LOCKHEED MARTIN ENERGY RESEARCH LIBRARIES
3 4456 0514416 2

CENTRAL RESEARCH LIBRARY
DOCUMENT COLLECTION

OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

ORNL-TM-3292

cy. 60

ISOTOPE KILOWATT PROGRAM QUARTERLY PROGRESS REPORT FOR PERIOD ENDING DECEMBER 31, 1970

A. P. Fraas, Program Director

OAK RIDGE NATIONAL LABORATORY
CENTRAL RESEARCH LIBRARY
DOCUMENT COLLECTION
LIBRARY LOAN COPY
DO NOT TRANSFER TO ANOTHER PERSON
If you wish someone else to see this document, send in name with document and the library will arrange a loan.
UCN-7969
(3 3-67)

NOTICE This document contains information of a preliminary nature and was prepared primarily for internal use at the Oak Ridge National Laboratory. It is subject to revision or correction and therefore does not represent a final report.

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.

ORNL-TM-3292

Contract No. W-7405-eng-26

REACTOR DIVISION

ISOTOPE KILOWATT PROGRAM QUARTERLY PROGRESS REPORT FOR PERIOD ENDING DECEMBER 31, 1970

A. P. Fraas, Program Director

FEBRUARY 1971

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

LOCKHEED MARTIN ENERGY RESEARCH LIBRARIES

3 4456 0514416 2

FOREWORD

In 1968 the Oak Ridge National Laboratory started work on a program to evaluate various types of radioisotope energy conversion systems for the production of 1 to 10 kw of electric power for terrestrial and undersea applications. This program is being carried out for the U.S. Atomic Energy Commission Division of Reactor Development and Technology and the Naval Facilities Engineering Command. The first phase of the program was a parametric and engineering analysis comparing the principal isotope fuels and the principal types of energy conversion system that have been proposed for applications of this sort, and the preparation of a set of conceptual designs for the more attractive systems. That work was completed in the summer of 1969 and was reported in Ref. 1. In October of 1969 ORNL was asked to proceed with a detailed engineering study of the three most promising systems selected from those covered in Phase I of the program. These three systems now under study are a 2-kw(e) thermoelectric system, a 3-kw(e) steam Rankine cycle system, and a 5-kw(e) organic Rankine cycle system.

The first step in the effort was to evolve a program plan for a three-year effort to be carried out in calendar years 1970, 1971, and 1972. The conceptual designs presented in Task I were reexamined and possible improvements were considered with particular attention to the difficult development problems. A variety of engineering tests was considered as a means of evaluating the technology, solving the principal technical problems, and investigating engineering uncertainties that should be resolved before settling on the design of a prototype power plant. In view of the limited funds and the desirability of narrowing the field to a single Rankine cycle system, particular attention was given to the relative merits of the steam and organic Rankine cycle systems.

The first quarter of 1970 was devoted to firming up reference designs for the three types of system, selecting the most crucial experiments required to evaluate the technology, and settling on a program plan for the three-year effort.[2] With this first quarter's work as a foundation, the second quarter was then devoted to firming up the details of the reference designs, firming up details of the experiments to be conducted, and preparation of topical reports covering the three reference designs with their

associated experiments.[3] The third and fourth quarters have been devoted to the design and construction of the most urgent experiments.[4] Subsequent quarters will be devoted to the design and construction of additional test equipment and to tests designed to investigate vital questions in the technology. As the results of these tests become available, the reference designs will be revised accordingly. The objective is to evolve by December 1972 a set of designs for two prototype power plants with a clear delineation of the development program required in each case including firm estimates of the cost and time for the various programmatic steps.

This is the fourth in a series of quarterly progress reports. Topical reports present the work carried out in particular areas when key tasks are completed. When a topical report is issued essentially concurrently with a quarterly report, to avoid duplication only a very brief summary of its contents is included in the quarterly.

CONTENTS

	Page
1. SUMMARY	1
2. ORGANIC SYSTEM	2
Organic Capsule Tests	2
Dose Rate Calibration	2
Dose Rate Near the Shield	4
Installation	4
Endurance Test	4
Heat Block-Shield Design	11
Organic Loop Decomposition Test	12
3. STEAM SYSTEM	13
Reentry Tube Boiler Tests	13
Reference Design of a Steam System	13
4. THERMOELECTRIC SYSTEM	14
Heat Transfer Test	15
Heat Pipe Design	15
Heat Pipe Fabrication	15
Full-Scale Thermoelectric Module	17
Test Program	18
Module Design for Advanced Materials	18
5. THERMAL FUSE AND INSULATION	18
6. FUEL CAPSULES	23
REFERENCES	24

ISOTOPE KILOWATT PROGRAM QUARTERLY REPORT
FOR PERIOD ENDING DECEMBER 31, 1970

1. SUMMARY

The organic fluid capsule test system was constructed, the test installation was completed, the system was brought up to temperature, and endurance testing was started at 600°F on December 30, 1970.

The heat pipe and associated test equipment for the thermoelectric heat transfer test were fabricated, the test installation was completed, and the shakedown tests were initiated. Some difficulty was experienced with overcooling of the condenser end of the heat pipe during the initial startup but this was overcome by changing the startup procedure. The heat pipe was started up and operated satisfactorily during the last week of December.

Analyses of the relative performance characteristics of iron and nickel heat block-shield assemblies have been completed. The study shows that nickel will be required if advanced thermoelectric materials become available and are to be operated with a hot junction temperature of 1350°F, but for the rest of the systems steel will be satisfactory. Nickel is generally superior to steel, but steel is adequate for the other applications. The cost and delivery time are, of course, much greater for nickel.

The 4.10-in. diameter fuel capsule for the $SrTiO_3$ source has been evaluated and a detailed report validating the capsule design with a safety analysis has been prepared.

The following reports have been issued during this quarter:

ORNL-TM-2803, Performance Characteristics of Cylindrical Heat Pipes for Nuclear Electric Space and Undersea Power Plants, January 1971

3M Report No. 8484-004, Reference Design Report, Advanced Technology Thermoelectric Module for a 2 kw Undersea Radioisotope Power Plant, Dec. 15, 1970.

The following reports were completed during the quarter and are now in reproduction:

ORNL-TM-2960, Reference Design for an Isotope Power Unit Employing an Organic Fluid Rankine Cycle.

ORNL-TM-3213, Comparison of Nickel and Iron Heat Block-Shields.

The following reports were completed in draft form and are being reviewed:

ORNL-TM-2961, Reference Design of a 3 kw(e) Steam Rankine Cycle System for an Isotope Power Plant.

ORNL-TM-3236, Performance Characteristics of a Short Reentry Tube Steam Generator at Low Steam Output.

ORNL-TM-3230, Fueled Capsule Design and Evaluation: A Safety Analysis.

2. ORGANIC SYSTEM

The effort on the organic Rankine cycle system during this quarter has been concerned primarily with three major areas. The first has been construction, calibration, installation, shakedown, and initiation of endurance tests on capsules filled with the organic fluid and operated at 600°F at various radiation dose rates. The second has been concerned with completion of a critical design comparison of steel and nickel heat block-shield assemblies for the full range of Rankine and thermoelectric power units believed to be of interest. The third item has been the design of an organic fluid circulating test loop in which the boiler will have an output about 25% that of the full-scale system and the turbine-generator unit will be replaced with a surrogate unit.

Organic Capsule Tests

The design of the organic fluid capsule test system was outlined in the previous quarterly report.[4] For the convenience of the reader an end view of the shield assembly showing the array of capsule test holes is reproduced here in Fig. 1 to indicate the way in which a wide range of radiation dose levels has been provided.

