isotope	Nonthermal ($E > 1.86 \text{ eV}$)		Thermal ($E < 1.86 \text{ eV}$)	
	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 polynomials 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

$$\langle \phi \rangle = \frac{\int_a^b \phi(Z) dZ}{\int_a^b dZ}, \quad (3)$$

where

$\langle \phi \rangle$ = 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 GENGTIC code. The GENGTIC 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 ${}^{235}\text{U}$ located in the uranium particle holders positioned along the length of each graphite sleeve. As ${}^{233}\text{U}$ is bred into the ThO_2 particles and the ${}^{235}\text{U}$ 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, $\text{ZDIM}_{n+1} - \text{ZDIM}_{n-1}$. The linear heat rate (LHR) in kW/ft for holder n is described by Eq. (4):

$$\text{LHR}_n = \left[Q_n^f + 1/2(Q_{n-1}^f + Q_{n+1}^f) \right] / \left(\text{ZDIM}_{n+1} - \text{ZDIM}_{n-1} \right) \quad (4)$$

ORNL-DWG 75-13476

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

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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 rate¹⁶ 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 polynomial 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 reactor HMP. The heat generated in the i th region due to gamma heating is

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

where

V_i = volume of i th region,

ρ_i = density of material in i th region,

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

ORNL-DWG 75-15375

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

and the total heat generated in a longitudinal section is

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

where J = total number of regions in the n th 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):

$$T_s = T_\infty + Q_t / h A_n , \quad (8)$$

where

T_∞ = average coolant temperature,

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

h = surface heat transfer coefficient,

A_n = surface area of aluminum containment vessel for n th 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):

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

where

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

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

G_i = volumetric heat source for i th region,

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

R_i = outside radius of i th region,

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

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

The volumetric heat source is described by

$$G_i = Q_i^Y / V_i \quad (10)$$

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

$$G_2 = \text{LHR}_n^*(1 \text{ ft}) + Q_2^Y. \quad (10a)$$

The incident heat flux on the inside surface is described by

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

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

$$q_1 = Q_1^Y / \left[2\pi R_1(1 \text{ ft}) \right]. \quad (11a)$$

HTCAP contains polynomials 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

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

where

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

T_i = temperature of outside radius of gas gap (known from previous calculation) ($^{\circ}\text{K}$),

T_{i-1} = unknown temperature of gas gap inside surface ($^{\circ}\text{K}$),

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

$$\mathcal{F}_\epsilon = \text{emissivity factor}^{17} \left[= \frac{1}{1(\epsilon_{i-1} + (R_{i-1}/R_i)^*(1/\epsilon_i - 1))} \right].$$

¹⁷S. 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 $+35^\circ\text{C}$ 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 polynomial 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:

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

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

where

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

F_3 = ratio of fast neutron fluence/ 11.84×10^{21} neutrons/cm².

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 $\leq 5^\circ\text{C}$.

For those particle holders containing ThO₂-coated particles, the computational model PARTMP¹⁸ is employed to determine particle

¹⁸Personal 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:

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

where

Q_p = heat transfer rate per particle,

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

assuming $\epsilon_1 = \epsilon_2 = \epsilon$,

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 area¹⁹ ($4\pi r_1 r_2$, r_2 = radius associated with volume of particle plus gas shell).

¹⁹R. 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/cm³) 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 ThO₂ 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 ThO₂ 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	—

^aBatch numbers are listed for ThO₂ test particles only.

^bGGA denotes Gulf General Atomic, presently General Atomic Company.

^cDesign given as kernel diameter, buffer thickness, outer pyrocarbon thickness, all in micrometers.

^dDistance 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	23 (total = 160)
						(total = 172)	

^aIncludes 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 uncertainties²⁰ in the calculated fluxes of $\pm 15\%$ and in the calculated ^{232}Th capture cross section of $\pm 25\%$, HTCAP calculates particle surface temperatures within $\pm 9\%$ 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.

²⁰Personal 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 $\left[\frac{(T_2 - T_1)}{T_1} \right]$
	Exposure Time (cycle, day)	Annulus Temp HEATING ³ (°C)	W/Particle	Particle Surface Temp T1 (°C)	Corresponding Exposure Time (cycle, day)	Annulus OD Temp (°C)	W/Particle	Particle Surface Temp T2 (°C)	
27 (334 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	1338	4.66
	3, 9	1316	0.82	1595	4, 7	1364	0.859	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	1530	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 (319 μm)	1, 0	1372	0.04	1585	1, 1	1324	0.007	1424	-4.40
	1, 23	1205	0.38	1565	1, 23	1281	0.351	1430	-2.56
	3, 9	1319	0.77	1585	4, 7	1383	0.755	1593	0.50
	6, 9	1322	0.93	1635	7, 9	1387	0.858	1602	-2.02
32 (506 μm)	1, 0	1349	0.02	1550	1, 1	1317	0.004	1417	-2.44
	1, 23	1184	0.19	1545	4, 23	1243	0.159	1430	-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	1521	-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	1575	0.03	1380	1, 1	1305	0.005	1305	-5.43
	1, 23	1180	0.32	1370	1, 23	1256	0.331	1327	-3.14
	3, 9	1282	0.67	1535	4, 7	1351	0.685	1608	1.45
	6, 9	1214	0.81	1650	7, 9	1357	0.732	1632	-1.09
38 (452 μm)	1, 0	1400	0.02	1405	1, 1	1497	0.001	1497	6.55
	1, 23	1241	0.18	1350	1, 23	1264	0.182	1446	4.89
	3, 9	1293	0.37	1505	4, 7	1279	0.381	1601	6.38
	6, 9	1203	0.45	1600	7, 9	1267	0.409	1647	1.06

^aDiameter of Th₂ 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.

