RECEIVED BY TIC MAR 28 1973

MASTER ✓

THERMAL TEST OF THE HEAT BLOCK-SHIELD FOR THE ISOTOPE KILOWATT PROGRAM

M. E. Lackey

1720

THIS DOCUMENT CONFIRMED AS
UNCLASSIFIED
DIVISION OF CLASSIFICATION
BY I. L. Cuccchiara / wer
DATE 4/10/73

OAK RIDGE NATIONAL LABORATORY

OPERATED BY UNION CARBIDE CORPORATION • FOR THE U.S. ATOMIC ENERGY COMMISSION

4 832 000

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

19 Aug
Specimen
ACRS Dist

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of 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. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy 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

REACTOR DIVISION

THERMAL TEST OF THE HEAT BLOCK-SHIELD FOR
THE ISOTOPE KILOWATT PROGRAM

M. E. Lackey

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy 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.

MARCH 1973

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

PC

page blank

CONTENTS

	<u>Page</u>
List of Figures	v
ABSTRACT	1
INTRODUCTION.	2
SYSTEM DESCRIPTION.	2
APPARATUS	6
Heat Block-shield	6
Electrical Heaters	7
Thermal Fuse/Insulation.	10
Electrical and Instrumentation System.	22
Cooling System	28
Cathetometer	28
TEST PROCEDURE	28
TEST DESCRIPTION AND RESULT	32
Shipping Accident Test	32
Thermoelectric Heat Pipe Insertion Test.	34
Fuel Element Loading Test.	38
Shipping and Storage Test.	38
Normal Operating Condition Test.	40
Loss-of-Coolant Accident Test.	43
Radial Expansion Test.	43
Heat Loss Test	48
GENERAL ANALYSIS AND CONCLUSIONS.	52
APPENDIX A	67
Heat Block-Shield Test Data	
APPENDIX B	77
Drawing List	
REFERENCES.	78
Distribution.	79

page blank

List of Figures

Figure

1. Heat block-shield test.
2. The full-scale heat block-shield unit being readied for test in its normal upright position.
3. Components used to simulate the isotope capsules for the full-scale heat block-shield test. The parts shown are the electric heater element (bottom), the shield plug (right middle), and the assembled heater (top).
4. Full-scale fusible insulation mandrel with half of bottom spacer removed to show the bottom cross support wires.
5. Full-scale fusible insulation mandrel with half of top spacer removed to show the top cross support wires.
6. The aluminum screen wire being wrapped onto the mandrel during fabrication of the fusible insulation.
7. The placement and attachment of the first row of internal thermocouples in the fusible insulation.
8. Completed fusible insulation with the outer layer of expanded metal installed.
9. Completed fusible insulation with the bottom cross wire supports installed.
10. Completed fusible insulation with the top cross wire supports installed.
11. The top retainer ring for the fusible insulation installed in the simulated pressure vessel.
12. Fusible insulation bundle installed in the upper retainer ring.
13. Fusible insulation completely installed in the simulated pressure vessel with the bottom retainer ring installed.
14. Instrument panel for the heat block-shield test.
15. Installation of the axial temperature probes in the heat block-shield.
16. Radial probe installation in the heat block-shield.
17. Bottom thermocouple feed-through and support shirt of the heat block-shield.

Figure

18. Simulated pressure vessel for the heat block-shield test.
19. Location of cooling coils on the bottom simulated elliptical head.
20. Cathetometer for measurement of the radial expansion of the heat block-shield.
21. Heat block-shield in the sand box to simulate a shipping accident.
22. Dummy heat pipe-thermoelectric module being inserted into the heat block-shield.
23. Dummy heat pipe-thermoelectric module fully inserted into the heat block-shield.
24. Heater element in position for full power heatup before being inserted into the heat block-shield as part of fueling test.
25. Temperature distribution in the heat block-shield during shipping and long-term storage with $^{90}\text{SrTiO}_3$ fuel.
26. Heat block-shield with thermal baffle in place.
27. Temperature distribution in the heat block-shield during normal operation at a surface temperature of 940°F.
28. Temperature distribution in the heat block-shield during normal operation with a surface temperature of 875°F.
29. Temperature distribution in the heat block-shield during a loss-of-coolant accident.
30. Incremental expansion of the heat block-shield from 32°F.
31. Comparison of the measured and calculated heat block-shield top surface temperature from the measured radial expansion.
32. The fusible insulation and simulated pressure vessel assembly being readied for the heat loss test.
33. Fusible insulation and pressure vessel assembly installed around the heat block-shield.
34. Total heat losses from the full scale heat block-shield with 3.0 in. of fusible insulation operating in air.
35. Adjusted heat losses from a full scale heat block-shield with 3.0 in. of fusible insulation operating in air.
36. Measured values of the thermal conductivity of the SAE 1010 steel of the heat block-shield.

Figure

- 37. Typical section of a seven-element heat block-shield.
- 38. Variation of the maximum temperature of the heater elements with the heat block-shield surface temperature.
- 39. Effects of pressure and temperature upon the thermal conductivity of combined aluminum foil-screen insulation operating in air.
- 40. Apparent emissivity of combined aluminum foil-screen insulation from 550 to 1100°F.
- A-1. Thermocouple coordinate system.
- A-2. Location of the thermocouples in the fusible insulation.

THERMAL TEST OF THE HEAT BLOCK-SHIELD FOR
THE ISOTOPE KILOWATT PROGRAM

M. E. Lackey

ABSTRACT

In support of the Isotope Kilowatt Program an experimental determination was made of the temperature distribution in a full scale heat block-shield under various operating conditions including shipping and storage, a shipping accident, normal operation, and a loss-of-coolant accident. In addition to the temperature distribution tests, determination of the heat losses from a full scale operating system was made with 3.0 in. of fusible insulation around the heat block-shield. A heat loss of 7.2% of full power was obtained with the system operating at a heat block-shield surface temperature of 800°F and an air pressure of 0.1 psia, and 15.9% when operating at a heat block-shield surface temperature of 1100°F and an air pressure of 1.0 psia.

INTRODUCTION

The isotope power unit reference designs evolved in the Isotope Kilowatt Program entail the use of a mild steel heat block-shield to serve both as a radiation shield and as a heat conduction medium between the radioisotopic heat source and the electric power conversion system. The electric power can be produced from either a thermoelectric or a Rankine cycle power conversion system.

The purpose of the heat block-shield test is to verify experimentally with a full-scale model the detailed analysis and design calculations for a heat block-shield unit that is suitable for use with either power generation system. Electric heaters were used to simulate the ^{90}Sr fuel capsules to determine the temperature distribution in the heat block-shield under various simulated operating conditions including shipping, normal operation, and accidents. The heaters were thermally sized and positioned to simulate individual fuel capsules, thus giving heat flux and temperature distributions throughout the heat block-shield the same as in the fueled unit.

The temperature distribution was obtained from thermocouples attached to the heater element cladding; to the surface of the heat block-shield and from probe thermocouples inserted in radial probe holes located in the heat block-shield at the top, bottom, and midplane of the heater elements.

SYSTEM DESCRIPTION

A full-scale steel heat block-shield with electric heaters to simulate the fuel capsules was used to determine the temperature distribution under various modes of operation. A total of seven heaters clad with 310 stainless steel to allow operation at 2000°F in air were used to simulate the fuel capsules. The heaters were located in the center of the block in seven 4.153 in. ID holes

in an hexagonal array with a web thickness of 1.5 in. The heaters were sized to deliver $5 \frac{2}{3}$ kW each, which allowed simulation of both $^{90}\text{SrTiO}_3$ fuel which requires 7 elements to deliver the design power of 34 kW, and $^{90}\text{SrF}_2$ fuel which requires only 6 elements to deliver the design power.

The heat block-shield has twelve holes for boiler tubes, and twelve holes for heat pipes. The heat block-shield has 45 vertical fins and is supported by a stainless steel skirt attached to an iron plate that simulates an elliptical head for the hull that would enclose the unit (see Fig. 1). The major design and dimensional data for the full-scale heat block-shield are given in Table 1.

The test to determine the temperature distribution during shipping and storage consisted of two main parts. One concerned the temperature during normal shipping or storage, i.e., in an upright position with the bare heat block-shield losing heat to the ambient air by radiation and convection. The second part of the shipping test considered a case in which an accident has caused the heat block-shield to fall on its side on sandy soil. The heat block-shield temperature distribution was determined for each of these conditions.

The temperature distribution was obtained for the normal operating conditions of the organic Rankine Cycle system with the heat block-shield outside surface at a temperature of approximately 875°F. This surface temperature was maintained by the use of 48-in. dia. radiation shield extending the full length of the block.

The approximate temperature distribution for the loss-of-coolant accident case was obtained with the heat block-shield outside surface at a temperature of 1220°F. This surface temperature was maintained by the use of a 0.002-in. thick aluminum radiation shield 48-in. in length wrapped around the 48-in. dia. radiation shield used for the normal operation condition test.

The normal operating heat loss test was run with 3 in. of fusible insulation around the outside diameter of the heat block-shield. The heat losses were determined for heat block-shield surface temperatures

ORNL DWG 73-1034

Fig. 1. Heat Block-Shield Test.

Table 1. Design and Dimensional Data for the
Full-Scale Heat Block-Shield Test

Material	SAE 1010 steel
Diameter	
Fin root, in.	35.5
Fin tip, in.	40.5
Height, in.	60
Number of fins	45
Fin height, in.	2.5
Fin thickness, in.	0.5
Holes for organic fluid boiler tubes	
Number	12
Diameter, in.	1.067
Length, in.	55
Bolt circle, in.	31
Holes for electric heaters	
Number	7
Diameter, in.	4.153
Length, in.	50.25
Centerline spacing, in.	5.653
Heaters	
Number	7
Outside diameter, in.	4.090
Inside diameter, in.	3.500
Assembled length, in.	40.300
Heated length, in.	38.33
Power @ 227 volts, kW	5.67
Power @ 208 volts, kW	4.85
Heat block-shield assembly shipping weight without heaters, lb	16,500

of 800 and 1100°F. The location of the fusible insulation relative to the heat block-shield is shown in Fig. 1.

The temperature distribution was obtained from thermocouples attached to the heater element cladding; to the surface of the heat block-shield and from probe thermocouples inserted in radial holes located in the heat block-shield at the top, bottom, and mid-plane of the heater elements. An additional hole for a probe thermocouple was located radially between the center heater element and the six outer heater elements. The holes for the boiler tubes and the heat pipes also were used for temperature probes.

APPARATUS

The major components of the heat block-shield test facility include the heat block-shield, electrical heaters, a sand box, a radiation shield, and a vacuum vessel containing the fusible insulation. The system operation entailed the arrangement of various components to simulate a specific test condition, adjusting the power level of the heaters, and allowing the temperature of the block to rise to equilibrium with the environment.