Dose Rate Calibration

The radiation dose rate was determined as a function of axial position for each of the test holes of Fig. 1 by inserting 15-mg LiF rods 1 mm in diameter by 6 mm long and irradiating them for appropriate periods. The

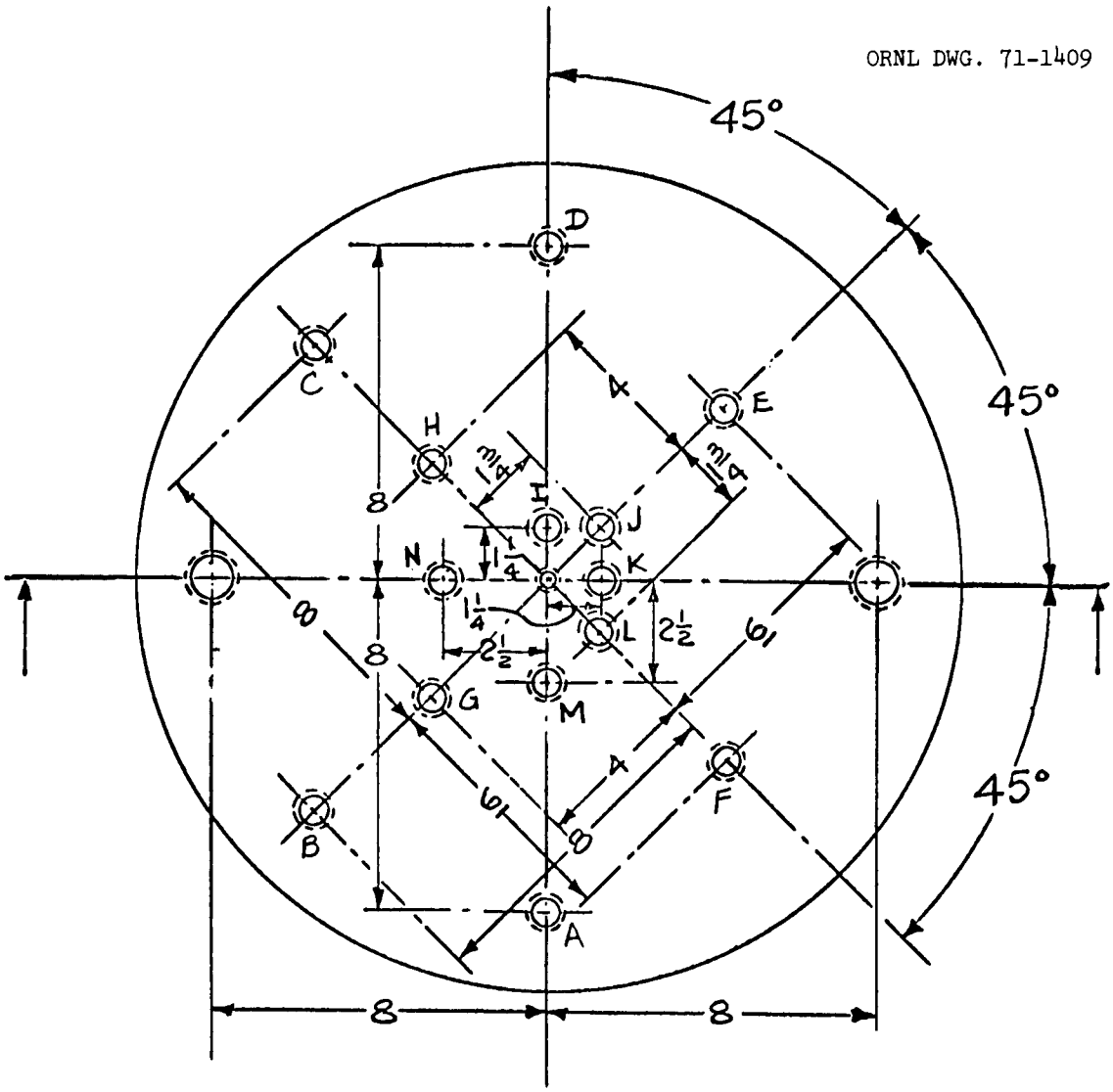

Fig. 1. Location of Holes in the Organic Capsule Decomposition Test Heat Block.

pellets were then removed and the extent to which they had been activated was determined. The results are plotted in Figs. 2 thru 7. The values agree well with the design calculations.

Dose Rate Near the Shield

The radiation dose level in the vicinity of the shield was monitored by Health Physics personnel to determine the maximum dose rate as well as the accumulated dose during actual loading of the test capsules. A maximum dose rate of 250 mr/hr was observed at the upper surface of the block when the plugs were removed from the two holes closest to the source. At a distance of 1 ft above the surface the dose rate was in the order of 70 mr/hr directly over the hole. The loading time per hole was approximately 2 min, and the entire procedure was completed within 35 min.

Installation

After the heaters and thermocouples were installed on the shield block and the OD and bottom of the block covered with 6 in. of insulation, the temperature control, alarm and readout were checked out. Results of the test on the temperature controller indicated the block can be controlled between ±2°F of a given set point.

In loading the capsules with the stainless steel wires and Dowtherm A some difficulties were experienced with capsule breakage when the steel wires were inserted, and with excessive splashing of the Dowtherm A in the relatively slender tubes. These difficulties were finally overcome but caused some delay.

Endurance Test

The capsules were installed in the shield block the latter part of December. The system was heated gradually and brought to the 600°F operating temperature on December 30 with no difficulties of consequence. The endurance test began on that date with automatic controls and data logging in the Dextir computer used here for that purpose.

ORNL DWG. 71-1410

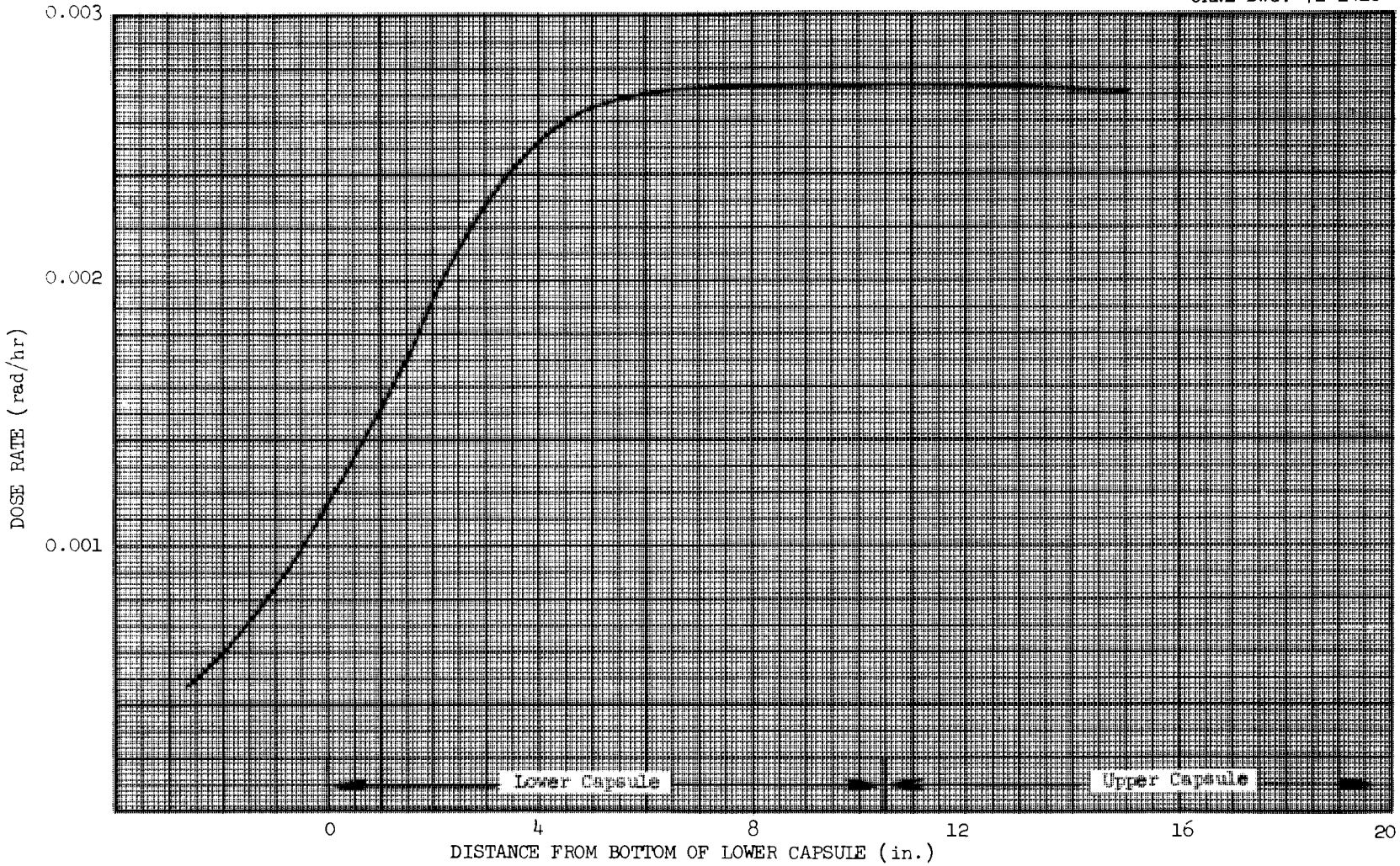

Fig. 2. Dose Rate in Holes A, B, C and D.

