Thermal Design and Analysis of the HTGR Fuel Element Vertical Carbonizing and Annealing Furnace

G. H. Llewellyn

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
Price: Printed Copy \$5.00; Microfiche \$3.00

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Energy Research and Development Administration, United States Nuclear Regulatory Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Contract No. W-7405-eng-26

ORNL Engineering

**THERMAL DESIGN AND ANALYSIS OF THE HGR FUEL ELEMENT
VERTICAL CARBONIZING AND ANNEALING FURNACE**

G. H. Llewellyn

Date Published: June 1977

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
Nuclear Division
for the
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

CONTENTS

Abstract	1
1. INTRODUCTION	1
2. CRITERIA	3
3. CARBONIZING AND ANNEALING FURNACE	5
Furnace Operation	5
Thermal Design	9
4. ENERGY TRANSPORT SIMULATION IN THE MOVING COLUMN	14
Determination of Volumetric Heat Generation Rate	15
Heat Balance in Graphite Column	17
5. HEAT TRANSFER MODELS AND BOUNDARY CONDITIONS	21
6. MATERIAL PROPERTIES USED IN THERMAL ANALYSIS	29
7. RESULTS OF THERMAL ANALYSIS, CONCLUSIONS, AND RECOMMENDATIONS	36
REFERENCES	42
Appendix A: MASS-FLOW SIMULATION DATA FOR FUEL ELEMENTS FABRICATED FROM H-327 GRAPHITE	45
Appendix B: MASS-FLOW SIMULATION DATA FOR FUEL ELEMENTS FABRICATED FROM H-451 GRAPHITE	69
Appendix C: THERMAL CONDUCTIVITY DATA AS A FUNCTION OF TEMPERATURE FOR FUEL ELEMENTS FABRICATED FROM TYPE H-327 AND TYPE H-451 GRAPHITE	79

LIST OF FIGURES

<u>Figure Number</u>	<u>Title</u>	<u>Page Number</u>
1	Typical Fort St. Vrain Active Core Element	4
2	Proposed HTGR Fuel Element Vertical Carbonizing and Annealing Furnace	6
3	Operational Diagram of Furnace Design	8
4	Desired Temperature of Outer Surface of Fuel Elements as a Function of Axial Location in Furnace	10
5	Internal Volumetric Heat Generation Rate Required for Simulation of Mass Flow of Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Top-Loaded Configuration	19
6	Internal Volumetric Heat Generation Rate Required for Simulation of Mass Flow of Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Bottom-Loaded Configuration	20
7	Computer Model of Upper Portion of Furnace for Top-Loaded Configuration	22
8	Computer Model of Middle Portion of Furnace for Top- and Bottom-Loaded Configurations	23
9	Computer Model of Lower Portion of Furnace for Top-Loaded Configuration	24
10	Computer Model of Upper Portion of Furnace for Bottom-Loaded Configuration	25
11	Computer Model of Lower Portion of Furnace for Bottom-Loaded Configuration	26
12	Results of Computer Analysis of Furnace Design Compared With Desired Temperature Profile for Top-Loaded Configuration	38
13	Results of Computer Analysis of Furnace Design Compared With Desired Temperature Profile for Bottom-Loaded Configuration	39
14	Results of Computer Analyses Obtained By Varying Insulation in Upper Portion of Furnace Compared With Desired Temperature Profile for Top-Loaded Configuration	40
15	Results of Computer Analyses Obtained By Varying Insulation in Upper Portion of Furnace Compared With Desired Temperature Profile for Bottom-Loaded Configuration	41

<u>Figure Number</u>	<u>Title</u>	<u>Page Number</u>
A.1	Centigrade Temperature Criteria for the Surface of Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Top-Loaded Configuration	54
A.2	Fahrenheit Temperature Criteria for the Surface of Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Top-Loaded Configuration	55
A.3	Axial Heat Transfer From Mass Flow of Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Top-Loaded Configuration	56
A.4	Axial Heat Transfer From Axial Conduction in Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Top-Loaded Configuration	57
A.5	Axial Heat Transfer From Mass Flow of Argon Gas as a Function of Axial Position in the Furnace for the Top-Loaded Configuration	58
A.6	Total Radial Power Input, Excluding External Losses, Required to Process Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Top-Loaded Configuration	59
A.7	Composite Axial Power Distribution for Processing Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Top-Loaded Configuration	60
A.8	Centigrade Temperature Criteria for the Surface of Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Bottom-Loaded Configuration	61
A.9	Fahrenheit Temperature Criteria for the Surface of Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Bottom-Loaded Configuration	62
A.10	Axial Heat Transfer From Mass Flow of Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Bottom-Loaded Configuration	63
A.11	Axial Heat Transfer From Axial Conduction in Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Bottom-Loaded Configuration	64

<u>Figure Number</u>	<u>Title</u>	<u>Page Number</u>
A-12	Axial Heat Transfer From Mass Flow of Argon Gas as a Function of Axial Position in the Furnace for the Bottom-Loaded Configuration	55
A-13	Total Radial Power Input, Excluding External Losses, Required to Process Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Bottom-Loaded Configuration	66
A-14	Composite Axial Power Distribution for Processing Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Bottom-Loaded Configuration	67
C-1	Axial and Radial Thermal Conductivities of Composite Fuel Elements Made With Unirradiated H-327 Graphite as a Function of Temperature	80
C-2	Axial and Radial Thermal Conductivities of Composite Fuel Elements Made With Unirradiated H-451 Graphite as a Function of Temperature	82

THERMAL DESIGN AND ANALYSIS OF THE HTGR FUEL ELEMENT VERTICAL CARBONIZING AND ANNEALING FURNACE

Abstract

Computer analyses of the thermal design for the proposed HTGR fuel element vertical carbonizing and annealing furnace were performed to verify its capability and to determine the required power input and distribution. Although the furnace is designed for continuous operation, steady-state temperature distributions were obtained by assuming internal heat generation in the fuel elements to simulate their mass movement. The furnace thermal design, the analysis methods, and the results are discussed herein.

1. INTRODUCTION

One step in the process under development at Oak Ridge National Laboratory (ORNL) for remote fabrication of fuel elements from recycled ^{233}U for use in high-temperature gas-cooled reactors (HTGR) operated on the thorium fuel cycle involves in-place carbonization and annealing of pitch-bonded fuel rods in graphite fuel element blocks. Coated fuel particles are bonded into rods with pitch, these rods are loaded into holes in prismatic graphite blocks, and the entire fuel element is heated to carbonize the pitch bonding material and then to anneal the carbon and produce stable fuel rods. To accomplish this step, the design for a vertical, remotely operable furnace was developed, and the thermal analysis of that furnace design is described in this report.

Thermal analyses were performed as part of the work involved in the development of the current furnace design. The steady-state thermal analysis of that design reported herein was performed to verify its capability to achieve the desired axial temperature distribution in the fuel elements as a function of time and to determine the power input and distribution to the furnace heaters required for maintenance of the desired temperature profile. As well as the power input to the heaters,

maintenance of the desired temperature profile is dependent upon the mass flow rate of the material going through the furnace, the thermal properties of the materials involved, and the boundary conditions at the cooling surfaces.

The criteria for the carbonizing and annealing furnace are discussed briefly in Section 2, and the furnace operation and thermal design are described in Section 3. The furnace design provided the basis for development of two-dimensional mathematical heat transfer models in the form of nodal layouts of the furnace. The HEATING4 computer program, which is a modification of the generalized heat conduction program HEATING3,¹ was used to obtain steady-state temperature distributions in these models. The HEATING programs have been used at ORNL for several years and have been updated during this period with new solution techniques and new boundary condition subroutines to the extent that any of the main variables can be expressed as functions of the other variables. The feature of anisotropic conduction was added to the program capabilities for analysis of the furnace. This feature was necessary inasmuch as the fuel elements, furnace liner, and some of the insulation have different axial and radial thermal conductivities.

The mass movement of fuel elements through the furnace was simulated to obtain heat input data for the HEATING4 program analysis of the furnace thermal design. This simulation is described in Section 4. The heat transfer models used in the computer analysis are described and the furnace boundary conditions developed for the analysis are discussed in Section 5. The thermal conductivity data for the furnace materials of construction used in the steady-state analysis are given in Section 6, and the results of the analysis are discussed in Section 7. The conclusions drawn from the results of the analysis are also presented in Section 7, as are recommendations relative to future analyses.

2. CRITERIA

The refabricated HTGR fuel elements which the carbonizing and annealing furnace was designed to accommodate are the type to be used in the active core of the Fort St. Vrain Reactor (FSVR). As illustrated in Fig. 1, a typical FSVR fuel element is a hexagonal prism that is 14.17 in. across the flats and 31.22 in. long at room temperature. The prism or fuel block is to be fabricated from unirradiated needle-coke (type H-327) graphite as manufactured by the Great Lakes Carbon Company. The block may possibly be fabricated from type H-451 graphite at a later date. As indicated in Fig. 1, each HTGR fuel element will contain six holes for burnable poison, 108 coolant holes, and 210 fuel holes. The fuel holes will be loaded with "green" fuel rods comprised of a mixture of graphite-coated uranium-oxide and thorium-oxide particles bonded with pitch. These holes will then be sealed with graphite plugs cemented in place at the top. Each assembled fuel element will have a maximum weight of approximately 300 lb.

The thermal criteria for the carbonization and annealing of HTGR fuel rods placed in the graphite blocks specify a beginning minimum carbonization temperature of 300°C and a thermal rise not to exceed 10°C per minute up to a temperature of 800°C, resulting in a carbonization period of 50 minutes. Following carbonization, an annealing step is required to completely drive off any remaining volatile materials. During this step, the temperature of the graphite must be maintained above 1750°C and below 1850°C for a period of at least 15 minutes but not to exceed 90 minutes. Before discharge from the furnace, each fuel element must be cooled so that the temperature of any graphite exposed to ambient air will be below 200°C.

Fig. 1. Typical Fort St. Vrain Active Core Element.

3. CARBONIZING AND ANNEALING FURNACE

A vertical furnace was designed for the carbonization and annealing step in the remote HTGR fuel element refabrication process. The vertical design, illustrated in Fig. 2, was considered the best configuration with respect to hot-cell space. From top to bottom, the furnace processing chamber is comprised of a charging gate valve, three temperature-controlled heating zones, two cooling zones, and a discharge gate valve. The processing chamber, with an overall length of approximately 203 in. between valve disks, is enclosed with a double-wall water-cooled metal shell which surrounds the heating elements and insulation in the heating zones and provides containment in the cooling zones for the inert atmosphere maintained within the chamber.

The overall height of the furnace is increased about 52 in. by the discharge chamber located below the discharge valve. This chamber provides additional cooling for fuel elements leaving the processing chamber and serves as a double-port lock to maintain the inert atmosphere in the furnace processing chamber during discharging and unloading of fuel elements.

The furnace can accommodate a maximum of six fuel elements and seven spacer pallets at any one time. Fuel elements travel downward through the furnace at an essentially continuous rate, and the furnace is purged continuously with argon gas in a flow path opposite the downward movement of the fuel elements. The furnace has a design processing capacity of about 14 elements a day, and its operation and thermal design are discussed in the following subsections.

Furnace Operation

A fuel element and its attendant spacer pallet are introduced into the furnace processing chamber from a portable charging chamber seated on the upper face of the charging valve. A pallet is placed on top of each element introduced into the furnace to receive the next element

ORNL DWG 76-18170

Fig. 2. Proposed HTGR Fuel Element Vertical Carbonizing and Annealing Furnace.

introduced. This spacer pallet is a 5-in.-thick circular disk with a hexagonally shaped socket about 1.5 in. deep milled into each face to fit the tops and bottoms of fuel elements. The 2-in.-thick hexagonal web of each pallet is drilled to match the 108 coolant passages of the fuel elements. The seated charging chamber is purged with argon, the upper valve gate is opened, and the charging chamber hoist is driven downward to introduce the element and pallet into the processing chamber. The bottom of the element is seated in the pallet resting on top of the fuel element below it in the processing chamber.

The entire column of elements and pallets is supported on a motor-driven elevator platform in the discharge chamber. This elevator controls the downward movement of the elements through the furnace heating and cooling zones to the bottom of the discharge chamber. When the spacer pallet on top of the bottom element in the column is a prescribed distance above the horizontally retractable support forks, which are mounted in the housing of the furnace discharge valve immediately above the valve disk, the downward movement of the elevator is continued while the forks are moved inward under the pallet. These forks provide interim support for the column of elements and pallets above while the bottom element is lowered by the elevator to the bottom of the discharge chamber. The discharge valve is closed, the unloading door in the discharge chamber is opened, and the fuel element and its supporting pallet are removed from the furnace. The unloading door is then closed and the discharge chamber is purged with argon, the discharge valve is opened, and the elevator platform is raised to again support the column of elements and pallets in the processing chamber. The support forks are retracted, the downward travel of the column is resumed, another fuel element is charged into the top of the furnace processing chamber, and the cycle is repeated.

A furnace cycle begins with what can be termed a "top-loaded" configuration consisting of six elements and seven pallets over the distance marked "A" in Fig. 3. About 90 minutes later, each element has moved down to comprise the "bottom-loaded" configuration over the distance marked "B" in Fig. 3. Production considerations led to the use of an average element movement of $3/8$ in. per minute. Based on an element length of 31.22 in. and a pallet web thickness of about 2 in., the

Fig. 3. Operational Diagram of Furnace Design.

travel time for a complete element unit from the top-loaded to the bottom-loaded configuration is 88.6 minutes. About 10 minutes more are required for unloading and loading procedures, resulting in an average production rate of about 14 fuel elements per day. However, the thermal analysis reported herein was based on the assumption of continuous mass movement of $3/8$ in. per minute.

Thermal Design

The thermal criteria for carbonization of the HTGR fuel rods in place in the graphite blocks stipulate heating of the blocks from 300°C to 800°C at a constant heating rate not to exceed 10°C per minute. A uniform thermal gradient of 26.67°C per inch (48°F per inch) was obtained by dividing the heating rate ($10^{\circ}\text{C}/\text{min.}$) by the mass movement rate (0.375 in./min). This information and the annealing criteria were adequate to establish the desired furnace axial temperature profile illustrated in Fig. 4.

Point A on the curve shown in Fig. 4 is the temperature at the top of the fuel element unit (element plus spacer pallet) or block introduced into the furnace processing chamber at elevation 202 in., and Point B is the temperature at the bottom of that element at furnace elevation 168 in. Point C denotes the beginning of the critical gradient at a temperature of 300°C and a furnace elevation of 142 in., and Point D denotes the end of the critical zone at a temperature of 800°C and a furnace elevation of 123.25 in. The temperature gradient used for carbonization was maintained during annealing to obtain the location of Point E at a temperature of 1750°C and a furnace elevation of 87.63 in. Point F, the inflection point of the gradients, is the maximum temperature of 1800°C reached at furnace elevation 81 in. Any zone above this point requires net heating, while any zone below it requires net cooling.

Point G on the curve is symmetrically adjacent to Point E at a temperature of 1750°C and a furnace elevation of 74.37 in. A heat balance must be achieved and, although it does not have to be, Point H was conveniently located at furnace elevation 40 in., resulting in a temperature

Fig. 4. Desired Temperature of Outer Surface of Fuel Elements as a Function of Axial Location in Furnace.

ORNL DMC 78 18172

of 770°C. Point I denotes the desired temperature of 200°C at furnace elevation 0 in., while Point J denotes the ambient temperature of 25°C at furnace elevation -34 in.

As previously discussed, the thermal criteria for carbonization of the fuel rods specify a beginning minimum temperature of 300°C. However, if the temperature in the uppermost portion of the furnace processing chamber were permitted to exceed 300°C, the gasket used in the charging valve would fail. If the temperature of the surface of the charging valve internal to the processing chamber were allowed to fall below 200°C, hydrocarbons would condense out on this surface. The furnace was therefore designed to provide an axial temperature profile ranging from 200°C in the upper section up to a maximum temperature of 1800°C in the center section and back down to a temperature of 200°C in the bottom section, with the temperature range up to about 800°C for carbonization and that between 800 and 1800°C for annealing.

Attainment of the desired axial temperature profile within the furnace processing chamber, and thus in the fuel elements, is based on the provision of three controlled heating zones, each designed to increase the temperature of a fuel element by a differing amount, and three cooling zones. Two of the cooling zones are within the furnace processing chamber (above the discharge valve), and the third is the discharge chamber below the processing chamber. Completion of the processing of an element in the furnace is a function of time and temperature in the various zones.

The first controlled heating zone in the furnace processing chamber below the charging valve, the low-temperature heating zone, is approximately 60 in. long and is heated with metallic strip heating elements interspersed with ceramic fiber insulation. When first introduced into the furnace processing chamber, a fuel element will be at hot-cell ambient temperature, which will be about 25°C. Upon leaving the low-temperature heating zone and entering the intermediate-temperature heating zone, the fuel element is expected to have an outer surface temperature of approximately 300°C. As indicated in Fig. 4, the temperature of the outer surface of the bottom of the fuel element is expected to increase from 25°C to 300°C in approximately 26 in. of travel. At 0.375 in. per minute, this would amount to an increase of about 4°C per minute.

The intermediate-temperature zone in the processing chamber is heated by a graphite resistance heater about 22 in. long that is surrounded with insulation. The evolution of volatiles from the pitch bonding material in the fuel rods (carbonization) will begin at a temperature of about 300°C and will be completed at a temperature of about 800°C. The coke yield, matrix-particle interaction, and resulting quality of the rods in each element are dependent upon the heating rate in the carbonization range (300 to 800°C). The critical heating rate in the intermediate temperature zone must be maintained at near 10°C per minute, and carbonization is expected to be completed when the fuel element leaves this heating zone with a surface temperature of about 800°C.

A fuel element leaving the intermediate-temperature zone enters the third (high-temperature) heating zone wherein the fuel rods are annealed in place in the element. A graphite resistance heating element about 43.5 in. long surrounded with insulation is used in the high-temperature zone to attain the maximum element surface temperature of 1300°C required to remove the last traces of volatiles and produce dimensionally stable fuel rods. The heating rate in the annealing zone is not critical. Once the maximum temperature has been reached, the temperature of the fuel element will be lowered as rapidly as possible. The surface temperature of an element is expected to already have begun falling from the 1800°C maximum as the element leaves the high-temperature heating zone and enters the high-temperature cooling zone.

Graphite is used in the high-temperature cooling zone, which is about 26 in. long, to conduct heat to the water-cooled surface of the processing chamber, thereby reducing the temperature of the fuel element as it progresses through the zone. It is estimated that the temperature of an element will be about 1060°C as it leaves the first cooling zone and enters the second or low-temperature cooling zone. The water-cooled surface of the chamber is in close proximity to a fuel element as it progresses through the 50-in. long low-temperature cooling zone. It is estimated that the surface temperature of the fuel element will be between 200 and 400°C as the element leaves the low-temperature cooling zone and enters the discharge chamber, which serves as the final cooling zone. The temperature of the element is expected to be reduced to at least 200°C during the time it is retained in the discharge chamber prior to unloading.

The radial thermal gradient in the column of fuel elements will also vary along the vertical length of the furnace. The radial gradient is expected to be at a minimum in the center of the column of fuel elements at mid-cycle. At the top of the column, the temperature at the center of an element should be less than that at the outer surface, while the temperature at the center is expected to be higher than that at the surface of an element at the bottom of the column. The temperature of the outer surface of an element in the intermediate-temperature heating zone, wherein carbonization takes place, is expected to be slightly higher than that at the center of the element. This means that the surface of an element subjected to the "critical-zone" temperature increase will reach the desired 800°C temperature sooner than the center of an element. It is estimated that the temperature lag will be less than 50°C.

4. ENERGY TRANSPORT SIMULATION IN THE MOVING COLUMN

The basic problem in performing a thermal analysis of the furnace design was to determine how the heating and cooling should be distributed in the moving column of fuel elements to achieve a Gaussian temperature profile along the axis of the column. In a simple analogy, the column of fuel elements and spacer pallets can be thought of as a rod. If the rod were stationary, it could be heated at its mid-point with a single heating zone and cooled at both ends to achieve the desired axial temperature profile. The heaters would be insulated on the outside to curtail heat losses. However, when the rod is moving, more heat must be added in the heating zone to account for the heat absorbed by the moving mass and more cooling must be provided in the downstream cooling zone to account for the heat released by that mass.

The material properties of the graphite spacer pallets were assumed to be the same as those of the fuel elements. On the basis of an average element weight of 295 lb and an assumed pallet weight of 40 lb, the column of elements and pallets in the furnace will weigh approximately 10.08 lb per linear inch. At an average mass flow rate of 3/8 in. per minute, the furnace will process 3.78 lb of graphite a minute but only about 88% of this weight will be comprised of element material.

If a mean value of 0.33 Btu/lb. $^{\circ}$ F is assumed as the specific heat of the moving column of graphite in the furnace, about 70 kW of power will be required to provide the heat absorbed by this mass movement. Continuing the simplified analogy, heat would be lost at both ends of the moving rod by conduction. This would amount to about 5 kW at the top and about 4.7 kW at the bottom. To this, heat must also be added to account for that lost by the heaters through the furnace insulation. This radial heat loss was estimated at about 10 kW. Thus, a rough estimate of the total power required for the furnace is about 90 kW. These estimated values indicate that the axial heat loss resulting from mass flow will be about seven times the loss from conduction and about 77.8% of the total heat input. Simulation of the mass movement is therefore quite important in obtaining a realistic solution to a steady-state analysis of the furnace.

Determination of Volumetric Heat Generation Rate

The amount of heat required to account for that given up or lost by the mass movement of graphite elements and pallets through the furnace was determined by evaluating an internal heat generation rate duplicating the mass flow loss. A negative heat generation rate was applied at the top of the furnace above elevation 81.0 in., and a positive heat generation rate was used below this elevation for both the top- and bottom-loaded configurations illustrated in Fig. 3.

Argon gas is to be introduced at the bottom of the furnace at an upward flow rate of 7.0 scfm and a temperature of 25°C. A flow of 5.0 scfm will be maintained through the fuel element coolant channels via distribution channels machined in the horizontal surfaces of the spacer pallets. The remaining 2.0 scfm of argon will flow through the annular space between the column of fuel elements and the furnace processing chamber liner. A total of about 6 scfm of argon gas will be in contact with the elements, and the total heat capacity of the flowing gas is about 4.35 kW. The gas will be moving at an average velocity of about 0.333 ft per second with a mass flow rate of 0.6204 lb/minute and a mass velocity of 122 lb/hour·ft². The resulting heat transfer coefficient is less than 2.0 Btu/hr·ft²·°F, and this limits the mean difference between the temperature of the argon gas and the fuel elements to about 25°C. Since the direction of the gas movement in the furnace will be opposite that of the elements, the heat from the argon mass flow was subtracted. Instead of acting as a heat sink, the gas will act as a distributor of heat. As for the fuel element movement, the volumetric heat generation rate at each increment will provide for the heat transport associated with the flow of argon gas.