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APPENDIX A

FORTRAN Listing of HTCAP


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**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),HTCAP 50
1W(9,15),F9(15,30,8),R(9,15),PGAM(15),V(9,15),G(9,15),P(9,15),A(9,15),HTCAP 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(15),HTCAP 53
45),RF(15),RBF(15),RLT1(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 UTILIZES TWO PROGRAMS AUTHORED BY HALL C.
C      ROLAND. THEY ARE 'GENGTC' AND 'FARGEN'. BOTH PROGRAMS HAVE BEEN
C      MODIFIED TO MEET THE NEEDS OF HTCAP.
C
C
C      'HT' CONSISTS OF A MAIN PROGRAM AND TWO SUBROUTINES, 'FARGEN' 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*      DATA FOR MATERIAL Z(I,J)
C*      I=1  POCO GRAPHITE
C*      =2  U OR TH FUELED REGION
C*      =3  ALUMINUM CONTAINMENT VESSEL
C*      =4  ARGON BACKFILL GAS
C*
C*      J=1  MATERIAL DENSITY (GM/CC)
C*      =2-6 COEFFICIENTS FOR MATERIAL THERMO CONDUCTIVITY (4TH ORDER)
C*      =7-9 COEFFICIENTS FOR MATERIAL DIMENSIONAL CHANGE CHARACTERISTS
C*
C*      DATA (Z(1,J),J=1,9)/1.79,17.34,0.0,0.0,0.0,0.0,0.0,11.6302,4.9709E-3,-HTCA 230
C*      12.808E-6/
C*      DATA (Z(3,J),J=1,9)/2.6989,117.0,0.0039,0.163E-4,0.813E-7,0.596E-1HTCA 240
C*      10,12.16,.00302,0.0/
C*      DATA (Z(4,J),J=1,9)/1.7838E-3,7.985E-3,1.924E-5,-3.607E-9,-2.792E-HTCA 250
C*      112,1.288E-15,0.0,0.0,0.0,0.0/
C*      READ 6225,(TITLE(I),I=1,18)
C*      READ 6235,NHOLD,M7,ND3,IDATA
C*      READ 6235,(L6(I),L9(I),I=1,M7)
C*      F(1)=1.0E+15
C*      F(2)=1.0E+15
C*      READ 6435,IPOL1,IPOL2,FLXI,FLXF
C*      NPOL1=IPOL1+1
C*      NPOL2=IPOL2+1
C*      READ 6375,(ZZ1(I),I=1,NPOL1)
C*      READ 6375,(ZZ2(I),I=1,NPOL2)
C*
C*      HTCA 260
C*      HTCA 270
C*      HTCA 280
C*      HTCA 290
C*      HTCA 300
C*      HTCA 310
C*      HTCA 320
C*      HTCA 330
C*      HTCA 340
C*      HTCA 341
C*      HTCA 350
C*      HTCA 351
C*      HTCA 360
C*      HTCA 361
C*      HTCA 370
C*      HTCA 380
C*      HTCA 390
C*      HTCA 400
C*      HTCA 410
C*      HTCA 420
C*      HTCA 430
C*      HTCA 440
C*      HTCA 450
C*      HTCA 460

```

	READ 6415,N9,T9,R9,M9,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),PNJ(J),ND9(J),J=1,15)	HTCA 490
	READ 6005,(B1NM(J),B2NM(J),J=1,NHOLD)	HTCA 491
6005	FORMAT(6(A8,A3))	HTCA 500
	T9=T9+460.0	HTCA 510
	PRINT 6305	HTCA 520
C	READ DATA FOR EACH THO2 PARTICLE HOLDER (I.E. EACH HOLDER)	HTCA 530
	DO 20 J=1,NHOLD	HTCA 540
	READ 6455,ANAME(J),CHAIN(J),STEMP(J)	HTCA 550
	READ 6425,(ZYX(J,K),K=1,8)	HTCA 560
	ZYX(J,9)=0.0	HTCA 570
	READ 6335,(TISO(I,J),I=1,6)	HTCA 580
	N9D=ND9(J)	HTCA 590
	READ 6295,(RDIM(I,J),I=1,N9D)	HTCA 600
	READ 6295,(E(I,J),I=1,N9D)	HTCA 610
	READ 6235,(MX(I,J),I=1,N9D)	HTCA 620
	READ 6235,(HW(I,J),I=1,N9D)	HTCA 630
	READ 6365,(AN(I,J),I=1,7),AH	HTCA 640
20	CONTINUE	HTCA 650
C	M=CYCLE NUMBER AND K=DAY NUMBER	HTCA 660
	DO 40 J=1,NHOLD	HTCA 670
	KKK=CHAIN(J)	HTCA 680
	JJJ=J	HTCA 690
	R0=RDIM(1,J)	HTCA 700
	R1=RDIM(2,J)	HTCA 710
	Z0=Z00(J)	HTCA 720
	Z1=Z10(J)	HTCA 730
	DO 30 I=1,9	HTCA 740
	AI(I)=AN(I,J)	HTCA 750
	TS(I)=TISO(I,J)	HTCA 760
30	CONTINUE	HTCA 770
	CALL FABGEN	HTCA 780
40	CONTINUE	HTCA 790
	DO 90 M=1,M7	HTCA 800
	N6=L6(M)	HTCA 810
	N9=L9(M)	HTCA 820
	DO 80 K=1,N6	HTCA 830
	DO 70 J=1,NHOLD	HTCA 840
	IF(J.GT.1) GO TO 50	HTCA 850
	F98=STKP(1,K,M)+.5*STKP(2,K,M)	HTCA 860
	F99=F98/(ZDIM(2)-.2188)	HTCA 870
	F9(1,K,M)=F99*12.0	HTCA 880
	GO TO 70	HTCA 890
50	IF(J.EQ.15) GO TO 60	HTCA 900
	F98=STKP(J,K,M)+.5*STKP(J-1,K,M)+.5*STKP(J+1,K,M)	HTCA 910
	F99=F98/(ZDIM(J+1)-ZDIM(J-1))	HTCA 920
	F9(J,K,M)=F99*12.0	HTCA 930
	GO TO 70	HTCA 940
60	F98=STKP(15,K,M)+.5*STKP(14,K,M)	HTCA 950
	F99=F98/(ZDIM(2)-.2188)	HTCA 960
	F9(15,K,M)=F99*12.0	HTCA 970
70	CONTINUE	HTCA 980
80	CONTINUE	HTCA 990
90	CONTINUE	HTC 1000
	DO 900 M=1,M7	HTC 1010