ORNL DWG. 71-1411

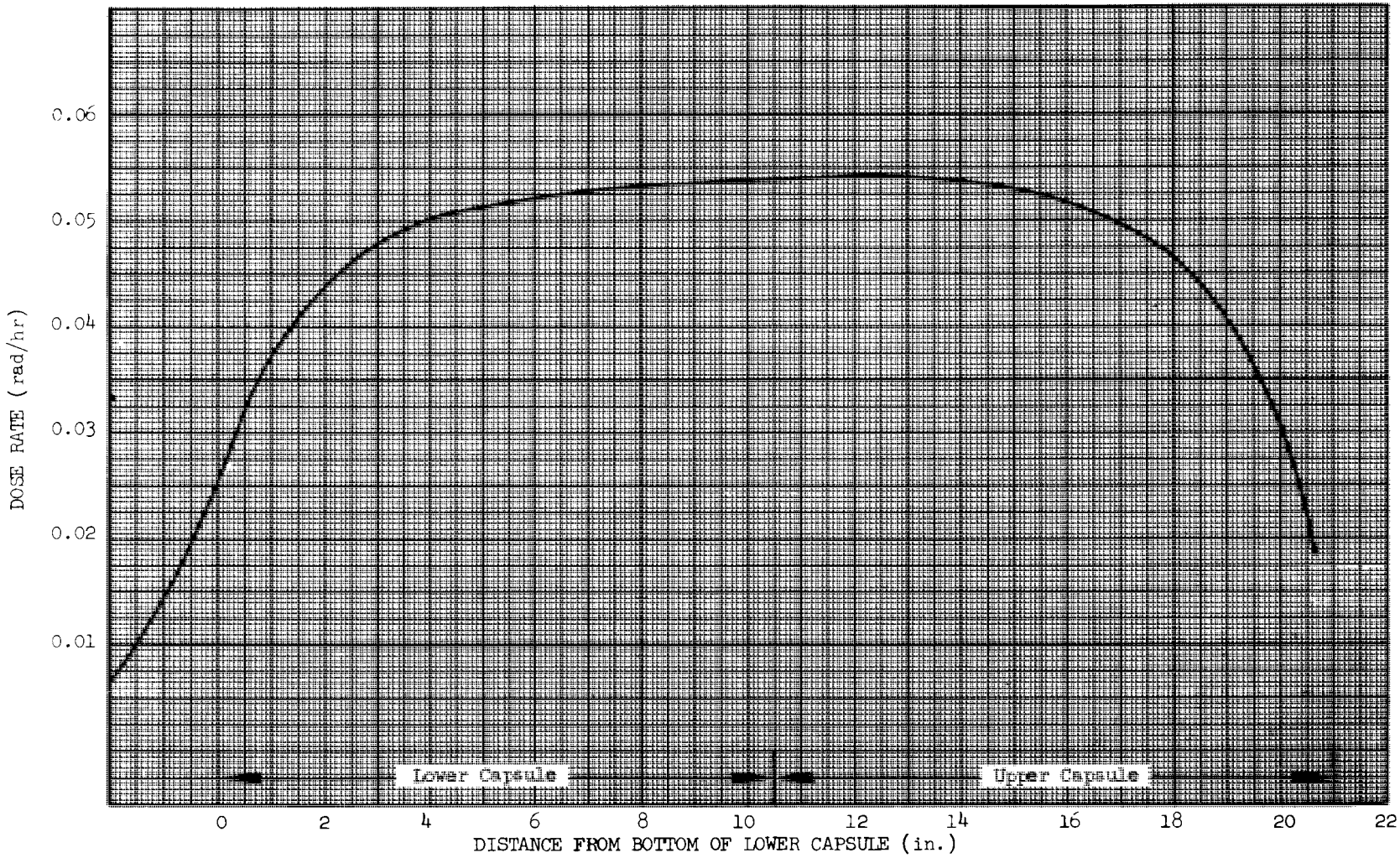

Fig. 3. Dose Rate in Holes E and F.

ORNL DWG. 71-1412

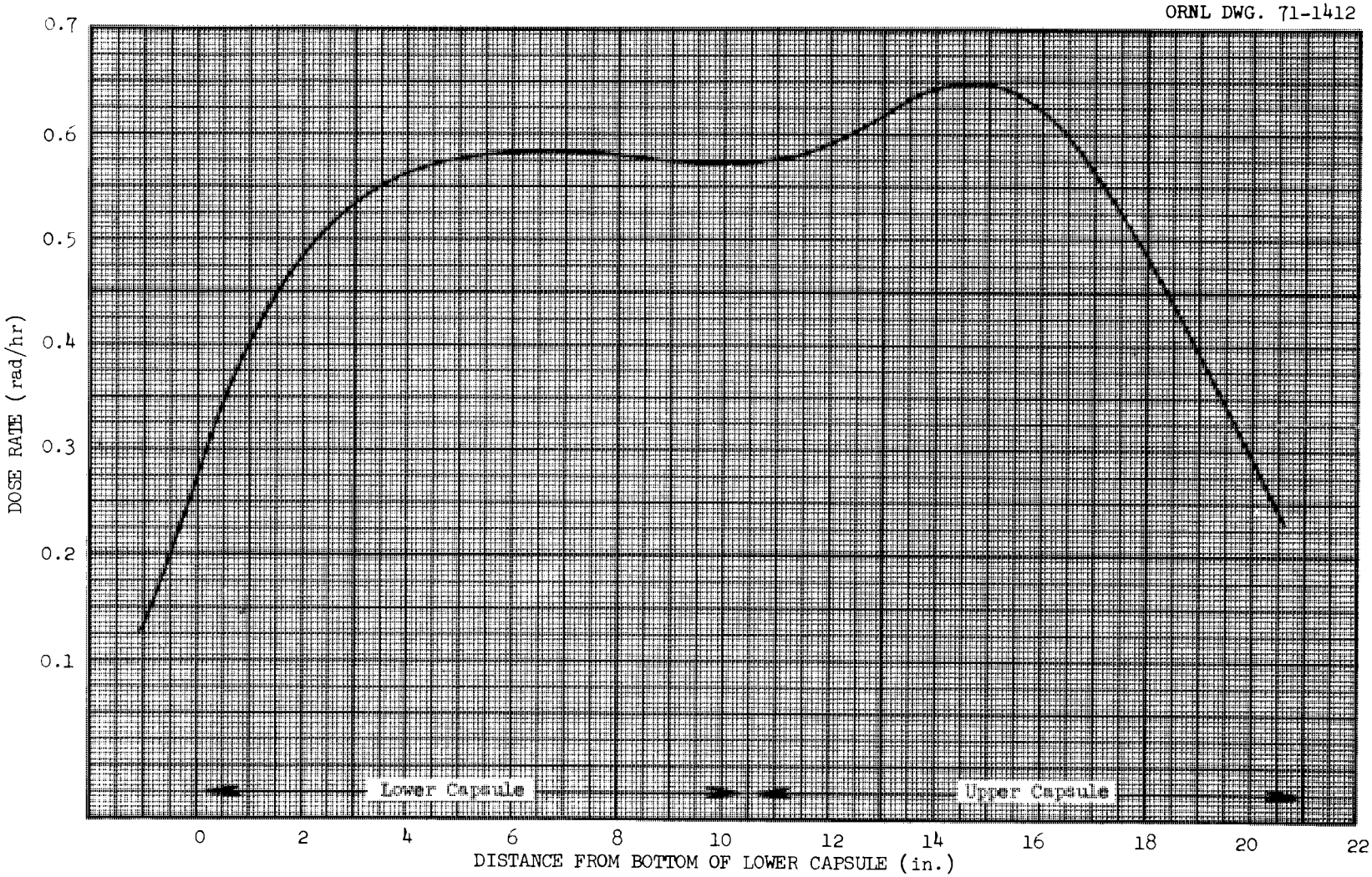

Fig. 4. Dose Rate in Holes G and H.