Heat Block-Shield

The full-scale heat block-shield, which was fabricated from SAE 1010 steel, is 35.5-in. OD by 60-in. long with 45 fins. The fins are 1/2-in. thick by 2 1/2-in. high and 53 in. in length. The block has twelve holes 1.067-in. ID x 55-in. deep located on a diameter of 31 in. These holes are used for boiler tubes if the heat is extracted from the block by boiling Dowtherm-A to supply the energy for the operation of a Rankine cycle. The block also has twelve holes 1.008-in. ID by 55-in. deep located on a diameter of 21.25 in. for heat pipes if the heat is used for thermoelectric generators.

In the center of the block are seven 4.153-in. ID x 50.25-in. deep holes located in a hexagonal array with a web thickness of 1.5 in. for the heat source. The heat will normally be supplied from a $^{90}\text{SrTiO}_3$ or a $^{90}\text{SrF}_2$ isotopic source. In these experiments an electrically heated source was used to simulate the isotopic source.

The bottom of the block is a truncated cone with a minor diameter of 25 in. and a slope of 45° . This shape was used to reduce the gross weight of the block and also to allow for better insulation of the block and the support skirt arrangement.

The block is supported by a stainless steel skirt 0.25-in. thick by 11-in. long attached to a 48-in. x 1.5-in. iron plate that simulates a bottom elliptical head. The skirt has 24 equally spaced 0.125-in. slots 10.5-in. long to relieve the stress induced by the differential expansion of the top and bottom of the skirt resulting from the temperature gradient in the skirt. The skirt is fabricated from stainless steel to take advantage of its low thermal conductivity relative to steel for the reduction of heat losses, and its good strength at 1100°F avoids difficulty with creep. Shown in Fig. 2 is the full-scale heat block-shield being readied for test in its normal upright position.

Electrical Heaters

Seven electrical heaters are used to simulate the isotopic heat sources. The heaters are clad with 310 stainless steel, and were designed to operate for short periods in air at a surface temperature of 2000°F . The heater clad is 4.090-in. OD by 40.3-in. long. The heater core is fabricated from 230 turns of 0.1144-in. OD Nichrome V wire on a 2.75-in. OD Alundum core, manufactured by the Norton Company, to give a heated length of 38.33 in. Each heater will deliver approximately 5.67 kW at 227 V and 4.85 kW at 208 V to simulate the power generation rates of $^{90}\text{SrF}_2$ and $^{90}\text{SrTiO}_3$, respectively. The component parts used to simulate the isotopic capsules are shown in Fig. 3.

Fig. 2. The full-scale heat block-shield unit being readied for test in its normal upright position.

Fig. 3. Components used to simulate the isotope capsules for the full-scale heat block-shield test. The parts shown are the electric heater element (bottom), the shield plug (right middle), and the assembled heater (top).

Thermal Fuse/Insulation

The thermal fuse/insulation was fabricated from aluminum screen wire and aluminum foil. The wire and foil were alternately wrapped around a mandrel made of stainless steel expanded metal. Eight layers of screen were wrapped first and then a layer of foil. This ratio of eight screen wire wraps to one foil wrap was continued until the desired thickness of insulation was obtained. The only exception to this ratio was that the last screen layer was preceded by a foil layer. After the desired insulation thickness was obtained, a final layer of stainless steel expanded metal was affixed around the outer diameter of the insulation bundle.

The screen was woven from Alcoa alloy 1100 wire. The wire diameter was 0.011 in. and the screen mesh 16 x 16 wires per in. The foil was 0.002-in. thick Alcoa alloy 5052. The chemical composition and melting range of these alloys as given in the Alcoa Aluminum Handbook are given in Table 2. The dimensions of the fusible insulation are given in Table 3.

The mandrel that was used for holding the dimension of the fusible insulation during the wrapping of the screen and foil layers is shown in Figs. 4 and 5. The inner liner was used to form the cylindrical section of the mandrel. The top thermocouple attachments can be seen in Fig. 4 and the bottom feed-through for thermocouples can be seen in Fig. 5. A view of the screen wire being wrapped onto the mandrel is shown in Fig. 6. The placement of the first row of upper thermocouples is shown in Fig. 7.

The completed screen with its outer layer of expanded metal installed is shown in Fig. 8. The bottom and top of the insulation bundle with the cross wires installed between the inner and outer expanded metal layers are shown in Figs. 9 and 10, respectively. The top retainer ring for the fusible insulation bundle is shown installed in the simulated pressure vessel in Fig. 11. Figure 12 shows the thermal insulation assembly installed in the upper retainer ring. Also shown in Fig. 12 are the shims that were used to insert the

Table 2. Chemical Composition and Melting Range of
the Fusible Insulation Wire and Foil

Element	Alloy	
	1100	5052
Silicon plus iron (max), %	1.0	0.45
Copper (max), %	0.20	0.10
Manganese (max), %	0.05	0.10
Magnesium, %		2.2-2.8
Chromium, %		0.15-0.35
Zinc (max), %	0.10	0.10
Other elements		
Each, %	0.05	0.05
Total, %	0.15	0.15
Aluminum (min), %	99.00	Remainder
Melting Range, deg F	1190-1215	1125-1200

Table 3. Dimensions of the Fusible
Insulation for the Full Scale Heat-Block Test

Expanded Metal Liners	
Type	1 1/2 in. No. 16-18
Flattened Expanded Metal	
Nominal thickness, in.	0.047
Width, in.	48
Material	Stainless steel
Inside diameter	
Inner liner, in.	41.375
Outer liner, in.	47.469
Number of Foil Layers	17
Number of Screen Layers	134
Total Insulation Thickness, in.	3
Average Screen Layer Thickness, in.	0.021

Fig. 4. Full-scale fusible insulation mandrel with half of bottom spacer removed to show the bottom cross support wires.

Fig. 5. Full scale fusible insulation mandrel with half of top spacer removed to show the top cross support wires.

Fig. 6. The aluminum screen wire being wrapped onto the mandrel during fabrication of the fusible insulation.

Fig. 7. The placement and attachment of the first row of internal thermocouples in the fusible insulation.

Fig. 8. Completed fusible insulation with the outer layer of expanded metal installed.

Fig. 9. Completed fusible insulation with the bottom cross wire supports installed.

PHOTO 0359-72

Fig. 10. Completed fusible insulation with the top cross wire supports installed.

Fig. 11. The top retainer ring for the fusible insulation installed in the simulated pressure vessel.

PHOTO 0363-72

Fig. 12. Fusible insulation bundle installed in the upper retainer ring.

bundle into the upper retainer ring. These shims were removed after final assembly. The completed assembly with the bottom retainer ring in place is shown in Fig. 13.

Electrical and Instrumentation System

Electrical power was supplied to the seven heaters from seven variable transformers which have a range of output voltage from 0 to 270 V. The voltage to each heater was measured with a multirange voltmeter that had full-scale ranges of 15, 30, 75, 150, and 300 V. The current to each heater was measured with a multirange ammeter that had full-scale ranges of 2, 5, 10, 20, and 50 amp.

The temperatures were measured using chromel-alumel thermocouples. The thermocouples on the heater surfaces and in the radial and axial block probes were sheathed, grounded junction thermocouples attached to the surface with spotwelded shim stock. The thermocouples on the block outer surface were bare junction thermocouples, which were insulated with ceramic beads on each wire near the junction. The junctions were spotwelded to the surface. The thermocouples used in the fusible insulation were of the sheathed, grounded junction type, and were wired to the screen to fix their positions (see Fig. 7).

The temperature data were collected with a DEXTIR data acquisition system. Key temperatures were recorded with a 12- and a 24-point Brown recorder to determine when equilibrium temperature conditions were reached.

The variable transformers, voltmeters, ammeters, recorders, and the DEXTIR system assembly are shown in Fig. 14. The positions of the axial and radial temperature probes are shown in Figs. 15 and 16, respectively. Details of the bottom thermocouple feed-throughs and the support skirt are shown in Fig. 17.

Fig. 13. Fusible insulation completely installed in the simulated pressure vessel with the bottom retainer ring installed.

Fig. 14. Instrument panel for the heat block-shield test.

Fig. 15. Installation of the axial temperature probes in the heat block-shield.

Fig. 16. Radial probe installation in the heat block-shield.

PHOTO 79216

Fig. 17. Bottom thermocouple feed-through and support shirt of the heat block-shield.

Cooling System

The heat from full-power tests was dissipated to the surroundings by radiation and natural thermal convection. The heat from the heat loss tests with the fusible insulation in place was transferred to cooling water coils located around the simulated pressure vessel and on the simulated bottom elliptical head. The simulated pressure vessel with the cooling coils in place is shown in Fig. 18. The location of the cooling coils on the underside of the simulated bottom elliptical head is shown in Fig. 19. Shown also in Fig. 19 is the continuation of the thermocouple feed-throughs shown in Fig. 11 as well as the system base support structure.

Cathetometer

A high precision cathetometer was used to measure the axial expansion and contraction of the heat block-shield during heating and cooling phases of the full power tests. The cathetometer is shown in place in Fig. 20.

TEST PROCEDURE

The independent variables for the test conditions included the power input, the number of simulated fuel elements, and the method of heat removal. These factors combined to determine the temperature profile of the heat block-shield. The power level was varied from approximately 2 kW to 34 kW. The number of simulated fuel elements was varied from one to seven, and the modes of heat removal were first, the bare heat block-shield in an upright position, second, the bare heat block-shield resting on its side in soft sand, and third, the fully insulated heat block-shield in an upright position.

PHOTO 0361-72

Fig. 18. Simulated pressure vessel for the heat block-shield test.

Fig. 19. Location of cooling coils on the bottom simulated elliptical head.

Fig. 20. Cathetometer for measurement of the radial expansion of the heat block-shield.

The procedure for each of the experiments was as follows:

1. The cooling conditions for the heat block-shield were fixed.
2. Power was supplied to a predetermined number of simulated fuel elements.
3. The heat block-shield temperature distribution was allowed to approach equilibrium.
4. As equilibrium was approached, the power was trimmed to compensate for changes in heater resistance.
5. When the heat block-shield appeared to be at thermal equilibrium, as indicated by the stabilization of the temperature distribution, the data were recorded. The voltage and current for each heater and the temperatures were read and recorded.

TEST DESCRIPTION AND RESULT

The test results are given for the most part in terms of the heat block-shield temperature profile. In addition to the tests that were run to determine the temperature characteristics of the heat block-shield, tests were conducted to determine the pressure rise in a hole for a thermoelectric heat pipe as a function of the insertion rate of a dummy heat pipe. Measurements of the radial expansion at the top of heat block-shield were taken for each heated test of the bare heat block-shield in an upright position.

Shipping Accident Test

During shipping an accident may occur that allows one side of the heat block-shield to be insulated. An accident was envisioned in which the heat block-shield was resting on its side in dry sand. The arrangement of the heat block-shield in the sand box is shown in Fig. 21. (See also Figs. 15 and 16.)

Fig. 21. Heat block-shield in the sand box to simulate a shipping accident.