		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)+1.29554	HTC 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 (720,690,720,690,690,720,690,690,720,690,720,720,	HTC 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 PTL TM(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(1,J),R(1,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

[illegible]

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      PRINT 6115, ANAME(2), ANAME(4), ANAME(5), ANAME(7), ANAME(8), ANAME(10), HTC 3210
1 ANAME(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(1 HTC 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 TH02 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
1 ANAME(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), PW(K, HTC 3420
11), PW(K, 13) HTC 3421
6185 FORMAT(14, 15, 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, 880, 890, 880, 880, 880, 890, 880, 890, 890) HTC 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, 11) 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 = ', I2) HTC 3610
1) HTC 3611
6275 FORMAT(1H0) HTC 3620
6285 FORMAT(' CYCLE ', I2, ' HAS ', I2, ' TOTAL DAYS WITH ', I2, ' FULL POWER' HTC 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# '.12,' HAS '.12,' 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(15.17.16.5X.F8.2.6X.F8.2.5X.F8.2.10X.F8.5.5X.F6.1.6X.F8.2)	HTC 3750
6415	FORMAT(18.5F8.0)	HTC 3760
6425	FORMAT(8E9.4)	HTC 3770
6435	FORMAT(214.2E8.0)	HTC 3780
6445	FORMAT(7F10.0.F5.0.15)	HTC 3790
6455	FORMAT(14.14.14)	HTC 3800
6465	FORMAT(3110.2F10.0.3F10.3)	HTC 3810
	STOP	HTC 3820
	END	HTC 3830

C	*****	10
C	*****	20
C	*****	30
C	*****	40
	SUBROUTINE FABGEN	50
	IMPLICIT REAL*8(A-H,O-Z)	60
	INTEGER*4 CHAIN	70
	COMMON/BLOCK1/M7,ND3,L6(30),L9(30),D1,D6,R0,R1,Z0,Z1,NCYC(10),	80
	1 AH,F(2),NPOL1,NPOL2,ZZ1(3),ZZ2(3),FLX1,FLXF,STKP(15,30,8),	81
	2NHOLD,JJJ,AI(9),TS(9),KKK,IDATA	82
	DIMENSION Q(6),S(6,2),C(6,2)T(6,2),A1(4),A2(4),FNCYC(112),H(6),R(6	90
	1),P(6),AL(6),O(6),G(6),X(6),B(7),POW(15,112,8),Z(6),Y(6),W(6),	91
	2 AN(9),TISO(9)	92
	EQUIVALENCE (NHOLD,NSTK),(AI(9),AN(9)),(KKK,CHAIN),(TS(9),TISO(9))	100
	IF(JJJ.EQ.15) GO TO 150	110
	DO 10 I=1,6	120
10	Q(I)=185.0	130
	DO 20 I=1,6	140
20	Q(I)=Q(I)*1.6E-16	150
	STKL=ABS(Z1-Z0)	160
	C0=.9994	170
	C1=-1.1967	180
	C2=.9635	190
	C3=-.4507	200
	C4=.10655	210
	C5=-9.79E-3	220
	V=3.1416*(R1**2-R0**2)*12.*(2.54**3)	230
	A8=6.2832*R1*12.*(2.54**2)	240
	NC=0	250
	ND4=ND3+1	260
	R9=2.*V/A8	270
	C7=.5*(R1*2.54/(.55*D1))	280
	IF(KKK.EQ.0) GO TO 50	290
	S(1,1)=.253E-25	300
	S(2,1)=.313E-24	310
	S(3,1)=50.0E-24	320
	S(4,1)=21.2E-24	330
	S(5,1)=.468E-24	340
	S(6,1)=9.21E-24	350
	S(1,2)=0.0	360
	S(2,2)=0.0	370
	S(3,2)=3500.E-24	380
	S(4,2)=391.E-24	390
	S(5,2)=0.0	400
	S(6,2)=402.E-24	410
	C(1,1)=3.145E-24	420
	C(2,1)=17.187E-24	430
	C(3,1)=0.0	440
	C(4,1)=4.6E-24	450
	C(5,1)=27.432E-24	460
	C(6,1)=6.19E-24	470
	C(1,2)=5.39E-24	480
	C(2,2)=54.4E-24	490
	C(3,2)=0.0	500
	C(4,2)=37.0E-24	510
	C(5,2)=66.7E-24	520

	C(6,2)=71.0E-24	530
	X(1)=0.0	540
	X(2)=2.928E-7	550
	X(3)=2.891E-5	560
	X(4)=0.0	570
	X(5)=0.0	580
	X(6)=0.0	590
	B(1)=12.5	600
	B(2)=10.0	610
	B(3)=10.0	620
	B(4)=8.3	630
	B(5)=8.3	640
	B(6)=8.3	650
	B(7)=4.2	660
	T5=6.*3600.	670
	DO 30 I=1,6	680
30	Y(1)=1.	690
	Y(1)=0.	700
	Y(4)=0.	710
	DO 40 I=1,6	720
40	W(1)=0.	730
	W(4)=1.	740
	W(5)=1.	750
	GO TO 90	760
50	T5=24.*3600.	770
	S(1,1)=9.21E-24	780
	S(2,1)=.101E-24	790
	S(3,1)=.514E-24	800
	S(4,1)=10.1E-24	810
	S(5,1)=.548E-24	820
	S(6,1)=23.3E-24	830
	S(1,2)=402.E-24	840
	S(2,2)=0.00E-24	850
	S(3,2)=0.00E-24	860
	S(4,2)=660.E-24	870
	S(5,2)=0.00E-24	880
	S(6,2)=823.E-24	890
	C(1,1)=6.19E-24	900
	C(2,1)=9.229E-24	910
	C(3,1)=20.986E-24	920
	C(4,1)=6.2E-24	930
	C(5,1)=7.072E-24	940
	C(6,1)=6.9E-24	950
	C(1,2)=71.0E-24	960
	C(2,2)=1.97E-24	970
	C(3,2)=39.2E-24	980
	C(4,2)=3.01E-22	990