ORNL DWG. 71-1413

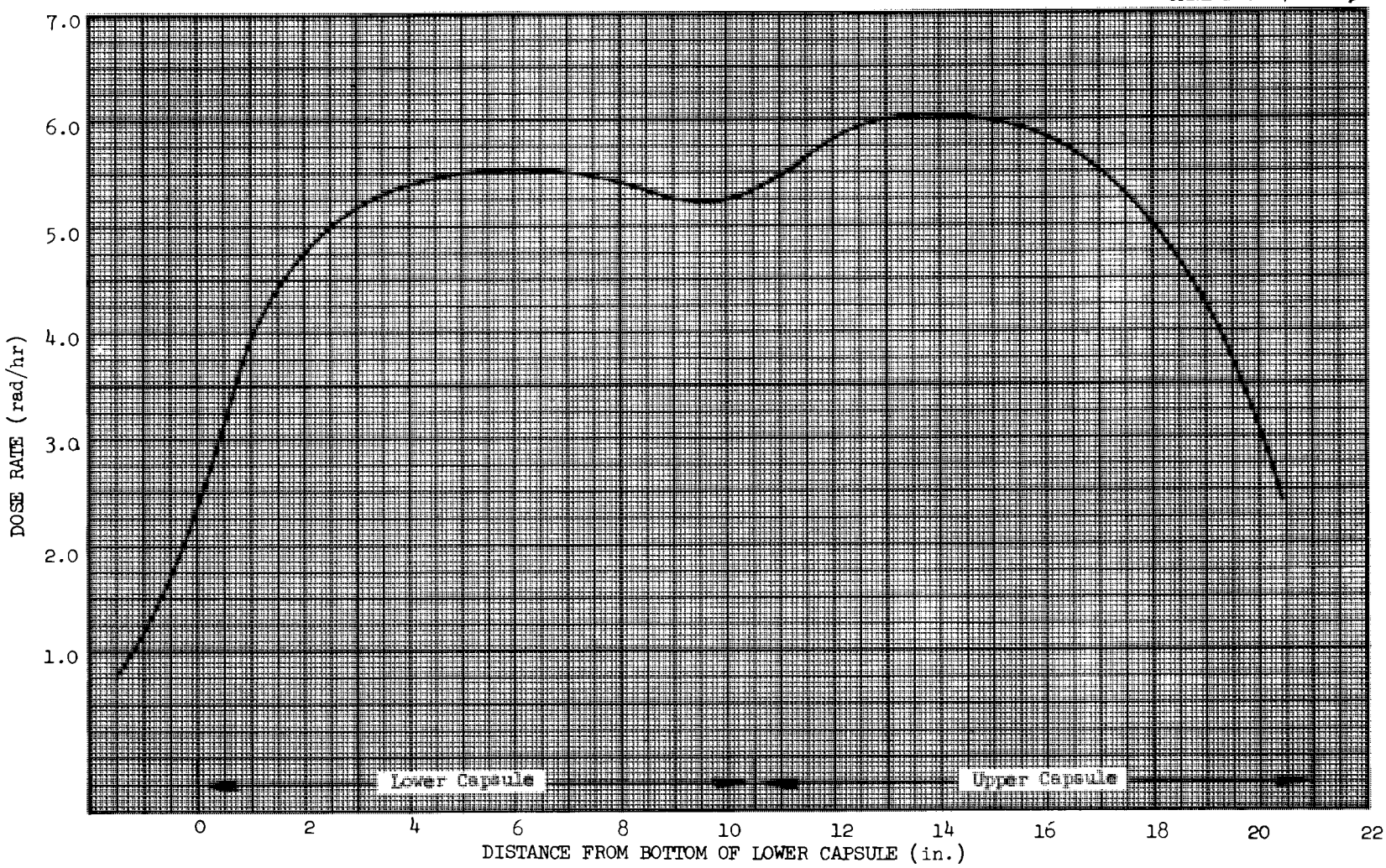

Fig. 5. Dose Rate in Holes M and N.

ORNL DWG. 71-1414

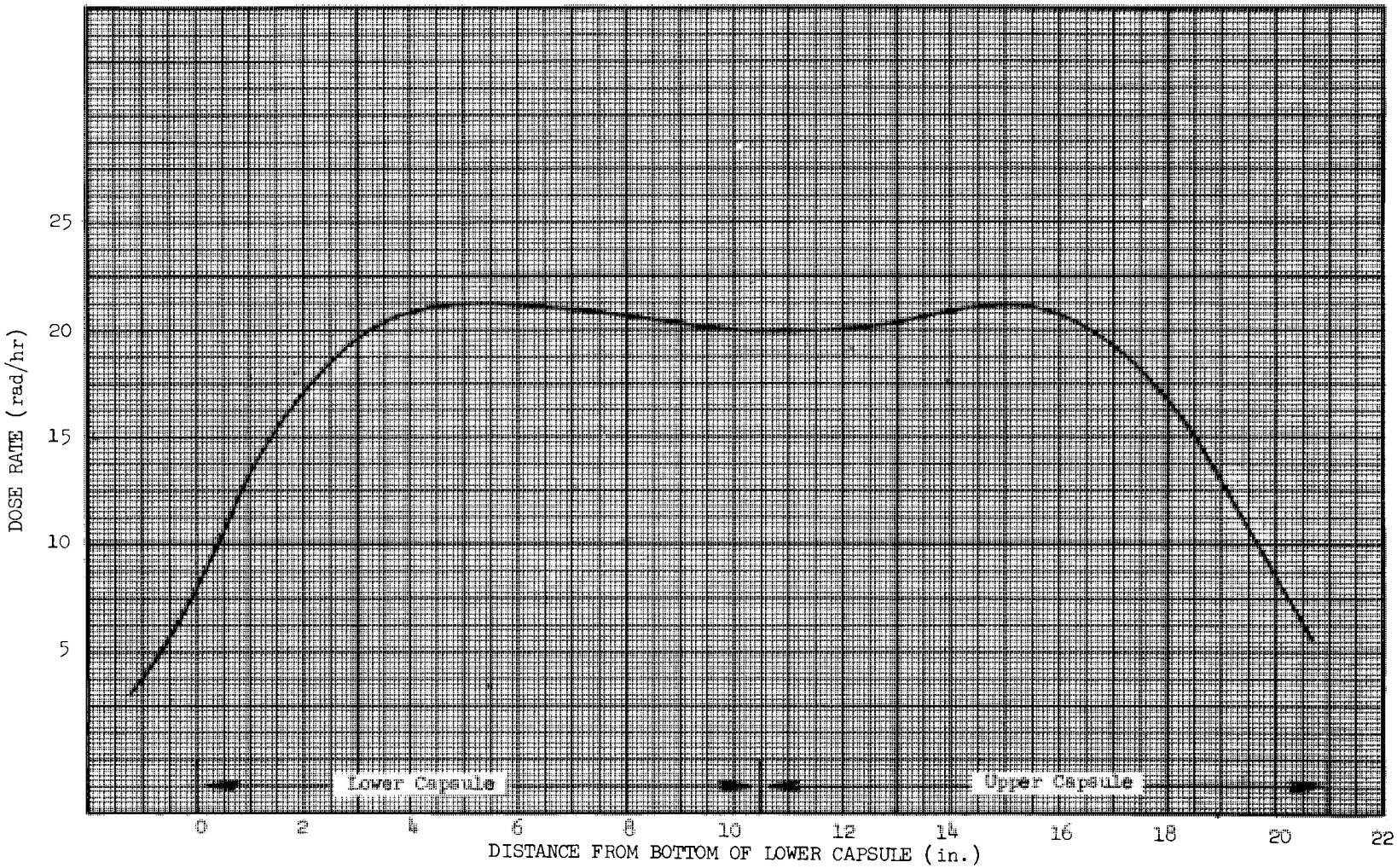

Fig. 6. Dose Rate in Holes J and L.