With approximately 60° of the heat block-shield in the sand, a series of tests were run with the seven electric heaters at several power levels ranging from 4 kW to 32.8 kW to simulate the $^{90}\text{SiTiO}_3$ fuel. A single test was run with the six outer electric heaters supplying 32.7 kW and with approximately 110° of the heat block-shield in the sand. The details of these tests (listed as tests 1 through 7) are given in Appendix A, Table A-1. Particularly significant surface temperatures were extrapolated to a power level of 34 kW and are given in Table 4.

Thermoelectric Heat Pipe Insertion Test

A test was run to determine the pressure developed in the thermoelectric module heat pipe holes at different rates of heat pipe insertion. A dummy heat pipe and thermoelectric module was fabricated and inserted into the heat block-shield at rates of 12 and 20 ft/min (Figs. 22 and 23). The resulting maximum pressures were 45 and 70 psig, respectively. These values were used to obtain Eq. 1 for the maximum back pressure as a function of the insertion rate from 0 to 20 ft/min with the air in the hole initially at atmospheric pressure.

$$P = 5.25R^{0.863} \quad (1)$$

where

P = maximum back pressure (psig)

R = insertion rate (ft/min)

Table 4. Surface Temperatures of the Full Scale
Heat Block-Shield During the Shipping
Accident Test at Power
Level of 34 kW

Heat Block-Shield Surface Temperatures			
In the sand, (°F)	770	775	825
Out of the sand,* (°F)	600	615	635
Heater Surface Temperature (max), (°F)	1165	1100	1190
Fraction of Heat Block-Shield Below Sand Surface, (deg.)	60	60	110
Number of Heaters	7	6	7

*These points are located on the heat block-shield surface approximately 90° measured from the sand surface.

PHOTO 2638-71

Fig. 22. Dummy heat pipe-thermoelectric module being inserted into the heat block-shield.

Fig. 23. Dummy heat pipe-thermoelectric module fully inserted into the heat block-shield.

Fuel Element Loading Test

A test to investigate the problems in loading hot fuel elements into the heat block-shield was performed. At the start of this test the heat block-shield was at an isothermal temperature of 80°F. During the test the electrically heated, simulated fuel elements were brought to a power level of approximately 4.8 kW outside the heat block-shield to simulate the $^{90}\text{SrTiO}_3$ fuel and allowed to heat up until their temperature reached equilibrium with the surroundings (see Fig. 24). They were then inserted into the heat block-shield at an average rate of 6 ft/min. After each element was inserted into the heat block-shield, the heat block-shield was allowed to come to equilibrium before the next element was inserted. No difficulties were encountered during the insertion of the seven elements. The details of these tests (listed as tests 8 through 14) are given in Appendix A, Table A-2.

The surface temperature of the elements in equilibrium in air was 965°F at a power level of 4.82 kW which simulates the $^{90}\text{SrTiO}_3$ fuel, and 1028°F at a power level of 5.73 kW which simulates the $^{90}\text{SrF}_2$ fuel. The emissivity of the heater surface was calculated to be 0.511 at 965°F, and 0.524 at 1028°F.

Shipping and Storage Test

The shipping and long-term storage test for the heat block-shield was run with the block in the upright position (see Fig. 2). A series of tests was run with electric heaters to simulate ^{90}Sr fuel. The details of these tests (listed as tests 14 through 18) are given in Appendix A, Table A-3. Test 15 was for the condition in which six electric heaters supplied 34 kW to simulate $^{90}\text{SrF}_2$ fuel and the remaining tests were with seven heaters to simulate $^{90}\text{SrTiO}_3$ fuel. Particularly significant surface temperatures at a power level of 34 kW are given in Table 5.

PHOTO 2635-71

Fig. 24. Heater element in position for full power heatup before being inserted into the heat block-shield as part of fueling test.

Table 5. Surface Temperatures of the Full Scale Heat Block-Shield During Shipping and Long-Term Storage

Test Number	14	15
Heat Block-Shield Surface Temperature (max), (°F)	500	498
Heater Surface Temperature (max), (°F)	1042	979
Number of Heaters	7	6

For the simulated $^{90}\text{SrTiO}_3$ fuel case (Test No. 14), the temperature distribution in the heat block-shield during shipping and long-term storage is shown in Fig. 25.

Normal Operating Condition Test

A thermal baffle with a diameter of 48 in. was installed around the heat block-shield to force the surface temperatures to levels approaching those that would exist during normal operation of the system. The heat block-shield with the baffle in place is shown in Fig. 26.

A series of tests was run with electric heaters to simulate ^{90}Sr fuel. The details of these tests (listed as tests 19 through 23) are given in Appendix A, Table A-4. Test 22 is for six electric heaters supplying 34 kW to simulate $^{90}\text{SrF}_2$ fuel and the remaining tests were with seven heaters to simulate $^{90}\text{SrTiO}_3$ fuel.

Fig. 25. Temperature distribution in the heat block-shield during shipping and long-term storage with $^{90}\text{SrTiO}_3$ fuel.

Fig. 26. Heat block-shield with thermal baffle in place.

The surface temperature for tests 21 and 22 was approximately 940°F which is believed to be approximately 140°F higher than the normal operating surface temperature for operation with an organic Rankine cycle. Fans were used to increase the heat transfer from the surface of the thermal baffle to the surroundings. The temperature of the baffle was reduced to approximately 535°F from 630°F and the resulting heat block-shield surface temperature was approximately 875°F. This test, listed as test 23 in Appendix A, Table A-4, was run with seven electric heaters supplying 34 kW to simulate the $^{90}\text{SrTiO}_3$ fuel.

The temperature profile in the heat block-shield for tests 21 and 23 are shown in Figs. 27 and 28, respectively.

Loss-of-Coolant Accident Test

A loss-of-coolant accident test was run with the thermal baffle in place. The surface temperature of the baffle was raised for this test by using an aluminum foil baffle in series with the thermal baffle. A series of tests was run with electric heaters to simulate the ^{90}Sr fuel. The details of these tests (listed as tests 24 through 28) are given in Appendix A, Table A-5. Test 28 is for six electric heaters supplying 34 kW to simulate $^{90}\text{SrF}_2$ fuel and the remaining tests were with seven heaters to simulate $^{90}\text{SrTiO}_3$ fuel. Particularly significant surface temperatures at a power level of 34 kW are given in Table 6.

The temperature distribution in the heat block-shield during a loss of coolant accident is shown in Fig. 29 for the simulated $^{90}\text{SrTiO}_3$ fuel case (Test no. 27).

Radial Expansion Test

The radial expansion of the top of the heat block-shield was measured during each heated test of the bare heat block-shield in the

Fig. 27. Temperature distribution in the heat block-shield during normal operation at a surface temperature of 940°F.

Fig. 28. Temperature distribution in the heat block-shield during normal operation with a surface temperature of 875°F.

Fig. 29. Temperature distribution in the heat block-shield during a loss-of-coolant accident.

Table 6. Surface Temperature of the Full Scale Heat
Block-Shield During a Loss of Coolant Accident

Test Number	27	28
Heat Block-Shield Surface Temperature, (°F)	1218	1210
Heater Surface Temperature (max), (°F)	1799	1720
Number of Heaters	7	6

upright position. Measurements of the expansion of the top of heat block-shield were taken at two locations, one was at the thermoelectric heat pipe bolt circle radius of 10.625 in. and one was at the organic Rankine cycle boiler tube bolt circle radius of 15.5 in. The measurements were taken by measuring the movement of a tapered plug located on each of the above bolt circles with a cathetometer (see Fig. 20).

A plot of the incremental expansion from 32°F was made from the data for the coefficient of thermal expansion of SAE 1020 steel given in Ref. 1 and Eq. 2 (see Fig. 30).

$$\alpha(T-32) = \frac{\Delta L}{L} \quad (2)$$

where

α = coefficient of thermal expansion (°F)⁻¹

T = temperature, °F

$\Delta L/L$ = incremental expansion

The temperature corresponding to the measured incremental expansion was read from Fig. 30 and compared to the measured temperature at the tapered plug location. The resulting values for the temperature range of 200 to 1200°F are shown in Fig. 31. Examination of these data indicate that the local heat block-shield temperature can be used to estimate the local radial expansion within 20%.

Heat Loss Test

To determine the effectiveness of the 3.0 in. fusible insulation, a heat loss test was run with the insulation bundle installed around the full scale heat block-shield. Shown in Fig. 32 is the fusible

Fig. 30. Incremental expansion of the heat block-shield from 32°F.

Fig. 31. Comparison of the measured and calculated heat block-shield top surface temperature from the measured radial expansion.

Fig. 32. The fusible insulation and simulated pressure vessel assembly being readied for the heat loss test.

insulation and simulated pressure vessel assembly being readied for installation around the heat block-shield. Shown in Fig. 33 is the fusible insulation and simulated pressure vessel assembly installed around the heat block-shield.

The heat loss tests were run at pressure levels of approximately 0.1, 1.0, and 14.4 psia. The details of these tests (listed as tests 29 through 40) are given in Appendix A, Table A-6. The total heat losses are given in Table 7 and are shown in Fig. 34 as a function of the heat block-shield midplane surface temperature and the operating pressure level. The losses peculiar to the test rig and not associated with an operational system, such as the heat losses through the top skirt, were estimated and subtracted from the measured values. These adjusted losses are shown in Fig. 35. Inspection of these adjusted data indicate heat losses of 7.2% when operating at a heat block-shield surface temperature of 800°F and a pressure of 0.1 psia, and 15.9% when operating at a heat block-shield surface temperature of 1100°F and a pressure of 1.0 psia.

GENERAL ANALYSIS AND CONCLUSIONS

An estimate of the thermal conductivity of the SAE 1010 steel block was made from the temperature drop measured between a radius of 10.625 and a radius of 15.5 in. in the heat block-shield when operating with various power and temperature levels. The estimated thermal conductivity calculated from the experimental data is shown in Fig. 36 compared to the thermal conductivity calculated from Eq. 3 taken from Ref. 2

$$k = 41.94 - 15.6 \times 10^{-3}t - 8.17 \times 10^{-6}t^2 + 5.09 \times 10^{-9}t^3 \quad (3)$$

where

k = thermal conductivity, Btu/(hr) (ft²) (°F/ft)

Fig. 33. Fusible insulation and pressure vessel assembly installed around the heat block-shield.

Table 7. Heat Loss from Full Scale Heat Block-Shield
with 3.0 in. of Fusible Insulation in an Air Atmosphere

Test Number	Heat Block-Shield Midplane Surface Temperature (°F)	Pressure (psia)	Heat Loss (% of Full Power*)
29	608.7	14.4	6.15
30	593.2	1.0	5.65
31	576.8	0.1	4.72
33	803.6	14.4	9.92
34	794.2	1.0	8.81
32	804.5	0.1	8.18
35	923.5	14.4	13.26
36	903.8	1.0	11.38
37	907.0	0.1	10.22
40	1093	14.4	18.75
39	1080	1.0	16.7
38	1077	0.1	14.32
**	1092	1.6×10^{-3}	9.08

*34 kW.

**This test was only run for heat loss measurements and no other data was taken. It is not reported in Appendix A.

Fig. 34. Total heat losses from the full scale heat block-shield with 3.0 in. of fusible insulation operating in air.