	C(5,2)=674.E-24	1000
	C(6,2)=2.67E-22	1010
	X(1)=0.0	1020
	X(2)=0.0	1030
	X(3)=3.487E-6	1040
	X(4)=0.0	1050
	X(5)=0.0	1060
	X(6)=0.0	1070
	B(1)=8.3	1080
	B(2)=12.5	1090

	B(3)=10.0	1100
	B(4)=8.3	1110
	B(5)=8.3	1120
	B(6)=8.3	1130
	B(7)=4.2	1140
	DO 60 I=1.5	1150
60	Z(1)=0.	1160
	Z(3)=1.	1170
	DO 70 I=1.5	1180
70	G(1)=1.	1190
	G(1)=0.	1200
	G(3)=0.	1210
	DO 80 I=1.4	1220
80	O(1)=0.	1230
	O(3)=1.	1240
90	DO 110 I=1.6	1250
	DO 100 J=1.2	1260
100	T(I,J)=S(I,J)+C(I,J)	1270
110	CONTINUE	1280
	ZF2=Z1	1290
	Z12=Z0	1300
120	A11=0.	1310
	A21=0.	1320
C*	CALCULATION FOR FAST AND THERMAL FLUX	1321
	DO 130 I=1,NPOL1	1340
	A1(I)=ZZ1(I)*(ZF2**I-Z12**I)/DFLOAT(I)	1350
	A11=A11+A1(I)	1360
130	CONTINUE	1370
	DO 140 I=1,NPOL2	1380
	A2(I)=ZZ2(I)*(ZF2**I-Z12**I)/DFLOAT(I)	1390
	A21=A21+A2(I)	1400
140	CONTINUE	1410
	V1=V*STKL/12.0	1420
	NT6=ND3+1	1430
	IF(IDATA.GE.0) GO TO 150	1431
	PRINT 6115	1440
	PRINT 6125	1450
150	DO 460 M=1,M7	1460
	NT7=NT6+1	1470
	IF(KKK.EQ.0) GO TO 160	1480
	N6=L6(M)*4	1490
	N9=L9(M)*4	1500
	GO TO 170	1510
160	N6=L6(M)	1520
	N9=L9(M)	1530
	IF(JJJ.EQ.15) GO TO 410	1540
170	DO 180 I=1,N6	1550
180	FNCYC(I)=1.	1560
190	DO 390 K1=1,N6	1570
	F7=F(2)*A21	1580
	F7=F7*D6	1590
	IF(NCYC(M).EQ.0) GO TO 200	1600
	F7=F7*FNCYC(K)	1610
200	B1=0.	1620
	B5=0.	1630
	DO 210 I=1,7	1640
210	B1=B1+AN(I)*B(I)*1.E-24	1650

	DO 220 I=1,6	1660
220	B5=B5+AN(I)*T(I,2)	1670
	B5=B5+B1	1680
	R5=B1/B5	1690
	S5=R9*B5	1700
	IF(S5-3.5) 230,230,370	1710
230	S1=R9*(B5-B1)	1720
	T3=C0+C1*S5+C2*S5**2+C3*S5**J+C4*S5**4+C5*S5**5	1730
	T3=T3/(1.-(1.-T3)*R5-S1*T3)	1740
	T2=1./(1.+T3*S1*C7)	1750
	T2=T2*T3	1760
	F2=F7*T2	1770
	PHI1=F(I)*A11	1780
	PHI2=F2	1790
	P7=0.	1800
	P8=0.	1810
	PSTK=0.	1820
	PDEN=0.	1830
	IF(FNCYC(K1)-0.) 240,240,250	1840
240	PHI1=PHI1*FNCYC(K1)	1850
	PHI2=PHI2*FNCYC(K1)	1860
250	DO 290 I=1,6	1870
	H(I)=0.	1880
	R(I)=0.	1890
	P(I)=0.	1900
	AL(I)=0.	1910
260	IF(K1-N9) 270,270,290	1920
270	H(I)=H(I)+PHI1*C(I,1)+PHI2*C(I,2)	1930
	R(I)=R(I)+PHI1*T(I,1)+PHI2*T(I,2)	1940
	AL(I)=AL(I)+PHI1*S(I,1)+PHI2*S(I,2)	1950
	H(I)=H(I)/STKL	1960
	R(I)=R(I)/STKL	1970
	P(I)=(P(I)+AL(I))/STKL	1980
	H(I)=H(I)*AN(I)	1990
	R(I)=R(I)*AN(I)	2000
280	P(I)=P(I)*AN(I)	2010
	P8=P8+P(I)	2020
	P(I)=P(I)*Q(I)	2030
	PDEN=PDEN+P(I)	2040
	P(I)=P(I)*V1	2050
290	PSTK=PSTK+P(I)	2060
	POW(JJJ,K1,N)=PSTK	2070
300	AH=AH+T5*H(1)	2080
	AH=AH+T5*H(6)	2090
	DO 360 J=1,6	2100
	IF(KKK.EQ.0) GO TO 330	2110
	AN(J)=AN(J)-T5*R(J)-AN(J)*[1.-EXP(0.-T5*X(J))]	2120
	IF(J-1) 360,360,310	2130
310	AN(J)=AN(J)+T5*Y(J)*H(J-1)	2140
	IF(J-2) 360,360,320	2150
320	AN(J)=AN(J)+AN(J-2)*W(J)*[1.-EXP(0.-T5*X(J-2))]	2160
	GO TO 360	2170
330	I=6-J	2180
	AN(I+1)=AN(I+1)-T5*R(I+1)-AN(I+1)*[1.-EXP(0.-T5*X(I+1))]	2190
	IF(I-1) 360,340,340	2200
340	AN(I+1)=AN(I+1)+T5*G(I)*H(I)+Z(I)*AN(I)*[1.-EXP(0.-T5*X(I))]	2210
	IF(I-2) 360,350,350	2220

350	AN(I+1)=AN(I+1)+TS*O(I-1)*H(I-1)	2230
360	CONTINUE	2240
	NT6=NT6+1	2250
	NT7=NT6+1	2260
	GO TO 390	2270
370	PRINT 6075	2280
380	PRINT 6085,SS	2290
390	CONTINUE	2300
	IF(KKK.EQ.0) GO TO 410	2310
	DO 400 II=4,N6,4	2320
	K=II/4	2330
	STKP(JJJ,K,M)=POW(JJJ,II,M)	2340
	IF(IDATA.GE.0) GO TO 400	2350
	PRINT 6135,JJJ,K,M,STKP(JJJ,K,M)	2360
400	CONTINUE	2370
	GO TO 460	2380
410	DO 450 K=1,N6	2390
	IF(JJJ-15)430,420,420	2400
420	POW(15,K,M)=0.	2410
	STKP(15,K,M)=0.	2420
	GO TO 440	2430
430	STKP(JJJ,K,M)=POW(JJJ,K,M)	2440
440	IF(IDATA.GE.0) GO TO 450	2450
	PRINT 6135,JJJ,K,M,STKP(JJJ,K,M)	2460
450	CONTINUE	2470
460	CONTINUE	2480
	RETURN	2490
6005	FORMAT(1H0)	2500
6015	FORMAT(15,I7,2X,A8,E12.5,F11.5)	2510
6025	FORMAT(2X,'CYCLE DAY ISOTOPE NO.DENSITY POWER(KWATT)')	2520
6035	FORMAT(14X,3H HM,E17.5)	2530
6045	FORMAT(16H0LINEAR POWER = ,F9.5,6H KW/FT)	2540
6055	FORMAT(21H0TOTAL STICK POWER = ,F9.5,3H KW)	2550
6065	FORMAT(19H0FISSION DENSITY = ,E12.3,16H FISSIONS/SEC/CC)	2560
6075	FORMAT(40H FLUX DEPRESSION PARAMETER EXCEEDS LIMIT)	2570