ORNL DWG. 71-1415

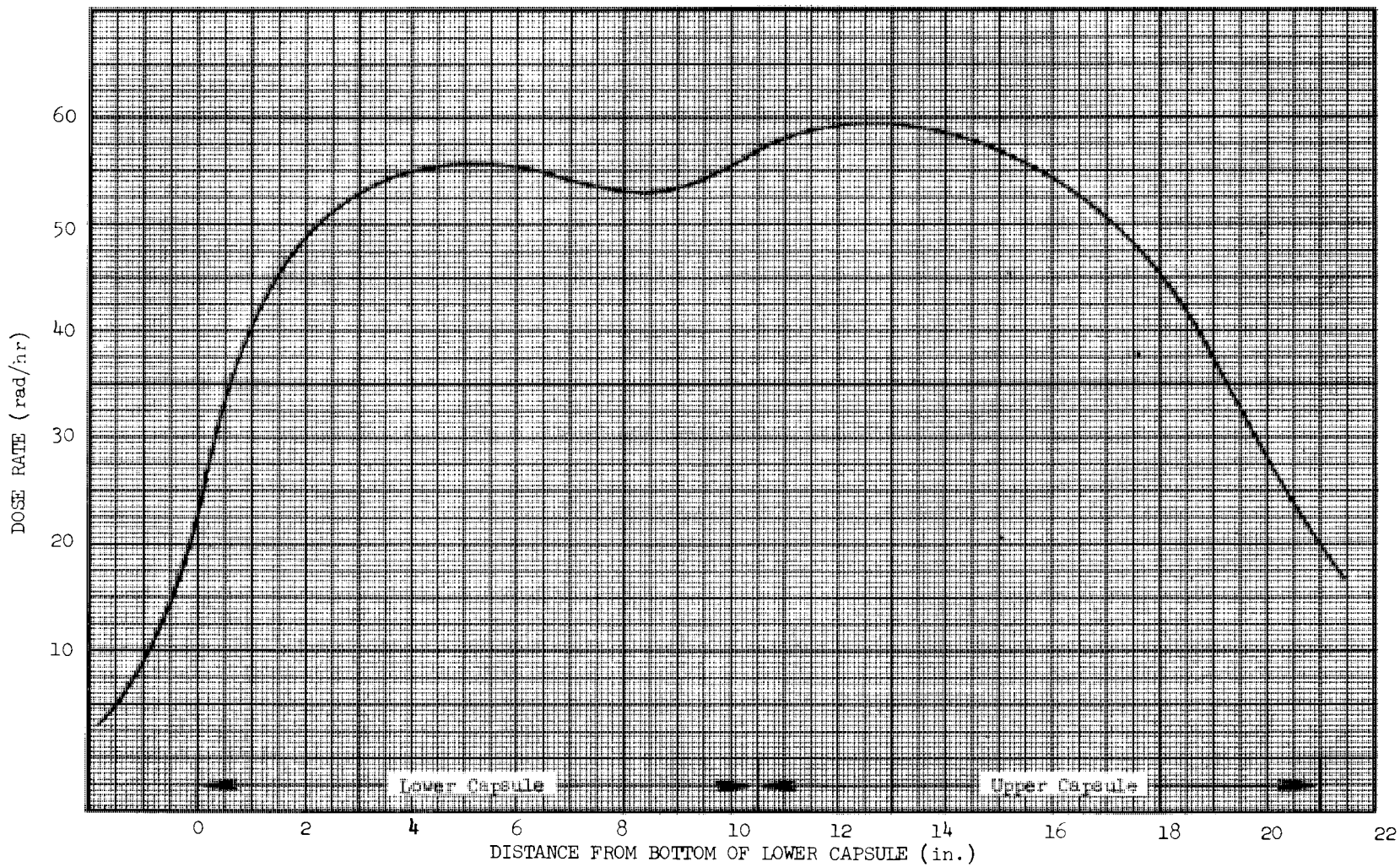

Fig. 7. Dose Rate in Holes I and K.

Heat Block-Shield Design

A range of heat block-shield geometries was investigated using both iron and nickel to delineate the relative advantages of each material, and a report covering this investigation has been prepared.[5] Data for some typical units are summarized in Table 1.

If the final requirements for the heat block-shield are such that one unit must serve all systems including the advanced thermoelectric system with a 1350°F hot junction, nickel must be used. The thermal conductivity of iron or steel is not high enough to avoid excessive heat block and fuel capsule temperatures for this application. Steel can be used for any of the other systems without a serious penalty.

Table 1. Comparison of Nickel and Iron Heat Block-Shields for Thermoelectric Power Units

Material	Fe	Ni	Ni	Ni
Electric output, kw	2	2	2.5	3.0
Hot junction temperature, °F	1050	1050	1350	1350
Peak heat block temperature, °F	1350	1310	1550	1550
Peak fuel capsule temperature, °F	1480	1410	1640	1640
Thermal power, kw	34	34	29	34
Fuel slug diam, in.	3.4	3.4	3.4	3.4
Fueled length, in.	38.4	38.4	38.4	44.8
Shield diam, in.	35.5	32.4	32.4	32.4
Shield length, in.	59.2	57.5	57.5	63.9
Weight, lb	17,200	14,700	14,700	16,300
Cost, $	10,000	45,000	45,000	50,000

The physical properties of nickel are much superior to those of iron or steel for use as the heat block-shield material. It has a 50% higher thermal conductivity, somewhat better shielding properties (higher density), does not undergo the crystalline transformation change characteristic of iron or steel, and will give a smaller and lighter system. Its main disadvantage is that the heat block-shield unit will cost about $35,000 more than for steel. However, this cost will be partially offset by a reduction in the size and cost of the system pressure vessel. The pressure vessel savings will depend on the type of system and the operating depth and will vary from negligible to as much as $20,000 to $25,000 for depths approaching 20,000 ft. With present fuel costs, the incremental $35,000 for the nickel would amount to only 3% of the total system cost.

Organic Loop Decomposition Test

The detail design of the 1/4-scale circulating loop organic fluid decomposition test was initiated. The primary purpose of this loop is to determine whether adverse effects will stem from the decomposition rate of Dowtherm A at the design operating conditions of temperature and dose rate with the fluid circulating through a system with approximately the same surface-volume ratio, fluid velocities, and temperature distribution as in the full-scale system.

The radiation dose rate to the boiler will be about five times the expected rate for a full-scale unit so that the total exposure for one year of loop operation will be the same as for five years with a full-size system. The radiation will be from four capsules each about 9 1/2 in. long containing a total of about 100 Ci of $SrTiO_3$. The capsules will be located in the center of a 16-in. diameter by 59-in. long forged steel block. The three reentry boiler tubes will be located on a 2 1/2 in. circle, i.e., with their centers 1 1/4 in. from the center of the $SrTiO_3$ source. A total of 7.5 kw of heat will be supplied to the boiler tubes from electrical heaters located on the outer surface of the steel block.

The analytical design of the system is largely completed, a revised layout has been prepared, and detailed design of the components is under way.

3. STEAM SYSTEM

A report[6] on tests to determine the performance characteristics of a short reentry tube steam generator at low steam flow and a report on the reference design of a steam Rankine cycle system for an isotope power plant are being reviewed, and will be ready for reproduction about February 1971.

Reentry Tube Boiler Tests

The performance of a short reentry tube steam generator was investigated for steam flow rates of 1–7 lb/hr and pressures from atmospheric to 200 psia for possible application in a radioisotope power plant. The outer boiler tube had an OD of 3/4 in. and a length of 50 in. Six combinations of internal geometry were tested to determine the configuration that would yield the highest exit steam temperature at 200 psia with an outer tube wall temperature of 1000°F.

An exit steam temperature of 720°F at a flow rate of 5.2 lb/hr was achieved with Model 2, which had a 12-in.-long insulating sleeve in the lower end of the central tube. A boiler tube having this configuration should operate in a stable manner for flow rates up to 6 lb/hr if a pressure drop of about 100 psi is provided between the feed pump discharge and the boiler.