The equation used to determine the net incremental volumetric heat generation rate is as follows.

$$q_1''' = (QW_1 - QA_1)/A_x, \quad (4.1)$$

where

$$\begin{aligned} q_1''' &= \text{net incremental volumetric heat generation rate, Btu/min}\cdot\text{in.}^3, \\ QW_1 &= \text{heat input per unit length from mass movement of fuel elements,} \\ &\quad \text{Btu/min}\cdot\text{in.}, \end{aligned}$$

QA_1 = heat input per unit length from mass flow of argon gas, Btu/min·in., and

A_x = cross-sectional area of fuel element = 173.93 in.²/in.

The heat input resulting from the mass movement of fuel elements

$$QW_1 = W_g C_g (dT/dz)_1 \quad (4.2)$$

where

W_g = mass flow rate of fuel elements = 3.78 lb/min,

C_g = specific heat of unirradiated fuel element composites
 $= f_1(\bar{T})$ Btu/lb·°F

where $\bar{T}$ = mean temperature of increment in °F, and

$(dT/dz)_1$ = incremental axial thermal gradient in fuel elements
 $= f_2(z) = d(T/z)_1$.

The incremental axial thermal gradients were determined from data illustrated in Figs. A.1 and A.2 in Appendix A for the top-loaded furnace configuration and Figs. A.8 and A.9 for the bottom-loaded configuration. These figures show modified profiles of the temperature distribution on the surface of the column of graphite elements and pallets in the top- and bottom-loaded furnace configurations. The desired temperature profile illustrated in Fig. 4 was used as a guide for these curves. Since inflections cannot be obtained in a real system, smooth functions were used to generate the more realistic temperature criteria profiles shown in Figs. A.1, A.2, A.8, and A.9. These profiles were broken down into polynomial functions of the sixth order or less, and it was a simple matter to obtain the derivatives of the functions to evaluate the desired incremental quantities.

The heat input resulting from the mass flow of argon gas

$$QA_1 = W_a C_a (dT/dz)_1 \quad (4.3)$$

where

W_a = mass flow rate of argon gas = 0.607 lb/minute and

C_a = specific heat of argon gas = 0.125 Btu/lb·°F.

Heat Balance in Graphite Column

A heat balance was made on incremental sections of the column of fuel elements and spacer pallets as encountered in the furnace. The heat inputs from the first and last increments were obtained from the prevailing boundary conditions. The heat entering the second increment by the process of conduction and mass flow of both the graphite and argon was subtracted from the summation for the first increment. The difference is the result of either an external heat input or rejection, depending on the sign. Successive summations were made over the complete range of the fuel elements to obtain the net external heat requirements.

An attempt to perform this heat balance manually by using rather large increments caused anomalies in the plots. The calculations were programmed and processed on the computer with much better results. Different heating and cooling rates resulted from not including the heat lost from the heaters through external surfaces of the furnace in the calculations. The difference between the heating and cooling requirements provides a rough estimate of this loss.

The incremental heat input per unit length from external sources resulting from conduction in the axial direction

$$QX_i = (QC_{i+1/2} - QC_{i-1/2})/dz_i, \quad (4.4)$$

where

$$\begin{aligned} QC_{i+1/2} &= \text{heat flow across increment by conduction} \\ &= -k_g A_x (dT/dz)_{i+1/2}, \end{aligned}$$

$$QC_{i-1/2} = -k_g A_x (dT/dz)_{i-1/2}, \text{ and}$$

$$k_g = \text{axial thermal conductivity of specified fuel element composite, Btu/min}\cdot\text{ft}\cdot^\circ\text{F}.$$

Therefore,

$$\begin{aligned} QX_i &= -k_g A_x [(dT/dz)_{i+1} - (dT/dz)_{i-1}]/dz_i \\ &= -k_g A_x (d^2T/dz^2)_i. \end{aligned} \quad (4.5)$$

The equations used to perform the heat balance expressed the total heat per unit length (QT) supplied to each increment(i) from an external source as follows.

$$QT_i = QW_i + QX_i - QA_i . \quad (4.6)$$

The pertinent quantities were calculated for each increment of the top- and bottom-loaded configurations of the furnace. The results for fuel element units or composites fabricated from H-327 graphite as a function of axial position in the furnace for the top-loaded configuration are given in Table A.1 of Appendix A, and those for the bottom-loaded configuration are given in Table A.2. Comparable data for fuel element composites fabricated from H-451 graphite are given in Tables B.1 and B.2 in Appendix B.

A graphics subroutine was written to plot the output data, and the resulting plots for the fuel element composites fabricated from H-327 graphite are shown in Appendix A. The axial heat transfer resulting from the mass flow of fuel elements is shown in Fig. A.3, that from conduction in fuel elements is shown in Fig. A.4, and the axial heat transfer from the mass flow of argon gas is shown in Fig. A.5. The sum of the heat input by all mechanisms is shown in Fig. A.6, which gives a good idea of the power distribution required to produce the desired temperature distribution. The composite axial power distribution for the top-loaded furnace configuration is shown in Fig. A.7. Comparable data for the bottom-loaded configuration are shown in Figs. A.10 through A.14.

The internal volumetric heat generation rate required for simulation of the mass movement of fuel elements fabricated from H-327 graphite is illustrated in Fig. 5 for the top-loaded furnace configuration and in Fig. 6 for the bottom-loaded configuration. These data are required as input to the HEATING4 computer program used to analyze the thermal design of the furnace. Tabular functions were used to put the data in the program to produce the desired internal heat generation for the steady-state analysis. It should be noted that simulation of the mass flow of material using internal heat generation causes a radial gradient in the fuel elements that really is not supposed to be present. This gradient amounts to about 100°C at the point of maximum heat generation and practically nothing at the ends of the column of fuel elements and pallets. Therefore, only the temperatures at the outer surfaces of the fuel elements were used for temperature comparisons.

Fig. 5. Internal Volumetric Heat Generation Rate Required for Simulation of Mass Flow of Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Top-Loaded Configuration.

Fig. 6. Internal Volumetric Heat Generation Rate Required for Simulation of Mass Flow of Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Bottom-Loaded Configuration.

5. HEAT TRANSFER MODELS AND BOUNDARY CONDITIONS

The mathematical heat transfer models used in the computer analysis of the thermal design for the HTGR fuel element carbonizing and annealing furnace were formulated from the actual furnace design and the operational diagram illustrated in Fig. 3. Two furnace heat transfer models were made: one for the top-loaded configuration and the other for the bottom-loaded configuration. The top-loaded model, shown in Figs. 7, 8, and 9, contains 1005 nodes generated from 77 regions. (A node is generated at the intersection of bilateral grid lines.) The column of fuel elements and spacer pallets extends from about furnace elevation 202 in. downward to elevation 0.0 in. in the top-loaded model.

The bottom-loaded model, shown in Figs. 10, 8, and 11, contains 1036 nodes generated by 76 regions. In this model, the column of elements and pallets extends from furnace elevation 168 in. downward to about elevation -34 in. This configuration differs from the top-loaded one only in the extent to which the column extends into the discharge chamber, with more column length being exposed to cooling and less to heating.

Both heat transfer models are axisymmetric and cylindrical, with the cross-sectional area of the modeled cylindrical fuel element being equal to that of the actual hexagonal element. In both configurations, the column of elements and pallets was assumed to be continuous and uniform. The models were divided into regions, and the data for each region included its material properties, dimensions, heat generation and initial temperature functions, and boundary conditions. Twenty-four regions in the heat transfer models were used to depict furnace heaters.

The low-temperature heating zone in the furnace processing chamber is heated with 16 electric strip heaters, and the regions in the models representing these heaters were programmed individually for internal heat generation. To keep the temperature of the bottom surface of the charging valve at the top of the chamber from falling below 200°C, the region depicting the valve gate was programmed with internal heat generation representing a heater.

Both the intermediate- and high-temperature heating zones in the furnace processing chamber are heated electrically with individual, three

Fig. 7. Computer Model of Upper Portion of Furnace for Top-Loaded Configuration.

Fig. 8. Computer Model of Middle Portion of Furnace for Top- and Bottom-Loaded Configurations.

Fig. 9. Computer Model of Lower Portion of Furnace for Top-Loaded Configuration.

Fig. 10. Computer Model of Upper Portion of Furnace for Bottom-Loaded Configuration.

Fig. 11. Computer Model of Lower Portion of Furnace for Bottom-Loaded Configuration.

phase, delta-connected graphite heaters supplied by individual circuits. In the heat transfer models, the two graphite heaters are shown in seven regions of internal heat generation. The upper heater, supplying the intermediate-temperature zone, is represented in the models by two regions; while the lower heater, supplying the high-temperature heating zone, is represented by five regions. These regions were based on variations in the cross-sectional area of the heater conductor. Theoretically, it probably would have been better to have used seven separate heaters with individual controls, but because of space limitations and complexity, the power supply to this area of the furnace was limited to two circuits (one for each heater). This means that power cannot be increased in one region of a heater without increasing it proportionately in all other regions of the heater supplied by the same circuit. The cross-sectional area of the conductor can be changed to vary the power distribution in the different regions of a heater only within certain limits based on the strength of the graphite.

Several modes of heat transfer at the furnace boundaries were accounted for in the thermal analysis. Internal heat was expected to be radiated to the bottom surface of the charging valve at the top of the furnace chamber, and as previously assumed, this surface was assumed to be held at a constant temperature of 200°C. Internal heat is expected to be transferred by forced convection to cooling surfaces, and it was assumed that these surfaces could be maintained at a constant temperature by using water-cooled plates. The column of graphite elements and pallets will be cooled directly along a water-cooled surface length of about 86 in. in the furnace bottom-loaded configuration. The average heat flux in this configuration is expected to amount to about 7000 Btu/hr·ft², which is normal for this type of cooling.

In the furnace top-loaded configuration, the directly cooled length is reduced to about 52 in. In this configuration, the average heat flux is expected to be about 14,000 Btu/hr·ft² at the beginning of the cycle and about 5300 Btu/hr·ft² at the end of the cycle when power to the upper (low-temperature) heaters has been reduced. The maximum internal temperature of about 1800°C is expected to be reached at a furnace elevation of about 81 in. Because of the furnace insulation, the heat flux on the

cooling surface at that location is expected to be about 8000 Btu/hr-ft². The maximum heat flux on the cooling surface is expected at a furnace elevation of about 51.75 in. where the surface is expected to experience temperatures of 700 to 1000°C, resulting in radiant heat fluxes as high as 40,000 Btu/hr-ft².

The difference in these estimated heat fluxes indicates that cooling could be a problem, and it is imperative that the radiation heat exchange to the cooling surfaces be increased as much as possible. To promote radiant heat exchange with the graphite, it was assumed that all interior metal cooling surfaces of the furnace were coated with "Japon" black, which is a commercially available blacking paint that will withstand temperatures as high as those that can be withstood by the metal it covers. For the thermal analysis, a constant boundary condition temperature of 25°C was assumed for all water-cooled surfaces. The furnace elevator platform that supports the column of graphite elements and pallets was also assumed to have a constant temperature of 25°C by virtue of cooling.

Heat transfer across the furnace annuli or gaps is expected to be by conduction, convection, and radiation with the shape factors varying from 0.5 to 0.75. All interior argon gas gaps adjacent to the column of fuel elements and spacers have a total spectral emissivity of 0.8, and the shape factor was determined for infinitely long concentric cylinders. Gas radiation is not a factor in the transfer of heat inasmuch as argon is not a reradiating gas. However, the argon must be kept free of moisture because of the reradiation properties of water vapor as well as the possibility of a chemical reaction with the graphite. It was assumed that the volatiles produced during carbonization would have no reradiation effects. The net result would be a slight decrease in the efficiency of the furnace. Radiation in the coolant holes of the fuel elements and pallets was accounted for in the calculated anisotropic conductivity of the graphite.

Heat transfer from the exterior surfaces of the furnace is expected to be by combined natural convection and radiation to the surrounding atmosphere. An emissivity of 0.6 was assumed for all external surfaces of the furnace.

6. MATERIAL PROPERTIES USED IN THERMAL ANALYSIS

In a steady-state thermal analysis, the physical property of primary concern is the thermal conductivity of the materials involved. The thermal conductivities of the twelve material conditions involved in the furnace analysis are given in Tables 1 and 2. The three materials given in Table 1 are anisotropic. At a given temperature, the thermal conductivity of such a material in the axial direction is different from that in the radial direction. As indicated in Figs. 7, 9, and 10, material number one in Table 1 (HLM graphite) was used as a liner material in the furnace, and the thermal conductivity data given for this material were obtained from prior investigations.² Material 3, Fiberform insulation, was used as a primary insulating material in the furnace, and its thermal conductivities were obtained from manufacturer's data.³

The thermal conductivities of the fuel element composite, material 2 in Table 1, were developed by using formulations set forth in Ref. 4. The conductivities developed and given in Table 1 are based on the use of a fuel block fabricated from unirradiated needle-coke (H-327) graphite as manufactured by the Great Lakes Carbon Company. The total cross-sectional area of the hexagonal graphite prism used for the reference Fort St. Vrain fuel element is 173.93 in.² To calculate the thermal conductivities of the reference fuel elements in the furnace, it was estimated that 56.95% of the total cross-sectional area of an element is comprised of graphite, 24.38% is comprised of fuel holes, and 18.67% is comprised of voids or coolant holes. These coolant holes will be filled with argon gas at atmospheric pressure when the fuel element is being processed in the carbonizing and annealing furnace, and they will be filled with helium gas under pressure when the element is in the reactor. However, the intended contents of the coolant holes will have little or no effect on the thermal conductivities of the fuel element composite.

The relationships required to calculate the axial and radial thermal conductivities of the fuel element composite as a function of temperature were programmed for the computer. Essentially, these relationships are as follows. The axial thermal conductivity of the fuel element was

Table 1. Thermal Conductivities of Anisotropic Materials
Used in Furnace Analysis

No.	Material Name	Temper- ature (°F)	Conductivity in Btu/min-in.-°F		Ref. No.
			Radial	Axial	
1	HLM Graphite	0	0.08189	0.11940	2
		500	0.06250	0.09780	
		1000	0.05000	0.07080	
		1500	0.04100	0.05900	
		2000	0.03430	0.04860	
		2500	0.02920	0.04160	
		3000	0.02630	0.03740	
		3500	0.02390	0.03400	
		4000	0.02220	0.03190	
		4500	0.02110	0.03050	
		5000	0.02060	0.02960	
2	Fuel Element	0	0.04429	0.10770	4 & 5
		200	0.03857	0.09167	
		400	0.03420	0.07859	
		600	0.03104	0.06798	
		800	0.02893	0.05942	
		1000	0.02767	0.05255	
		1200	0.02703	0.04705	
		1400	0.02678	0.04267	
		1600	0.02670	0.03919	
		1800	0.02664	0.03642	
		2000	0.02653	0.03423	
		2200	0.02634	0.03250	
		2400	0.02607	0.03116	
		2600	0.02573	0.03013	
		2800	0.02535	0.02938	
		3000	0.02494	0.02888	
		3200	0.02448	0.02861	
		3400	0.02400	0.02856	
		3600	0.02348	0.02871	
		3800	0.02292	0.02905	
		4000	0.02233	0.02956	
		4200	0.02170	0.02920	
		4400	0.02105	0.03094	
		4600	0.02040	0.03168	
		4800	0.01979	0.03236	
3	Fiberform Insulation	0	3.472 E-5	1.042 E-4	3
		800	6.944 E-5	1.944 E-4	
		1300	8.681 E-5	2.292 E-4	
		1700	1.157 E-4	2.720 E-4	
		2000	1.505 E-4	3.472 E-4	
		2500	2.315 E-4	4.051 E-4	
		3000	2.697 E-4	4.919 E-4	
		3500	3.669 E-4	6.076 E-4	
		4000	5.208 E-4	9.838 E-4	

Table 2. Thermal Conductivity of Isotropic Materials Used in Furnace Analysis

No.	Material Name	Temperature (°F)	Conductivity (Btu/min·in.·°F)	Ref. No.
5	Fiberfrax-H	0	0.00002315	6
		500	0.00004630	
		1000	0.00009028	
		1500	0.00014470	
		2000	0.00021060	
		2500	0.00030210	
		3000	0.00036460	
		3500	0.00043400	
6	Modified Stainless Steel	0	0.001260	
		1000	0.001420	
		1800	0.001530	
7	Argon	0	0.00001250	9
		400	0.00002000	
		800	0.00002640	
		1200	0.00003330	
		1600	0.00003820	
		2000	0.00004170	
		2400	0.00004510	
		2800	0.00004860	
		3200	0.00005130	
		3600	0.00005550	
		4000	0.00005830	
		4400	0.00006250	
		4800	0.00006520	
		5200	0.00006670	
9	Strip Heaters	0	0.3330	
11	Electrode Grade Graphite	0	0.10560	7
		200	0.09310	
		400	0.08330	
		600	0.07500	
		800	0.06810	
		1000	0.06110	
		1200	0.05560	
		1400	0.05000	
		1600	0.04610	
		1800	0.04310	
		2200	0.03860	
		2800	0.03470	
		3200	0.03190	
		3632	0.03010	
		4532	0.02780	
		5432	0.02640	

Table 2 (continued)

No.	Material Name	Temperature (°F)	Conductivity (Btu/min·in·°F)	Ref. No.
12	Type 304 Stainless Steel	0	0.01260	8
		1000	0.01420	
		1800	0.01530	
14	Porous Carbon	0	0.001290	7
		5000	0.007640	
17	Argon-3	0	0.00010400	9
		500	0.00007180	&
		1000	0.00006270	10
		1500	0.00006040	
		2000	0.00006580	
		2500	0.00007430	
		3000	0.00008330	
		3500	0.00009030	
18	Argon-4	0	0.00012300	9
		500	0.00008790	&
		1000	0.00007160	10
		1500	0.00006900	
		2000	0.00006780	
		2500	0.00007430	
		3000	0.00008330	
		3500	0.00009030	

calculated by using the following equation.⁴

$$K_a = Ak_g + Bk_f + Ck_r, \quad (6.1)$$

where

K_a = the axial thermal conductivity of the fuel element composite as a function of temperature, Btu/hr·ft·°F,

A = ratio of cross-sectional area of graphite (G) in in.² to total cross-sectional area of fuel element composite (Z) = G/Z
= 99.053/173.93 = 0.5695,

k_g = the axial thermal conductivity as a function of temperature of the particular graphite used in the fuel element, Btu/hr·ft·°F,

B = ratio of cross-sectional area of fuel holes (F) in in.² to total cross-sectional area of fuel element composite (Z) = F/Z
= 42.404/173.93 = 0.2438,

k_f = thermal conductivity of the fuel rods

= a constant 3.0 Btu/hr·ft·°F,

C = ratio of cross-sectional area of coolant holes (V) in in.² to total cross-sectional area of fuel element composite (Z) = V/Z
= 32.473/173.93 = 0.1867, and

k_r = net equivalent thermal conductivity resulting from radiation across the coolant holes, Btu/hr·ft·°F.

The axial thermal conductivities as a function of temperature (k_g) used in Eq. 6.1 for the H-327 graphite were those reported by Price⁵ for the unirradiated material. The net equivalent thermal conductivity resulting from radiation across the coolant holes in the reference fuel element is given by the following equation.⁴

$$k_r = (0.444 \times 10^8) \sigma \epsilon d T^3, \quad (6.2)$$

where

σ = Stefan-Boltzmann constant

= 0.171×10^{-8} Btu/hr·ft²·°R⁴,

ϵ = emissivity of graphite = 0.8,

d = diameter of coolant hole = 0.625 in., and

$T = T_R/1000$

where T_R = mean temperature of fuel element, °R.

The algorithm used to calculate the radial thermal conductivity (K_r) of the composite fuel element in Btu/hr·ft·°F is as follows.⁴

$$K_r = (C_1 k_g) \frac{1 + C_2 T/k_g [(C_4 + k_g/k_f)/(C_8 + k_g/k_f)]}{1 + C_3 T/k_g [(C_5 + k_g/k_f)/(C_8 + k_g/k_f)]}$$

where

k_g = radial thermal conductivity as a function of temperature of the particular graphite used in the fuel element composite, Btu/hr·ft·°F,

$T = T_R/1000$,

k_f = thermal conductivity of fuel rods = a constant
= 3.0 Btu/hr·ft·°F, and

$C_1 - C_8$ = constants whose values are defined⁴ as

$C_1 = 0.360$,

$$\begin{aligned}
 C_2 &= 0.523, \\
 C_3 &= 2.500, \\
 C_4 &= 4.100, \\
 C_5 &= 1.200, \text{ and} \\
 C_6 &= 8.700.
 \end{aligned}$$

The axial and radial thermal conductivities and specific heat of reference fuel elements fabricated from unirradiated H-327 graphite were computed as a function of temperature, and the resulting output for temperatures from zero to 5000°F are given in Table C.1 of Appendix C. The computed conductivity data are illustrated as a function of temperature in Fig. C.1 (Appendix C). The thermal conductivities and specific heats were also computed for reference fuel elements fabricated from unirradiated H-451 graphite. The resulting output is given in Table C.2 of Appendix C, and the thermal conductivity data are illustrated in Fig. C.2.

The remaining nine materials or material conditions involved in the steady-state analysis of the furnace thermal design are not anisotropic, and the thermal conductivities for these materials are given in Table 2. The area between the strip heaters (material 9) was filled with Fiberfrax-H Felt (material 5), which is a ceramic fiber insulation whose thermal conductivity data were supplied by the manufacturer.⁶ The strip heaters were given relatively high conductivities to curtail internal gradients. Electrode-grade graphite (material 11) was used as the material of construction for the graphite heaters in the intermediate- and high-temperature heating zones of the furnace, and the thermal conductivities of this material as a function of temperature were also obtained from manufacturer's data.⁷ The thermal conductivity data for type 304 stainless steel (material 12) used in the analysis were reported by Kim.⁸ Those data were modified in some locations (material 6) to permit an increase in nodal spacing and enhance computer running time. For these reasons, strip heater material (material 9) was substituted for the thin stainless steel strip connecting the hot interior of the furnace with the water-cooled wall and used as an insulation interface, thereby increasing the material thickness by a factor of four and reducing the conductivity by a factor of four.

The thermal conductivities of the argon gas in the main channel of the furnace (material 7) used in the analysis were reported in a National Bureau of Standards Circular.⁹ Argon-3 (material 17) and argon-4 (material 18) were defined to account for enhanced thermal conductivity resulting from natural convection in a cylindrical annulus filled with stagnant gas. This enhanced conductivity is a function of the Raleigh number and the length-to-diameter ratios of the annuli,¹⁰ and materials 17 and 18 were used in the analysis to depict different L/D ratios. No allowance was made for natural convection in the main channel of the furnace inasmuch as the system was designed to curtail this phenomenon. Convection in the interior channels of the fuel elements was accounted for in computing the anisotropic conductivities of the fuel element composite.