Fig. 35. Adjusted heat losses from a full scale heat block-shield with 3.0 in. of fusible insulation operating in air.

Fig. 36. Measured values of the thermal conductivity of the SAE-1010 steel of the heat block-shield.

t = temperature, °F

These data indicate that Eq. 3 from Ref. 2 is an adequate description of the thermal conductivity of SAE 1010 steel and may be used for detailed calculations of the temperature distribution in the heat block-shield when operating with various power and temperature levels.

As further evidence of the validity of the assumptions and calculational procedure outlined in Ref. 2, a comparison of selected measured temperatures in the heat block-shield was made with the corresponding temperatures calculated by the procedures given in Ref. 2. A 1400°F reference condition at the midplane of the outer periphery of the heater elements was assumed for the comparison. A 1400°F reference condition was obtained for the measured temperatures by cross plotting the data from tests 21, 23, and 27 and interpolating to obtain the 1400°F values. These values are given in Table 8.

The heat block-shield surface temperatures calculated from the heater element surface temperature by the procedures of Ref. 2 are shown in Fig. 38 together with the experimental values of tests 14, 21, 23, and 27. Both are given as functions of the heater element maximum surface temperature for the $^{90}\text{SrTiO}_3$ fuel case. Inspection of these data indicates a heat block-shield surface temperature of 1360 to 1370°F at a heater element maximum surface temperature of 2000°F.

After the completion of test 28, the heat block-shield was allowed to cool to room temperature. At this time the weld between the stainless steel support skirt and the heat block-shield was checked for flaws by the use of a dye penetrant. No flaws were found in the weld and the weld was judged to be sound.

From the heat loss test data an estimate of the thermal conductivity of the fusible insulation was made by using the general heat transfer equation (4).

$$q = kA\Delta t \quad (4)$$

where q = heat flow through the insulation, Btu/hr

Table 8. Comparison of Measured and Calculated Temperatures
in the Full Scale Heat Block-Shield Operating at 34 kW with
 $^{90}\text{SrTiO}_3$ Fuel and the 1400°F Reference Temperature

Line No.	<u>Element Surface</u>		<u>Element Hole Surface</u>		<u>1.191 in. from Central Element Hole Surface</u>		<u>2.836 in. from Central Element Hole Surface</u>	
	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.
1	1738	1771.6						
2			1715	1677.9	1655	1650.5	1583	1572.1
3	1715	1721						
6	1604	1612.3						
9			1425	1420.3				

*Line numbers correspond to line numbers shown on Fig. 37
taken from Fig. 6 of Ref. 2.

ORNL DWG 70-13980

Fig. 37. Typical section of a seven-element block-shield.

Fig. 38. Variation of the maximum temperature of the heater elements with the heat block-shield surface temperature.

k = thermal conductivity of the insulation, Btu/ft/hr°F

A = area of the insulation, ft²

Δt = temperature difference across the insulation, °F

The losses from the system other than through the fusible insulation are calculated using equation (4) and subtracted from the electrical input to the heater elements to give the heat flow through the fusible insulation. Since the area of the fusible insulation is defined by a thick cylinder, the log mean area is used for the calculation. Equation (4) is modified to give

$$q = \frac{2\pi L k \Delta t}{\ln D_2/D_1} \quad (5)$$

where L = height of the insulation, ft

D_2 = outside diameter of the insulation, in.

D_1 = inside diameter of the insulation, in.

Substitution in equation (5) of the values of $D_2 = 47.5$, $D_1 = 41.5$, and $L = 4$ gives

$$q = \frac{(2\pi)(4)k\Delta t}{\ln \frac{47.5}{41.5}} = 186 k\Delta t \quad (6)$$

An example of the use of this calculational procedure is given for run 29 listed in Table A-6. The electrical heat input to the system is given as 2.091 kW which is equivalent to 7138 Btu/hr. The heat losses from the system other than through the fusible insulation are calculated to be 2502 Btu/hr to give a flow (q) through the fusible insulation of 4636 Btu/hr. The inside temperature of fusible insulation is taken as the average of TE's 214 and 218 to be 580.4°F and the outside temperature of fusible insulation is taken as the average of TE's 264 and 224 to be 113.5°F. The difference of these average temperatures is 466.9°F. Substitution of these values in equation (6) and solving for k gives

$$k = \frac{4636}{186(466.9)} = .0534 \quad (7)$$

The mean temperature of the fusible insulation is taken as the average between the inside and outside temperatures. For this example the mean fusible insulation temperature is 347°F.

The thermal conductivities are shown in Fig. 39. Also shown in Fig. 39 for comparison are conductivities taken from Fig. 8 of Ref. 3 which were obtained from the small scale fusible insulation tests. The small scale test had a screen packing density of 0.0193 in. per screen layer as compared to 0.021 in. per screen layer for the full scale test. As can be seen from Fig. 39, good agreement between the two sets of data was obtained in this range of packing density and at pressure levels of interest, namely 0.1 and 1.0 psia.

The apparent inside surface emissivity of the screen was estimated from the low pressure heat loss test data. The screen emissivity was estimated by assuming an emissivity of 1 for the heat block-shield fin tips. The fin tip heat flux and temperature were used in conjunction with the screen surface temperature as determined from a thermocouple located under the first layer of screen. The resulting apparent screen emissivities are shown in Fig. 40. Comparative values taken from Fig. 11 of Ref. 2 indicate a heat block-shield surface temperature of 1357°F will be attained with a screen emissivity of 0.50 and 1370°F with a screen emissivity of 0.46 when the screen temperature is 1200°F during a loss-of-coolant accident. These values compared to the measured value and the estimated surface temperature of 1360-1370°F indicate the accuracy of the calculational methods of Ref. 2.

Fig. 39. Effects of pressure and temperature upon the thermal conductivity of combined aluminum foil-screen insulation operating in air.

ORNL DWG 73-1046

Fig. 40. Apparent emissivity of combined aluminum foil-screen insulation from 550 to 1100°F.

page blank

APPENDIX A

Heat Block-Shield Test Data

The heat block-shield temperature data under various operating conditions are given in Tables A-1 through Table A-5. The data for the heat loss tests with the fusible insulation in place are given in Table A-6.

The location of the thermocouples are given in X , R , and θ coordinates. The reference conditions are shown in Fig. A-1 where $X = 0$ is located at the top surface of the heat block-shield, $R = 0$ is located at the center and θ is measured clockwise. The location of the thermocouples on the heater element surface is shown in Fig. A-1 where θ is used to designate the orientation of the element relative to the center of the heat block-shield and θ' is used to designate the orientation of the heater element thermocouples relative to the center of the heater element.

The location of the thermocouples in the fusible insulation is shown in Fig. A-2 dimensioned relative to the insulation. The dimensions given in Table A-6 are X , R , and θ as designated in Fig. A-1.

Fig. A.1. Thermocouple coordinate system.

PT	TE	PT	TE
1	214	12	254
2	216	13	255
3	218	14	256
4	220	15	257
5	222	16	258
6	223	17	259
7	224	18	260
8	250	19	261
9	251	20	262
10	252	21	263
11	253	22	264

Fig. A.2. Location of the thermocouples in the fusible insulation.

Table A-1. Shipping Accident Test Data

Test Number*				1	2	3	4	5	6	7	
No. Elements				7	7	7	7	7	6	7	
Power Level, kW				4.004	8.313	16.142	25.530	33.060	32.740	32.830	
TE No.	Location				Temperature (°F)						
	X (in.)	R (in.)	θ (deg)	θ' (deg)							
1	0	8.500	300		151.3	255.8	355.0	465.6	524.7	527.7	542.7
2	30.125	0	0	0	253.3	460.0	708.4	992.6	1150.0	1019.0	1176.0
3	0	10.625	300		150.4	254.6	350.1	454.9	516.4	520.7	542.4
4	30.125	0	0	270	265.8	468.8	712.6	987.1	1135.0	994.8	1161.0
5	0	15.500	300		145.9	236.0	345.0	442.0	500.1	502.7	519.6
6	30.125	0	0	180	268.5	468.5	710.5	984.6	1131.0	986.4	1159.0
7	30.125	18.000	288		162.6	280.0	395.6	525.4	597.1	602.3	623.3
8	30.125	5.653	330	300	260.9	459.3	668.0	933.8	1087.0	1101.0	1135.0
9	30.125	20.000	288		159.4	270.9	378.6	493.8	556.2	559.2	578.2
10	30.125	5.653	330	210	235.9	429.0	657.8	905.6	1054.0	1067.0	1081.0
11	54.750	18.000	180		149.5	253.1	384.3	454.5	518.1	520.3	533.7
12	30.125	5.653	330	120	245.7	439.3	670.2	914.0	1065.0	1083.0	1091.0
13	11.875	3.364	0		178.4	317.6	465.0	626.4	781.9	761.9	814.1
14	65.500	18.000	180		65.8	76.9	78.0	79.0	80.0	80.0	81.0
15	24.250	3.364	0		201.3	363.9	563.7	820.9	1018.0	981.7	1057.0
16	11.875	7.729	270		182.9	313.2	466.9	627.7	707.3	667.0	704.9
17	30.125	3.364	0		204.0	372.2	574.3	840.0	1045.0	1004.5	1080.0
18	11.875	2.0765	300		195.5	348.5	489.4	716.6	833.0	753.8	860.3
19	36.000	3.364	0		204.0	372.6	576.9	853.6	1043.0	1007.0	1082.0
20	30.125	7.729	270		190.5	343.7	513.9	678.9	845.3	821.9	847.2
21	60.000	0	0		170.7	304.3	433.0	593.5	689.3	692.7	720.3
22	30.125	2.0765	300		234.5	415.4	635.3	911.9	1087.0	994.0	1109.0
23	48.375	7.729	270		—	—	—	—	720.0	—	—
24	48.375	2.0765	300		209.7	373.6	556.8	708.5	925.9	825.3	948.7
25	6.000	15.500	15		156.1	274.4	378.5	517.7	592.7	597.2	629.0
26	11.875	15.500	15		163.8	291.4	406.5	561.4	648.5	655.1	691.7
27	24.250	15.500	15		173.7	312.7	444.3	625.8	733.4	741.6	785.2
28	30.125	15.500	15		193.0	319.8	455.6	645.4	758.9	768.9	814.1
29	36.000	15.500	15		177.3	322.0	458.2	659.2	763.6	773.1	818.4
30	48.375	15.500	15		173.2	315.3	443.4	623.7	728.2	735.6	775.4
31	55.000	15.500	15		171.4	310.5	434.3	606.7	700.1	711.7	748.2
32	6.000	10.625	15		159.2	278.4	383.8	525.8	—	—	632.0
33	11.875	10.625	15		167.8	296.7	416.1	578.1	669.1	675.2	708.9
34	24.250	10.625	15		179.5	312.4	462.5	659.0	777.3	786.3	822.7
35	30.125	10.625	15		181.3	328.6	472.4	675.6	799.0	807.6	851.1
36	36.000	10.625	15		181.8	329.5	474.2	679.0	803.2	811.8	855.3
37	48.375	10.625	15		175.9	320.2	453.4	640.3	750.0	756.9	795.0
38	55.000	10.625	15		172.3	312.2	438.2	613.9	713.3	718.1	753.3
39	18.125	18.000	112		158.8	271.3	368.9	496.2	556.6	557.2	577.8
40	11.875	18.000	288		154.7	261.0	357.1	474.6	532.6	534.4	547.7
41	30.125	18.000	112		163.8	283.3	390.3	531.4	598.8	602.4	622.5
42	30.125	20.000	112		161.5	274.9	374.6	503.5	559.7	562.8	579.6
43	48.375	18.000	288		162.8	281.6	381.6	514.3	582.7	582.0	600.0
44	42.125	18.000	112		164.7	284.2	388.2	525.8	590.6	593.7	612.1
45	60.250	18.000	180		95.3	132.1	150.4	193.0	204.7	206.6	213.2
46	60.000	10.625	180		166.9	293.1	401.3	551.1	630.8	633.1	651.4
47	60.000	5.000	180		170.5	301.6	416.5	576.4	663.5	666.2	688.3
48	60.000	8.500	0		171.9	309.7	432.9	602.5	699.5	703.8	736.7
49	56.750	15.500	0		174.6	313.9	435.6	604.7	699.1	705.3	744.6
50	11.875	10.604	270		174.2	281.0	385.9	522.1	594.4	597.3	618.0
51	11.875	15.479	270		159.7	269.6	364.9	486.8	545.2	549.0	565.5
52	11.875	4.9515	300		178.7	313.5	445.1	623.0	724.8	724.6	756.9
53	11.875	7.7015	300		171.0	297.9	416.0	572.7	660.5	663.3	691.5
54	11.875	10.5765	300		167.0	289.0	397.7	541.4	616.5	619.8	646.9
55	30.125	10.604	270		176.9	309.9	435.2	605.5	700.8	704.9	729.6
56	30.125	15.479	270		169.7	293.9	404.7	552.1	624.7	622.6	649.9
57	30.125	4.9515	300		200.6	361.9	538.2	786.9	947.0	934.2	986.5
58	30.125	7.7015	300		187.7	334.2	482.3	686.4	809.1	812.4	849.2
59	30.125	10.5765	300		180.0	318.8	452.5	621.9	732.5	737.0	771.0
60	48.375	10.604	270		171.9	302.8	418.6	576.9	661.8	664.6	688.1
61	48.375	15.479	270		167.4	289.9	395.5	535.0	603.1	604.2	623.6
62	48.375	4.9515	300		187.7	336.4	485.3	679.6	808.3	808.5	844.1
63	48.375	7.7015	300		180.0	321.4	454.7	627.7	738.4	742.5	774.0
64	48.375	10.5765	300		—	—	—	—	689.7	693.3	724.9
65	6.125	18.000	0		170.0	270.0	390.0	520.0	595.0	600.0	635.0
66	6.125	20.000	0		170.0	270.0	390.0	520.0	595.0	600.0	635.0
67	30.125	18.000	0		170.0	310.0	465.0	640.0	755.0	760.0	810.0
68	30.125	20.000	0		170.0	310.0	460.0	635.0	748.0	755.0	805.0
69	51.125	18.000	0		170.0	305.0	445.0	610.0	710.0	718.0	758.0
70	51.125	20.000	0		170.0	305.0	442.0	605.0	705.0	710.0	750.0