Reference Design of A Steam System

The reference design presented in this report[7] uses as its point of departure the conceptual design presented in the initial survey report prepared at the beginning of the Isotope Kilowatt Program.[1] The principal changes have stemmed from experimental work on the reentry tube boiler and revisions to the heat block-shield design that have yielded a basic unit well suited to all three types of power plant chosen by the Navy for detailed study, i.e., the steam and organic Rankine cycle systems and the thermoelectric units. A review of turbine design considerations coupled with continued surveys of the development programs underway in the U.S. on small steam turbine-generator units indicates that the Swenson unit[1] still provides as good a basis as any for a reference design. In general,

the review has favored some small changes in the original conceptual design but no major changes.

The detailed analysis of the heat block-shield assembly is presented in the report covering the reference design for the organic Rankine cycle system[8] and is not repeated here. Experimental tests on the reentry tube steam boiler are presented in another report.[6] The problems of system control are so important from the reliability standpoint that a substantial section on system control is included in this report and another comprehensive topical report on system control is being prepared.

A review of the proposed reference design for the steam Rankine cycle system coupled to an isotope power source indicates that it has a number of important advantages as well as disadvantages. It appears that it will be possible to get a steam system in which radiation damage to the steam will have essentially no effect on the reliability or lifetime of the system, but this will require some new approaches in handling the water chemistry problem.[9] If these new approaches do prove successful they would be applicable to much larger systems. This is important because in the larger sizes – above about 100 kw(e) – the steam systems will give higher thermal efficiencies than would be obtainable with either organic Rankine cycle or thermoelectric systems.

The principal barrier to the development of the steam Rankine cycle system is the fact that a suitable small turbine-generator unit has not been built and operated sufficiently to demonstrate the reliability of the design. However, there appears to be no basic reason why this could not be done at a reasonable cost.

4. THERMOELECTRIC SYSTEM

The ORNL effort this quarter was devoted mainly to the fabrication of the heat pipe and related equipment for the heat transfer test. Concurrently with this work a joint effort was launched with the 3M Company to integrate the heat pipe into a complete thermoelectric module and work out the test equipment to be supplied to 3M by ORNL. This equipment will be used by 3M to carry out a set of tests that will provide a thorough

evaluation of their design including both a detailed analysis of internal losses and a full set of overall performance characteristics.

Heat Transfer Test

Heat Pipe Design

The topical report covering the basic design considerations, performance characteristics, and operating problems of heat pipes has been amplified substantially over its original draft form of June 1970 to meet requests of reviewers and has been issued.[10]

Heat Pipe Fabrication

As described in the previous quarterly report, the details of the techniques evolved by LASL for fabricating wicks for heat pipes were obtained through J. Kemme and applied by ORNL to produce a series of wicks. Several minor difficulties were encountered and overcome to yield full length (about 6 ft) porous tubes having a maximum pore diameter of 31 microns.

The parts for the full-scale heat pipe were fabricated, assembled, welded, and the completed heat pipe was attached to the distillation pot as shown in Fig. 8. The assembly was placed in a dry box and 75.1 grams of potassium were placed in the distillation pot.

The assembly was removed from the dry box and the heat pipe was placed in a tube furnace. The distillation pot and the connecting lines were wrapped with tape heaters and then insulated. The system was evacuated and outgassed at 500°C for 16.5 hr. (The distillation pot was not heated during the outgassing.) The indicated system pressure at the end of the outgassing was 1.7×10^{-7} torr.

The heat pipe was then installed in the test rig and started up. The first attempt to start was unsuccessful because excessive cooling of the condenser end led to an accumulation of frozen potassium at the top depleting the inventory of potassium in the boiler end sufficiently that the boiler section was dried out. This experience shows that it will be

ORNL DWG. 71-1416

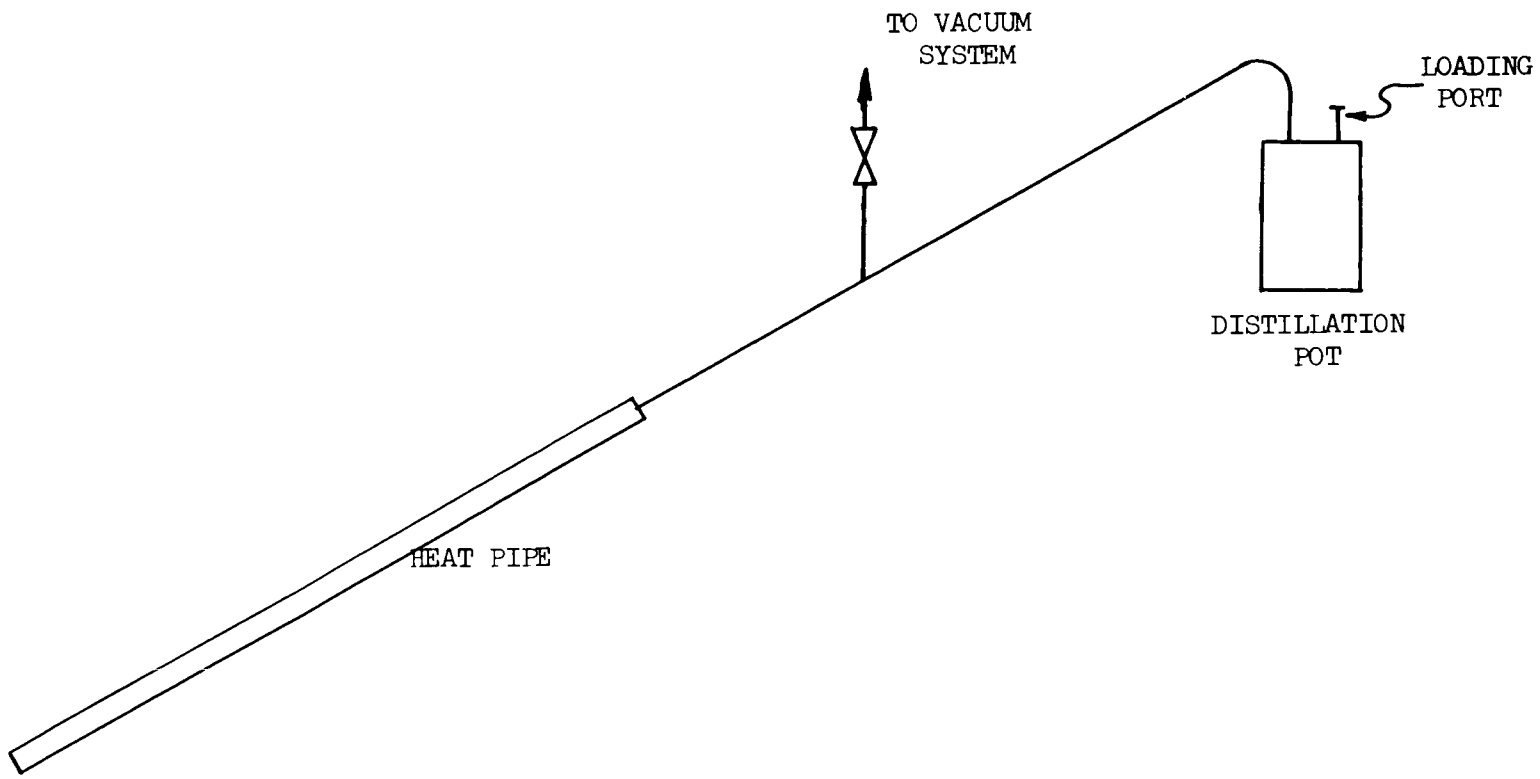

Fig. 8. Potassium Loading Arrangement.

particularly important with the much higher heat capacity of the thermoelectric module to preheat the thermoelectric module and heat pipe assembly to about 200°F before attempting to insert it into the heat block-shield assembly. (The melting point of potassium is 145°F.) Inasmuch as the cold junction temperature employed with lead telluride thermoelectric junctions is commonly operated at a temperature of around 250°F or higher, it is not expected that this will lead to any difficulty. Also, inasmuch as the thermoelectric junction portion of the module will be encased in an outer steel sleeve designed to withstand seawater pressures and the flange for this sleeve will be at the lower end of the thermoelectric module, it would be possible to invert the thermoelectric modules and stand them in a pot of boiling water to preheat the thermoelectric region. The heating might also be done in a dry oven.