7. RESULTS OF THERMAL ANALYSIS, CONCLUSIONS, AND RECOMMENDATIONS

The HEATING4 program was run on the IBM 360/91 computer at ORNL to perform the thermal analysis of the furnace design described here. Like any other general heat transfer computer program, the HEATING4 program calls for the heat source distribution to be specified by the user. Therefore, the initial task of the analysis was performance of a lengthy trial-and-error process by which the power distribution for the heaters was estimated and the resulting temperatures were compared with the desired axial temperature profile in the furnace. This process was difficult and time consuming because of the complex interaction between the various zones of the furnace. The best distribution of heat sources (heaters) and sinks (cooling water) that could be obtained with a reasonable effort was used for the final temperature distribution analysis.

The power input for the top-loaded furnace configuration totaled 101.44 kW. About 2.28 kW were supplied to the strip heaters in the furnace low-temperature heating zone in amounts that varied from 286 watts in the last heater to zero watts in the first heater at the top of the furnace processing chamber. The charging valve at the top of the chamber was supplied with 325 watts of power. The power input to the graphite heaters in the intermediate- and high-temperature heating zones of the furnace totaled 98.83 kW. The distribution of power to the regions in these portions of the furnace was 23.12 kW to graphite heater region 1, 17.82 kW to region 2, 12.86 kW to region 3, 14.34 kW to region 4, 7.87 kW to region 5, 12.83 kW to region 6, and 9.99 kW to region 7.

The power input used for the bottom-loaded configuration was 96.6 kW. No power was input to the charging valve or the strip heaters, and that input for the graphite heater regions was the same as for the top-loaded configuration except for region 7. In the bottom-loaded configuration, the power input to graphite heater region 7 was reduced to 8.34 kW. Computer runs were made using these power distributions, the furnace boundary conditions discussed in Section 5, the internal heat generation simulating the energy transport resulting from mass movement discussed in Section 4, and the materials and their conductivities given in Section 6. The

computed temperature profile is compared with the desired profile for the top-loaded furnace configuration in Fig. 12 and for the bottom-loaded configuration in Fig. 13.

As a result of the thermal analysis described herein, it was concluded that the furnace design has the potential capability of meeting the desired thermal criteria. With respect to the power requirements of the furnace, the results of the computer analysis agree closely with those of the simple mass transfer calculations. However, those results are only as reliable as the thermal transport data used, and the accuracy tolerance assumed for those data was plus or minus 10 to 15%.

The results of the steady-state analysis indicate that the axial temperature profile in the furnace is quite sensitive to both the input and distribution of power to the heaters, particularly the strip heaters in the upper portion of the furnace processing chamber. It was concluded that the desired temperature profile can be obtained by further refinement of the power supply and distribution to the strip heaters. Further, the data illustrated in Figs. 14 and 15 indicate that temperature profiles that are both higher and lower than the desired profile can be obtained by varying the type and thickness of the insulation used in connection with the strip heaters in the upper portion of the furnace. This capability will afford a means of adjusting the temperature profile if the thermophysical properties of the furnace were either overestimated or underestimated.

It should be noted that the analysis reported herein was based on a continuous steady-state simulation. In reality, there will be a pause of about 10 minutes at the end of every 90-minute cycle for unloading and loading procedures and a new fuel element and pallet will be introduced into the furnace, resulting in the disturbance of any equilibrium that may have been achieved. Therefore, it is recommended that transient thermal analyses of the furnace design be performed to verify the results obtained from the steady-state analysis described herein. Transient analyses could also be performed to determine the control limitations necessary for safe operation of the furnace by changing the boundary conditions to simulate mechanical failure, loss-of-cooling, and loss-of-power conditions.

Fig. 12. Results of Computer Analysis of Furnace Design Compared With Desired Temperature Profile for Top-Loaded Configuration.

Fig. 13. Results of Computer Analysis of Furnace Design Compared With Desired Temperature Profile for Bottom-Loaded Configuration.

Fig. 14. Results of Computer Analyses Obtained By Varying Insulation in Upper Portion of Furnace Compared With Desired Temperature Profile for Top-Loaded Configuration.

Fig. 15. Results of Computer Analyses Obtained By Varying Insulation in Upper Portion of Furnace Compared With Desired Temperature Profile for Bottom-Loaded Configuration.

REFERENCES

1. W. D. Turner and M. Siman-Tov, "HEATING3-- An IBM 360 Heat Conduction Program," USAEC Report ORNL TM-3208, Oak Ridge National Laboratory, Oak Ridge, Tennessee, February 1971.
2. W. P. Eatherly, Metals and Ceramics Division, Oak Ridge National Laboratory, personal communication to G. H. Llewellyn, Oak Ridge National Laboratory.
3. "Product Data," Fiber Materials, Inc., Biddeford Industrial Park, Biddeford, Maine 04005.
4. Public Service Company of Colorado, page 39 in Section 3 of "Preliminary Safety Analysis Report for the Fort St. Vrain Reactor (Docket Number 50-267)."
5. R. J. Price, "Thermal Conductivity of Neutron-Irradiated Reactor Graphites," Report GA-A13157, General Atomic Company, San Diego, California 92138, October 8, 1974.
6. "Product Specifications," The Carborundum Company, Refractories and Electronics Division, Ceramic Fiber Plant, Niagara Falls, New York.
7. "Carbon Products Pocket Handbook," Union Carbide Corporation, Carbon Products Division, New York, New York.
8. Choong S. Kim, "Thermophysical Properties of Stainless Steels," Report ANL-75-55, Argonne National Laboratory, Argonne, Illinois, September 1975.
9. Joseph Hilsenrath et al., Tables of Thermal Properties of Gases, National Bureau of Standards Circular 564, U.S. Government Printing Office, Washington, D. C., November 1, 1955, Table 3-9, p. 129.
10. E. R. G. Eckert and R. M. Drake, Jr., Heat and Mass Transfer, McGraw-Hill Book Company, Inc., New York, New York, 1959, p. 328.

APPENDICES

Appendix A

MASS-FLOW SIMULATION DATA
FOR FUEL ELEMENTS FABRICATED FROM H-327 GRAPHITE

Table A.1

HEAT PICO RATE FOR TOP LOADED CONFIGURATION USING PSV ACTIVE CONE ELEMENTS FAR FROM DISSIPATED R-327 GRAPHITE
 REQUIRED TOTAL MINIMUM POWER INPUT RATE = 79.00803 KILOWATTS
 REQUIRED TOTAL MINIMUM COOLING RATE = 83.75285 KILOWATTS

DISTANCE INCHES	TEMPERATURE DEGS FARN	TEMPERATURE DEGS CENT	TEMP DIFF DEGS FARN	MASS FLOW LB/MIN	COOL RATE BTU/MIN	ARGON FLOW LB/MIN	VOL B/M ³ IN	FOR WATT/IN ²	TOTAL PER WATT/IN ²	TEMP COR B/MIN/IN ²	SPEC HEAT BTU/LB/IN ²
0.00	392.00	200.00	15.07	13.56804	5.89668	1.16883	0.071287	362.7	0.078616	0.238994	0.238994
1.00	427.07	208.37	15.51	14.16959	5.94658	1.20361	0.078552	378.78	0.077723	0.242590	0.242590
2.00	422.54	216.99	15.95	14.74277	5.99287	1.23705	0.077936	397.16	0.076820	0.246196	0.246196
3.00	438.53	225.05	16.40	15.43791	6.03566	1.27217	0.081888	399.87	0.075906	0.249841	0.249841
4.00	454.98	234.96	16.87	16.10535	6.07891	1.30796	0.085074	412.92	0.074982	0.253511	0.253511
5.00	471.40	244.33	17.34	16.79540	6.11064	1.34482	0.088833	424.32	0.074084	0.257203	0.257203
6.00	489.14	253.97	17.81	17.50838	6.14245	1.38155	0.092718	440.07	0.073187	0.260916	0.260916
7.00	506.95	263.86	18.30	18.28445	6.17157	1.41935	0.096733	458.18	0.072158	0.264645	0.264645
8.00	524.26	274.03	18.80	19.00397	6.19888	1.45695	0.100879	483.89	0.070238	0.272182	0.272182
9.00	543.04	284.47	19.30	19.78713	6.21868	1.49567	0.105154	498.70	0.068271	0.279504	0.279504
10.00	563.36	295.20	19.82	20.59413	6.23706	1.53676	0.109567	518.29	0.066232	0.287590	0.287590
11.00	583.17	306.21	20.38	21.43515	6.25214	1.57724	0.114112	530.57	0.064232	0.296338	0.296338
12.00	603.51	317.51	20.87	22.28038	6.26393	1.61839	0.118793	546.60	0.062182	0.297206	0.297206
13.00	624.38	329.10	21.41	23.15985	6.27288	1.66021	0.123609	563.33	0.060130	0.299964	0.299964
14.00	645.79	340.99	21.96	24.06377	6.27980	1.70270	0.128561	580.46	0.058176	0.299728	0.299728
15.00	667.74	353.19	22.51	25.94521	6.28018	1.74586	0.133651	597.97	0.056192	0.298869	0.298869
16.00	690.26	365.70	23.08	26.92284	6.27586	1.78969	0.138818	615.87	0.054209	0.298201	0.298201
17.00	713.34	378.52	23.65	27.92509	6.26982	1.83420	0.144283	634.17	0.052226	0.297517	0.297517
18.00	736.99	391.66	24.23	28.95199	6.26026	1.87937	0.149966	652.87	0.050246	0.296815	0.296815
19.00	761.22	405.12	24.83	29.99199	6.24888	1.92521	0.155886	671.97	0.048269	0.296149	0.296149
20.00	786.05	418.91	25.43	30.00350	6.23619	1.97172	0.161968	691.46	0.046296	0.295493	0.295493
21.00	811.47	433.04	26.03	31.07959	6.22149	2.01890	0.167080	711.36	0.044324	0.294859	0.294859
22.00	837.51	447.50	26.65	32.18022	6.21751	2.06675	0.172333	731.64	0.042354	0.294144	0.294144
23.00	864.16	462.31	27.28	33.30730	6.19857	2.11528	0.177806	752.36	0.040381	0.293455	0.293455
24.00	891.43	477.46	27.91	34.45877	6.17789	2.16447	0.183448	773.46	0.038411	0.292784	0.292784
25.00	919.34	492.97	28.55	35.63851	6.15581	2.21333	0.189210	794.97	0.036446	0.292132	0.292132
26.00	947.90	508.83	29.21	36.82684	6.12945	2.26287	0.195106	816.89	0.034486	0.291499	0.291499
27.00	977.10	525.06	29.87	38.08843	6.10276	2.31607	0.201438	839.21	0.032531	0.290885	0.290885
28.00	1006.97	541.65	30.53	39.28837	6.07488	2.36794	0.208217	861.93	0.030584	0.290289	0.290289
29.00	1037.50	558.61	31.21	40.58413	6.04475	2.42049	0.215331	885.06	0.028641	0.289716	0.289716
30.00	1068.71	575.95	31.90	41.85757	6.01372	2.47379	0.222841	908.59	0.026701	0.289164	0.289164
31.00	1100.61	593.67	32.59	43.17857	5.98153	2.52759	0.230749	932.53	0.024764	0.288638	0.288638
32.00	1133.21	611.78	33.30	44.51700	5.94834	2.58214	0.239066	956.88	0.022831	0.288134	0.288134
33.00	1166.50	630.28	34.01	45.87871	5.91430	2.63736	0.247809	981.63	0.020901	0.287651	0.287651
34.00	1200.51	648.47	34.73	47.26558	5.87954	2.69326	0.256962	1006.79	0.018974	0.287188	0.287188
35.00	1235.24	668.47	35.46	48.67548	5.84423	2.74981	0.266542	1032.36	0.017051	0.286744	0.286744
36.00	1270.70	688.17	36.20	50.10827	5.80840	2.80706	0.276551	1058.33	0.015131	0.286320	0.286320
37.00	1306.89	708.27	36.94	51.56385	5.77251	2.86497	0.286987	1084.71	0.013214	0.285915	0.285915
38.00	1343.84	728.80	37.70	53.04208	5.73767	2.92354	0.298019	1111.50	0.011301	0.285527	0.285527
39.00	1381.54	749.74	38.46	54.54288	5.70000	2.98279	0.309646	1138.70	0.009391	0.285156	0.285156
40.00	1420.00	771.11	39.24	56.06602	5.66141	3.04271	0.321886	1166.31	0.007484	0.284801	0.284801
41.00	1459.24	792.91	40.02	57.61150	5.62188	3.10329	0.334741	1194.32	0.005581	0.284461	0.284461
42.00	1499.25	815.14	40.81	59.17915	5.58144	3.16455	0.348207	1222.75	0.003684	0.284136	0.284136
43.00	1540.06	837.81	41.61	60.76885	5.53974	3.22648	0.362281	1251.54	0.001794	0.283826	0.283826
44.00	1581.66	860.92	42.41	62.38047	5.49647	3.28907	0.376973	1280.81	0.000909	0.283531	0.283531
45.00	1624.08	884.49	43.23	64.01387	5.45147	3.35238	0.392281	1310.48	0.000024	0.283250	0.283250
46.00	1667.30	908.50	44.05	65.66898	5.40512	3.41628	0.408207				

Table A.1 (continued)

DISTANCES INCHES	TEMPERATURE DEGS. FAH	TEMPERATURE DEGS. CENT	TEMP. DIFF DEGS. FAH	MASS FLOW LB/HR/IN	CORR. HEAT BT/HR/IN	ARGON FLOW LB/HR/IN	VOL. ARGON B/HR/CD IN	TOTAL PER BATT/INCH	TEMP. CORR. B/HR/CD IN	SPEC. HEAT BTU/LB/DEG
47.00	1711.36	932.98	48.89	67.18532	5.42777	3.80089	0.567178	1380.53	0.03268	0.348326
48.00	1756.24	957.91	45.73	69.08301	5.39754	3.54617	0.376568	1370.99	0.036678	0.400844
49.00	1801.97	983.32	46.58	70.76171	5.36851	3.41212	0.386066	1401.86	0.041112	0.460347
50.00	1848.55	1009.19	47.44	72.50117	5.34079	3.26783	0.395688	1433.12	0.045565	0.485758
51.00	1895.98	1035.45	48.30	74.24108	5.31447	3.14602	0.404945	1468.74	0.050039	0.508142
52.00	1944.29	1062.38	49.18	76.04110	5.28863	3.01398	0.414248	1496.63	0.054533	0.530533
53.00	1993.47	1089.71	50.07	77.88086	5.26336	2.88261	0.423521	1529.27	0.059087	0.552766
54.00	2043.54	1117.52	50.96	79.65990	5.23876	2.75191	0.432815	1555.08	0.063591	0.575003
55.00	2094.50	1145.63	51.86	81.48773	5.21486	2.62168	0.442108	1582.83	0.068135	0.597247
56.00	2146.36	1174.64	52.77	83.35380	5.19060	2.49252	0.451403	1612.74	0.072702	0.619482
57.00	2199.13	1203.96	53.69	85.22747	5.16648	2.35883	0.460693	1642.74	0.077315	0.641740
58.00	2252.82	1233.79	54.62	87.11007	5.14238	2.23581	0.469981	1673.57	0.081988	0.663988
59.00	2307.44	1264.14	55.56	89.02488	5.11843	2.10847	0.479261	1704.84	0.086719	0.686242
60.00	2363.00	1295.00	56.50	90.94696	5.09465	1.98479	0.488548	1737.19	0.091466	0.708496
61.00	2419.50	1326.39	57.46	92.88357	5.07079	1.86149	0.497838	1772.97	0.096266	0.730749
62.00	2476.96	1358.31	58.42	94.83371	5.04687	1.73885	0.507099	1809.01	0.101099	0.752997
63.00	2535.38	1390.77	59.39	96.79642	5.02286	1.61677	0.516306	1847.27	0.105965	0.775240
64.00	2594.77	1423.76	60.37	98.77064	5.00000	1.49545	0.525499	1887.29	0.110865	0.797482
65.00	2655.18	1457.30	61.36	100.75539	4.97836	1.37485	0.534685	1929.01	0.115800	0.819724
66.00	2716.50	1491.39	62.36	102.74956	4.95735	1.25480	0.543860	1972.53	0.120761	0.841966
67.00	2778.86	1526.03	63.36	104.75213	4.93693	1.13529	0.553025	2017.85	0.125747	0.864208
68.00	2842.22	1561.23	64.38	106.76206	4.91718	1.01638	0.562180	2064.86	0.130757	0.886449
69.00	2906.60	1597.00	65.46	108.77842	4.89800	0.89800	0.571325	2113.56	0.135791	0.908690
70.00	2972.00	1633.33	66.59	110.80083	4.87939	0.78085	0.580459	2163.96	0.140849	0.930931
71.00	3038.46	1670.48	67.73	112.82971	4.86143	0.66428	0.589582	2215.06	0.145931	0.953172
72.00	3106.00	1708.49	68.97	114.87472	4.84412	0.54865	0.598695	2267.86	0.151036	0.975413
73.00	3131.36	1721.41	69.77	116.93592	4.82736	0.43428	0.607798	2322.35	0.156164	0.997654
74.00	3168.93	1722.41	70.77	119.01481	4.81115	0.32094	0.616891	2378.53	0.161315	1.019895
75.00	3199.66	1739.81	71.78	121.11150	4.79548	0.20869	0.625994	2436.40	0.166489	1.042136
76.00	3226.11	1753.40	72.83	123.22698	4.78036	0.09762	0.635097	2495.94	0.171686	1.064377
77.00	3248.51	1763.81	73.91	125.36097	4.76579	0.00000	0.644199	2557.16	0.176906	1.086618
78.00	3265.47	1791.36	75.01	127.51397	4.75177	0.00000	0.653301	2620.06	0.182149	1.108859
79.00	3279.46	1796.37	76.14	129.68597	4.73829	0.00000	0.662403	2684.64	0.187415	1.131100
80.00	3279.46	1800.00	77.30	131.87797	4.72536	0.00000	0.671505	2750.90	0.192702	1.153341
81.00	3272.00	1800.00	78.49	134.08997	4.71298	0.00000	0.680607	2818.84	0.198010	1.175582
82.00	3268.39	1797.99	79.70	136.32197	4.70115	0.00000	0.689709	2888.46	0.203339	1.197823
83.00	3258.00	1792.22	80.93	138.57397	4.68987	0.00000	0.698811	2959.76	0.208689	1.220064
84.00	3241.92	1783.07	82.18	140.84597	4.67914	0.00000	0.707913	3032.74	0.214060	1.242305
85.00	3219.01	1770.91	83.57	143.13797	4.66891	0.00000	0.717015	3107.40	0.219461	1.264546
86.00	3193.01	1756.12	85.00	145.44997	4.65918	0.00000	0.726117	3183.74	0.224882	1.286787
87.00	3162.34	1739.08	86.50	147.78197	4.64995	0.00000	0.735219	3261.76	0.230323	1.309028
88.00	3128.30	1720.16	88.00	150.13397	4.64122	0.00000	0.744321	3341.46	0.235784	1.331269
89.00	3091.56	1699.76	89.50	152.50597	4.63300	0.00000	0.753423	3422.84	0.241265	1.353510
90.00	3052.81	1678.23	91.00	154.89797	4.62527	0.00000	0.762525	3505.90	0.246766	1.375751
91.00	3012.73	1655.96	92.50	157.30997	4.61804	0.00000	0.771627	3590.64	0.252287	1.398000
92.00	2972.00	1633.33	94.00	159.74197	4.61129	0.00000	0.780729	3677.06	0.257828	1.420241
93.00	2930.80	1610.45	95.50	162.19397	4.60504	0.00000	0.789831	3765.16	0.263389	1.442482
94.00	2889.89	1587.16	97.00	164.66597	4.59929	0.00000	0.798933	3854.94	0.268960	1.464723
95.00	2848.28	1563.49	98.50	167.15797	4.59404	0.00000	0.808035	3946.40	0.274541	1.486964
96.00	2806.01	1539.05	100.00	169.66997	4.58929	0.00000	0.817137	4039.54	0.280142	1.509205
97.00	2763.10	1515.06	101.50	172.19197	4.58504	0.00000	0.826239	4134.36	0.285763	1.531446
98.00	2719.59	1490.13	103.00	174.72397	4.58129	0.00000	0.835341	4230.86	0.291404	1.553687
99.00	2676.49	1465.27	104.50	177.26597	4.57804	0.00000	0.844443	4329.04	0.297065	1.575928
100.00	2632.85	1440.42	106.00	179.81797	4.57529	0.00000	0.853545	4428.90	0.302746	1.598169
101.00	2577.67	1415.56	107.50	182.37997	4.57304	0.00000	0.862647	4530.44	0.308447	1.620410

Table A.1 (continued)