6085	FORMAT(29H0FLUX DEPRESSION PARAMETER = ,F10.3)	2580
6095	FORMAT(6E12.5)	2590
6105	FORMAT(' POWER DENSITY = ',E10.5,' KW/CC')	2600
6115	FORMAT(1H1)	2610
6125	FORMAT(2X,'HOLDER# DAY CYCLE STICK POWER(KWATT)')	2620
6135	FORMAT(2X,I4,I7,16,7X,F8.5)	2630
	END	2640

	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/	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

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Data Preparation Guide for HTCAP

HTCAP Data Input Variables and Formats

Card Type

1											72
1	TITLE(I), Job Description (18A4)										
2	NHOLD (14)	M7 (14)	ND3 (14)	IDATA (14)							
	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										
1											72
3	L6(I) (14)	L9(I) (14)	Continue in pairs for I = 1, M7 Format (1814)								
	L6(I) = Number of days in HFIR Cycle I L9(I) = Number of full power days in HFIR Cycle I										
1											72
4	IPOL1 (14)	IPOL2 (14)	FLX1 (E8.0)	FLXF (E8.0)							
	IPOL1 = Order of fast flux polynomial IPOL2 = Order of thermal flux polynomial FLX1 = Minimum Z of flux, in. FLXF = Maximum Z of flux, in.										
1											72
5	ZZ1(I) (E8.0)	Continue for I=1, IPOL1+1 Format (9E8.0)									
	ZZ1(I) = Coefficients for fast flux polynomial										
1											72
6	ZZ2(I) (E8.0)	Continue for I=1, IPOL2+1 Format (9E8.0)									
	ZZ2(I) = Coefficients for thermal flux polynomial										
1											72
7	N9 (18)	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										
1											72
8	NCYC(J) (14)	Continue for I=1, M7 Format (1814)									
	NCYC(I) = Input 0 for each cycle considered.										
1											80
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)	Z10(J) (F10.0)	PNO(J) (F5.0)	ND9(J) (15)		
	Repeat Card 9 J = NHOLD times DIA(J) = Particle diameter, um RF(J) = Kernel radius, cm RBF(J) = Buffer thickness, cm ZOO(J) = Position of top of fueled annulus relative to reactor HMP, in. Z10(J) = Position of bottom of fueled annulus relative to reactor HMP, in. 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	<div> <div> BINM(J) (A8) </div> <div> B2NM(J) (A3) </div> </div>	<div> Continue in pairs; 6 pairs per card; repeat for J=1,NHOLD Format (6(A8,A3)) </div>	
		<div> BINM(J),B2NM(J) = Batch name associated with each ThO₂ particle. If no batch name, leave blank. Example → GGA-4252-06 BINM B2NM </div>	
		<div> 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. </div>	
1		12	
11	<div> <div> ANAME(J) (14) </div> <div> CHAIN(J) (1) </div> <div> STEMP(J) (1) </div> </div>	<div> 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 </div>	
1			72
12	<div> ZYX(J,K) (E9.4) </div>	<div> Continue for K=1,8 Format (8E9.4) </div>	
		<div> ZYX(J,K) = Material data for fueled annulus of Holder J K=1, Material density, g/cm³ K=2-6, Coefficients for material thermal conductivity (4th order) K=7-8, Coefficients for dimensional change characteristics </div>	
2		48	
13	<div> TISO(I,J) (A8) </div>	<div> Continue for I=1,6 Format (6A8) </div>	
		<div> TISO(I,J) = Isotope names for the initial fissionable isotope and five other chain isotopes. If CHAIN(J) = 0, TISO(I,J) = ²³⁵U, ²³⁸U, ²³⁹Pu, ²⁴⁰Pu, ²⁴¹Pu. If CHAIN(J) = 1, TISO(I,J) = ²³²Th, ²³³Pa, ²³⁴Pa, ²³³U, ²³⁴U, ²³⁵U. </div>	
1			72
14	<div> RDIM(I,J) (E8.0) </div>	<div> Continue for I=1, ND9(J) Format (9E8.0) </div>	
		<div> RDIM(I,J) = Initial radius of Ith node of Jth holder, in. </div>	
1			72
15	<div> E(I,J) (E8.0) </div>	<div> Continue for I=1, ND9(J) Format (9E8.0) </div>	
		<div> E(I,J) = Emissivity at material surface (denoted by Ith node of the Jth holder) </div>	
1			72
16	<div> MX(J,J) (14) </div>	<div> Continue for I=1, ND9(J) Format (18I4) </div>	
		<div> MX(I,J) = FLAG: = 0, Indicates material immediately inside Node I is a gas = 1, Indicates material immediately inside Node I is a solid </div>	