*Tests 1 through 6 were run with 60° of the heat block-shield below the sand level. Test 7 was run with 110° of the heat block-shield below the sand level.

Table A-2. Fuel Element Loading Test Data

TE No.	Test Number				8	9	10	11	12	13	14
	No. Elements				1	2	3	4	5	6	7
	Power Level, kW				4.721	9.935	14.192	19.249	23.945	28.831	33.860
TE No.	Location				Temperature (°F)						
	X (in.)	R (in.)	θ (deg)	θ' (deg)							
1	0	8.500	300		164.1	233.8	306.3	358.1	382.9	424.0	459.4
2	30.125	0	0	300	571.3	666.6	736.3	827.3	885.2	969.0	1042.0
3	0	10.625	300		160.2	237.2	298.2	348.6	372.1	411.5	442.8
4	30.125	0	0	210	535.5	636.5	706.7	793.7	857.1	945.0	1020.0
5	0	15.500	300		158.9	234.6	295.5	344.1	367.2	403.1	432.7
6	30.125	0	0	120	551.6	644.2	709.3	797.1	856.6	944.0	1026.0
7	30.125	18.000	288		166.7	258.2	339.7	396.3	428.1	469.0	499.6
8	30.125	5.653	330	90	—	679.1	744.0	833.6	866.4	920.8	959.5
9	30.125	20.000	288		162.8	247.2	322.1	373.4	401.3	437.0	462.5
10	30.125	5.653	330	0	—	674.6	738.0	821.7	853.7	911.1	959.9
11	54.750	18.000	180		155.0	217.2	276.2	328.4	362.7	416.9	456.3
12	30.125	5.653	330	270	—	664.8	722.6	808.1	835.4	890.9	938.8
13	11.875	3.364	0		200.8	265.6	396.7	498.1	534.6	599.9	660.2
14	65.500	18.000	180		78.0	79.0	79.0	80.0	80.0	79.0	81.0
15	24.250	3.364	0		231.8	372.6	484.4	634.9	688.7	776.3	870.9
16	11.875	7.729	270		—	—	442.7	520.0	559.5	606.0	633.1
17	30.125	3.364	0		236.6	399.0	492.9	649.8	698.7	786.4	882.4
18	11.875	2.0765	300		310.3	401.8	488.4	567.7	616.0	664.2	717.3
19	36.000	3.364	0		233.6	395.5	490.6	646.5	698.1	784.8	881.9
20	30.125	7.729	270		—	—	531.0	576.4	612.9	672.8	715.5
21	60.000	0	0		174.9	263.9	336.5	412.8	446.3	513.5	573.6
22	30.125	2.0765	300		402.5	525.0	598.2	748.5	815.9	890.4	972.6
23	48.375	7.729	270		—	—	—	—	—	—	640.0
24	48.375	2.0765	300		404.8	492.4	574.6	660.9	709.8	771.7	829.1
25	6.000	15.500	285		160.5	237.0	302.0	351.3	378.2	418.1	448.4
26	11.875	15.500	285		164.4	248.4	321.8	375.1	405.1	447.5	480.0
27	24.250	15.500	285		169.1	264.2	349.3	409.1	444.8	490.9	526.2
28	30.125	15.500	285		170.0	267.8	356.1	418.5	454.6	503.4	538.0
29	36.000	15.500	285		168.7	266.4	354.3	417.6	453.7	502.0	526.7
30	48.375	15.500	285		164.8	255.0	335.8	399.3	430.5	479.4	515.6
31	55.000	15.500	285		163.9	251.5	328.6	392.1	422.9	472.8	511.2
32	6.000	10.625	285		161.3	242.7	312.8	367.0	395.7	440.4	474.7
33	11.875	10.625	285		167.0	259.4	342.5	402.9	435.9	484.7	521.3
34	24.250	10.625	285		174.3	282.9	385.3	455.1	496.6	551.9	592.9
35	30.125	10.625	285		175.6	286.5	392.0	463.9	507.2	562.4	605.1
36	36.000	10.625	285		174.3	285.2	389.8	462.6	505.0	561.9	604.7
37	48.375	10.625	285		168.7	267.8	359.2	429.7	465.7	521.7	564.2
38	55.000	10.625	285		166.1	259.4	341.2	410.5	443.4	500.2	543.2
39	18.125	18.000	112		160.9	223.6	273.3	333.2	360.2	421.2	475.5
40	11.875	18.000	288		160.0	241.0	310.1	361.2	387.6	427.9	456.9
41	30.125	18.000	112		167.4	234.0	285.8	348.4	380.0	444.8	507.7
42	30.125	20.000	112		163.5	224.5	273.3	332.3	359.3	416.3	470.7
43	48.375	18.000	288		162.2	247.1	320.9	379.1	406.9	449.3	480.0
44	42.125	18.000	112		163.1	228.8	281.8	344.1	372.8	432.8	490.6
45	60.250	18.000	180		99.1	114.7	133.7	146.0	156.4	168.6	180.4
46	60.000	10.625	180		169.1	247.5	317.3	382.7	422.5	490.9	543.2
47	60.000	5.000	180		171.7	255.4	326.8	398.0	436.3	505.0	561.6
48	60.000	8.500	0		165.3	256.3	325.1	403.1	432.1	487.2	537.6
49	56.750	15.500	0		166.7	256.2	320.8	395.1	418.9	468.6	519.3
50	11.875	10.604	270		—	—	341.6	396.9	435.4	484.3	525.9
51	11.875	15.479	270		—	—	320.4	370.5	404.2	449.0	484.1
52	11.875	4.9515	300		190.9	310.6	413.4	485.9	525.1	585.2	632.5
53	11.875	7.7015	300		175.4	283.7	374.0	439.3	472.8	524.5	567.4
54	11.875	10.5765	300		168.9	266.8	347.0	407.7	437.6	485.0	523.7
55	30.125	10.604	270		—	—	388.3	454.5	506.3	564.3	607.8
56	30.125	15.479	270		—	—	353.3	411.2	453.2	503.0	539.0
57	30.125	4.9515	300		215.5	376.8	513.6	613.5	674.3	750.8	816.4
58	30.125	7.7015	300		187.9	326.0	441.0	524.6	569.7	630.7	681.1
59	30.125	10.5765	300		177.6	297.6	396.8	471.8	510.7	564.3	607.8
60	48.375	10.604	270		—	—	356.9	423.3	464.8	521.5	564.8
61	48.375	15.479	270		—	—	333.0	392.9	428.3	477.9	514.0
62	48.375	4.9515	300		190.9	318.8	424.1	511.1	555.8	623.8	681.5
63	48.375	7.7015	300		177.1	292.2	389.2	466.5	504.5	562.6	611.7
64	48.375	10.5765	300		174.2	276.5	362.1	443.6	469.8	530.5	586.9
65	6.125	18.000	0		145.0	235.0	281.0	345.0	359.0	395.0	425.0
66	6.125	20.000	0		145.0	228.0	273.0	330.0	345.0	378.0	403.0
67	30.125	18.000	0		155.0	259.0	319.0	400.0	420.0	459.0	498.0
68	30.125	20.000	0		155.0	252.0	308.0	380.0	399.0	431.0	465.0
69	51.125	18.000	0		150.0	243.0	305.0	375.0	395.0	433.0	471.0
70	51.125	20.000	0		150.0	243.0	305.0	375.0	395.0	433.0	471.0