DISTANCES INCHES	TEMPERATURE DEGS FARN	TEMPERATURE DEGS CENT	TEMP DIPP DEGS FARN	MASS FLOW BO/HIN*IN	COND HEAT BO/HIN*IN	ARGON FLO BO/HIN*IN	VOL RGP B/H*CD IN	TOTAL PER WATT/INCH	THIR COND B/HIN*IN	SPEC HEAT BTD/L*BOF
102.00	2531.00	1388.34	-47.14	-76.53128	-2.82691	-3.65577	-0.818986	-1852.38	0.030560	0.831004
103.00	2483.86	1362.15	-47.58	-76.94936	-2.29914	-3.69011	-0.821423	-1858.75	0.030804	0.824550
104.00	2436.28	1335.71	-48.00	-77.38463	-2.17034	-3.72231	-0.823510	-1868.07	0.031077	0.828019
105.00	2388.24	1309.04	-48.39	-77.71629	-2.04031	-3.75238	-0.825284	-1878.07	0.031366	0.831677
106.00	2339.89	1282.16	-48.74	-77.98427	-1.90881	-3.78032	-0.826624	-1870.96	0.031677	0.835411
107.00	2291.15	1255.08	-49.08	-78.18437	-1.77558	-3.80612	-0.827689	-1872.66	0.032009	0.839133
108.00	2242.07	1227.82	-49.38	-78.32841	-1.64036	-3.82978	-0.828318	-1873.17	0.032366	0.842842
109.00	2192.68	1200.38	-49.66	-78.40426	-1.50284	-3.85131	-0.828630	-1873.84	0.032787	0.846548
110.00	2143.02	1172.79	-49.91	-78.41577	-1.36480	-3.87070	-0.828585	-1870.58	0.033155	0.850249
111.00	2093.11	1145.06	-50.13	-78.36288	-1.22682	-3.88796	-0.828182	-1867.80	0.033544	0.853943
112.00	2042.97	1117.21	-50.33	-78.28537	-1.08851	-3.90309	-0.827419	-1863.03	0.033954	0.857624
113.00	1992.64	1089.25	-50.50	-78.05328	-0.94974	-3.91608	-0.826294	-1857.82	0.034384	0.861294
114.00	1942.15	1061.19	-50.64	-77.81466	-0.79881	-3.92643	-0.824816	-1850.57	0.034834	0.864949
115.00	1891.41	1033.06	-50.75	-77.50881	-0.64149	-3.93561	-0.823274	-1842.84	0.035304	0.868584
116.00	1840.74	1004.87	-50.83	-77.12824	-0.48821	-3.94223	-0.821671	-1834.09	0.035794	0.872204
117.00	1789.92	976.62	-50.89	-76.68652	-0.32951	-3.94699	-0.819989	-1824.83	0.036304	0.875804
118.00	1739.03	948.35	-50.92	-76.17981	-0.16881	-3.94899	-0.818289	-1815.49	0.036834	0.879384
119.00	1688.11	920.00	-50.92	-75.60761	0.00632	-3.94917	-0.816589	-1806.08	0.037384	0.882944
120.00	1637.19	891.77	-50.90	-74.96992	0.24861	-3.94721	-0.814889	-1796.58	0.037954	0.886484
121.00	1586.29	863.49	-50.85	-74.26657	0.48667	-3.94312	-0.813189	-1786.98	0.038544	0.889994
122.00	1535.44	835.25	-50.77	-73.49705	0.66518	-3.93689	-0.811489	-1777.25	0.039154	0.893484
123.00	1484.68	807.04	-50.66	-72.66141	0.87886	-3.92843	-0.809789	-1767.48	0.039784	0.896944
124.00	1434.02	778.90	-50.52	-71.75938	1.10246	-3.91803	-0.808089	-1757.68	0.040434	0.900384
125.00	1383.49	750.81	-50.34	-70.79066	1.36881	-3.90580	-0.806389	-1747.88	0.041104	0.903804
126.00	1333.14	722.85	-50.17	-69.75507	1.58273	-3.89091	-0.804689	-1737.98	0.041794	0.907194
127.00	1282.97	694.98	-49.95	-68.65283	1.84112	-3.87373	-0.802989	-1728.08	0.042504	0.910564
128.00	1233.01	667.23	-49.71	-67.48262	2.12889	-3.85449	-0.801289	-1718.18	0.043234	0.913914
129.00	1183.31	639.62	-49.43	-66.24560	2.39879	-3.83352	-0.799589	-1708.28	0.043984	0.917244
130.00	1133.88	612.15	-49.13	-64.94184	2.70041	-3.81021	-0.797889	-1698.38	0.044754	0.920564
131.00	1084.74	584.86	-48.80	-63.57031	3.01820	-3.78476	-0.796189	-1688.48	0.045544	0.923884
132.00	1035.94	557.74	-48.45	-62.13263	3.35136	-3.75719	-0.794489	-1678.58	0.046354	0.927194
133.00	987.49	530.83	-48.07	-60.62890	3.70646	-3.72787	-0.792789	-1668.68	0.047184	0.930504
134.00	939.43	504.13	-47.65	-59.05991	4.08008	-3.69562	-0.791089	-1658.78	0.048034	0.933814
135.00	891.77	477.65	-47.22	-57.42673	4.48380	-3.66164	-0.789389	-1648.88	0.048904	0.937124
136.00	844.55	451.42	-46.75	-55.73059	4.91821	-3.62552	-0.787689	-1638.98	0.049794	0.940434
137.00	797.80	425.45	-46.26	-53.97349	5.37377	-3.58726	-0.785989	-1629.08	0.050704	0.943744
138.00	751.55	399.75	-45.74	-52.14720	5.84936	-3.54687	-0.784289	-1619.18	0.051634	0.947054
139.00	705.81	374.34	-45.19	-50.28429	6.27619	-3.50435	-0.782589	-1609.28	0.052584	0.950364
140.00	660.22	349.23	-44.61	-48.35770	6.78888	-3.45969	-0.780889	-1600.38	0.053554	0.953674
141.00	616.01	324.45	-44.07	-46.38082	7.32838	-3.41289	-0.779189	-1591.48	0.054544	0.956984
142.00	572.00	300.00	-43.54	-44.38388	7.89934	-3.36479	-0.777489	-1582.58	0.055554	0.960294
143.00	526.25	274.58	-43.09	-42.38461	8.51203	-3.31586	-0.775789	-1573.68	0.056584	0.963604
144.00	480.16	252.11	-42.61	-40.38462	9.16731	-3.26619	-0.774089	-1564.78	0.057634	0.966914
145.00	433.07	232.81	-42.18	-38.38462	9.86584	-3.21586	-0.772389	-1555.88	0.058704	0.970224
146.00	385.35	215.75	-41.75	-36.38462	10.60826	-3.16477	-0.770689	-1546.98	0.059794	0.973534
147.00	337.46	200.81	-41.31	-34.38462	11.39508	-3.11289	-0.768989	-1538.08	0.060904	0.976844
148.00	289.19	187.77	-40.87	-32.38462	12.22831	-3.06026	-0.767289	-1529.18	0.062034	0.980154
149.00	240.97	176.42	-40.43	-30.38462	13.10886	-3.00689	-0.765589	-1520.28	0.063184	0.983464
150.00	192.74	167.09	-40.00	-28.38462	14.03831	-2.95289	-0.763889	-1511.38	0.064354	0.986774
151.00	144.51	158.85	-39.57	-26.38462	15.01886	-2.89826	-0.762189	-1502.48	0.065544	0.990084
152.00	96.28	150.61	-39.14	-24.38462	16.04931	-2.84319	-0.760489	-1493.58	0.066754	0.993394
153.00	48.05	142.37	-38.71	-22.38462	17.13086	-2.78786	-0.758789	-1484.68	0.067984	0.996704
154.00	0.00	134.13	-38.28	-20.38462	18.26331	-2.73219	-0.757089	-1475.78	0.069234	0.999994
155.00	0.00	125.89	-37.85	-18.38462	19.44686	-2.67619	-0.755389	-1466.88	0.070504	1.003304
156.00	0.00	117.65	-37.42	-16.38462	20.68141	-2.61986	-0.753689	-1457.98	0.071794	1.006614

Table A.1 (continued)

DISTANCES INCHES *****	TEMPERATURE DEGS FARN *****	TEMPERATURE DEGS CENT *****	TEMP DIFF DEGS FARN *****	MASS FLOW LB/HR*IN *****	COND HEAT BTU/HR*IN *****	ARGON FLO LB/HR*IN *****	VOL ARG B/HR*IN *****	TOTAL FWR WATT/INCH *****	TEMP COND B/HR*IN*DP *****	SPEC HEAT BTU/LB*DP *****
157.00	247.26	119.59	-8.28	-6.17383	5.23798	-0.64206	-0.031802	25.01	0.089116	0.147974
158.00	238.98	118.99	-7.40	-5.76803	6.76582	-0.60855	-0.029589	7.34	0.089175	0.145615
159.00	231.18	118.61	-7.40	-5.39070	5.56861	-0.57392	-0.027493	-7.03	0.089707	0.143380
160.00	223.78	108.55	-7.08	-5.09750	4.60751	-0.56881	-0.026152	-18.26	0.090218	0.141229
161.00	216.71	102.61	-6.81	-4.85089	3.84806	-0.52861	-0.024858	-26.46	0.090712	0.139180
162.00	209.90	98.83	-6.58	-4.63947	3.32038	-0.51046	-0.023719	-32.16	0.091191	0.137123
163.00	203.32	95.18	-6.39	-4.45373	2.93922	-0.47526	-0.022759	-35.33	0.091659	0.135185
164.00	196.93	91.63	-6.21	-4.28583	2.70053	-0.44763	-0.021872	-36.34	0.092116	0.133208
165.00	190.72	88.18	-6.05	-4.12947	2.58114	-0.46892	-0.021086	-35.46	0.092568	0.131301
166.00	184.67	84.82	-5.89	-3.97945	2.55913	-0.45461	-0.020255	-33.00	0.093002	0.129483
167.00	178.78	81.55	-5.73	-3.83260	2.61380	-0.44026	-0.019481	-29.28	0.093431	0.127618
168.00	173.06	78.36	-5.67	-3.68555	2.73577	-0.43157	-0.018708	-28.88	0.093851	0.125722
169.00	167.49	75.27	-5.39	-3.53667	2.87703	-0.41810	-0.017929	-18.95	0.094261	0.123871
170.00	162.10	72.28	-5.21	-3.38892	3.05181	-0.40632	-0.017137	-12.98	0.094660	0.122065
171.00	156.88	69.38	-5.02	-3.22992	3.23260	-0.38955	-0.016310	-6.80	0.095046	0.120306
172.00	151.86	66.59	-4.82	-3.07183	3.40828	-0.37800	-0.015511	-0.64	0.095420	0.118511
173.00	147.04	63.91	-4.61	-2.91128	3.56607	-0.35773	-0.014691	5.22	0.095780	0.116755
174.00	142.42	61.35	-4.40	-2.74924	3.69570	-0.34088	-0.013847	10.65	0.096126	0.115061
175.00	138.03	58.90	-4.17	-2.58703	3.78858	-0.32350	-0.013018	15.48	0.096456	0.113405
176.00	133.86	56.59	-3.94	-2.42600	3.83787	-0.30589	-0.012189	19.44	0.096770	0.111790
177.00	129.91	54.40	-3.72	-2.26786	3.83856	-0.28821	-0.011382	22.55	0.097067	0.110205
178.00	126.20	52.33	-3.49	-2.11411	3.78767	-0.27070	-0.010598	24.54	0.097348	0.108791
179.00	122.71	50.39	-3.27	-1.96642	3.68329	-0.25359	-0.009848	25.72	0.097613	0.107466
180.00	119.44	48.58	-3.04	-1.82836	3.52664	-0.23713	-0.009137	25.72	0.097861	0.106170
181.00	116.38	46.88	-2.86	-1.69537	3.32065	-0.22151	-0.008478	24.67	0.098094	0.104900
182.00	113.52	45.29	-2.67	-1.57475	3.06880	-0.20702	-0.007868	22.61	0.098312	0.103613
183.00	110.85	43.81	-2.50	-1.46557	2.77690	-0.19376	-0.007312	19.65	0.098516	0.102374
184.00	108.35	42.42	-2.35	-1.36864	2.45512	-0.18192	-0.006823	15.90	0.098709	0.101189
185.00	106.01	41.12	-2.21	-1.28448	2.11299	-0.17161	-0.006398	11.55	0.098890	0.100010
186.00	103.79	39.89	-2.10	-1.21322	1.76279	-0.16288	-0.006039	6.80	0.099062	0.100052
187.00	101.69	38.72	-2.01	-1.15456	1.41873	-0.15573	-0.005783	1.91	0.099226	0.100000
188.00	99.69	37.60	-1.94	-1.10776	1.09700	-0.15010	-0.005506	-2.83	0.099388	0.100000
189.00	97.75	36.53	-1.88	-1.07153	0.81573	-0.14583	-0.005322	-7.06	0.099547	0.100000
190.00	95.87	35.60	-1.80	-1.04401	0.59500	-0.14278	-0.005182	-10.80	0.099698	0.100000
191.00	94.03	34.86	-1.81	-1.02269	0.45701	-0.14038	-0.005073	-12.81	0.099833	0.100000
192.00	92.22	33.46	-1.79	-1.00840	0.42576	-0.13885	-0.004979	-12.61	0.099977	0.100000
193.00	90.63	32.46	-1.76	-0.98525	0.52739	-0.13639	-0.004880	-10.45	0.100122	0.100000
194.00	89.68	31.49	-1.72	-0.96055	0.79006	-0.13392	-0.004755	-5.34	0.100262	0.100000
195.00	88.95	30.53	-1.66	-0.92882	1.28392	-0.12909	-0.004575	1.34	0.100400	0.100000
196.00	88.29	29.61	-1.58	-0.87172	1.92116	-0.12218	-0.004310	16.30	0.100531	0.100000
197.00	87.71	28.73	-1.48	-0.79399	2.85588	-0.11166	-0.003923	38.28	0.100654	0.100000
198.00	87.27	27.93	-1.28	-0.68333	4.08383	-0.09661	-0.003378	58.09	0.100763	0.100000
199.00	86.03	27.24	-0.97	-0.53036	5.68259	-0.07503	-0.002618	88.45	0.100853	0.100000
200.00	85.06	26.70	-0.59	-0.32838	7.57081	-0.04598	-0.001601	126.58	0.100917	0.100000
201.00	79.47	26.37	-2.47	-1.28688	18.82000	-0.19163	-0.006682	303.81	0.101062	0.100000

Table A.2 (continued)

DISTANCES INCHES	TEMPERATURE DEGS F/°F	TEMPERATURE DEGS C/°C	TEMP DIFF DEGS F/°F	MASS FLOW G/MIN	CORP HEAT BTU/MIN	ARGON FLO G/MIN	VOL B/MIN	HGR IN	TOTAL PER BATT/INCH	THIN COND N/MIN	SPEC HEAT BTU/LB/°F
13.00	628.38	329.10	21.81	23.15985	6.27288	1.64021	0.123409	0.123409	584.60	0.044482	0.287204
15.00	605.79	309.99	21.96	26.06377	6.27780	1.70270	0.128561	0.128561	563.33	0.045360	0.270968
18.00	647.78	351.19	22.51	28.99221	6.27780	1.74886	0.138561	0.138561	580.86	0.046376	0.258178
18.00	690.26	365.70	23.08	25.98521	6.27948	1.78969	0.138561	0.138561	597.97	0.046376	0.248869
17.00	713.36	379.52	23.63	26.92288	6.27948	1.83820	0.148203	0.148203	615.87	0.046209	0.242201
18.00	736.99	391.66	24.23	27.92509	6.26982	1.87937	0.159786	0.159786	638.17	0.046184	0.235917
19.00	761.22	405.12	24.83	28.95199	6.26026	1.92421	0.155366	0.155366	652.97	0.046088	0.229615
20.00	786.65	418.91	25.43	30.00350	6.23888	1.97172	0.161168	0.161168	671.97	0.045989	0.223291
21.00	811.87	433.08	26.03	31.07954	6.23888	2.01890	0.167080	0.167080	691.66	0.045896	0.216983
22.00	837.51	447.50	26.63	32.18022	6.21951	2.06675	0.173132	0.173132	711.76	0.045752	0.210584
23.00	868.15	462.31	27.28	33.30530	6.19857	2.11528	0.179322	0.179322	731.66	0.045661	0.204166
24.00	891.43	477.96	27.91	34.45877	6.17489	2.16487	0.185688	0.185688	752.36	0.045611	0.197732
25.00	919.38	492.97	28.55	35.62851	6.15181	2.21833	0.192110	0.192110	773.86	0.045564	0.191265
26.00	947.90	509.03	29.21	36.82688	6.12965	2.26887	0.198706	0.198706	796.97	0.045472	0.184761
27.00	977.10	525.06	29.87	38.04883	6.10276	2.31607	0.205638	0.205638	816.99	0.045295	0.178249
28.00	1006.97	541.65	30.53	39.29837	6.07888	2.36798	0.212303	0.212303	839.21	0.045167	0.171689
29.00	1037.50	558.61	31.21	40.58813	6.04875	2.42089	0.219301	0.219301	861.93	0.045068	0.165013
30.00	1068.71	575.95	31.90	41.95757	6.01372	2.47570	0.226631	0.226631	885.06	0.045011	0.158316
31.00	1100.41	593.57	32.59	43.37857	5.98153	2.52959	0.234393	0.234393	908.59	0.044918	0.151616
32.00	1133.21	611.78	33.30	44.85150	5.94836	2.58218	0.242686	0.242686	932.53	0.044838	0.144916
33.00	1166.50	630.28	34.01	46.37851	5.91828	2.63736	0.251426	0.251426	956.08	0.044761	0.138217
34.00	1200.51	649.17	34.73	47.95558	5.87958	2.69324	0.260609	0.260609	980.17	0.044680	0.131517
35.00	1235.20	668.47	35.46	49.58788	5.83823	2.75093	0.270182	0.270182	1004.79	0.044598	0.124817
36.00	1270.70	688.17	36.20	51.27057	5.80850	2.80768	0.280197	0.280197	1029.33	0.044518	0.118117
37.00	1306.89	708.27	36.98	53.00385	5.77251	2.86597	0.290689	0.290689	1054.71	0.044435	0.111417
38.00	1343.88	728.90	37.70	54.78208	5.73639	2.92594	0.301689	0.301689	1080.71	0.044357	0.104717
39.00	1381.58	749.78	38.46	56.60288	5.70029	2.98779	0.313186	0.313186	1107.70	0.044281	0.098017
40.00	1420.00	771.11	39.24	58.46602	5.66336	3.05271	0.325231	0.325231	1135.31	0.044206	0.091317
41.00	1459.28	792.31	40.02	60.37150	5.62888	3.12029	0.337866	0.337866	1163.31	0.044131	0.084617
42.00	1499.25	815.18	40.81	62.32087	5.59388	3.18955	0.351093	0.351093	1191.72	0.044056	0.077917
43.00	1540.06	837.81	41.61	64.31387	5.55878	3.26089	0.364918	0.364918	1220.75	0.043981	0.071217
44.00	1581.66	860.94	42.41	66.34332	5.52871	3.33434	0.379348	0.379348	1250.32	0.043906	0.064517
45.00	1624.08	884.49	43.23	68.41387	5.49187	3.41097	0.394381	0.394381	1280.83	0.043831	0.057817
46.00	1667.30	908.50	44.05	70.52117	5.45912	3.49089	0.409918	0.409918	1311.84	0.043756	0.051117
47.00	1711.36	932.98	44.89	72.66108	5.42777	3.57487	0.425963	0.425963	1343.32	0.043681	0.044417
48.00	1756.28	957.91	45.73	74.83101	5.39754	3.66217	0.442518	0.442518	1375.39	0.043606	0.037717
49.00	1801.97	983.32	46.58	77.03171	5.36851	3.75387	0.459581	0.459581	1408.06	0.043531	0.031017
50.00	1848.55	1009.19	47.44	79.26108	5.34079	3.84987	0.477163	0.477163	1441.32	0.043456	0.024317
51.00	1895.98	1035.55	48.30	81.52108	5.31487	3.95097	0.495286	0.495286	1475.17	0.043381	0.017617
52.00	1944.29	1062.18	49.18	83.81110	5.28963	4.05787	0.513963	0.513963	1509.63	0.043306	0.010917
53.00	1993.87	1089.71	50.07	86.13108	5.26636	4.17097	0.533186	0.533186	1544.70	0.043231	0.004217
54.00	2044.58	1117.52	50.96	88.48101	5.24078	4.28987	0.552963	0.552963	1580.32	0.043156	0.000000
55.00	2096.50	1145.83	51.84	90.96108	5.22086	4.41487	0.573318	0.573318	1616.49	0.043081	0.000000
56.00	2148.36	1174.68	52.77	93.47108	5.20380	4.54587	0.594286	0.594286	1653.26	0.043006	0.000000
57.00	2199.13	1203.96	53.69	96.00108	5.19065	4.68287	0.615781	0.615781	1690.63	0.042931	0.000000
58.00	2252.82	1233.79	54.62	98.61108	5.17688	4.82587	0.637863	0.637863	1728.63	0.042856	0.000000
59.00	2307.88	1264.18	55.56	101.26108	5.16338	4.97487	0.660486	0.660486	1767.26	0.042781	0.000000
60.00	2363.00	1295.00	56.50	103.94108	5.15085	5.12987	0.683663	0.683663	1806.49	0.042706	0.000000
61.00	2419.50	1326.19	57.44	106.66108	5.13879	5.29087	0.707386	0.707386	1846.32	0.042631	0.000000
62.00	2476.96	1358.31	58.42	109.41108	5.12688	5.45787	0.731463	0.731463	1886.75	0.042556	0.000000
63.00	2535.38	1390.77	59.43	112.18108	5.11512	5.63087	0.756086	0.756086	1927.86	0.042481	0.000000
64.00	2594.77	1423.76	60.47	115.00108	5.10355	5.80987	0.781263	0.781263	1969.63	0.042406	0.000000
65.00	2655.18	1457.30	61.56	117.86108	5.09208	6.00487	0.806986	0.806986	2012.06	0.042331	0.000000
66.00	2716.60	1491.39	62.76	120.76108	5.08085	6.21587	0.833163	0.833163	2055.17	0.042256	0.000000
67.00	2778.86	1526.03	63.96	123.69108	5.06988	6.43287	0.860386	0.860386	2108.93	0.042181	0.000000

Table A.2 (continued)