1			72
17	<div> HW(I,J) (14) </div>	<div> Continue for I=1, ND9(J) Format (18I4) </div>	
		<div> 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 </div>	
1			72
18	<div> AN(I,J) (E9.3) </div>	<div> Continue for I=1,7 Format (7E9.3) </div>	<div> AH (E9.3) </div>
		<div> AN(I,J) for I=1-6 = Number density of Ith isotope in TISO(I,J) (nuclei/cm³) I=7 = Number density of O, C, or N contained in fuel (atoms/cm³) AH = Heavy metal content at day zero (usually 0) </div>	

HTCAP Data Deck Arrangement

ORNL-DWG 75-13475R

APPENDIX C

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

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

HIGH TEMPERATURE SLEEVE APPLICABLE TO HT-14 AND -15 HOLDERS 27--38														Title	
15	8	0	-1	3	1	22	21	24	23	24	23	26	23	23	Description of reactor operation over life of irradiation exp't.
24	23	26	23	3	1	22	21	24	23	24	23	26	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	0	140.0	0.0	1510.0				.500		1.0					
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	Description of ThO ₂
761.0		.02435		.00610		.00760		2.7790		2.73525		2.86025	75.	7	Coated Particles
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	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	Regional description of fueled end cap longitudinal section.
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	0.9	0.825	0.750								
1	1	1	0	1	0	1									
1	2	1	4	1	4	3									
9.5611E19	1.2575E21	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	
27	1	1													
1.0725E0	.57225E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	Regional description of holder No. 27 longitudinal section.
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	0.9	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	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	
28	0	1													
1.0725E0	.57225E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	Regional description of holder No. 28 longitudinal section.
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	.9	.825	.75								
1	1	1	0	1	0	1									
1	2	1	4	1	4	3									
5.5474E19	7.2963E20	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	
29	1	1													
6.3571E-1	.36865E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	Regional description of holder No. 29 longitudinal section
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	.9	.825	.75								

50

1	2	1	4	1	4	3			
1.0719E21	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0
30	1	1	1	1	1	1	1	1	1
1.0414E0	.55239E0	.0000E0	.0000E0	.0000E0	.0000EC	.0000E0	.0000E0	.0000E0	.0000E0
TH-232	PA-233	PA-234	U-233	U-234	U-235				
0.120	0.160	0.1925	0.1935	0.2448	0.2655	0.3275			
.9	.9	.9	.9	.9	.825	.75			
1	1	1	1	1	1	1	1	1	1
1.563E+21	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0
31	0	1	1	1	1	1	1	1	1
1.0725E0	.57225E0	.0000E0	.0000E0	.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	1	1	1	1	1	1	1
5.5474E197.2963E20	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00
32	1	1	1	1	1	1	1	1	1
5.5040E-1	.23124E0	.0000E0	.0000E0	.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	1	1	1	1	1	1	1
1.072E+21	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0
33	1	1	1	1	1	1	1	1	1
9.3512E-1	.5170SE0	.0000E0	.0000E0	.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	1	1	1	1	1	1	1
1.436E+21	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0
34	0	1	1	1	1	1	1	1	1
1.0725E0	.57225E0	.0000E0	.0000E0	.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			
.9	.9	.9	.9	.9	.825	.75			
1	1	1	1	1	1	1	1	1	1
5.5474E197.2963E20	.0000E0C	.0000E0C	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00
35	1	1	1	1	1	1	1	1	1
6.630BE-1	.28273E0	.0000E0	.0000E0	.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	1	1	1	1	1	1	1
1.324E+21	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0
36	1	1	1	1	1	1	1	1	1