Table A-3. Shipping and Storage Test Data

TE No.	Test Number				14	15	16	17	18
	No. Elements				7	6	7	7	7
	Power Level, kW				33.860	34.027	25.480	17.249	8.520
TE No.	Location				Temperature (°F)				
	X (in.)	R (in.)	θ (deg)	θ' (deg)					
1	0	8.500	300		459.4	455.0	401.6	319.6	228.4
2	30.125	0	0	300	1042.0	867.9	862.9	666.6	426.2
3	0	10.625	300		442.8	441.2	390.9	312.4	223.5
4	30.125	0	0	210	1020.0	865.3	843.0	650.2	416.4
5	0	15.500	300		432.7	429.6	382.4	307.5	222.2
6	30.125	0	0	120	1026.0	862.8	851.0	657.5	423.5
7	30.125	18.000	288		499.6	497.5	437.3	347.1	242.2
8	30.125	5.653	330	90	959.5	978.6	820.0	643.8	427.1
9	30.125	20.000	288		462.5	460.3	408.8	329.1	234.3
10	30.125	5.653	330	0	959.9	965.8	811.5	637.3	420.4
11	54.750	18.000	180		456.3	452.3	402.5	321.4	228.7
12	30.125	5.653	330	270	938.8	953.5	793.7	616.1	402.1
13	11.875	3.364	0		660.2	640.8	554.6	417.5	276.7
14	65.500	18.000	180		81.0	81.0	79.0	75.0	75.0
15	24.250	3.364	0		870.9	828.8	704.9	513.3	323.0
16	11.875	7.729	270		633.1	643.4	547.2	412.2	272.2
17	30.125	3.364	0		882.4	842.9	714.6	517.2	326.3
18	11.875	2.0765	300		717.3	647.7	604.2	438.5	284.2
19	36.000	3.364	0		881.9	840.3	712.6	519.0	325.7
20	30.125	7.729	270		715.5	758.3	600.3	456.7	300.9
21	60.000	0	0		573.6	566.7	494.5	383.1	263.3
22	30.125	2.0765	300		972.6	856.9	757.5	555.3	348.2
23	48.375	7.729	270		~640.0	~650.0	—	—	—
24	48.375	2.0765	300		829.1	690.1	699.5	536.4	350.1
25	6.000	15.500	285		448.4	446.9	395.5	313.4	224.7
26	11.875	15.500	285		480.0	478.4	421.0	331.4	235.1
27	24.250	15.500	285		526.2	525.0	457.5	357.1	249.1
28	30.125	15.500	285		538.0	536.8	467.3	354.7	252.6
29	36.000	15.500	285		526.7	535.5	466.8	365.2	253.0
30	48.375	15.500	285		515.6	513.2	450.8	355.7	249.1
31	55.000	15.500	285		511.2	507.9	447.7	353.0	246.9
32	6.000	10.625	285		474.7	472.6	413.8	324.6	229.9
33	11.875	10.625	285		521.3	520.2	450.4	349.9	243.8
34	24.250	10.625	285		592.9	592.3	505.2	386.7	262.7
35	30.125	10.625	285		605.1	604.8	515.8	394.3	264.7
36	36.000	10.625	285		604.7	604.4	515.8	395.2	267.1
37	48.375	10.625	285		564.2	562.2	486.3	377.3	258.7
38	55.000	10.625	285		543.2	539.9	471.7	367.4	253.9
39	18.125	18.000	112		475.5	474.0	416.9	330.5	234.2
40	11.875	18.000	288		456.9	455.3	400.4	317.9	227.2
41	30.125	18.000	112		507.7	505.7	444.6	350.8	247.3
42	30.125	20.000	112		470.7	468.6	416.5	332.7	238.1
43	48.375	18.000	288		480.0	476.2	425.4	340.0	240.7
44	42.125	18.000	112		490.6	480.1	433.0	344.0	243.8
45	60.250	18.000	180		180.4	177.9	166.0	142.1	120.7
46	60.000	10.625	180		543.2	539.5	473.0	367.9	255.7
47	60.000	5.000	180		561.6	556.1	486.3	376.4	259.6
48	60.000	8.500	0		537.6	531.1	466.4	363.7	252.9
49	56.750	15.500	0		519.3	515.1	453.3	356.2	248.8
50	11.875	10.604	270		525.9	523.4	454.6	352.6	244.8
51	11.875	15.479	270		484.1	481.6	422.5	331.9	234.3
52	11.875	4.9515	300		632.5	622.2	532.2	403.3	268.6
53	11.875	7.7015	300		567.4	564.1	483.9	372.4	254.0
54	11.875	10.5765	300		523.7	521.2	451.9	351.3	243.9
55	30.125	10.604	270		607.8	606.2	516.9	396.2	267.7
56	30.125	15.479	270		539.0	536.1	468.2	363.9	251.4
57	30.125	4.9515	300		816.4	796.1	668.5	491.4	313.5
58	30.125	7.7015	300		681.1	677.3	572.1	430.6	284.3
59	30.125	10.5765	300		607.8	605.8	516.9	397.1	267.3
60	48.375	10.604	270		564.8	560.6	486.5	377.8	258.9
61	48.375	15.479	270		514.0	509.3	448.8	354.9	247.0
62	48.375	4.9515	300		681.5	667.9	571.5	431.9	275.2
63	48.375	7.7015	300		611.7	606.7	513.2	400.6	270.0
64	48.375	10.5765	300		586.9	569.2	486.5	390.3	264.9
65	6.125	18.000	0		425.0	425.0	365.0	308.0	222.0
66	6.125	20.000	0		403.0	403.0	350.0	295.0	219.0
67	30.125	18.000	0		498.0	498.0	427.0	349.0	245.0
68	30.125	20.000	0		465.0	466.0	406.0	335.0	238.0
69	51.125	18.000	0		471.0	469.0	402.0	338.0	241.0
70	51.125	20.000	0		471.0	469.0	402.0	338.0	241.0

Table A-4. Normal Operating Conditions Test Data

	Test Number				19	20	21	22	23
	No. Elements				7	7	7	6	7
	Power Level, kW				17.298	25.185	33.072	34.100	33.704
	Location								
TE No.	X (in.)	R (in.)	θ (deg)	θ' (deg)					
1	0	8.500	300		801.4	889.3	928.0	921.7	862.2
2	30.125	0	0	300	1118.0	1328.0	1459.0	1387.0	1376.0
3	0	10.625	300		792.5	876.2	908.2	902.3	849.1
4	30.125	0	0	210	1110.0	1311.0	1453.0	1383.0	1372.0
5	0	15.500	300		783.0	859.3	886.7	879.6	828.0
6	30.125	0	0	120	1110.0	1311.0	1456.0	1386.0	1372.0
7	30.125	18.000	288		813.3	902.8	940.7	936.5	873.5
8	30.125	5.653	330	90	1066.0	1244.0	1366.0	1370.0	1297.0
9	30.125	20.000	288		791.6	870.3	899.3	895.2	831.8
10	30.125	5.653	330	0	1070.0	1280.0	1447.0	1414.0	1368.0
11	54.750	18.000	180		782.3	872.6	938.1	931.8	862.0
12	30.125	5.653	330	270	1048.0	1231.0	1350.0	1358.0	1282.0
13	11.875	3.364	0		910.7	1051.0	1148.0	1124.0	1081.0
14	65.500	18.000	180		115.0	120.0	122.0	120.0	120.0
15	24.250	3.364	0		1010.0	1220.0	1383.0	1343.5	1306.0
16	11.875	7.729	270		888.0	975.8	1061.0	1040.0	983.0
17	30.125	3.364	0		1024.0	1231.0	1391.0	1357.0	1317.0
18	11.875	2.0765	300		951.2	1108.0	1192.0	1125.0	1138.0
19	36.000	3.364	0		1010.0	1224.0	1389.0	1351.5	1303.0
20	30.125	7.729	270		930.1	1084.0	1238.0	1260.0	1191.0
21	60.000	0	0		843.1	961.5	1038.0	1029.0	959.3
22	30.125	2.0765	300		1078.0	1290.0	1440.0	1374.0	1361.0
23	48.375	7.729	270		886.3	1047.0	1107.0	1120.0	1042.0
24	48.375	2.0765	300		987.7	1150.0	1265.0	1167.5	1204.0
25	6.000	15.500	285		792.4	874.3	903.6	898.7	832.7
26	11.875	15.500	285		811.5	898.4	940.0	933.7	870.3
27	24.250	15.500	285		832.8	932.1	977.1	973.9	911.2
28	30.125	15.500	285		835.4	938.8	987.3	985.3	919.2
29	36.000	15.500	285		829.8	935.5	984.3	982.8	916.2
30	48.375	15.500	285		804.3	908.0	960.7	958.0	893.1
31	55.000	15.500	285		798.4	903.0	959.0	954.8	891.8
32	6.000	10.625	285		797.7	898.4	938.7	933.7	876.2
33	11.875	10.625	285		835.4	935.9	987.7	983.2	923.0
34	24.250	10.625	285		873.1	994.7	1065.0	1064.0	996.9
35	30.125	10.625	285		875.2	1002.3	1076.0	1076.0	1006.2
36	36.000	10.625	285		871.4	999.3	1074.0	1074.0	1002.9
37	48.375	10.625	285		837.1	956.6	1026.0	1024.0	955.9
38	55.000	10.625	285		822.2	935.5	1000.8	997.1	931.4
39	18.125	18.000	112		803.5	887.0	928.5	927.8	860.5
40	11.875	18.000	288		794.5	873.5	899.0	897.0	839.3
41	30.125	18.000	112		819.2	910.2	958.5	957.0	884.2
42	30.125	20.000	112		796.7	878.5	917.6	916.0	844.4
43	48.375	18.000	288		779.6	875.6	917.1	911.9	849.5
44	42.125	18.000	112		804.3	896.8	943.3	941.7	870.3
45	60.250	18.000	180		495.3	562.9	600.6	598.1	546.4
46	60.000	10.625	180		823.0	935.9	1001.6	996.3	926.8
47	60.000	5.000	180		834.5	951.1	1024.0	1017.0	950.0
48	60.000	8.500	0		820.0	934.0	~1000.0	990.0	925.0
49	56.750	15.500	0		813.7	921.6	982.0	978.0	909.5
50	11.875	10.604	270		833.2	932.2	982.0	978.3	918.8
51	11.875	15.479	270		808.6	893.4	927.9	924.8	867.3
52	11.875	4.9515	300		894.2	1025.0	1107.0	1102.0	1043.0
53	11.875	7.7015	300		858.7	971.1	1036.0	1035.0	972.0
54	11.875	10.5765	300		833.2	933.4	984.5	973.1	921.7
55	30.125	10.604	270		873.9	999.0	1072.0	1072.0	1002.4
56	30.125	15.479	270		833.2	935.0	984.1	983.1	919.2
57	30.125	4.9515	300		987.9	1175.0	1320.0	1306.0	1246.0
58	30.125	7.7015	300		916.5	1063.0	1163.6	1162.0	1093.0
59	30.125	10.5765	300		874.8	1000.6	1073.0	1071.0	1005.4
60	48.375	10.604	270		833.7	951.6	1022.0	1019.5	953.9
61	48.375	15.479	270		827.0	913.5	971.4	963.2	894.1
62	48.375	4.9515	300		904.7	1056.0	1161.0	1151.0	1089.0
63	48.375	7.7015	300		862.9	995.2	1080.0	1077.5	1011.0
64	48.375	10.5765	300		846.9	957.7	1027.0	1026.0	959.1
65	6.125	18.000	0		780.0	863.0	885.0	880.0	825.0
66	6.125	20.000	0		773.0	848.0	865.0	860.0	805.0
67	30.125	18.000	0		812.0	905.0	940.0	940.0	875.0
68	30.125	20.000	0		790.0	875.0	900.0	897.0	839.0
69	51.125	18.000	0		785.0	890.0	930.0	928.0	860.0
70	51.125	20.000	0		765.0	862.0	900.0	895.0	828.0