DISTANCES INCHES	TEMPERATURE DEGS FARN	TEMPERATURE DEGS CENT	TEMP DIFF DEGS FARN	MASS FLOW G/G/MIN	COND HEAT G/G/MIN	ARGON FLO G/G/MIN	VOL M/MIN	TOTAL PWR WATT/INCH	TRMR COND S/MIN	SPEC HEAT BTU/LB-DEG
68.00	2922.22	1561.23	68.38	106.74204	5.16638	9.99289	0.585108	2055.85	0.029151	0.480272
69.00	2924.50	1597.00	65.80	108.77812	5.18137	9.07188	0.596245	2092.56	0.028940	0.481588
70.00	2932.00	1633.33	61.86	102.50893	98.22808	8.76488	0.561908	1108.29	0.028844	0.482785
71.00	3033.86	1637.48	52.93	88.67331	-81.28921	9.10898	0.885062	902.34	0.028745	0.483745
72.00	3086.80	1696.89	88.97	75.29372	-30.33318	3.88725	0.812800	711.07	0.028683	0.484525
73.00	3131.36	1721.87	37.57	62.98952	-35.65791	2.51328	0.385399	535.22	0.028632	0.485157
74.00	3168.93	1782.74	30.73	51.58151	-32.61052	2.38295	0.282899	378.80	0.028578	0.485854
75.00	3199.66	1759.81	28.45	41.08887	-29.78189	1.89639	0.225308	232.05	0.028549	0.486082
76.00	3228.11	1773.80	18.78	31.51150	-26.98896	1.45354	0.172813	105.88	0.028549	0.486550
77.00	3282.85	1763.91	13.60	22.86498	-28.15595	1.05882	0.085825	-0.07	0.028582	0.486550
78.00	3256.85	1791.34	9.01	15.16617	-21.35177	0.69903	0.081179	-171.57	0.028549	0.486584
79.00	3265.87	1796.37	8.99	8.80597	-18.55054	0.38735	0.086102	-279.25	0.028537	0.486810
80.00	3270.86	1799.18	1.54	2.59138	-15.75107	0.11980	0.018212	-732.85	0.028518	0.486816
81.00	3272.00	1800.00	-3.61	-6.08089	-35.30139	-0.28018	-0.033308	-882.71	0.028541	0.486827
82.00	3268.39	1797.99	-10.39	-17.87888	-31.93138	-0.80517	-0.095819	-1011.82	0.028544	0.486852
83.00	3288.00	1792.22	-16.88	-27.71535	-28.56281	-1.27781	-0.151998	-1119.68	0.028561	0.486827
84.00	3281.52	1783.07	-21.89	-16.79788	-25.19593	-1.64752	-0.201802	-1206.23	0.028579	0.486850
85.00	3219.68	1770.91	-26.62	-88.71900	-21.83117	-2.06889	-0.285215	-1271.45	0.028608	0.486850
86.00	3193.01	1746.12	-10.67	-51.87862	-18.88690	-2.37871	-0.282292	-1315.29	0.028638	0.486850
87.00	3162.38	1739.08	-38.05	-57.07686	-15.10118	-2.68019	-0.312973	-1337.73	0.028681	0.486850
88.00	3128.30	1720.16	-36.78	-61.51398	-11.73181	-2.88893	-0.337285	-1338.76	0.028716	0.486850
89.00	3091.84	1699.76	-38.75	-64.79381	-8.34838	-3.00893	-0.355284	-1319.80	0.028801	0.486850
90.00	3052.81	1678.23	-80.08	-64.92012	-6.96880	-3.10818	-0.366877	-1276.66	0.028876	0.486850
91.00	3012.73	1655.46	-80.73	-67.89821	-3.43633	-3.15870	-0.372210	-1326.28	0.028943	0.486850
92.00	2972.00	1633.33	-80.20	-68.59926	-3.88701	-3.19893	-0.375902	-1383.76	0.029060	0.486850
93.00	2930.80	1610.85	-81.92	-69.62675	-3.45026	-3.25062	-0.381619	-1360.22	0.029170	0.486850
94.00	2888.89	1587.16	-82.81	-70.63557	-3.38800	-3.30818	-0.387111	-1375.60	0.029292	0.486850
95.00	2866.28	1563.89	-83.27	-71.58517	-3.10812	-3.35460	-0.392275	-1389.90	0.029428	0.486850
96.00	2831.01	1539.85	-83.91	-72.87501	-3.18251	-3.40889	-0.397108	-1403.11	0.029577	0.486850
97.00	2759.10	1515.06	-84.51	-73.39855	-3.05705	-3.45208	-0.401626	-1415.21	0.029781	0.486850
98.00	2718.59	1490.33	-85.09	-78.07330	-2.93160	-3.49705	-0.405767	-1428.20	0.029921	0.486850
99.00	2669.49	1465.27	-85.65	-78.82658	-2.80017	-3.53993	-0.409548	-1446.77	0.030117	0.486850
100.00	2623.85	1439.92	-86.17	-75.82658	-2.66017	-3.58068	-0.413064	-1468.77	0.030310	0.486850
101.00	2577.67	1418.26	-86.67	-76.01016	-2.53385	-3.61929	-0.416200	-1492.38	0.030540	0.486850
102.00	2531.00	1388.38	-87.18	-76.53128	-2.42691	-3.65977	-0.418986	-1518.75	0.030809	0.486850
103.00	2483.86	1362.15	-87.58	-76.98958	-2.29918	-3.69811	-0.421823	-1548.00	0.031077	0.486850
104.00	2436.28	1335.71	-88.00	-77.38863	-2.17035	-3.72231	-0.423510	-1578.07	0.031366	0.486850
105.00	2388.28	1309.04	-88.35	-77.71629	-2.04031	-3.74238	-0.425248	-1608.07	0.031677	0.486850
106.00	2339.89	1282.16	-88.75	-77.98827	-1.90881	-3.78032	-0.426628	-1637.56	0.031913	0.486850
107.00	2291.15	1255.08	-89.08	-78.18837	-1.77558	-3.80612	-0.427689	-1670.64	0.032209	0.486850
108.00	2242.07	1227.82	-89.38	-78.32881	-1.64034	-3.82978	-0.428318	-1672.86	0.032566	0.486850
109.00	2192.68	1200.38	-89.66	-78.40826	-1.50286	-3.85131	-0.428610	-1670.58	0.032887	0.486850
110.00	2143.02	1172.79	-89.91	-78.41577	-1.36280	-3.87070	-0.428595	-1673.80	0.033150	0.486850
111.00	2093.11	1145.06	-90.13	-78.36288	-1.21982	-3.88788	-0.428192	-1673.01	0.033458	0.486850
112.00	2042.97	1117.21	-90.33	-78.28537	-1.07359	-3.90309	-0.427819	-1673.82	0.033798	0.486850
113.00	1992.88	1089.25	-90.50	-78.06328	-0.92378	-3.91608	-0.426298	-1670.57	0.034188	0.486850
114.00	1942.15	1061.19	-90.68	-77.91881	-0.76985	-3.92693	-0.424816	-1650.57	0.034635	0.486850
115.00	1891.41	1033.06	-90.75	-77.50881	-0.61169	-3.93565	-0.422979	-1633.09	0.035111	0.486850
116.00	1840.76	1008.87	-90.83	-77.12825	-0.48821	-3.94233	-0.420771	-1622.83	0.035688	0.486850
117.00	1789.92	978.62	-90.85	-76.68682	-0.27951	-3.94889	-0.418207	-1610.23	0.036388	0.486850
118.00	1739.03	948.35	-90.92	-76.17881	-0.07045	-3.95489	-0.415280	-1397.25	0.037356	0.486850
119.00	1688.11	920.06	-90.92	-75.60763	0.07632	-3.96017	-0.411989	-1382.70	0.038005	0.486850
120.00	1637.14	891.77	-90.90	-74.96992	0.28421	-3.96721	-0.408438	-1368.21	0.038806	0.486850
121.00	1586.24	863.89	-90.85	-74.26887	0.60617	-3.97312	-0.404813	-1354.51	0.039806	0.486850
122.00	1535.88	835.25	-90.77	-73.49705	0.85818	-3.97689	-0.399925	-1339.58	0.040855	0.486850

Table A.2 (continued)

DISTANCES INCHES	TEMPERATURE DEGS FARN	TEMPERATURE DEGS CENT	TEMP DIFF DEGS FARN	MASS FLOW G0/INCH	COND REAT G0/INCH	ARGON FLO G0/INCH	VOL MGR M/INCH	TOTAL PER MIST/INCH	TEMP COND M/INCH	SPDC REAT G0/INCH
123.00	188.68	807.04	-50.65	-72.64183	0.87886	-3.92853	-0.395169	-1330.99	0.081542	0.310178
124.00	188.02	778.90	-50.52	-71.75938	1.10286	-3.91803	-0.390083	-1311.02	0.082502	0.310178
125.00	183.49	750.83	-50.36	-70.70566	1.33681	-3.90561	-0.385066	-1289.04	0.083504	0.310178
126.00	133.14	722.85	-50.17	-69.75507	1.58273	-3.89063	-0.378677	-1264.04	0.084563	0.310178
127.00	1282.97	699.98	-49.95	-68.63283	1.84112	-3.87373	-0.372035	-1242.63	0.085679	0.310178
128.00	1233.01	667.23	-49.71	-67.48262	2.11289	-3.85669	-0.365819	-1216.65	0.086855	0.310178
129.00	1183.31	639.62	-49.53	-66.29560	2.39899	-3.83952	-0.358928	-1189.81	0.088092	0.310178
130.00	1133.88	612.15	-49.33	-65.08184	2.70033	-3.82221	-0.352168	-1161.17	0.089393	0.310178
131.00	1084.78	584.86	-49.00	-63.84733	3.01820	-3.79876	-0.345328	-1131.03	0.090759	0.310178
132.00	1035.94	557.78	-48.65	-62.58263	3.35336	-3.77119	-0.338420	-1099.38	0.092193	0.310178
133.00	987.89	530.83	-48.27	-61.28990	3.70694	-3.73747	-0.331486	-1066.21	0.093698	0.310178
134.00	939.83	503.13	-47.85	-59.95991	4.08008	-3.69662	-0.324508	-1031.51	0.095265	0.310178
135.00	891.77	475.65	-47.32	-57.62673	4.47380	-3.65168	-0.317518	-995.28	0.096907	0.310178
136.00	843.55	448.42	-46.75	-55.28369	4.88923	-3.60426	-0.310570	-957.52	0.098620	0.310178
137.00	795.80	421.85	-46.26	-52.93389	5.32737	-3.55487	-0.303688	-918.21	0.099805	0.310178
138.00	751.55	395.75	-45.78	-50.58229	5.78936	-3.50335	-0.296877	-877.49	0.098193	0.310178
139.00	705.81	370.38	-45.19	-48.23770	6.27619	-3.45035	-0.289958	-835.26	0.095193	0.310178
140.00	660.62	345.23	-44.61	-45.89888	6.78988	-3.39569	-0.283138	-791.54	0.091698	0.310178
141.00	616.01	320.65	-44.01	-43.56881	7.32838	-3.34289	-0.276337	-746.53	0.087872	0.310178
142.00	572.00	300.00	-43.91	-41.23837	7.89251	-3.29032	-0.269591	-700.78	0.083931	0.310178
143.00	528.00	278.98	-43.28	-38.90777	8.48283	-3.23832	-0.262831	-654.61	0.079908	0.310178
144.00	485.59	252.00	-42.63	-36.58088	9.09675	-3.18611	-0.256111	-608.41	0.075910	0.310178
145.00	443.16	228.31	-41.98	-34.2518	9.73281	-3.13461	-0.249461	-562.19	0.071931	0.310178
146.00	400.86	204.86	-41.30	-31.92057	10.39061	-3.08326	-0.242872	-516.07	0.067962	0.310178
147.00	358.03	181.02	-40.61	-29.58806	11.07226	-3.03201	-0.236341	-470.03	0.064003	0.310178
148.00	315.83	157.02	-40.00	-27.25458	11.77881	-2.98076	-0.229871	-424.07	0.060053	0.310178
149.00	273.63	132.02	-39.39	-24.92011	12.51026	-2.92951	-0.223461	-378.19	0.056103	0.310178
150.00	231.43	107.02	-38.78	-22.58564	13.26661	-2.87826	-0.217091	-332.31	0.052153	0.310178
151.00	189.23	82.02	-38.17	-20.25117	14.04806	-2.82701	-0.210721	-286.43	0.048203	0.310178
152.00	147.03	57.02	-37.56	-17.91670	14.85451	-2.77576	-0.204351	-240.55	0.044253	0.310178
153.00	104.83	32.02	-36.95	-15.58223	15.68696	-2.72451	-0.197981	-194.67	0.040303	0.310178
154.00	62.63	7.02	-36.34	-13.24776	16.54541	-2.67326	-0.191611	-148.79	0.036353	0.310178
155.00	20.43	-18.02	-35.73	-10.91329	17.42986	-2.62201	-0.185241	-102.91	0.032403	0.310178
156.00	-21.77	-43.02	-35.12	-8.57982	18.34031	-2.57076	-0.178871	-57.03	0.028453	0.310178
157.00	-63.97	-68.02	-34.51	-6.24535	19.27676	-2.51951	-0.172501	-11.15	0.024503	0.310178
158.00	-106.17	-93.02	-33.90	-3.91088	20.23921	-2.46826	-0.166131	34.73	0.020553	0.310178
159.00	-148.37	-118.02	-33.29	-1.57641	21.22766	-2.41701	-0.159761	88.85	0.016603	0.310178
160.00	-190.57	-143.02	-32.68	7.75806	22.24211	-2.36576	-0.153391	142.97	0.012653	0.310178
161.00	-232.77	-168.02	-32.07	12.88859	23.28356	-2.31451	-0.147021	197.09	0.008703	0.310178
162.00	-274.97	-193.02	-31.46	17.92912	24.35101	-2.26326	-0.140651	251.21	0.004753	0.310178
163.00	-317.17	-218.02	-30.85	22.96965	25.44446	-2.21201	-0.134281	305.33	0.000803	0.310178
164.00	-359.37	-243.02	-30.24	27.99018	26.56391	-2.16076	-0.127911	359.45	0.000003	0.310178
165.00	-401.57	-268.02	-29.63	32.99071	27.70936	-2.10951	-0.121541	413.57	0.000003	0.310178
166.00	-443.77	-293.02	-29.02	37.99124	28.85881	-2.05826	-0.115171	467.69	0.000003	0.310178
167.00	-485.97	-318.02	-28.41	42.99177	29.93826	-2.00701	-0.108801	521.81	0.000003	0.310178
168.00	-528.17	-343.02	-27.80	47.99230	31.04771	-1.95576	-0.102431	575.93	0.000003	0.310178
169.00	-570.37	-368.02	-27.19	52.99283	32.18716	-1.90451	-0.096061	630.05	0.000003	0.310178
170.00	-612.57	-393.02	-26.58	57.99336	33.35661	-1.85326	-0.089691	684.17	0.000003	0.310178
171.00	-654.77	-418.02	-25.97	62.99389	34.55606	-1.80201	-0.083321	738.29	0.000003	0.310178
172.00	-696.97	-443.02	-25.36	67.99442	35.78551	-1.75076	-0.076951	792.41	0.000003	0.310178
173.00	-739.17	-468.02	-24.75	72.99495	37.04496	-1.69951	-0.070581	846.53	0.000003	0.310178
174.00	-781.37	-493.02	-24.14	77.99548	38.33441	-1.64826	-0.064211	900.65	0.000003	0.310178
175.00	-823.57	-518.02	-23.53	82.99601	39.65386	-1.59701	-0.057841	954.77	0.000003	0.310178
176.00	-865.77	-543.02	-22.92	87.99654	40.99331	-1.54576	-0.051471	1008.89	0.000003	0.310178
177.00	-907.97	-568.02	-22.31	92.99707	42.36276	-1.49451	-0.045101	1063.01	0.000003	0.310178
178.00	-950.17	-593.02	-21.70	97.99760	43.76221	-1.44326	-0.038731	1117.13	0.000003	0.310178
179.00	-992.37	-618.02	-21.09	102.99813	45.19166	-1.39201	-0.032361	1171.25	0.000003	0.310178
180.00	-1034.57	-643.02	-20.48	107.99866	46.65111	-1.34076	-0.025991	1225.37	0.000003	0.310178
181.00	-1076.77	-668.02	-19.87	112.99919	48.14056	-1.28951	-0.019621	1279.49	0.000003	0.310178
182.00	-1118.97	-693.02	-19.26	117.99972	49.66001	-1.23826	-0.013251	1333.61	0.000003	0.310178
183.00	-1161.17	-718.02	-18.65	122.99925	51.20946	-1.18701	-0.006881	1387.73	0.000003	0.310178
184.00	-1203.37	-743.02	-18.04	127.99978	52.79891	-1.13576	-0.000511	1441.85	0.000003	0.310178
185.00	-1245.57	-768.02	-17.43	132.99931	54.42836	-1.08451	0.005851	1495.97	0.000003	0.310178
186.00	-1287.77	-793.02	-16.82	137.99984	56.09781	-1.03326	0.011481	1550.09	0.000003	0.310178
187.00	-1329.97	-818.02	-16.21	142.99937	57.80726	-0.98201	0.017111	1604.21	0.000003	0.310178
188.00	-1372.17	-843.02	-15.60	147.99990	59.55671	-0.93076	0.022741	1658.33	0.000003	0.310178
189.00	-1414.37	-868.02	-14.99	152.99943	61.34616	-0.87951	0.028371	1712.45	0.000003	0.310178
190.00	-1456.57	-893.02	-14.38	157.99996	63.17561	-0.82826	0.034001	1766.57	0.000003	0.310178
191.00	-1498.77	-918.02	-13.77	162.99949	65.04506	-0.77701	0.039631	1820.69	0.000003	0.310178
192.00	-1540.97	-943.02	-13.16	167.99902	66.95451	-0.72576	0.045261	1874.81	0.000003	0.310178
193.00	-1583.17	-968.02	-12.55	172.99955	68.90396	-0.67451	0.050891	1928.93	0.000003	0.310178
194.00	-1625.37	-993.02	-11.94	177.99908	70.89341	-0.62326	0.056521	1983.05	0.000003	0.310178
195.00	-1667.57	-1018.02	-11.33	182.99961	72.92286	-0.57201	0.062151	2037.17	0.000003	0.310178
196.00	-1709.77	-1043.02	-10.72	187.99914	75.00231	-0.52076	0.067781	2091.29	0.000003	0.310178
197.00	-1751.97	-1068.02	-10.11	192.99967	77.12176	-0.46951	0.073411	2145.41	0.000003	0.310178
198.00	-1794.17	-1093.02	-9.50	197.99920	79.28121	-0.41826	0.079041	2199.53	0.000003	0.310178
199.00	-1836.37	-1118.02	-8.89	202.99973	81.48066	-0.36701	0.084671	2253.65	0.000003	0.310178
200.00	-1878.57	-1143.02	-8.28	207.99926	83.71911	-0.31576	0.090301	2307.77	0.000003	0.310178
201.00	-1920.77	-1168.02	-7.67	212.99979	85.99856	-0.26451	0.095931	2361.89	0.000003	0.310178
202.00	-1962.97	-1193.02	-7.06	217.99932	88.31801	-0.21326	0.101561	2416.01	0.000003	0.310178
203.00	-2005.17	-1218.02	-6.45	222.99985	90.67746	-0.16201	0.107191	2470.13	0.000003	0.310178
204.00	-2047.37	-1243.02	-5.84	227.99938	93.07691	-0.11076	0.112821	2524.25	0.000003	0.310178
205.00	-2089.57	-1268.02	-5.23	232.99991	95.51636	-0.05951	0.118451	2578.37	0.000003	0.310178
206.00	-2131.77	-1293.02	-4.62	237.99944	97.99581	-0.00826	0.124081	2632.49	0.000003	0.310178
207.00	-2173.97	-1318.02	-4.01	242.99997	100.51526	0.04301	0.129711	2686.61	0.000003	0.310178
208.00	-2216.17	-1343.02	-3.40	247.99950	103.07471	0.09176	0.135341	2740.73	0.000003	0.310178
209.00	-2258.37	-1368.02	-2.79	252.99903	105.67416	0.14051	0.140971	2794.85	0.000003	0.310178
210.00	-2300.57	-1393.02	-2.18	257.99956	108.31361	0.18926	0.146601	2848.97	0.000003	0.310178
211.00	-2342.77	-1418.02	-1.57	262.99909	110.99306	0.23

Fig. A.1. Centigrade Temperature Criteria for the Surface of Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Top-Loaded Configuration.

SURFACE TEMPERATURE OF FUEL BLOCK - DEGREES FAHRENHEIT

Fig. A.2. Fahrenheit Temperature Criteria for the Surface of Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Top-Loaded Configuration.

Fig. A.3. Axial Heat Transfer From Mass Flow of Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Top-Loaded Configuration.

Fig. A.4. Axial Heat Transfer From Axial Conduction in Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Top-loaded Configuration.

Fig. A.5. Axial Heat Transfer From Mass Flow of Argon Gas as a Function of Axial Position in the Furnace for the Top-Loaded Configuration.

LINEAR HEAT DEPOSITION RATE - WATTS PER INCH

Fig. A.6. Total Radial Power Input, Excluding External Losses, Required to Process Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Top-Loaded Configuration.

Fig. A.7. Composite Axial Power Distribution for Processing Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Top-Loaded Configuration.

Fig. A.8. Centigrade Temperature Criteria for the Surface of Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Bottom-Loaded Configuration.

Fig. A.9. Fahrenheit Temperature Criteria for the Surface of Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Bottom-Loaded Configuration.

Fig. A.10. Axial Heat Transfer From Mass Flow of Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Bottom-Loaded Configuration.

Fig. A.11. Axial Heat Transfer From Axial Conduction in Fuel Elements Fabricated From H-227 Graphite as a Function of Their Axial Position in the Furnace for the Bottom-Loaded Configuration.

Fig. A.12. Axial Heat Transfer From Mass Flow of Argon Gas as a Function of Axial Position in the Furnace for the Bottom-Loaded Configuration.

Fig. A.13. Total Radial Power Input, Excluding External Losses, Required to Process Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Bottom-Loaded Configuration.

Fig. A.14. Composite Axial Power Distribution for Processing Fuel Elements Fabricated From H-327 Graphite as a Function of Their Axial Position in the Furnace for the Bottom-Loaded Configuration.