9.3753E-1	.42385E0	.0000E0	.0000E0	.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)

1	.9	1	.9	1	.9	1	.9	.825	.75		
1	1	1	0	1	0	1	0				
1	2	1	4	1	4	3					
1.677E+21	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	3.355E+21	.0000E0	
37	0	1									
1.0725E0	.57225E0	.0000E0	.0000E0	.0000E0	.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	0.9	0.825	0.75				
1	1	1	0	1	0	1					
1	2	1	4	1	4	3					
5.5474E19	7.2963E20	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	1.5702E21	.0000E00	
38	1	1									
6.3058E-1	.23622E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	.0000E0	
TM-232	PA-233	PA-234	U-233	U-234	U-235						
0.137	0.160	0.1925	0.1935	0.23993	0.2655	0.3275					
.9	.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	.0000E0	.0000E0	.0000E0	.0000E0	2.648E+21	.0000E0	
39	0	1									
1.0725E0	.57225E0	.0000E0	.0000E0	.0000E0	.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	0.9	0.825	0.75				
1	1	1	0	1	0	1					
1	2	1	4	1	4	3					
5.5474E19	7.2963E20	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	.0000E00	1.5702E21	.0000E00	
2	0	1									
1.79E0	17.34E0	0.00E0	0.0E0	0.0E0	0.0E0	0.00E0	3.5896E01	5.342E-3			
U235	U238	N239	P239	P240	P241						
0.1925	0.1935	0.23800	0.2655	0.3275							
0.9	0.9	0.9	0.9	0.825	0.750						
1	0	1	0	1							
1	2	1	4	3							
.0000E00	.0000E00	.0000E00	.0000E00	.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

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 20 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

HOLDER#	BATCH#	PARTICLE DIA. (MICRON)	PARTICLE GEOMETRY		
			KERNEL RAD. (CM)	BUFFER THICK. (CM)	LTJ 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	751.0	0.02435	0.00610	0.00760
35	ORNL-1830	450.0	0.02010	0.00010	0.00380
36	GGA-4252-07	577.0	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.C. TEMPERATURE

CYCLE DAY		TEMPERATURE(C) FOR ANNULUS OF SPECIFIC 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 SPECIFIC HOLDERS							
		27	29	30	32	33	35	36	38
1	1	1481.	1322.	1324.	1317.	1313.	1318.	1305.	1497.
1	3	1418.	1260.	1288.	1283.	1277.	1284.	1272.	1431.
1	5	1384.	1265.	1271.	1267.	1268.	1269.	1268.	1399.
1	7	1368.	1265.	1277.	1275.	1270.	1276.	1271.	1383.
1	9	1363.	1274.	1288.	1286.	1275.	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.	1336.	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	0.046	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	0.166	0.322	0.163	0.267	0.157	0.271	0.149
1	21	0.379	0.186	0.357	0.182	0.316	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 SPECIFIC 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.	1261.	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 SPECIFIC 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.	1430.	1499.
2	9	1494.	1452.	1480.	1486.	1475.	1496.	1492.	1509.
2	11	1502.	1460.	1492.	1499.	1481.	1507.	1503.	1514.
2	13	1506.	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	0.354	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	0.456	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 SPECIFIC HOLDERS							
CYCLE	DAY	27	29	30	32	33	35	36	38
3	1	1418.	1372.	1415.	1357.	1391.	1352.	1382.	1337.
3	3	60.	60.	60.	60.	60.	60.	60.	60.
AVERAGE		1418.	1372.	1415.	1357.	1391.	1352.	1382.	1337.

TIME-TEMPERATURE HISTORY OF MAXIMUM PARTICAL SURFACE TEMPERATURE

		PARTICLE SURFACE TEMPERATURE(C) FOR SPECIFIC 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

CYCLE DAY		TEMPERATURE (C) FOR ANNULUS OF SPECIFIC HOLDERS							
		27	29	30	32	33	35	36	38
4	1	1427.	1384.	1434.	1370.	1406.	1367.	1398.	1343.
4	3	1369.	1350.	1405.	1342.	1378.	1339.	1370.	1300.
4	5	1370.	1341.	1390.	1226.	1366.	1327.	1357.	1282.
4	7	1364.	1335.	1383.	1320.	1355.	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

CYCLE DAY		PARTICLE SURFACE TEMPERATURE (C) FOR SPECIFIC HOLDERS							