Table A-5. Loss of Coolant Accident Test Data

Test Number					24	25	26	27	28
No. Elements					7	7	7	7	6
Power Level, kW					8.309	17.152	25.297	34.045	33.933
TE No.	Location								
	X (in.)	R (in.)	θ (deg)	θ' (deg)					
1	0	8.500	300		624.9	870.8	1047.0	1185.0	1174.0
2	30.125	0	0	300	759.2	1173.0	1496.0	1799.0	1694.0
3	0	10.625	300		620.6	864.5	1038.0	1174.0	1163.0
4	30.125	0	0	210	756.6	1169.0	1490.0	1791.0	1696.0
5	0	15.500	300		615.4	852.2	1017.0	1144.0	1133.0
6	30.125	0	0	120	749.8	1170.0	1492.0	1795.0	1697.0
7	30.125	18.000	288		632.2	896.6	1080.0	1218.0	1210.0
8	30.125	5.653	330	90	753.2	1126.0	1403.0	1670.0	1661.0
9	30.125	20.000	288		622.7	878.4	1054.0	1183.0	1175.0
10	30.125	5.653	330	0	783.9	1165.0	1467.0	1770.0	1721.0
11	54.750	18.000	180		597.6	851.8	1016.0	1139.0	1135.0
12	30.125	5.653	330	270	743.0	1117.0	1391.0	1656.0	1649.0
13	11.875	3.364	0		674.0	988.0	1232.0	1453.0	1415.0
14	65.500	18.000	180		95.0	115.0	128.0	135.0	135.0
15	24.250	3.364	0		714.3	1095.0	1415.0	1711.0	1653.0
16	11.875	7.729	270		652.9	983.6	1181.0	1350.0	1356.0
17	30.125	3.364	0		713.5	1100.0	1426.0	1713.0	1658.0
18	11.875	2.0765	300		694.2	1118.0	1266.0	1497.0	1417.0
19	36.000	3.364	0		705.8	1091.0	1406.0	1700.0	1645.0
20	30.125	7.729	270		707.0	1000.0	1247.0	1472.0	1472.0
21	60.000	0	0		633.1	909.6	1101.0	1253.0	1244.0
22	30.125	2.0765	300		737.9	1143.0	1474.0	1776.0	1678.0
23	48.375	7.729	270		683.0	983.1	1200.0	1352.0	1346.0
24	48.375	2.0765	300		693.0	1041.0	1292.0	1517.0	1418.0
25	6.000	15.500	285		620.2	866.6	1041.0	1174.0	1166.0
26	11.875	15.500	285		632.3	887.8	1071.0	1201.0	1196.0
27	24.250	15.500	285		641.8	913.0	1110.0	1265.0	1257.0
28	30.125	15.500	285		640.1	914.7	1112.0	1268.0	1260.0
29	36.000	15.500	285		634.5	907.1	1101.0	1252.0	1245.0
30	48.375	15.500	285		614.2	874.3	1049.0	1180.0	1173.0
31	55.000	15.500	285		609.0	866.2	1038.0	1166.0	1158.0
32	6.000	10.625	285		627.1	881.0	1065.0	1212.0	1201.0
33	11.875	10.625	285		641.8	910.5	1109.0	1271.0	1261.0
34	24.250	10.625	285		657.8	951.5	1174.0	1364.0	1355.0
35	30.125	10.625	285		656.5	954.3	1178.0	1369.0	1360.0
36	36.000	10.625	285		651.3	947.5	1167.0	1353.0	1345.0
37	48.375	10.625	285		628.9	907.9	1102.0	1259.0	1250.0
38	55.000	10.625	285		620.7	889.0	1073.0	1217.0	1208.0
39	18.125	18.000	112		633.2	889.9	1075.0	1214.0	1208.0
40	11.875	18.000	288		624.1	873.0	1048.0	1181.0	1171.0
41	30.125	18.000	112		638.8	904.2	1094.0	1233.0	1229.0
42	30.125	20.000	112		629.7	886.9	1068.0	1198.0	1194.0
43	48.375	18.000	288		601.6	850.1	1013.0	1128.0	1123.0
44	42.125	18.000	112		620.7	878.9	1056.0	1183.0	1179.0
45	60.250	18.000	180		372.8	538.7	657.4	748.6	744.8
46	60.000	10.625	180		623.7	891.6	1074.0	1215.0	1207.0
47	60.000	5.000	180		629.3	902.5	1093.0	1243.0	1232.0
48	60.000	8.500	0		622.8	890.0	1072.0	1216.0	1202.0
49	56.750	15.500	0		617.7	879.8	1055.0	1190.0	1181.0
50	11.875	10.604	270		640.6	906.8	1105.0	1267.0	1258.0
51	11.875	15.479	270		630.6	883.2	1066.0	1210.0	1200.0
52	11.875	4.9515	300		666.8	968.5	1201.0	1413.0	1391.0
53	11.875	7.7015	300		651.4	931.3	1144.0	1328.0	1315.0
54	11.875	10.5765	300		641.0	906.4	1105.0	1269.0	1256.0
55	30.125	10.604	270		656.5	950.3	1173.0	1363.0	1354.0
56	30.125	15.479	270		639.3	911.9	1109.0	1265.0	1256.0
57	30.125	4.9515	300		702.0	1064.0	1365.0	1648.0	1618.0
58	30.125	7.7015	300		674.6	993.8	1245.0	1473.0	1460.0
59	30.125	10.5765	300		657.8	952.8	1176.0	1364.0	1355.0
60	48.375	10.604	270		628.5	903.0	1098.0	1254.0	1247.0
61	48.375	15.479	270		615.9	886.8	1048.0	1173.0	1166.0
62	48.375	4.9515	300		659.1	974.4	1212.0	1418.0	1396.0
63	48.375	7.7015	300		641.0	932.1	1144.0	1322.0	1312.0
64	48.375	10.5765	300		629.4	907.0	1101.0	1254.0	1247.0
65	6.125	18.000	0		612.0	848.0	1018.0	1143.0	1133.0
66	6.125	20.000	0		609.0	840.0	1003.0	1125.0	1113.0
67	30.125	18.000	0		628.0	892.0	1080.0	1217.0	1208.0
68	30.125	20.000	0		623.0	881.0	1058.0	1188.0	1178.0
69	51.125	18.000	0		603.0	856.0	1015.0	1132.0	1125.0
70	51.125	20.000	0		597.0	835.0	980.0	1085.0	1080.0