Appendix B

**MASS-FLOW SIMULATION DATA
FOR FUEL ELEMENTS FABRICATED FROM H-451 GRAPHITE**

Table B.1

HEAT PROD RATE FOR TOP LOADED CONFIGURATION USING 73V ACTIVE CORE ELEMENTS PAD FROM UNIRRADIATED M-551 GRAPHITE

 REQUIRE TOTAL MINIMUM POWER INPUT RATE = 79.99360 KILOWATTS
 REQUIRED TOTAL MINIMUM COOLING RATE = 80.09598 KILOWATTS

DISTANCES INCHES	TEMPERATURE DEGS FARR	TEMPERATURE DEGS CENT	TEMP DIFF DEGS FARR	MASS FLOW KG/HR	CORE HEAT KG/HR	ARGON FLO KG/HR	VOL R M/SEC	TOTAL PWR WATT/INCH	THIN CORN M/HR	SPEC HEAT BTU/LB-DEG
0.0	392.00	200.00	19.07	13.16904	8.32009	1.16883	0.071287	335.02	0.057591	0.218948
1.00	407.07	208.17	19.51	18.16959	8.36798	1.20361	0.074552	347.03	0.047091	0.212540
2.00	422.58	216.99	19.95	18.79277	8.41337	1.23705	0.077936	359.39	0.046174	0.206196
3.00	438.53	225.85	16.80	15.83791	8.46211	1.27210	0.081888	372.10	0.050882	0.209881
4.00	454.98	234.96	16.87	16.18535	8.49847	1.30796	0.085075	385.17	0.055899	0.213511
5.00	471.80	244.33	17.34	16.79580	8.53812	1.34442	0.088833	398.60	0.058895	0.217201
6.00	489.18	253.97	17.81	17.50838	8.56915	1.38155	0.092718	412.81	0.054378	0.210914
7.00	506.95	263.86	18.30	18.24885	8.60153	1.41935	0.096733	426.98	0.053801	0.204685
8.00	525.26	274.03	18.80	19.03097	8.63277	1.45781	0.100879	441.13	0.053214	0.204378
9.00	544.05	284.47	19.30	19.78713	8.65937	1.49695	0.105144	456.06	0.052614	0.204188
10.00	563.36	295.10	19.82	20.59815	8.68288	1.53676	0.109567	471.38	0.052010	0.215408
11.00	583.17	306.21	20.34	21.42515	8.70872	1.57728	0.114112	487.09	0.051398	0.219670
12.00	603.51	317.51	20.87	22.28038	8.72557	1.61839	0.118791	503.18	0.050772	0.218158
13.00	624.38	329.10	21.61	23.15985	8.74080	1.66021	0.123609	519.68	0.050187	0.217204
14.00	645.79	340.99	22.41	24.06377	8.75511	1.70270	0.128561	536.56	0.049564	0.216988
15.00	667.78	353.19	22.91	24.99221	8.76922	1.74586	0.133651	553.85	0.048921	0.216789
16.00	690.26	364.70	23.08	25.94521	8.78325	1.78969	0.138878	571.54	0.048271	0.216599
17.00	713.34	376.52	23.65	26.92284	8.79719	1.83420	0.144246	589.65	0.047615	0.216424
18.00	736.99	391.66	24.23	27.92509	8.81095	1.87937	0.149766	608.15	0.046955	0.216261
19.00	761.22	405.12	24.83	28.95199	8.82450	1.92521	0.155386	627.07	0.046291	0.216101
20.00	786.05	418.91	25.43	30.00350	8.83789	1.97172	0.161168	646.40	0.045625	0.215941
21.00	811.57	433.08	26.03	31.07959	8.85114	2.01890	0.167080	666.18	0.044959	0.215781
22.00	837.51	447.50	26.65	32.18022	8.86428	2.06674	0.173133	686.29	0.044293	0.215624
23.00	864.16	462.31	27.28	33.30530	8.87733	2.11528	0.179322	706.87	0.043627	0.215469
24.00	891.83	477.46	27.91	34.45577	8.89030	2.16487	0.185658	727.94	0.042965	0.215314
25.00	919.38	492.97	28.55	35.62851	8.90318	2.21533	0.192110	749.27	0.042300	0.215165
26.00	947.90	508.82	29.21	36.82688	8.91598	2.26687	0.198706	771.11	0.041625	0.215016
27.00	977.10	525.06	29.87	38.04883	8.92871	2.31907	0.205438	793.37	0.040959	0.214869
28.00	1006.97	541.65	30.53	39.29437	8.94138	2.36794	0.212303	816.05	0.040294	0.214724
29.00	1037.50	558.61	31.21	40.56813	8.95395	2.42049	0.219301	839.16	0.039628	0.214579
30.00	1068.31	575.95	31.90	41.85757	8.96646	2.47170	0.226431	862.70	0.038964	0.214436
31.00	1100.61	593.67	32.59	43.17887	8.97894	2.52759	0.233693	886.67	0.038305	0.214294
32.00	1133.21	611.78	33.30	44.51500	8.99138	2.58218	0.241086	911.00	0.037652	0.214151
33.00	1166.50	630.28	34.01	45.87871	8.99880	2.63736	0.248609	935.91	0.037000	0.214008
34.00	1200.51	649.17	34.73	47.26558	8.99880	2.69324	0.256251	961.19	0.036348	0.213865
35.00	1235.28	668.47	35.46	48.67588	8.99880	2.74982	0.264082	986.90	0.035697	0.213721
36.00	1270.70	688.17	36.20	50.10827	8.99880	2.80706	0.271991	1013.08	0.035047	0.213578
37.00	1306.89	708.27	36.94	51.56385	8.99880	2.86497	0.279987	1039.63	0.034399	0.213435
38.00	1343.88	728.60	37.70	53.04208	8.99880	2.92358	0.288189	1066.66	0.033753	0.213292
39.00	1381.58	749.74	38.46	54.54284	8.99880	2.98279	0.296636	1094.13	0.033101	0.213149
40.00	1420.00	771.11	39.24	56.06602	8.99880	3.04271	0.305389	1122.08	0.032452	0.213006
41.00	1459.28	792.91	40.02	57.61150	8.99880	3.10329	0.314431	1150.35	0.031802	0.212863
42.00	1499.25	815.14	40.81	59.17915	8.99880	3.16455	0.323881	1179.18	0.031155	0.212720
43.00	1540.06	837.81	41.61	60.76885	8.99880	3.22648	0.333737	1208.81	0.030509	0.212577
44.00	1581.66	860.92	42.41	62.38807	8.99880	3.28907	0.343937	1238.08	0.029864	0.212434
45.00	1624.08	884.89	43.23	64.03807	8.99880	3.35238	0.354488	1268.18	0.029221	0.212291
46.00	1667.30	908.50	44.05	65.64888	8.99880	3.41628	0.365411	1298.72	0.028580	0.212148

Table B.1 (continued)

DISTANCES INCHES *****	TEMPERATURE DEGS FARN *****	TEMPERATURE DEGS CENT *****	TEMP DIFF DEGS FARN *****	MASS FLOW LB/HIN*IN *****	COND HEAT BTU/HIN*IN *****	ARGON FLO LB/HIN*IN *****	VOL HMR M ³ /H*CU IN *****	TOTAL PER WATT/INCH *****	THER COND B/H*IN*DOF *****	SPEC HEAT BTU/LB*DOF *****
47.00	1711.36	932.98	44.89	67.34532	4.81013	3.44089	0.367178	1329.68	0.033023	0.344526
48.00	1756.28	957.41	45.73	69.04301	4.83211	3.54617	0.376568	1361.05	0.032815	0.340884
49.00	1801.97	983.32	46.58	70.74171	4.85388	3.61212	0.386066	1392.85	0.032605	0.340331
50.00	1848.55	1009.19	47.44	72.40117	4.88121	3.67873	0.394688	1424.64	0.0317505	0.345158
51.00	1895.98	1035.55	48.30	74.26108	4.90782	3.74602	0.405415	1457.63	0.032158	0.340162
52.00	1944.29	1062.38	49.18	76.04110	4.93580	3.81398	0.415248	1490.60	0.032221	0.340878
53.00	1993.47	1089.71	50.07	77.84686	4.96360	3.88261	0.425211	1523.94	0.032090	0.342766
54.00	2043.54	1117.52	50.96	79.65990	4.99201	3.95191	0.435271	1557.64	0.031963	0.345005
55.00	2094.50	1145.83	51.86	81.47773	5.02022	4.02188	0.445435	1591.64	0.031837	0.341148
56.00	2146.36	1174.64	52.77	83.35380	5.04776	4.09242	0.455700	1626.03	0.031710	0.349340
57.00	2199.13	1203.96	53.69	85.22747	5.07417	4.16383	0.466063	1660.69	0.031577	0.342162
58.00	2252.82	1233.79	54.62	87.11807	5.09896	4.23581	0.476518	1695.63	0.031457	0.342880
59.00	2307.44	1264.14	55.46	89.02888	5.12163	4.30867	0.487263	1730.82	0.031287	0.342562
60.00	2363.00	1295.00	56.50	90.98696	5.14172	4.38179	0.497693	1766.25	0.031124	0.342328
61.00	2419.50	1326.39	57.44	92.98357	5.15875	4.45578	0.508402	1801.90	0.030946	0.342477
62.00	2476.96	1358.31	58.42	94.83371	5.17232	4.53068	0.519188	1837.73	0.030750	0.340966
63.00	2535.38	1390.77	59.39	96.79642	5.18205	4.60577	0.530036	1873.73	0.030545	0.342641
64.00	2594.77	1423.76	60.37	98.77065	5.18764	4.68177	0.540949	1909.88	0.030299	0.344388
65.00	2655.14	1457.30	61.36	100.75539	5.18893	4.75885	0.551919	1946.18	0.030083	0.344547
66.00	2716.50	1491.39	62.34	102.74956	5.18577	4.83579	0.562980	1982.50	0.029766	0.344855
67.00	2778.86	1526.03	63.31	104.75213	5.17822	4.91380	0.574009	2018.94	0.029468	0.344800
68.00	2842.22	1561.23	64.38	106.76206	5.16688	4.99249	0.585108	2055.45	0.029152	0.344022
69.00	2906.60	1597.00	65.40	108.77882	5.15090	5.07188	0.596285	2092.02	0.028820	0.344568
70.00	2972.00	1633.33	61.46	102.50083	-43.65961	4.76668	0.561508	1118.21	0.028488	0.342745
71.00	3033.46	1667.44	52.93	88.47331	-40.43341	4.10498	0.485062	916.70	0.028186	0.344711
72.00	3086.80	1696.89	44.97	75.29372	-37.32486	3.44772	0.412880	728.77	0.027929	0.344525
73.00	3131.36	1721.87	37.57	62.48952	-34.32189	2.91324	0.345399	545.19	0.027715	0.344157
74.00	3168.93	1742.74	30.73	51.58181	-31.40539	2.38295	0.282859	396.54	0.027541	0.344555
75.00	3199.66	1759.81	24.45	41.08487	-28.56062	1.89639	0.225308	251.51	0.027403	0.344042
76.00	3224.40	1773.40	18.74	31.51150	-25.77315	1.45354	0.172813	126.43	0.027276	0.344336
77.00	3242.85	1783.41	13.60	22.86994	-23.03017	1.05442	0.125425	15.72	0.027218	0.344550
78.00	3256.45	1791.36	9.01	15.16657	-20.32069	0.69903	0.083179	-78.32	0.027168	0.344644
79.00	3265.47	1796.37	4.49	8.40597	-17.63534	0.38714	0.046102	-155.40	0.027131	0.344674
80.00	3270.46	1799.14	1.54	2.59138	-14.96630	0.11940	0.018212	-215.45	0.027116	0.344610
81.00	3272.00	1800.00	-3.61	-6.68049	-33.54992	-0.28018	-0.033388	-701.62	0.027121	0.344616
82.00	3268.39	1797.99	-10.39	-17.47888	-30.37875	-0.80537	-0.095839	-855.42	0.027158	0.344621
83.00	3258.00	1792.22	-16.48	-27.71525	-27.23080	-1.27781	-0.151998	-988.41	0.027218	0.344555
84.00	3241.52	1783.07	-21.89	-36.78748	-24.09316	-1.69752	-0.201802	-1100.29	0.027311	0.344247
85.00	3219.64	1770.91	-26.62	-44.71900	-20.95397	-2.06449	-0.245215	-1190.81	0.027430	0.344565
86.00	3193.01	1756.12	-30.67	-51.47862	-17.80220	-2.37471	-0.282292	-1259.76	0.027578	0.344560
87.00	3162.34	1739.08	-34.05	-57.07644	-14.62771	-2.64019	-0.312973	-1306.94	0.027760	0.344505
88.00	3128.30	1720.16	-36.74	-61.51394	-11.42147	-2.87493	-0.337285	-1332.28	0.027928	0.344582
89.00	3091.56	1699.73	-38.75	-64.79381	-8.17588	-3.00493	-0.355245	-1335.62	0.028122	0.344584
90.00	3052.81	1678.26	-40.08	-66.92012	-4.84515	-3.10818	-0.366877	-1316.97	0.028124	0.344214
91.00	3012.73	1655.96	-40.73	-67.89821	-1.54554	-3.15870	-0.372210	-1276.34	0.028582	0.344554
92.00	2972.00	1633.33	-41.20	-68.55924	-3.66079	-3.19493	-0.375802	-1225.78	0.028757	0.344800
93.00	2930.80	1610.45	-41.92	-69.62675	-3.54941	-3.25062	-0.381619	-1183.57	0.028972	0.344942
94.00	2888.89	1587.16	-42.61	-70.63447	-3.43545	-3.30818	-0.387111	-1140.25	0.029186	0.344930
95.00	2846.28	1563.49	-43.27	-71.48517	-3.32025	-3.35560	-0.392275	-1095.82	0.029399	0.344211
96.00	2803.01	1539.45	-43.91	-72.47501	-3.20218	-3.40449	-0.397108	-1050.24	0.029610	0.344234
97.00	2759.10	1515.06	-44.51	-73.30455	-3.08167	-3.45204	-0.401806	-1003.54	0.029815	0.344714
98.00	2714.59	1490.33	-45.09	-74.07330	-2.95465	-3.49705	-0.405767	-955.67	0.030016	0.344604
99.00	2669.49	1465.27	-45.65	-74.78074	-2.83310	-3.53993	-0.409488	-907.14	0.030210	0.344526
100.00	2623.85	1439.92	-46.17	-75.42654	-2.70508	-3.58068	-0.413066	-857.49	0.030397	0.343640
101.00	2577.67	1414.26	-46.67	-76.01014	-2.57452	-3.61929	-0.416200	-805.13	0.030575	0.343291

Table B.1 (continued)

DISTANCES INCHES	TEMPERATURE DEGS F	TEMPERATURE DEGS C	TEMP DIFF DEGS F	MASS FLOW LB/HR	COND HEAT BTU/HR	ARGON FLOW LB/HR	VOL B/HR	TOTAL PER CATT/INCH	THIN COND W/HR	SPEC HEAT BTU/LB
107.00	2431.00	1338.34	-87.14	-76.53129	-2.44162	-3.65577	-0.818986	-1852.60	0.030745	0.451004
108.00	2433.84	1342.15	-87.58	-76.98954	-2.10648	-3.69011	-0.821823	-1854.84	0.030907	0.451550
109.00	2436.24	1345.71	-88.00	-77.38463	-2.16912	-3.72231	-0.823510	-1863.84	0.031060	0.452114
110.00	2438.28	1349.05	-88.39	-77.71624	-2.23910	-3.75234	-0.825204	-1867.89	0.031205	0.452699
111.00	2439.89	1352.16	-88.75	-77.98427	-1.88868	-3.78032	-0.826628	-1870.61	0.031342	0.453117
112.00	2441.15	1355.08	-89.08	-78.18837	-1.74582	-3.80632	-0.827649	-1872.18	0.031474	0.453482
113.00	2442.07	1357.82	-89.38	-78.32841	-1.60188	-3.82978	-0.828314	-1872.48	0.031594	0.453782
114.00	2442.69	1360.38	-89.66	-78.40426	-1.45579	-3.85131	-0.828945	-1871.63	0.031722	0.454034
115.00	2443.02	1362.74	-89.91	-78.41577	-1.30887	-3.87070	-0.829485	-1869.59	0.031845	0.454248
116.00	2443.11	1365.06	-90.13	-78.46284	-1.16083	-3.88796	-0.829882	-1866.16	0.031965	0.454423
117.00	2443.37	1367.21	-90.31	-78.48437	-1.01173	-3.90309	-0.829819	-1861.94	0.032092	0.454575
118.00	2443.64	1369.25	-90.50	-78.46328	-0.86161	-3.91604	-0.829294	-1856.33	0.032225	0.454704
119.00	2443.15	1371.19	-90.68	-77.91846	-0.71084	-3.92493	-0.828414	-1849.51	0.032368	0.454800
120.00	2442.71	1373.06	-90.75	-77.70431	-0.55912	-3.93565	-0.827271	-1841.52	0.032525	0.454866
121.00	2442.04	1374.87	-90.83	-77.12824	-0.40852	-3.94723	-0.825771	-1832.32	0.032649	0.454911
122.00	2441.26	1376.62	-90.89	-76.68662	-0.25841	-3.95644	-0.824207	-1821.91	0.032784	0.454945
123.00	2440.31	1378.35	-90.92	-76.17981	-0.09250	-3.96399	-0.822580	-1810.28	0.032918	0.454964
124.00	2439.19	1379.99	-90.92	-75.56763	0.06657	-3.96917	-0.821114	-1797.63	0.033048	0.454967
125.00	2437.79	1381.57	-90.92	-74.86992	0.22826	-3.97231	-0.820334	-1783.38	0.033168	0.454954
126.00	2436.19	1383.11	-90.94	-74.09705	0.39308	-3.97312	-0.820111	-1768.00	0.033274	0.454924
127.00	2434.44	1384.61	-90.94	-73.26687	0.56163	-3.97289	-0.820169	-1751.53	0.033371	0.454874
128.00	2432.58	1386.07	-90.94	-72.36143	0.73458	-3.97053	-0.820483	-1734.37	0.033458	0.454804
129.00	2430.64	1387.49	-90.94	-71.39380	0.91266	-3.96580	-0.820944	-1716.85	0.033535	0.454714
130.00	2428.64	1388.87	-90.94	-70.39066	1.09664	-3.95963	-0.821544	-1698.94	0.033604	0.454604
131.00	2426.59	1390.21	-90.94	-69.35507	1.28780	-3.95217	-0.822285	-1680.68	0.033666	0.454474
132.00	2424.41	1391.51	-90.94	-68.28243	1.48577	-3.94369	-0.823166	-1662.04	0.033721	0.454324
133.00	2422.11	1392.77	-90.94	-67.18262	1.69266	-3.93432	-0.824186	-1643.04	0.033770	0.454164
134.00	2419.71	1393.99	-90.94	-66.05560	1.90898	-3.92417	-0.825344	-1623.68	0.033814	0.454004
135.00	2417.21	1395.17	-90.94	-64.89144	2.13563	-3.91321	-0.826644	-1604.04	0.033854	0.453844
136.00	2414.61	1396.31	-90.94	-63.59733	2.37389	-3.90076	-0.828084	-1584.12	0.033890	0.453684
137.00	2411.91	1397.41	-90.94	-62.18243	2.62341	-3.88719	-0.829664	-1563.84	0.033922	0.453524
138.00	2409.11	1398.47	-90.94	-60.65890	2.88417	-3.87247	-0.831384	-1543.20	0.033950	0.453364
139.00	2406.21	1399.49	-90.94	-59.05991	3.16251	-3.85642	-0.833244	-1522.24	0.033974	0.453204
140.00	2403.21	1400.47	-90.94	-57.37671	3.45308	-3.83914	-0.835244	-1500.96	0.033994	0.453044
141.00	2400.11	1401.41	-90.94	-55.63069	3.75830	-3.82052	-0.837344	-1479.36	0.034010	0.452884
142.00	2396.91	1402.31	-90.94	-53.83344	4.07871	-3.79976	-0.839544	-1457.44	0.034022	0.452724
143.00	2393.61	1403.17	-90.94	-51.98442	4.41659	-3.77726	-0.841844	-1435.20	0.034030	0.452564
144.00	2390.21	1403.99	-90.94	-50.08442	4.76589	-3.75315	-0.844244	-1412.64	0.034034	0.452404
145.00	2386.71	1404.77	-90.94	-48.13570	5.13277	-3.72747	-0.846744	-1389.84	0.034034	0.452244
146.00	2383.11	1405.51	-90.94	-46.14802	5.51898	-3.69969	-0.849344	-1366.80	0.034030	0.452084
147.00	2379.41	1406.21	-90.94	-44.12388	5.91663	-3.67026	-0.852044	-1343.52	0.034022	0.451924
148.00	2375.61	1406.87	-90.94	-42.05461	6.32597	-3.63915	-0.854844	-1319.96	0.034010	0.451764
149.00	2371.71	1407.49	-90.94	-39.93339	6.75859	-3.60607	-0.857744	-1296.12	0.034004	0.451604
150.00	2367.71	1408.07	-90.94	-37.75461	7.21489	-3.57052	-0.860744	-1271.96	0.033994	0.451444
151.00	2363.61	1408.61	-90.94	-35.51461	7.69663	-3.53215	-0.863844	-1247.48	0.033980	0.451284
152.00	2359.41	1409.11	-90.94	-33.21861	8.19389	-3.49052	-0.867044	-1222.68	0.033962	0.451124
153.00	2355.11	1409.57	-90.94	-30.86139	8.70763	-3.44515	-0.870344	-1197.56	0.033940	0.450964
154.00	2350.71	1410.00	-90.94	-28.44861	9.23789	-3.39652	-0.873744	-1172.04	0.033914	0.450804
155.00	2346.21	1410.39	-90.94	-25.98461	9.78489	-3.34415	-0.877244	-1146.20	0.033884	0.450644
156.00	2341.61	1410.75	-90.94	-23.47331	10.34889	-3.28747	-0.880844	-1120.04	0.033850	0.450484
157.00	2336.91	1411.07	-90.94	-20.91131	10.93039	-3.22615	-0.884544	-1093.56	0.033812	0.450324
158.00	2332.11	1411.35	-90.94	-18.29461	11.53089	-3.16052	-0.888344	-1066.76	0.033770	0.450164
159.00	2327.21	1411.59	-90.94	-15.62861	12.15089	-3.09015	-0.892244	-1039.64	0.033724	0.450004
160.00	2322.21	1411.79	-90.94	-12.91861	12.79089	-3.01552	-0.896244	-1012.20	0.033674	0.449844
161.00	2317.11	1411.95	-90.94	-10.16861	13.45189	-2.93715	-0.900344	-984.44	0.033620	0.449684
162.00	2311.91	1412.07	-90.94	-7.38461	14.13489	-2.85452	-0.904544	-956.36	0.033562	0.449524
163.00	2306.61	1412.15	-90.94	-4.58461	14.83989	-2.76715	-0.908844	-927.88	0.033500	0.449364
164.00	2301.21	1412.19	-90.94	-1.77461	15.56689	-2.67452	-0.913244	-899.00	0.033434	0.449204
165.00	2295.71	1412.19	-90.94	1.13461	16.31689	-2.57515	-0.917744	-869.72	0.033364	0.449044
166.00	2290.11	1412.15	-90.94	4.07461	17.09089	-2.46952	-0.922344	-840.04	0.033290	0.448884
167.00	2284.41	1412.07	-90.94	7.04461	17.88989	-2.35715	-0.927044	-810.00	0.033212	0.448724
168.00	2278.61	1411.95	-90.94	10.04861	18.71489	-2.23852	-0.931844	-779.64	0.033130	0.448564
169.00	2272.71	1411.79	-90.94	13.07861	19.56689	-2.11315	-0.936744	-748.96	0.033044	0.448404
170.00	2266.71	1411.59	-90.94	16.13461	20.44689	-1.98052	-0.941744	-717.96	0.032954	0.448244
171.00	2260.61	1411.35	-90.94	19.21861	21.35689	-1.83215	-0.946844	-686.64	0.032860	0.448084
172.00	2254.41	1411.07	-90.94	22.32861	22.29689	-1.67752	-0.952044	-655.00	0.032762	0.447924
173.00	2248.11	1410.75	-90.94	25.47461	23.26689	-1.50615	-0.957344	-623.12	0.032660	0.447764
174.00	2241.71	1410.39	-90.94	28.65461	24.26689	-1.32852	-0.962744	-590.96	0.032554	0.447604
175.00	2235.21	1410.00	-90.94	31.87861	25.29689	-1.14015	-0.968244	-558.48	0.032444	0.447444
176.00	2228.61	1409.57	-90.94	35.14461	26.35689	-0.94052	-0.973844	-525.68	0.032330	0.447284
177.00	2221.91	1409.11	-90.94	38.45861	27.44689	-0.72915	-0.979544	-492.56	0.032212	0.447124
178.00	2215.11	1408.61	-90.94	41.81461	28.56689	-0.50552	-0.985344	-459.12	0.032090	0.446964
179.00	2208.21	1408.07	-90.94	45.21861	29.71689	-0.27015	-0.991244	-425.36	0.031962	0.446804
180.00	2201.21	1407.49	-90.94	48.66861	30.89689	-0.02052	-0.997244	-391.20	0.031830	0.446644
181.00	2194.11	1406.87	-90.94	52.16861	32.10689	0.24415	-1.003344	-356.72	0.031694	0.446484
182.00	2186.91	1406.21	-90.94	55.72461	33.34689	0.51115	-1.009544	-321.96	0.031554	0.446324
183.00	2179.61	1405.51	-90.94	59.31461	34.61689	0.77252	-1.015844	-286.96	0.031410	0.446164
184.00	2172.21	1404.77	-90.94	62.93861	35.91689	1.01715	-1.022244	-251.68	0.031262	0.446004
185.00	2164.71	1403.99	-90.94	66.59861	37.24689	1.24852	-1.028744	-216.00	0.031110	0.445844
186.00	2157.11	1403.17	-90.94	70.29861	38.60689	1.46915	-1.035344	-180.00	0.030954	0.445684
187.00	2149.41	1402.31	-90.94	74.03861	40.00689	1.67852	-1.042044	-143.68	0.030794	0.445524
188.00	2141.61	1401.41	-90.94	77.81861	41.44689	1.87615	-1.048844	-107.04	0.030630	0.445364
189.00	2133.71	1400.47	-90.94	81.63861	42.92689	2.06215	-1.055744	-70.16	0.030462	0.445204
190.00	2125.71	1399.49	-90.94	85.46861	44.44689	2.23615	-1.062744	-32.80	0.030290	0.445044
191.00	2117.61	1398.47	-90.94	89.33861	46.00689	2.39852	-1.069844	4.04	0.030114	0.444884
192.00	2109.41	1397.41	-90.94	93.24861	47.60689	2.54915	-1.077044	40.36	0.029934	0.444724
193.00	2101.11	1396.21	-90.94	97.19861	49.24689	2.68815	-1.084344	76.80	0.029750	0.444564
194.00	2092.71	1394.99	-90.94	101.28861	50.92689	2.81552	-1.091744	113.36	0.029562	0.444404