		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.	1500.	1600.	1611.	1556.	1622.	1622.	1612.
4	7	1584.	1555.	1593.	1600.	1584.	1616.	1611.	1604.
4	9	1561.	1552.	1585.	1600.	1578.	1608.	1603.	1601.
4	11	1576.	1546.	1582.	1597.	1578.	1608.	1603.	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.	1603.	1599.
4	21	1579.	1547.	1585.	1595.	1578.	1608.	1608.	1599.
AVERAGE		1589.	1558.	1594.	1605.	1587.	1617.	1615.	1608.

TIME-POWER GENERATION HISTORY FOR THO2 PARTICLES

CYCLE DAY		POWER GENERATION (WATTS) PER PARTICLE FOR HOLDERS							
		27	29	30	32	33	35	36	38
4	1	0.932	0.459	0.882	0.450	0.752	0.437	0.756	0.419
4	3	0.892	0.439	0.844	0.431	0.759	0.419	0.725	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	0.816	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

CYCLE DAY	TEMPERATURE(C) FOR ANNULUS OF SPECIFIC HOLDERS							
	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

CYCLE DAY	PARTICLE SURFACE TEMPERATURE(C) FOR SPECIFIC HOLDERS							
	27	29	30	32	33	35	36	38
5 1	1609.	1573.	1612.	1621.	1600.	1631.	1634.	1629.
5 3	1593.	1564.	1600.	1614.	1555.	1622.	1622.	1615.
5 5	1592.	1563.	1597.	1611.	1555.	1619.	1619.	1609.
5 7	1587.	1558.	1597.	1608.	1552.	1619.	1619.	1609.
5 9	1589.	1558.	1596.	1608.	1552.	1619.	1619.	1609.
5 11	1589.	1558.	1594.	1608.	1552.	1619.	1619.	1609.
5 13	1589.	1558.	1597.	1608.	1552.	1619.	1619.	1609.
5 15	1589.	1558.	1597.	1608.	1553.	1619.	1619.	1609.
5 17	1589.	1563.	1597.	1606.	1553.	1619.	1619.	1614.
5 19	1592.	1563.	1597.	1608.	1555.	1624.	1619.	1614.
5 21	1592.	1563.	1597.	1611.	1555.	1624.	1624.	1614.
5 23	1592.	1563.	1597.	1611.	1555.	1624.	1622.	1614.
AVERAGE	1592.	1562.	1598.	1610.	1595.	1621.	1621.	1613.

TIME-POWER GENERATION HISTORY FOR THO2 PARTICLES

CYCLE DAY	POWER GENERATION(WATTS) PER PARTICLE FOR HOLDERS							
	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 SPECIFIC 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 PARTICLE SURFACE TEMPERATURE

CYCLE DAY		PARTICLE SURFACE TEMPERATURE (C) FOR SPECIFIC HOLDERS							
		27	29	30	32	33	35	36	38
6	1	1617.	1554.	1624.	1635.	1622.	1645.	1646.	1638.
6	3	1604.	1530.	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.	1560.	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 SPECIFIC HOLDERS							
CYCLE	DAY	27	29	30	32	33	35	36	38
7	1	1386.	1356.	1408.	1345.	1384.	1342.	1376.	1297.
7	3	1370.	1350.	1396.	1335.	1375.	1333.	1367.	1279.
7	5	1364.	1344.	1393.	1329.	1365.	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.	1355.	1321.	1351.	1267.
7	21	1352.	1332.	1381.	1320.	1359.	1321.	1351.	1264.
7	23	1352.	1332.	1380.	1320.	1355.	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 SPECIFIC 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.	1556.	1629.	1629.	1612.
7	13	1588.	1560.	1599.	1613.	1557.	1626.	1624.	1612.
7	15	1588.	1560.	1599.	1610.	1557.	1626.	1624.	1612.
7	17	1585.	1560.	1598.	1610.	1552.	1626.	1624.	1612.
7	19	1585.	1559.	1598.	1610.	1554.	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.	1555.	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	0.426	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 SPECIFIC 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.	1316.	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 SPECIFIC 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.	1648.	1630.
8	7	1590.	1568.	1607.	1623.	1606.	1634.	1637.	1619.
8	9	1587.	1564.	1599.	1615.	1597.	1626.	1625.	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		1567.	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	0.450	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	0.735	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	0.416	0.738	0.410	0.715	0.401
8	15	0.846	0.418	0.806	0.413	0.721	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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