Table A-6. Heat Loss Test Data

		Test Number	29	30	31	32	33	34	35	36	37	38	39	40		
		Pressure, psia	14.4	1.0	0.1	0.1	14.4	1.0	14.4	1.0	0.1	0.1	1.0	14.4		
		Power Level, kW	2.091	1.920	1.603	2.782	3.372	2.996	4.507	3.869	3.474	4.867	5.678	6.374		
		Location														
TE No.	X (in.)	R (in.)	θ (deg)	θ' (deg)												
1	0	8.500	300		599.4	579.7	564.5	788.3	787.8	778.0	904.7	884.7	887.5	1056.0	1059.0	1072.0
2	30.125	0	0	300	637.9	622.6	600.9	841.5	847.8	838.8	990.5	963.6	964.8	1156.0	1173.0	1194.0
3	0	10.625	300		597.3	578.4	563.1	786.6	786.1	775.9	901.8	881.7	884.5	1053.0	1055.0	1068.0
4	30.125	0	0	210	637.0	622.6	600.0	843.6	848.6	838.0	985.0	961.9	962.6	1149.0	1170.0	1191.0
5	0	15.500	300		595.1	574.6	559.2	782.4	781.9	770.8	895.9	872.0	874.8	1041.0	1042.0	1054.0
6	30.125	0	0	120	636.6	620.4	599.2	843.2	849.4	837.6	981.6	955.2	955.9	1143.0	1159.0	1178.0
7	30.125	18.000	288		607.7	593.1	576.6	804.5	802.3	793.8	922.0	904.1	906.9	1077.0	1080.0	1092.0
8	30.125	5.653	330	90	639.2	623.0	601.8	841.5	848.6	836.3	980.8	956.0	952.9	1139.0	1154.0	1168.0
9	30.125	20.000	288		605.9	591.8	575.8	802.4	799.7	791.7	918.6	900.7	903.5	1074.0	1075.0	1086.0
10	30.125	5.653	330	0	644.8	631.2	608.7	850.4	860.0	846.5	994.3	967.0	966.9	1153.0	1170.0	1190.0
11	54.750	18.000	180		580.8	570.6	555.3	772.6	766.5	761.4	881.1	869.5	871.9	1034.0	1035.0	1043.0
12	30.125	5.653	330	270	633.1	618.4	597.9	835.5	842.7	830.4	974.6	949.2	949.1	1132.0	1146.0	1164.0
13	11.875	3.364	0		612.0	590.7	578.4	808.8	812.1	800.2	936.8	913.7	914.5	1094.0	1102.0	1117.0
214	30.125	20.734	112		579.5	568.9	555.3	782.8	773.8	768.7	892.1	878.3	882.4	1055.0	1054.0	1062.0
15	24.250	3.364	0		619.8	603.7	586.2	823.6	829.9	818.0	963.0	937.4	937.3	1124.0	1137.0	1155.0
216	42.125	20.984	288		548.1	538.9	526.5	742.8	733.3	729.9	845.6	834.8	838.5	1002.0	1000.0	1006.0
17	30.125	3.364	0		617.5	604.5	586.2	822.5	829.3	818.7	962.0	937.2	937.4	1124.0	1137.0	1155.0
218	30.125	20.734	288		581.2	569.7	555.7	785.8	776.8	770.4	895.5	876.7	885.0	1059.0	1056.0	1066.0
19	36.000	3.364	0		617.2	605.3	585.3	822.8	828.2	817.2	960.5	937.0	937.3	1123.0	1136.0	1152.0
220	30.125	20.984	288		554.7	542.7	529.5	747.9	739.7	734.2	853.3	839.4	844.0	1010.0	1010.0	1019.0
21	60.000	0	0		601.6	590.1	574.0	799.0	793.4	788.7	913.2	898.6	901.4	1069.0	1071.0	1081.0
222	30.125	22.234	288		379.5	358.2	345.2	480.9	497.6	489.2	577.6	564.2	561.1	660.2	680.4	688.2
223	30.125	23.484	288		167.8	155.1	148.6	191.4	212.5	205.6	249.6	239.7	232.5	275.1	302.1	312.1
224	30.125	23.734	288		113.4	104.6	97.5	123.9	143.1	138.3	168.2	161.3	152.6	183.3	207.4	216.1
25	6.000	15.500	285		601.4	580.2	564.2	792.5	791.6	780.0	907.6	882.4	885.1	1061.0	1061.0	1074.0
26	11.875	15.500	285		605.7	588.5	572.5	798.9	798.0	787.7	915.2	894.7	896.9	1070.0	1070.0	1083.0
27	24.250	15.500	285		608.3	593.2	576.9	804.9	803.9	794.9	924.1	906.0	907.4	1081.0	1084.0	1096.0
28	30.125	15.500	285		607.9	594.1	577.3	804.5	803.1	795.3	923.7	906.9	908.7	1082.0	1085.0	1096.0
29	36.000	15.500	285		605.7	592.5	576.0	802.8	800.6	793.6	920.7	905.2	906.6	1079.0	1082.0	1092.0
30	48.375	15.500	285		597.9	586.7	570.8	793.0	788.7	784.2	905.1	893.4	895.2	1062.0	1064.0	1071.0
31	55.000	15.500	285		593.6	582.8	567.3	787.9	782.3	778.3	896.7	886.7	888.0	1053.0	1054.0	1060.0
32	6.000	10.625	285		602.2	583.7	568.2	794.7	795.5	784.2	911.9	889.2	891.0	1067.0	1068.0	1081.0
33	11.875	10.625	285		606.6	590.2	573.8	801.5	802.3	791.5	921.1	900.1	901.5	1077.0	1079.0	1092.0
34	24.250	10.625	285		610.5	595.8	579.0	809.1	810.3	800.8	933.4	913.6	914.6	1092.0	1097.0	1110.0
35	30.125	10.625	285		611.2	595.8	578.2	807.9	809.1	800.0	932.5	914.0	914.6	1092.0	1098.0	1109.0
36	36.000	10.625	285		607.4	595.0	577.7	806.6	807.0	798.7	929.6	912.8	913.7	1090.0	1095.0	1106.0
37	48.375	10.625	285		598.8	588.5	571.6	796.4	793.4	788.5	911.0	898.4	899.4	1071.0	1074.0	1082.0
38	55.000	10.625	285		594.4	585.4	569.0	791.7	787.8	783.0	904.3	892.5	893.9	1062.0	1065.0	1070.0
39	18.125	18.000	112		606.1	590.2	573.8	798.9	801.9	789.4	919.0	897.6	899.4	1070.0	1071.0	1084.0
40	11.875	18.000	288		603.1	587.2	571.2	796.0	796.8	785.1	912.3	890.0	892.3	1065.0	1065.0	1077.0
41	30.125	18.000	112		609.6	593.2	576.9	804.5	804.8	794.5	924.9	903.5	907.0	1077.0	1079.0	1093.0
42	30.125	20.000	112		607.4	592.4	575.9	802.8	802.3	792.3	920.7	901.0	904.1	1073.0	1075.0	1087.0
43	48.375	18.000	288		597.5	585.9	570.3	793.0	787.0	782.5	902.2	889.2	891.8	1056.0	1056.0	1064.0
44	42.125	18.000	112		602.7	589.3	573.4	798.9	795.0	788.9	913.1	897.6	899.8	1068.0	1070.0	1079.0
45	60.250	18.000	180		358.7	354.2	344.5	485.7	479.0	480.7	556.6	552.3	553.3	665.1	666.3	668.1
46	60.000	10.625	180		598.8	586.7	570.3	794.2	789.5	783.8	905.9	892.1	893.9	1061.0	1062.0	1071.0
47	60.000	5.000	180		600.1	588.0	572.1	796.0	792.0	786.4	909.3	895.1	896.5	1065.0	1067.0	1076.0
48	60.000	8.500	0		446.4	446.4	431.7	592.4	587.2	588.5	670.9	669.6	668.3	777.7	778.6	778.1
49	56.750	15.500	0		596.1	585.0	568.2	790.5	784.1	779.5	900.0	887.0	889.1	1054.0	1054.0	1063.0
250	18.125	22.234	288		385.9	363.7	348.1	485.9	509.2	495.1	587.4	568.8	564.0	668.6	694.2	707.4
251	18.125	23.484	288		183.4	167.7	157.0	204.5	234.5	221.8	271.7	256.6	247.8	282.0	319.7	335.5
252	42.125	22.234	288		374.7	355.6	341.8	478.4	489.3	485.9	566.1	557.1	552.7	651.4	672.7	677.0
253	42.125	23.484	288		167.9	158.6	150.1	199.7	217.4	212.2	256.6	248.2	240.8	294.2	316.6	324.2
254	11.875	20.984	112		546.8	530.1	518.1	724.4	721.8	711.9	826.5	812.2	817.2	977.9	977.1	987.8
255	11.875	22.235	112		399.3	368.6	354.4	492.5	520.5	501.7	590.9	575.8	570.6	661.7	687.7	706.1
256	11.875	22.484	112		184.7	164.7	152.2	198.4	236.5	224.6	280.2	261.1	252.2	297.8	318.8	343.6
257	30.125	20.984	112		547.8	536.2	522.7	736.9	726.1	721.1	837.4	825.2	830.3	995.1	992.4	999.1
258	30.125	22.235	112		387.7	369.1	353.9	493.8	512.1	503.9	590.9	577.1	572.3	676.3	699.3	706.6
259	30.125	23.484	112		168.3	155.6	146.2	191.1	216.6	208.4	259.7	248.2	238.1	287.3	316.1	327.4
260	48.375	20.984	112		545.1	540.1	525.8	738.6	726.0	727.1	837.9	831.6	835.0	995.1	995.3	997.8
261	48.375	22.234	112		377.4	366.8	352.1	495.1	500.4	505.2	583.9	582.3	577.5	691.3	713.9	710.8
262	48.375	23.484	112		167.9	168.1	156.1	210.1	227.0	227.9	273.0	269.1				

page blank

APPENDIX B

Drawing List

I-10583-QG-001-D	Heat Block Instrument Schematic
E-10583-RE-500	Schematic Diagram-Power System
E-10583-RE-501	Variac Cabinet No. 1 - Assembly and Wiring Diagram
D-115D-1	Heat Block Subassembly and Details
D-115D-2	Test Location Plan
D-115D-3	Heater Subassembly and Details
D-115D-4	Heater Ceramic Details
C-115D-5	Insulator Details
D-115D-6	General Assembly
D-115D-7	Heat Shield Subassembly
D-115D-8	Vacuum Can Subassembly
D-115D-9	Shell Subassembly
D-115D-10	Instrument Support Stand and Subassembly
D-115D-11	Caliper Subassembly
D-115D-12	Thermocouple Locations
D-115D-13	Thermocouple Probe Assemblies
D-115D-14	Sand Box Assembly
D-115D-15	Utilities
D-115D-16	Fusible Insulation and Thermocouple Subassembly
E-115D-17	Inner and Outer Mesh Liner Weldments
E-115D-18	Insulation Mandrel Subassembly
E-115D-19	Insulation Mandrel Weldments
E-115D-20	Insulation Mandrel Weldments and Details
E-115D-21	Fusible Insulation Retainer Weldment and Details

REFERENCES

1. Metals Handbook, American Society for Metals, p. 309, January 1958.
2. G. Samuels, Comparison of Nickel and Iron Heat Block-Shields, USAEC Report ORNL-TM-3213, Oak Ridge National Laboratory, January 1971.
3. A. P. Fraas and G. Samuels, Isotope Kilowatt Program Quarterly Progress Report for Period Ending December 30, 1971, USAEC Report ORNL-TM-3687, Oak Ridge National Laboratory, April 1972.

Internal Distribution

1. S. E. Beall	37. A. M. Perry
2. T. A. Butler	38. R. A. Robinson
3. W. B. Cottrell	39. M. W. Rosenthal
4. W. C. Cox	40. A. F. Rupp
5. F. L. Culler	41-50. G. Samuels
6. R. G. Donnelly	51. M. R. Sheldon
7-16. A. P. Fraas	52. A. C. Schaffhauser
17. J. H. Frye, Jr.	53. M. J. Skinner
18. J. H. Gillette	54. A. M. Smith
19. A. G. Grindell	55. I. Spiewak
20. K. W. Haff	56. D. A. Sundberg
21. H. W. Hoffman	57. D. B. Trauger
22. R. S. Holcomb	58. J. J. Tudor
23. P. R. Kasten	59. A. M. Weinberg
24-28. M. E. Lackey	60. G. D. Whitman
29. E. Lamb	61. J. V. Wilson
30. M. E. LaVerne	62. H. C. Young
31. D. B. Lloyd	63. Biology Library
32. M. I. Lundin	64-65. Central Research Library
33. R. N. Lyon	66. Y-12 Document Reference Section
34. R. E. MacPherson	67-91. Laboratory Records Department
35. H. C. McCurdy	92. Laboratory Records Department (RC)
36. A. J. Miller	

External Distribution

- 93. D. F. Cope, RDT Site Office, ORNL
- 94. W. M. Crim, Jr., Research and Technology Department, Building 322,
Ft. Belvoir, Virginia 22060.
- 95. R. E. English, NASA, Lewis Research Center, Cleveland, Ohio
44135.
- 96. E. E. Fowler, Division of Applied Technology, AEC, Washington, D.C.
20545.
- 97-100. W. D. Holloman, Division of Reactor Development and Technology,
AEC, Washington, D.C. 20545.
- 101-102. M. Klein, Division of Space Nuclear Systems, AEC, Washington, D.C.
20545.
- 103. J. J. Lynch, NASA Headquarters, Washington, D.C. 20546.
- 104. S. V. Manson, NASA Headquarters, Washington, D.C. 20546.
- 105. T. A. McLaughlin, Isotopic Auxiliary Power Branch, AEC,
Washington, D.C. 20545.
- 106-110. Nuclear Engineering Division, Naval Facilities Engineering Command,
Washington, D.C. 20545.
- 111. J. Pidkowitz, RDT Site Office, ORNL.
- 112. W. B. Taylor, Technical Director. U.S. Army Mobility Equipment
Research and Development Center, Ft. Belvoir, Virginia 22060.
- 113. J. G. Whiteaker, Chief, Auxiliary Projects Branch, Division of
Reactor Development and Technology, AEC, Washington, D.C. 20545
- 114. E. S. Wilson, Space Nuclear Systems, AEC, Germantown, Maryland
20767.
- 115-117. Director, Division of Reactor Licensing, USAEC, Washington, D.C.
20545.
- 118-119. Director, Division of Reactor Standards, USAEC, Washington, D.C.
20545.
- 120-136. Manager, Technical Information Center, AEC. (For ACRS Members)
- 137. Research and Technical Support Division, AEC, ORO.
- 138-139. Technical Information Center, AEC.