Table B.1 (continued)

DISTANCES INCHES	TEMPERATURE DEGS FARN	TEMPERATURE DEGS CENT	TEMP DIPP DEGS FARN	MASS FLOW LB/HIN*IN	COND HEAT BTU/HIN*IN	ARGON FLO LB/HIN*IN	VOL. RGR R/HIN IN	TOTAL PER WATT/INCH	THER COND R/HIN*IN	SPEC HEAT BTU/LB*IN
157.00	247.26	119.59	-8.28	-6.17383	5.83718	-0.68206	-0.031802	-17.20	0.062780	0.197954
158.00	248.98	118.99	-7.80	-5.74803	4.78801	-0.60856	-0.029589	-27.51	0.063056	0.197615
159.00	251.18	118.66	-7.40	-5.39070	3.78070	-0.71192	-0.027693	-35.83	0.063302	0.197380
160.00	223.78	106.55	-7.08	-5.09750	3.28895	-0.58881	-0.026152	-82.22	0.063531	0.197129
161.00	216.71	102.61	-6.81	-4.85089	2.71897	-0.52801	-0.024858	-84.76	0.063748	0.196918
162.00	209.90	98.83	-6.51	-4.63987	2.32959	-0.51086	-0.023739	-89.58	0.063981	0.196723
163.00	203.32	95.18	-6.34	-4.45373	2.05838	-0.49526	-0.022759	-50.82	0.064190	0.196545
164.00	196.93	91.63	-6.21	-4.28583	1.88778	-0.48163	-0.021872	-50.62	0.064394	0.196380
165.00	190.72	88.18	-6.05	-4.12987	1.80118	-0.46892	-0.021086	-49.18	0.064584	0.196217
166.00	184.67	84.82	-5.89	-3.97965	1.78255	-0.45661	-0.020255	-46.65	0.064780	0.196063
167.00	178.78	81.55	-5.73	-3.83260	1.81784	-0.44426	-0.019481	-83.24	0.064965	0.195918
168.00	173.06	78.36	-5.57	-3.68555	1.89202	-0.43157	-0.018708	-39.12	0.065188	0.195722
169.00	167.49	75.27	-5.39	-3.53667	1.99361	-0.41830	-0.017929	-29.51	0.065488	0.195471
170.00	162.10	72.38	-5.21	-3.38492	2.11065	-0.40432	-0.017137	-38.88	0.065737	0.195206
171.00	156.88	69.38	-5.02	-3.22992	2.23263	-0.38955	-0.016330	-28.38	0.065965	0.194906
172.00	151.86	66.59	-4.82	-3.07183	2.35827	-0.37400	-0.015511	-19.26	0.066179	0.194585
173.00	147.08	63.91	-4.61	-2.91128	2.48526	-0.35773	-0.014681	-9.64	0.066385	0.194267
174.00	142.82	61.35	-4.40	-2.74926	2.61074	-0.34084	-0.013887	-5.88	0.066577	0.193953
175.00	138.03	58.90	-4.17	-2.58703	2.60087	-0.32350	-0.013018	-1.77	0.066762	0.193640
176.00	133.86	56.59	-3.98	-2.42604	2.63112	-0.30589	-0.012189	1.27	0.066930	0.193322
177.00	129.59	54.40	-3.72	-2.26714	2.62818	-0.28721	-0.011382	3.61	0.067094	0.192999
178.00	126.20	52.33	-3.49	-2.11111	2.59000	-0.27170	-0.010598	5.20	0.067255	0.192686
179.00	122.71	50.39	-3.27	-1.96682	2.51582	-0.25159	-0.009888	6.02	0.067402	0.192384
180.00	119.44	48.58	-3.06	-1.82636	2.40617	-0.23113	-0.009137	6.08	0.067549	0.192090
181.00	116.38	46.88	-2.86	-1.69537	2.26288	-0.22153	-0.008378	5.80	0.067682	0.191811
182.00	113.52	45.29	-2.67	-1.57875	2.08908	-0.20702	-0.007688	4.08	0.067802	0.191540
183.00	110.85	43.81	-2.50	-1.46557	1.88910	-0.19376	-0.007112	2.08	0.067920	0.191275
184.00	108.35	42.42	-2.35	-1.36868	1.66875	-0.18142	-0.006621	-0.37	0.068032	0.191011
185.00	106.01	41.12	-2.21	-1.28488	1.43503	-0.17161	-0.006198	-3.16	0.068141	0.190752
186.00	103.78	39.89	-2.10	-1.21322	1.19828	-0.16284	-0.006049	-6.12	0.068286	0.190504
187.00	101.69	38.72	-2.01	-1.15856	0.96206	-0.15571	-0.005783	-9.04	0.068454	0.190269
188.00	99.69	37.60	-1.98	-1.10776	0.78335	-0.15010	-0.005506	-11.69	0.068602	0.189998
189.00	97.75	36.53	-1.88	-1.07153	0.55237	-0.14583	-0.005322	-13.78	0.068757	0.189740
190.00	95.87	35.48	-1.84	-1.04801	0.40266	-0.14270	-0.005182	-15.01	0.068911	0.189488
191.00	94.03	34.46	-1.81	-1.02269	0.28772	-0.13945	-0.005073	-15.03	0.069058	0.189255
192.00	92.22	33.46	-1.79	-1.00440	0.28772	-0.13639	-0.004979	-13.46	0.069196	0.189029
193.00	90.43	32.46	-1.76	-0.98525	0.35617	-0.13352	-0.004880	-9.86	0.069316	0.188794
194.00	88.68	31.49	-1.72	-0.96055	0.53321	-0.13088	-0.004755	-3.78	0.069427	0.188561
195.00	86.95	30.53	-1.66	-0.92882	0.83889	-0.12908	-0.0046310	5.29	0.069528	0.188300
196.00	85.29	29.61	-1.58	-0.89172	1.29898	-0.12214	-0.0043310	17.90	0.069608	0.188000
197.00	83.71	28.73	-1.44	-0.79399	1.92391	-0.11166	-0.003921	38.43	0.069687	0.187622
198.00	82.27	27.93	-1.28	-0.68333	2.78979	-0.09481	-0.003374	56.12	0.069780	0.187247
199.00	81.03	27.24	-0.97	-0.53036	3.79776	-0.07503	-0.002618	83.08	0.069892	0.186792
200.00	80.06	26.70	-0.59	-0.32438	5.09803	-0.04598	-0.001601	266.80	0.069987	0.186498
201.00	79.47	26.37	-2.47	-1.38688	16.71521	-0.19163	-0.006682			

Table B.2
 NEAL PROD RATE FOR POT-4 LOADED CONFIGURATION USING PSV ACTIVE CORE ELEMENTS FAR FROM UNIRADIATED H-451 GRAPHITE
 REQUIRED TOTAL MINIMUM POWER INPUT RATE = 74,34572 KILOWATTS
 REQUIRED TOTAL MINIMUM COOLING RATE = 48,35233 KILOWATTS

DISTANCE INCHES	TEMPERATURE DEGS F	TEMP DIFF DEGS F	MASS FLOW GPM	COND HEAT BTU/H	ARGON FLO GPM	VOL GPM	HGR BTU/H	TOTAL HGR WATT/H	TEMP CORP B/MIN	SPEC NEAL BTU/H
-34.00	77.00	5.41	2.95689	1.42259	0.41920	0.018590	17.88	0.047908	0.047908	0.145228
-33.00	82.41	5.94	3.07523	1.72061	0.43018	0.015207	91.87	0.067784	0.067784	0.149176
-32.00	87.95	5.70	3.07523	1.81801	0.44116	0.015207	94.01	0.067784	0.067784	0.149176
-31.00	93.55	5.84	3.13566	1.91475	0.45214	0.015207	100.28	0.067784	0.067784	0.151201
-30.00	99.51	6.02	3.27796	2.01080	0.46312	0.017310	104.70	0.067232	0.067232	0.153274
-29.00	105.51	6.20	3.42026	2.10611	0.47410	0.018590	109.28	0.067049	0.067049	0.155390
-28.00	111.73	6.39	3.56256	2.20066	0.48508	0.018590	114.90	0.066663	0.066663	0.157522
-27.00	118.12	6.58	3.70486	2.29440	0.49606	0.020769	123.94	0.066459	0.066459	0.160016
-26.00	124.70	6.78	3.84716	2.38729	0.50704	0.022938	129.76	0.066247	0.066247	0.162521
-25.00	131.48	6.99	3.98946	2.47927	0.51802	0.025107	134.61	0.066034	0.066034	0.165026
-24.00	138.27	7.21	4.13176	2.57032	0.52900	0.027276	140.21	0.065820	0.065820	0.167531
-23.00	145.05	7.44	4.27406	2.66036	0.54000	0.029445	146.00	0.065606	0.065606	0.170036
-22.00	151.84	7.68	4.41636	2.74937	0.55100	0.031614	151.98	0.065392	0.065392	0.172541
-21.00	158.62	7.92	4.55866	2.83727	0.56200	0.033783	158.17	0.065178	0.065178	0.175046
-20.00	165.41	8.18	4.70096	2.92402	0.57300	0.035952	164.57	0.064964	0.064964	0.177551
-19.00	172.20	8.44	4.84326	3.00958	0.58400	0.038121	171.19	0.064750	0.064750	0.180056
-18.00	178.99	8.71	4.98556	3.09382	0.59500	0.040290	178.03	0.064536	0.064536	0.182561
-17.00	185.78	8.99	5.12786	3.17676	0.60600	0.042459	185.10	0.064322	0.064322	0.185066
-16.00	192.57	9.28	5.27016	3.25831	0.61700	0.044628	192.40	0.064108	0.064108	0.187571
-15.00	199.36	9.58	5.41246	3.33880	0.62800	0.046797	199.95	0.063894	0.063894	0.190076
-14.00	206.15	9.88	5.55476	3.41837	0.63900	0.048966	207.74	0.063680	0.063680	0.192581
-13.00	212.94	10.20	5.69706	3.49692	0.65000	0.051135	215.81	0.063466	0.063466	0.195086
-12.00	219.73	10.52	5.83936	3.57447	0.66100	0.053304	224.00	0.063252	0.063252	0.197591
-11.00	226.52	10.85	5.98166	3.65102	0.67200	0.055473	232.32	0.063038	0.063038	0.200096
-10.00	233.31	11.19	6.12396	3.72657	0.68300	0.057642	240.79	0.062824	0.062824	0.202601
-9.00	240.10	11.54	6.26626	3.80112	0.69400	0.059811	249.43	0.062610	0.062610	0.205106
-8.00	246.89	11.90	6.40856	3.87467	0.70500	0.061980	258.18	0.062396	0.062396	0.207611
-7.00	253.68	12.26	6.55086	3.94722	0.71600	0.064149	267.03	0.062182	0.062182	0.210116
-6.00	260.47	12.64	6.69316	4.01877	0.72700	0.066318	275.98	0.061968	0.061968	0.212621
-5.00	267.26	13.02	6.83546	4.08932	0.73800	0.068487	285.03	0.061754	0.061754	0.215126
-4.00	274.05	13.42	6.97776	4.15887	0.74900	0.070656	294.18	0.061540	0.061540	0.217631
-3.00	280.84	13.82	7.12006	4.22742	0.76000	0.072825	303.43	0.061326	0.061326	0.220136
-2.00	287.63	14.23	7.26236	4.29497	0.77100	0.074994	312.78	0.061112	0.061112	0.222641
-1.00	294.42	14.65	7.40466	4.36152	0.78200	0.077163	322.23	0.060898	0.060898	0.225146
0.00	301.21	15.07	7.54696	4.42707	0.79300	0.079332	331.78	0.060684	0.060684	0.227651
1.00	308.00	15.51	7.68926	4.49162	0.80400	0.081501	341.43	0.060470	0.060470	0.230156
2.00	314.79	15.95	7.83156	4.55517	0.81500	0.083670	351.18	0.060256	0.060256	0.232661
3.00	321.58	16.40	7.97386	4.61772	0.82600	0.085839	361.03	0.060042	0.060042	0.235166
4.00	328.37	16.87	8.11616	4.67927	0.83700	0.087998	370.98	0.059828	0.059828	0.237671
5.00	335.16	17.34	8.25846	4.73982	0.84800	0.090167	381.03	0.059614	0.059614	0.240176
6.00	341.95	17.81	8.40076	4.79937	0.85900	0.092336	391.18	0.059400	0.059400	0.242681
7.00	348.74	18.30	8.54306	4.85792	0.87000	0.094505	401.43	0.059186	0.059186	0.245186
8.00	355.53	18.80	8.68536	4.91547	0.88100	0.096674	411.78	0.058972	0.058972	0.247691
9.00	362.32	19.30	8.82766	4.97202	0.89200	0.098843	422.23	0.058758	0.058758	0.250196
10.00	369.11	19.82	8.96996	5.02757	0.90300	0.101012	432.78	0.058544	0.058544	0.252701
11.00	375.90	20.34	9.11226	5.08212	0.91400	0.103181	443.43	0.058330	0.058330	0.255206
12.00	382.69	20.87	9.25456	5.13567	0.92500	0.105350	454.18	0.058116	0.058116	0.257711

Table B.2 (continued)

DISTANCES INCHES *****	TEMPERATURE DEGS FARN *****	TEMPERATURE DEGS CENT *****	TEMP DIFF DEGS FARN *****	MASS FLOW LB/HRS*IN *****	COND HEAT BTU/HRS*IN *****	ARGON FLO SC/HRS*IN *****	VOL FLOW SC/HRS*IN *****	TOTAL PWR WATT/INCH *****	THER COND B/HRS*IN*DEG *****	SPEC HEAT BTU/LB*DEG *****
13.00	624.88	329.10	21.41	23.15985	4.74080	1.66021	0.123609	519.68	0.050182	0.287206
14.00	645.79	340.99	21.96	24.06377	4.75411	1.70270	0.128461	536.46	0.044506	0.290968
15.00	667.74	353.19	22.51	24.99221	4.76702	1.74586	0.133651	553.45	0.040864	0.294728
16.00	690.26	365.70	23.08	25.94521	4.77662	1.78939	0.138878	571.55	0.048221	0.298469
17.00	713.34	378.52	23.65	26.92284	4.78399	1.83420	0.144243	589.65	0.047573	0.302201
18.00	736.49	391.66	24.23	27.92509	4.78924	1.87937	0.149746	608.15	0.046924	0.305917
19.00	761.22	405.12	24.83	28.95199	4.79250	1.92521	0.155386	627.07	0.046274	0.309615
20.00	786.05	418.91	25.43	30.00350	4.79389	1.97172	0.161164	646.40	0.045625	0.313241
21.00	811.47	433.04	26.03	31.07959	4.79355	2.01890	0.167080	666.14	0.044979	0.316943
22.00	837.51	447.50	26.65	32.18022	4.79164	2.06675	0.173133	686.29	0.044335	0.320564
23.00	864.16	462.31	27.28	33.30530	4.78833	2.11524	0.179322	706.87	0.043697	0.324166
24.00	891.43	477.46	27.91	34.45477	4.78380	2.16447	0.185688	727.86	0.043065	0.327742
25.00	919.34	492.97	28.55	35.62851	4.77824	2.21433	0.192110	749.27	0.042440	0.331284
26.00	947.90	508.83	29.21	36.82644	4.77184	2.26487	0.198706	771.11	0.041825	0.334761
27.00	977.10	525.06	29.87	38.04863	4.76481	2.31607	0.205438	793.37	0.041221	0.338225
28.00	1006.97	541.65	30.53	39.29437	4.75738	2.36794	0.212303	816.05	0.040628	0.341684
29.00	1037.50	558.61	31.21	40.56413	4.74975	2.42049	0.219301	839.16	0.040044	0.345135
30.00	1068.71	575.95	31.90	41.85757	4.74216	2.47370	0.226431	862.70	0.039468	0.348574
31.00	1100.61	593.67	32.59	43.17457	4.73484	2.52759	0.233693	886.67	0.038906	0.351976
32.00	1133.21	611.78	33.30	44.51500	4.72800	2.58214	0.241086	911.08	0.038345	0.355341
33.00	1166.40	630.28	34.01	45.87871	4.72188	2.63736	0.248609	935.91	0.037789	0.358687
34.00	1200.51	649.17	34.73	47.26558	4.71670	2.69326	0.256261	961.19	0.037240	0.361916
35.00	1235.24	668.47	35.46	48.67548	4.71267	2.74983	0.264042	986.90	0.036698	0.365140
36.00	1270.70	688.17	36.20	50.10827	4.71000	2.80706	0.271951	1013.04	0.036177	0.368351
37.00	1306.89	708.27	36.94	51.56385	4.70884	2.86497	0.279987	1039.63	0.035664	0.371550
38.00	1343.84	728.80	37.70	53.04208	4.70948	2.92344	0.288149	1066.66	0.035161	0.374735
39.00	1381.54	749.74	38.46	54.54284	4.71197	2.98279	0.296436	1094.13	0.034661	0.377905
40.00	1420.00	771.11	39.24	56.06602	4.71648	3.04271	0.304849	1122.04	0.034172	0.381061
41.00	1459.24	792.91	40.02	57.61150	4.72313	3.10329	0.313386	1150.39	0.033697	0.384205
42.00	1499.25	815.14	40.81	59.17915	4.73199	3.16455	0.322047	1179.18	0.033235	0.387335
43.00	1540.06	837.81	41.61	60.76885	4.74312	3.22648	0.330831	1208.41	0.032784	0.390451
44.00	1581.66	860.92	42.41	62.38047	4.75654	3.28907	0.339737	1238.08	0.032344	0.393554
45.00	1624.08	884.49	43.23	64.01387	4.77222	3.35234	0.348764	1268.14	0.031914	0.396644
46.00	1667.30	908.40	44.05	65.66888	4.79012	3.41628	0.357911	1298.72	0.031494	0.399721
47.00	1711.36	932.98	44.89	67.34532	4.81013	3.48089	0.367178	1329.68	0.031083	0.402786
48.00	1756.24	957.91	45.73	69.04301	4.83211	3.54617	0.376564	1361.05	0.030681	0.405839
49.00	1801.97	983.32	46.58	70.76171	4.85588	3.61212	0.386064	1392.85	0.030286	0.408881
50.00	1848.55	1009.19	47.44	72.50117	4.88121	3.67873	0.395684	1425.05	0.029905	0.411914
51.00	1895.98	1035.55	48.30	74.26108	4.90782	3.74602	0.405415	1457.63	0.029538	0.414938
52.00	1944.29	1062.38	49.18	76.04110	4.93540	3.81398	0.415258	1490.60	0.029182	0.417954
53.00	1993.47	1089.71	50.07	77.84086	4.96360	3.88261	0.425211	1523.94	0.028837	0.420961
54.00	2043.54	1117.52	50.96	79.65990	4.99201	3.95191	0.435271	1557.64	0.028503	0.423959
55.00	2094.50	1145.83	51.86	81.49773	5.02022	4.02184	0.445435	1591.68	0.028179	0.426949
56.00	2146.36	1174.64	52.77	83.35380	5.04776	4.09252	0.455700	1626.03	0.027865	0.429932
57.00	2199.13	1203.95	53.69	85.22747	5.07417	4.16383	0.466063	1660.69	0.027561	0.432907
58.00	2252.82	1233.79	54.62	87.11807	5.09896	4.23581	0.476516	1695.63	0.027267	0.435874
59.00	2307.44	1264.14	55.56	89.02484	5.12163	4.30847	0.487063	1730.82	0.026982	0.438832
60.00	2363.00	1295.00	56.50	90.94696	5.14172	4.38179	0.497693	1766.25	0.026707	0.441781
61.00	2419.50	1326.39	57.46	92.88357	5.15875	4.45578	0.508402	1801.90	0.026441	0.444721
62.00	2476.96	1358.31	58.42	94.83371	5.17232	4.53044	0.519184	1837.73	0.026183	0.447654
63.00	2535.38	1390.77	59.39	96.79642	5.18205	4.60577	0.530036	1873.73	0.025935	0.450581
64.00	2594.77	1423.76	60.37	98.77066	5.18766	4.68177	0.540949	1909.88	0.025696	0.453501
65.00	2655.14	1457.30	61.36	100.75539	5.18893	4.75845	0.551919	1946.14	0.025467	0.456415
66.00	2716.50	1491.39	62.36	102.74956	5.18577	4.83579	0.562940	1982.50	0.025246	0.459325
67.00	2778.86	1526.01	63.36	104.75213	5.17822	4.91380	0.574005	2019.94	0.025034	0.462230

Table B.2 (continued)