Full-Scale Thermoelectric Module

A series of discussions with R. R. Dahlen of the 3M Company have served to firm up details of the thermoelectric module test. ORNL will provide the heat pipe nickel sleeve assembly, the calorimeter-flange assembly, and the electric heater. The 3M Company will install the thermoelectric elements and will perform the final welding.

The design of the full-scale thermoelectric unit has been revised to eliminate the temperature drop through the gap between the sleeve surrounding the cold junctions and the pressure vessel housing it. This has been made possible because 3M has reduced the diameter of the module sufficiently to give enough space between modules close to the top of the full-scale pressure vessel so that circumferential seal welds can be made. The design of the test module being fabricated by 3M will incorporate this feature and should give an increase in efficiency of about 7%. The drawings for the test equipment to be supplied to 3M by ORNL have been modified accordingly.

The heat pipe for installation in the thermoelectric module that 3M is fabricating is being fabricated and is scheduled to be shipped to 3M at the end of January. Fabrication has also been initiated on the test equipment that will be supplied to 3M for heating and cooling their module for test purposes.

Test Program

A tentative outline of the test program envisioned for both the heat pipe and the full-scale thermoelectric module is presented in Table 2. These tests are intended to yield a comprehensive delineation of the performance characteristics of the heat pipe as designed for this application and provide a basis for establishing procedures for use of operational units in the field. These tests differ from those projected at 3M in that the latter are intended to give an insight into the internal losses that depend on the details of the design and installation of the individual thermoelectric junctions. The tests will serve to relate the overall performance of the module over a wide range of temperature and electrical load conditions to the performance of individual junctions. Performance maps will be prepared to define the output voltage, current, and efficiency as functions of the hot and cold junction temperatures and the electrical load.

Module Design for Advanced Materials

The design study at 3M on a thermoelectric module employing advanced materials has been completed and reported by 3M.[11] The results of the design effort are summarized in Tables 3, 4, and 5. That for Case I gives the estimated performance assuming that they are able to develop an N-type material that will be equivalent in performance to their present P-type material TPM-217. The second table, Case 2, is for their present N-type TPM-217 material, and is presented by 3M as representative of the lower limit of what they expect to achieve. Case 3 gives similar data for a system making use of the current lead telluride and BiSbTe/PbSnTe junctions of the type currently being fabricated by 3M for ORNL for test purposes.

5. THERMAL FUSE AND INSULATION

The heater for the next series of tests has been coated with a high emissivity ceramic silicone paint, PT-404A, to give the heater surface an emissivity of about 0.89. This will be nearly constant over the

Table 2. Test Program to Define Startup Procedure, Performance, and Practicable Operating Regimes for Field Service of Thermoelectric Modules and Investigate System Control Problems and Endurance Test Characteristics

A. Heat pipe

1. Startup

Start with T_c = 150, 200, and 250°F, allow T_c to rise to temperatures of 800, 1000, 1200, and 1400°F. (T_c = temperature at condenser end.)

Start with fast heat to several different values of T_b, i.e., 800, 1000, 1200, and 1400°F and then stabilize heat input to .5, 1.0, 2.5, and 4.5 kw or until heat pipe or system capacity is reached. Adjust cooling to hold T_b. (T_b = temperature at boiler end.)

Determine axial temperature distribution and heat balance. (These data will provide a performance map for this heat pipe up to the limits of the test equipment and will provide a thorough check of the analytical design.)

2. Attitude effects

Repeat representative elements of the above for each of a series of heat pipe attitudes ranging from vertical through several inclinations to fully inverted.

3. Investigate shock effects

4. Endurance test at system design conditions

B. Full-scale thermoelectric module

1. Repeat elements of A-1 with emphasis on those that will show up effects of the thermal inertia of the thermoelectric junctions.

2. Investigate the effectiveness of one or more simple control arrangements for coupling the thermoelectric module to a battery bank and I^2R load for representative loading cycles (e.g., steady load, heavy load for short period followed by long period of light load, etc.)

3. Endurance test

Look for deterioration in performance with operating time.

Table 3. Case I — Module Characteristics

Based Upon Development of N-Type Material Yielding Results Equivalent to Present P-Type TPM-217

P Material — TPM-217
N Material — Ultimately developed equivalent to P-type TPM-217
Number of Couples — 144
Cold Junction Temperature — 50°C (122°F)
Load Voltage — 24 volts
Electrical Losses — 10%

Time* (Years)	Heat Input (watts)	Heat Loss (watts)	Hot Junction Temperature (°F)	Power (watts)	Efficiency (%)
0	1850	236	1304	207	11.17
1	1805	232	1284	199	11.04
2	1761	229	1264	192	10.90
3	1718	225	1246	185	10.75
4	1676	221	1228	177	10.59
5	1635	218	1210	170	10.41

*Note: The values given are for operation with $SrTiO_3$ fuel which has a 28 yr half life. Thus the electrical output falls off with time both because of decay of the isotope and because of gradual degradation of the thermoelectric material.

Table 4. Case II — Module Characteristics

Based Upon Current Status of N-Type TPM-217 Characteristics: A Lower Limit

P Material — TPM-217
N Material — N-type TPM-217 current status of development
Number of Couples — 160
Cold Junction Temperature — 50°C (122°F)
Load Voltage — 24 volts
Electrical Losses — 10%

Time (Years)	Heat Input (watts)	Heat Loss (watts)	Hot Junction Temperature (°F)	Power (watts)	Efficiency (%)
0	2350	250	1304	208	8.87
1	2293	245	1284	201	8.77
2	2237	241	1263	194	8.65
3	2182	236	1243	186	8.53
4	2129	232	1223	179	8.40
5	2077	228	1204	171	8.26

Table 5. Case III — Module Characteristics

Based Upon Present SNAP-21 and SNAP-23A Technology

P Material — Segmented BiSbTe/PbSnTe
N Material — Segmented PbTe
Number of Couples — 208
Cold Junction Temperature — 50°C (122°F)
Load Voltage — 24 volts
Electrical Loss — 10%

Time (Years)	Heat Input (watts)	Heat Loss (watts)	Hot Junction Temperature (°F)	Power (watts)	Efficiency (%)
0	2350	224	1000	200	8.53
1	2293	220	986	194	8.46
2	2237	217	975	187	8.38
3	2182	214	963	181	8.29
4	2129	211	950	174	8.20
5	2076	208	937	168	8.10

temperature range of the tests. The thermocouples for the heater and the insulation test specimen are being fabricated and should be installed in January 1971.

The specification for the aluminum wire screen that has been used for the insulation specimens to date has been determined. The screen was purchased through the General Services Administration and was bought under Federal Specification RR-W-365, Wire Fabric (Insect Screening). In this specification, screen of Type VII, aluminum alloy is to be of cladded aluminum alloy wire and have a chemical composition within the following limits as shown in Table 6. Data from the Alcoa Aluminum Handbook indicate the core is composed of alloy 5056 and the cladding is composed of alloy 6253. A melting range of 1055–1180°F is given for the core material, but no melting range is given for the cladding material.

Table 6. Composition of Aluminum Wire Screen Used for Thermal Insulation Tests

Material	Core Percent	Cladding Percent
Magnesium	4.5 to 5.6	1.0 to 1.5
Silicon	0.3 maximum	45 to 65 of mg.
Manganese	0.05 to 0.2	
Chromium	0.05 to 0.2	0.15 to 0.35
Zinc	0.1 maximum	1.6 to 2.4
Iron	0.4 maximum	0.5 maximum
Copper	0.1 maximum	0.1 maximum
Other elements each	0.05 maximum	0.05 maximum
Other elements total	0.15 maximum	0.15 maximum
Aluminum (by difference)	Remainder	Remainder

Since the lower limit of the melting range of the core material, 1055°F, may be rather low for extended operation in the thermoelectric power plant, it is now planned to obtain for testing wire screen of another aluminum alloy that will have a melting range of about 1170–1200°F. There are a number of alloys available that have a melting range of this order.