DISTANCES INCHES	TEMPERATURE DEGS FARN	TEMPERATURE DEGS CENT	TEMP DIFF DEGS FARN	MASS FLOW LB/HR*IN	COND HEAT BU/HR*IN	1.000 PLO BU/HR*IN	VOL MGR B/HR*CD IN	TOTAL PWR WATT/INCH	TEMP COMP B/HR*IN	SPEC HEAT BTU/LB*DF
68.00	2842.22	1561.23	64.38	106.76206	5.16688	4.99289	0.585108	2051.45	0.024152	0.480272
69.00	2906.60	1597.00	65.40	108.77882	5.15090	5.07188	0.596285	2092.02	0.028820	0.481568
70.00	2972.00	1633.33	61.46	102.50081	4.76684	4.76684	0.561908	1118.21	0.028888	0.482785
71.00	3033.46	1667.48	52.93	88.47331	40.43381	8.10898	0.485062	916.70	0.028186	0.483133
72.00	3086.40	1696.89	48.97	75.29372	37.32584	3.88725	0.412884	788.77	0.027924	0.483525
73.00	3131.36	1721.87	37.57	62.98952	34.32189	2.91326	0.345399	555.19	0.027715	0.483757
74.00	3168.93	1742.74	30.73	51.58181	31.40539	2.38295	0.282859	396.58	0.027581	0.483975
75.00	3199.66	1759.81	24.45	41.08487	28.56062	1.89639	0.225308	233.51	0.027403	0.484142
76.00	3224.31	1773.40	18.74	31.51150	25.77315	1.45359	0.172813	126.43	0.027286	0.484316
77.00	3242.85	1783.81	13.60	22.86998	23.03017	1.05882	0.125425	15.72	0.027218	0.484500
78.00	3256.45	1791.36	9.01	15.16657	20.32069	0.69903	0.083179	-78.32	0.027168	0.484658
79.00	3265.47	1796.37	4.99	8.40597	17.63534	0.38735	0.046102	-155.48	0.027111	0.484788
80.00	3270.86	1799.14	1.54	2.59138	14.96630	0.11980	0.018216	-215.45	0.027114	0.484816
81.00	3272.00	1800.00	-3.61	-6.08049	33.34992	-0.28018	-0.013388	-701.62	0.027124	0.484816
82.00	3268.39	1797.99	-10.39	-17.47888	30.37895	-0.80537	-0.095839	-855.82	0.027158	0.484727
83.00	3258.00	1792.22	-16.48	-27.71525	27.23080	-1.27781	-0.151998	-988.81	0.027218	0.484542
84.00	3241.52	1783.07	-21.89	-36.79788	24.09316	-1.69752	-0.201802	-1100.29	0.027311	0.484247
85.00	3219.68	1770.91	-26.62	-44.71900	20.95397	-2.06449	-0.245235	-1190.81	0.027430	0.483865
86.00	3193.01	1756.12	-30.67	-51.47862	17.80220	-2.37871	-0.312973	-1259.76	0.027780	0.483550
87.00	3162.34	1739.08	-34.04	-57.07884	14.52771	-2.68019	-0.337285	-1322.28	0.027928	0.483584
88.00	3128.30	1720.16	-36.78	-61.51394	11.82147	-2.88893	-0.366877	-1316.97	0.028324	0.483916
89.00	3091.56	1699.76	-38.75	-64.79381	8.17588	-3.00893	-0.355285	-1355.62	0.028722	0.483273
90.00	3052.81	1678.23	-40.08	-66.92012	4.88515	-3.10818	-0.345877	-1376.34	0.028582	0.482559
91.00	3012.73	1655.96	-42.73	-67.89821	1.54554	-3.15870	-0.372210	-1276.38	0.027957	0.481800
92.00	2972.00	1633.33	-41.20	-68.54326	-3.60679	-3.19892	-0.375802	-1325.74	0.026472	0.480942
93.00	2930.80	1610.45	-41.92	-69.62675	-3.58981	-3.25062	-0.381619	-1383.57	0.024945	0.479146
94.00	2888.89	1587.16	-42.61	-70.63557	-3.83595	-3.30818	-0.387311	-1360.25	0.029185	0.478110
95.00	2846.28	1563.45	-43.27	-71.58517	-3.32025	-3.35960	-0.392275	-1375.82	0.029399	0.479211
96.00	2801.01	1539.45	-43.91	-72.47501	-3.20218	-3.40889	-0.397108	-1390.54	0.029610	0.478238
97.00	2759.10	1515.06	-44.51	-73.30555	-3.08167	-3.45208	-0.401606	-1403.54	0.030014	0.476948
98.00	2714.59	1490.31	-45.05	-74.07330	-2.95865	-3.49705	-0.405787	-1415.69	0.030375	0.475950
99.00	2669.49	1465.27	-45.65	-74.78078	-2.83310	-3.53993	-0.409588	-1426.67	0.030745	0.474924
100.00	2623.85	1439.92	-46.17	-75.42648	-2.70504	-3.58068	-0.413066	-1436.44	0.031080	0.473690
101.00	2577.67	1414.26	-46.67	-76.01016	-2.57852	-3.61929	-0.416200	-1445.13	0.031375	0.472381
102.00	2531.00	1388.34	-47.14	-76.53328	-2.45162	-3.65577	-0.419286	-1452.60	0.031680	0.471008
103.00	2483.86	1362.15	-47.55	-76.98598	-2.32688	-3.69011	-0.422123	-1458.88	0.031980	0.469579
104.00	2436.29	1335.71	-48.00	-77.38663	-2.19912	-3.72231	-0.425310	-1463.98	0.032275	0.468019
105.00	2384.28	1309.05	-48.39	-77.71625	-2.02980	-3.75238	-0.428524	-1467.89	0.032525	0.466404
106.00	2339.89	1282.16	-48.75	-77.98327	-1.88868	-3.78032	-0.431783	-1470.61	0.032775	0.464711
107.00	2291.15	1255.08	-49.08	-78.18937	-1.74582	-3.80612	-0.434989	-1472.18	0.033007	0.462942
108.00	2242.07	1227.82	-49.38	-78.32811	-1.60148	-3.82978	-0.438118	-1472.88	0.033259	0.462108
109.00	2192.67	1200.88	-49.66	-78.40326	-1.45579	-3.85131	-0.441260	-1473.63	0.033511	0.461194
110.00	2143.02	1172.79	-50.11	-78.41577	-1.30887	-3.87070	-0.444385	-1474.59	0.033764	0.460283
111.00	2093.11	1145.06	-50.47	-78.35284	-1.16083	-3.88796	-0.447482	-1475.76	0.034019	0.459343
112.00	2042.97	1117.21	-50.73	-78.24527	-1.01173	-3.90309	-0.450549	-1477.14	0.034275	0.458375
113.00	1992.64	1089.25	-50.94	-78.06329	-0.86161	-3.91608	-0.453588	-1478.63	0.034532	0.457384
114.00	1942.15	1061.19	-50.98	-77.81681	-0.71088	-3.92693	-0.456581	-1479.53	0.034789	0.456340
115.00	1891.51	1033.06	-50.75	-77.50181	-0.55812	-3.93565	-0.459535	-1481.52	0.035045	0.455255
116.00	1840.76	1004.81	-50.81	-77.12824	-0.40852	-3.94223	-0.462471	-1482.32	0.035298	0.454183
117.00	1789.32	976.62	-50.99	-76.68662	-0.24981	-3.94899	-0.465380	-1482.91	0.035548	0.453118
118.00	1739.03	948.35	-50.92	-76.17981	-0.09250	-3.95589	-0.468269	-1483.41	0.035794	0.452064
119.00	1688.11	920.06	-50.91	-75.61763	0.06657	-3.96177	-0.471138	-1483.84	0.036034	0.451016
120.00	1637.19	891.77	-50.90	-74.99472	0.22824	-3.96721	-0.474000	-1484.00	0.036275	0.450000
121.00	1586.24	863.49	-50.85	-74.44447	0.39308	-3.97232	-0.476833	-1484.51	0.036511	0.449000
122.00	1535.44	835.25	-50.77	-73.89705	0.56163	-3.97689	-0.479625	-1485.00	0.036744	0.448000

Table B.2 (continued)

DISTANCES INCHES	TEMPERATURE DEGS FARM	TEMPERATURE DEGS CENT	TEMP DIFF DEGS FARM	MASS FLOW BO/MIN-IN	COND HEAT BO/MIN-IN	ARGON FLO BO/MIN-IN	VOL. MGR B/MCO IN	TOTAL PWR WATT/INCH	TMPR COND B/M-INCH	SPRC REA- STN/LIN-IN
123.00	1488.68	807.04	-50.66	-72.66143	0.73858	-3.92853	-0.395149	-1333.53	0.038731	0.340744
124.00	1478.02	778.90	-50.52	-70.75938	0.91266	-3.91803	-0.390083	-1318.35	0.035188	0.337018
125.00	1383.49	750.81	-50.36	-71.79066	1.09666	-3.90540	-0.388586	-1293.79	0.035689	0.333191
126.00	1333.14	722.85	-50.17	-69.74507	1.28780	-3.89063	-0.378677	-1272.05	0.036244	0.329124
127.00	1282.97	694.98	-49.95	-67.65283	1.48575	-3.87173	-0.372434	-1248.18	0.036863	0.324818
128.00	1233.01	667.23	-49.71	-65.48262	1.69266	-3.84649	-0.365819	-1224.36	0.037536	0.320532
129.00	1183.31	639.62	-49.43	-63.24560	1.90898	-3.81352	-0.358828	-1198.82	0.038269	0.315714
130.00	1133.88	612.15	-49.13	-60.96144	2.13563	-3.81021	-0.351864	-1171.10	0.039062	0.310904
131.00	1084.74	584.86	-48.80	-63.57033	2.37349	-3.78476	-0.343728	-1142.37	0.039917	0.305409
132.00	1035.94	557.74	-48.45	-62.33263	2.62341	-3.74719	-0.335620	-1112.21	0.040841	0.300464
133.00	987.49	530.83	-48.07	-60.62890	2.88617	-3.72747	-0.327186	-1080.68	0.041805	0.294818
134.00	939.83	504.11	-47.65	-59.05991	3.16251	-3.69462	-0.318108	-1047.68	0.042816	0.289073
135.00	891.77	477.65	-47.22	-57.42673	3.45308	-3.66168	-0.309114	-1013.22	0.043823	0.282444
136.00	844.55	451.42	-46.75	-55.73069	3.75830	-3.62552	-0.299570	-977.80	0.044861	0.275814
137.00	797.80	425.85	-46.26	-53.97389	4.07871	-3.58726	-0.289888	-940.21	0.045927	0.269174
138.00	751.55	399.75	-45.74	-52.15720	4.41852	-3.54835	-0.280954	-901.81	0.047025	0.262524
139.00	705.81	374.34	-45.19	-50.28429	4.76589	-3.50739	-0.272477	-861.81	0.048145	0.255871
140.00	660.62	349.23	-44.61	-48.35777	5.13277	-3.46469	-0.264331	-820.71	0.049284	0.249174
141.00	616.01	324.45	-44.01	-46.38082	5.51848	-3.42144	-0.256797	-778.81	0.050437	0.242414
142.00	572.00	300.00	-43.39	-44.33777	5.92259	-3.37957	-0.249391	-736.50	0.051601	0.235671
143.00	528.09	278.94	-42.88	-42.28597	6.35467	-3.33849	-0.242379	-694.68	0.052783	0.228931
144.00	507.22	264.01	-42.62	-41.23337	6.80667	-3.29816	-0.235705	-652.31	0.053981	0.222174
145.00	485.59	252.00	-42.43	-40.18383	7.27880	-3.25849	-0.229315	-610.48	0.055193	0.215418
146.00	468.16	242.31	-42.14	-39.13714	7.77400	-3.21944	-0.223173	-568.65	0.056422	0.208674
147.00	448.03	234.46	-41.60	-38.09006	8.29159	-3.18112	-0.217245	-526.82	0.057673	0.201914
148.00	428.43	228.02	-41.27	-37.04006	8.83166	-3.14358	-0.211631	-485.00	0.058943	0.195174
149.00	408.74	222.64	-40.82	-35.98191	9.39416	-3.10684	-0.206305	-443.17	0.060231	0.188432
150.00	388.47	218.04	-40.35	-34.91893	9.97816	-3.07084	-0.201245	-401.34	0.061537	0.181694
151.00	367.22	214.01	-40.01	-33.85084	10.58366	-3.03544	-0.196349	-359.51	0.062853	0.174954
152.00	345.69	210.38	-39.60	-32.77814	11.21080	-3.00064	-0.191679	-317.68	0.064179	0.168214
153.00	323.95	207.04	-39.25	-31.70113	11.85960	-2.96644	-0.187245	-275.85	0.065515	0.161474
154.00	301.65	203.92	-38.93	-30.61975	12.53080	-2.93274	-0.183031	-234.02	0.066861	0.154734
155.00	278.72	200.90	-38.65	-29.53414	13.22440	-2.90044	-0.179045	-192.19	0.068217	0.147994
156.00	255.67	198.15	-38.46	-28.44458	13.94040	-2.86944	-0.175245	-150.36	0.069583	0.141254
157.00	232.91	195.51	-38.34	-27.35113	14.67880	-2.83944	-0.171679	-108.53	0.070959	0.134514
158.00	209.47	193.04	-38.27	-26.25406	15.43960	-2.81044	-0.168341	-66.70	0.072345	0.127774
159.00	185.80	190.78	-38.25	-25.15214	16.22280	-2.78244	-0.165245	-24.87	0.073741	0.121034
160.00	161.74	188.75	-38.22	-24.04614	17.02840	-2.75544	-0.162345	17.04	0.075147	0.114294
161.00	137.47	186.98	-38.20	-22.93614	17.85560	-2.72944	-0.159545	59.21	0.076553	0.107554
162.00	113.20	185.47	-38.19	-21.82014	18.70440	-2.70444	-0.156845	117.38	0.077959	0.100814
163.00	88.93	184.21	-38.18	-20.70014	19.57480	-2.68044	-0.154245	175.55	0.079365	0.094074
164.00	64.66	183.16	-38.17	-19.57614	20.46680	-2.65644	-0.151745	233.72	0.080771	0.087334
165.00	40.39	182.25	-38.16	-18.45014	21.38040	-2.63344	-0.149345	291.89	0.082177	0.080594
166.00	16.12	181.37	-38.15	-17.32214	22.31560	-2.61144	-0.147045	350.06	0.083583	0.073854
167.00	318.64	180.36	-38.14	-16.19414	23.27280	-2.59044	-0.144845	408.23	0.084989	0.067114

Appendix C

THERMAL CONDUCTIVITY DATA AS A FUNCTION OF TEMPERATURE
FOR FUEL ELEMENTS FABRICATED FROM TYPE H-327 AND TYPE H-451 GRAPHITE

Table C.1. Thermal Conductivity and Specific Heat of Composite
Fuel Elements Made With Unirradiated H-327 Graphite as a Function of
Temperature

TEMPERATURE DEGREES F	AXIAL CONDUCTIVITY BTU / HOUR FT DEG F	AXIAL CONDUCTIVITY BTU / HOUR FT DEG F	SPECIFIC HEAT BTU/LB. DEG F
0.0	77.5424	31.8901	0.1152
100.0	71.4825	29.7077	0.1524
200.0	66.0908	27.7694	0.1851
300.0	61.0496	26.0821	0.2138
400.0	56.5842	24.6251	0.2391
500.0	52.5427	23.3855	0.2613
600.0	48.9460	22.3494	0.2808
700.0	45.6977	21.5022	0.2981
800.0	42.7838	20.8276	0.3133
900.0	40.1729	20.3073	0.3269
1000.0	37.8359	19.9213	0.3389
1100.0	35.7462	19.6474	0.3497
1200.0	33.8790	19.4646	0.3594
1300.0	32.2119	19.3499	0.3681
1400.0	30.7243	19.2831	0.3760
1500.0	29.3976	19.2462	0.3832
1600.0	28.2149	19.2244	0.3898
1700.0	27.1612	19.2059	0.3958
1800.0	26.2228	19.1824	0.4013
1900.0	25.3877	19.1485	0.4064
2000.0	24.6454	19.1011	0.4111
2100.0	23.9864	19.0390	0.4154
2200.0	23.4027	18.9621	0.4194
2300.0	22.8873	18.8713	0.4231
2400.0	22.4342	18.7680	0.4265
2500.0	22.0385	18.6534	0.4295
2600.0	21.6959	18.5270	0.4323
2700.0	21.4129	18.3860	0.4348
2800.0	21.1568	18.2353	0.4371
2900.0	20.9553	18.1079	0.4391
3000.0	20.7965	17.9541	0.4409
3100.0	20.6790	17.7844	0.4424
3200.0	20.6015	17.6280	0.4438
3300.0	20.5630	17.4571	0.4450
3400.0	20.5624	17.2796	0.4460
3500.0	20.5987	17.0957	0.4469
3600.0	20.6708	16.9053	0.4476
3700.0	20.7772	16.7080	0.4483
3800.0	20.9162	16.5039	0.4489
3900.0	21.0857	16.2930	0.4495
4000.0	21.2830	16.0754	0.4500
4100.0	21.5048	15.8516	0.4505
4200.0	21.7471	15.6226	0.4510
4300.0	22.0052	15.3895	0.4515
4400.0	22.2734	15.1542	0.4521
4500.0	22.5449	14.9191	0.4527
4600.0	22.8121	14.6873	0.4533
4700.0	23.0658	14.4429	0.4538
4800.0	23.2959	14.2508	0.4543
4900.0	23.4907	14.0571	0.4547
5000.0	23.6170	13.8990	0.4549

Fig. C.1. Axial and Radial Thermal Conductivities of Composite Fuel Elements Made With Unirradiated H-327 Graphite as a Function of Temperature.

Table C.2. Thermal Conductivity and Specific Heat of Composite Fuel Elements Made With Unirradiated H-451 Graphite as a Function of Temperature

TEMPERATURE DEGREES F *****	AXIAL CONDUCTIVITY BTU / HOUR FT DEG F *****	RADIAL CONDUCTIVITY BTU / HOUR FT DEG F *****	SPECIFIC HEAT BTU / LB. DEG F *****
0.0	50.4639	29.7272	0.1152
100.0	48.4610	28.2322	0.1524
200.0	46.2197	26.9340	0.1851
300.0	43.8544	25.8185	0.2138
400.0	41.4586	24.8728	0.2391
500.0	39.1072	24.0854	0.2613
600.0	36.8584	23.4451	0.2808
700.0	34.7551	22.9404	0.2981
800.0	32.8275	22.5596	0.3133
900.0	31.0943	22.2896	0.3269
1000.0	29.5644	22.1166	0.3389
1100.0	28.2382	22.0256	0.3497
1200.0	27.1096	22.0012	0.3594
1300.0	26.1665	22.0274	0.3681
1400.0	25.3931	22.0886	0.3760
1500.0	24.7599	22.1786	0.3832
1600.0	24.2757	22.2603	0.3898
1700.0	23.8876	22.3470	0.3958
1800.0	23.5838	22.4224	0.4013
1900.0	23.3312	22.4887	0.4064
2000.0	23.1393	22.5484	0.4111
2100.0	22.9986	22.5933	0.4154
2200.0	22.9023	22.6291	0.4194
2300.0	22.8567	22.6605	0.4231
2400.0	22.8501	22.6836	0.4265
2500.0	22.8853	22.7098	0.4295
2600.0	21.8875	22.7366	0.4323
2700.0	21.5862	22.7775	0.4348
2800.0	21.2538	22.8258	0.4371
2900.0	20.8958	22.8822	0.4391
3000.0	20.5217	22.9445	0.4409
3100.0	20.1423	21.9981	0.4424
3200.0	19.7726	21.9362	0.4438
3300.0	19.4278	21.8785	0.4450
3400.0	19.1249	21.8250	0.4460
3500.0	18.8816	21.7746	0.4469
3600.0	18.7151	21.7264	0.4476
3700.0	18.6418	21.6786	0.4483
3800.0	18.6758	21.6299	0.4489
3900.0	18.8300	21.5797	0.4495
4000.0	19.1070	21.5251	0.4500
4100.0	19.5097	21.4678	0.4505
4200.0	20.0344	21.4069	0.4510
4300.0	20.6653	21.3437	0.4515
4400.0	21.3819	21.2800	0.4521
4500.0	22.1483	21.2201	0.4527
4600.0	22.9106	21.1687	0.4533
4700.0	23.6125	21.1342	0.4538
4800.0	24.1730	21.1249	0.4543
4900.0	24.4856	21.1547	0.4547
5000.0	24.4498	21.2363	0.4550

ORNL DWG 76-18183

Fig. C.2. Axial and Radial Thermal Conductivities of Composite Fuel Elements Made With Unirradiated H-451 Graphite as a Function of Temperature.

Internal Distribution

1. P. Angelini	27. B. Lieberman
2. R. J. Beaver	28-29. G. W. Llewellyn
3. M. Bender	30. A. L. Lotts
4. R. J. Braatz	31. J. E. Mack
5. R. A. Bradley	32. S. R. McNeany
6. A. J. Caputo	33. K. J. Notz
7. W. G. Cobb	34. A. R. Olsen
8. H. E. Cochran	35. T. W. Pickel
9. J. H. Coobs	36. A. S. Pruitt
10. B. F. Crump	37. D. P. Reid
11. F. C. Davis	38. J. E. Rushton
12. R. G. Donnelly	39. T. F. Scanlan
13. B. C. Duggins	40. M. Siman-Tov
14. W. P. Eatherly	41. D. P. Stinton
15. F. C. Fitzpatrick	42. R. R. Suchomel
16. W. R. Hamel	43. V. J. Tennery
17. F. E. Harrington	44. S. M. Tieg
18. L. C. Hensley	45. D. B. Trauger
19. R. M. Hill	46. J. E. Van Cleve
20. J. R. Horton	47. J. R. Weir
21. L. N. Howell	48. R. M. Young
22. D. R. Johnson	49-50. Central Research Library
23. P. R. Kasten	51. Document Reference Section
24. J. J. Kurtz	52-64. Laboratory Records Department
25. W. J. Lackey	65. Laboratory Records, ORNL R.C.
26. G. M. Lawson	66. ORNL Patent Office

External Distribution

- 67. J. G. Grundmann, Penn State University, Department of Mechanical Engineering, 208 Mechanical Engineering Building, University Park, Pennsylvania 16802.
- 68-69. Director, ERDA, Division of Nuclear Fuel Cycle and Production, Washington, D.C. 20545.
- 70-71. Director, ERDA, Division of Reactor Development and Demonstration, Washington, D.C. 20545.
- 72. Director, Reactor Division, ERDA, Oak Ridge Operations Office, Post Office Box E, Oak Ridge, Tennessee 37830.
- 73. Research and Technical Support Division, ERDA, Oak Ridge Operations Office, Post Office Box E, Oak Ridge, Tennessee 37830.
- 74-100. Technical Information Center, ERDA, Office of Information Services, Post Office Box 62, Oak Ridge, Tennessee 37830.