Wire screen insulation specimens fabricated of the original material will be used to determine the effects of reduced air pressure upon the thermal conductivity. These tests will be run during the time required for delivery of the new aluminum alloy screen.

6. FUEL CAPSULES

A draft of the fuel capsule design and safety analysis report[12] has been completed and is in the process of review prior to publication. The large heat source capsule designed for the Isotopes Kilowatt Program meets the containment criteria for safe operation in terrestrial systems and probable accident conditions. The capsule meets all the requirements of operational safety and the particular hazards to which it might be exposed in its operational environment and transportation to and from its use site.

REFERENCES

1. R. A. Robinson, Isotope Kilowatt Program Task 1 – Conceptual Design and Evaluation, USAEC Report ORNL-TM-2366, Oak Ridge National Laboratory, January 1970.

2. A. P. Fraas, Program Director, Isotope Kilowatt Program Quarterly Progress Report for Period Ending March 31, 1970, USAEC Report ORNL-TM-3011, Oak Ridge National Laboratory, July 1970.

3. A. P. Fraas, Program Director, Isotope Kilowatt Program Quarterly Progress Report for Period Ending June 30, 1970, USAEC Report ORNL-TM-3099, Oak Ridge National Laboratory, September 1970.

4. A. P. Fraas, Program Director, Isotope Kilowatt Program Quarterly Progress Report for Period Ending September 30, 1970, USAEC Report ORNL-TM-3214, Oak Ridge National Laboratory, December 1970.

5. G. Samuels, Comparison of Nickel and Iron Heat Block-Shields, USAEC Report ORNL-TM-3213, Oak Ridge National Laboratory (to be published).

6. R. S. Holcomb and M. E. Lackey, Performance Characteristics of a Short Reentry Tube Steam Generator at Low Steam Output, USAEC Report ORNL-TM-3236, Oak Ridge National Laboratory (to be published).

7. A. P. Fraas, Reference Design of a 3 Kw(e) Steam Rankine Cycle System for an Isotope Power Plant, USAEC Report ORNL-TM-2961, Oak Ridge National Laboratory (to be published).

8. G. Samuels and R. S. Holcomb, Reference Design for an Isotope Power Unit Employing an Organic Rankine Cycle, USAEC Report ORNL-TM-2960, Oak Ridge National Laboratory, January 1971.

9. G. H. Jenks and J. C. Griess, Water Chemistry in Pressurized and Boiling Water Power Reactors, USAEC Report ORNL-4173, Oak Ridge National Laboratory, November 1967.

10. M. E. LaVerne, Performance Characteristics of Cylindrical Heat Pipes for Nuclear Electric Space and Undersea Power Plants, USAEC Report ORNL-TM-2803, Oak Ridge National Laboratory, January 1971.

11. Advanced Technology Thermoelectric Module for a 2 kw Undersea Radioisotope Power System, Report 8484-0004, Minnesota Mining and Manufacturing Company, Dec. 5, 1970.

12. K. W. Haff, Isotopes Kilowatt Program Fueled Capsule Design and Evaluation – A Safety Analysis, USAEC Report ORNL-TM 3230, Oak Ridge National Laboratory (to be published).

Internal Distribution

1. S. E. Beall
2. T. A. Butler
3. W. B. Cottrell
4. W. C. Cox
5. F. L. Culler
6. R. G. Donnelly
7-16. A. P. Fraas
17. J. H. Frye, Jr.
18. J. H. Gillette
19. A. G. Grindell
20. K. W. Haff
21. H. W. Hoffman
22. R. S. Holcomb
23. P. R. Kasten
24. M. E. Lackey
25. E. Lamb
26. M. E. LaVerne
27. D. B. Lloyd
28. M. I. Lundin
29. R. N. Lyon
30. R. E. MacPherson
31. H. C. McCurdy
32. A. J. Miller
33. A. M. Perry
34. R. A. Robinson
35. M. W. Rosenthal
36. A. F. Rupp
37-46. G. Samuels
47. A. W. Savolainen
48. A. C. Schaffhauser
49. M. J. Skinner
50. A. M. Smith
51. I. Spiewak
52. D. A. Sundberg
53. D. B. Trauger
54. J. J. Tudor
55. A. M. Weinberg
56. G. D. Whitman
57. J. V. Wilson
58. H. C. Young
59. Biology Library
60-62. Central Research Library
63-64. Y-12 Technical Library Document Reference Section
65-114. Laboratory Records Department
115. Laboratory Records Department (RC)

External Distribution

116. F. P. Baranowski, Division of Production AEC, Washington, D.C. 20545
117. D. R. Bartz, Jet Propulsion Lab., NASA, 4800 Oak Grove Drive, Pasadena, California 91103
118. H. Bibb, Naval Facilities Engineering Command, Washington, D.C. 20390
119. Les Chadbourne, AiResearch Manufacturing Company, 402 S. 36th Street, Phoenix, Arizona 85034
120. D. F. Cope, RDT Site Office, ORNL
121. W. M. Crim, Jr., Research and Technology Department, Building 322, Ft. Belvoir, Virginia 22060
122. R. R. Dahlen, Advanced Engineering, 3-M Company, Building 551, 2501 Walnut Street, Roseville, Minnesota 55113
123. R. V. Degner, Rocketdyne, 6633 Canoga Avenue, Canoga Park, California 91303
124. R. N. Endebrock, Isotopic Auxiliary Power Branch, AEC, Washington, D.C. 20545
125. R. E. English, NASA, Lewis Research Center, Cleveland, Ohio 44135

126. E. E. Fowler, Division of Isotopes Development, AEC, Washington, D.C. 20545
127. N. C. Gibbon, Cryogenic Products Department, Linde Division, P. O. Box 44, Tonawanda, New York 14150
128. J. C. Graf, General Electric, Valley Forge, Pennsylvania 19481
129-133. W. D. Holloman, Division of Reactor Development and Technology, AEC, Washington, D.C. 20545
134. M. Klein, Division of Reactor Development and Technology, AEC, Washington, D.C. 20545
135. G. S. Leighton, Sundstrand Aviation, 1100 Connecticut Avenue, N.W., Washington, D.C. 20036
136. J. J. Lynch, NASA Headquarters, Washington, D.C. 20546
137. S. V. Manson, NASA Headquarters, Washington, D.C. 20546
138. R. F. Mather, NASA, Lewis Research Center, Cleveland, Ohio 44135
139. B. T. McCauley, Aerojet-General Corporation, Azusa, California 91702
140. R. E. Niggeman, Sundstrand Aviation, 4747 Harrison Avenue, Rockford, Illinois 61101
141-150. Nuclear Engineering Division, Naval Facilities Engineering Command, Washington, D.C. 20390
151. J. Pidkowicz, RDT Site Office, ORNL
152. W. D. Pouchot, Westinghouse Astronuclear Laboratory, P. O. Box 10864, Pittsburgh, Pennsylvania 15236
153. D. F. Rife, Westinghouse, Lima, Ohio 45801
154. C. R. Ross, Savannah River Laboratory, Aiken, South Carolina 29801
155. George Shepherd, Fairchild Technology Corporation, One Goddard Drive, Rockaway, New Jersey 07866
156. G. W. Sherman, Aeronautical Space Power Division, Air Force Aeronautical Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio 45433
157. Anthony Stathoplos, Nuclear Technology Corporation, 116 Main Street, White Plains, New York 10600
158. B. Sternlicht, Mechanical Technology, Inc., 968 Albany-Shaker Road, Latham, New York 12110
159. D. Stewart, Battelle Northwest Laboratory, Richland, Washington 99352
160. P. Swenson, Jr., Swenson Research, Inc., 5135 Richmond Road, Bedford Heights, Ohio 44146
161. J. E. Taylor, Thompson-Ramo-Wooldridge, 23555 Euclid Avenue, Cleveland, Ohio 44117
162. W. B. Taylor, Technical Director, U.S. Army Mobility Equipment Research and Development Center, Ft. Belvoir, Virginia 22060
163. Tom Widmer, Thermo Electron Corporation, 85 First Avenue, Waltham, Massachusetts 02173
164. E. S. Wilson, Space Nuclear Systems, AEC, Germantown, Maryland 20767
165-179. Division of Technical Information Extension (DTIE)
180. Laboratory and University Division, ORO