W

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

ORNL - TM - 3592

THIS DOCUMENT CONFIRMED AS
UNCLASSIFIED
DIVISION OF CLASSIFICATION
BY JH Kahn/amb
DATE 12/1/71

ISOTOPE KILOWATT PROGRAM QUARTERLY PROGRESS REPORT
FOR PERIOD ENDING SEPTEMBER 30, 1971

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.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

R2211

209
RECEIVED BY DTIE NOV 16 1971
RECEIVED BY DTIE NOV 16 1971

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

ISOTOPE KILOWATT PROGRAM QUARTERLY PROGRESS REPORT
FOR PERIOD ENDING SEPTEMBER 30, 1971

A. P. Fraas, Program Director
G. Samuels, Associate Director

NOVEMBER 1971

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.

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

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

123

Blank Page

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 under-sea 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 subsequent quarters have been devoted to the design and construction of the most urgent experiments.^{4,5,6} The remaining period 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 seventh 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

	<u>Page</u>
1.0 SUMMARY	1
2.0 ORGANIC FLUID EVALUATION TESTS	2
Organic fluid capsule decomposition test	2
One-quarter scale organic fluid decomposition test	3
loop	
3.0 THERMOELECTRIC SYSTEM	3
Heat pipe tests	3
Thermoelectric module	8
Heat pipe-thermoelectric module test program	16
4.0 THERMAL FUSE AND INSULATION	21
5.0 HEAT BLOCK-SHIELD DESIGN	23
6.0 FULL-SCALE ORGANIC RANKINE CYCLE SYSTEM TEST WITH A	25
TURBINE-GENERATOR PUMP UNIT	
REFERENCES	33

ISOTOPE KILOWATT PROGRAM QUARTERLY PROGRESS REPORT
FOR PERIOD ENDING SEPTEMBER 30, 1971

1.0 SUMMARY

The organic capsule test continued during the quarter and has completed 6576 hr of operation as of the end of September.

Construction of the 1/4-scale organic fluid decomposition test loop is proceeding. Most of the components have been fabricated and the measurements of the dose rates in the boiler region of the heat block shield have been completed. Assembly will begin in October.

Efforts to correct conditions that might cause a loss in the capillary pumping capacity of the heat pipe have continued to meet with little success; a pronounced loss in performance still occurs when the boiler is tilted a bit above the level of the condenser. The most probable explanation for this appears to lie in complex surface chemistry factors that affect surface tension and wetting in the wick. Funds do not permit further investigation, hence the heat pipe is being returned to an endurance test and this unsolved problem left for some future time.

The thermoelectric module was subjected to a set of performance tests which were completed satisfactorily on July 29, 1971, at 3M and delivered to ORNL. Tests were initiated at ORNL on August 24, 1971, and have been continuing since. Two performance maps were completed for hot junction temperatures of 1000 and 1055°F (at 8 amps). The 1000°F hot junction map shows the unit output to be about 170 watts rather than the predicted value of 200 watts.

Further tests of the aluminum wire screen thermal insulation-thermal fuse indicate that the combined effects of a low rate of temperature rise inherent in the application at hand, the very substantial heat of fusion of aluminum, and the inhibiting effects to the flow of molten aluminum imposed by a thick aluminum oxide film lead to a much less sharp melting of the thermal fuse than had been anticipated. To reduce thermal radiation losses, the next test sample has aluminum foil in the aluminum screen. A nitrogen atmosphere was employed to minimize the effects of the oxide film. At 15 psia and a mean temperature of 600°F the thermal conductivity was found to be 0.077 compared to 0.114 Btu/hr.ft.°F found during tests without

the foil. A significant reduction in the thermal conductivity was also observed at 1.0 psia. However, during the course of this test the value of the conductivity shifted upward to form a higher curve. These tests will be repeated.

Delivery of the heat block shield has been delayed because a 4-in. drill broke in one of the deep holes for the simulated fuel capsules. The unit is expected to be completed October 5 and an ORNL inspector is scheduled to check the unit October 6.

A conceptual design for the dummy heat pipes for the test of the heat block with a thermoelectric module and 11 dummy modules has been prepared. The cost of fabricating these is being investigated.

A topical report reviewing the status of the development of various small turbine- and engine-generator units suitable for Navy undersea nuclear power plants has been prepared and is being submitted for review. This indicates that the most promising candidate for an organic Rankine cycle system is the Sundstrand 6 kW(e) turbine-generator unit.

The design of a full-scale organic Rankine cycle system employing the Sundstrand kW(e) turbine-generator unit is proceeding. A layout drawing has been obtained from Sundstrand showing the revised arrangement of the 13 pipes and electrical cables which must be coupled to the turbine-generator-pump unit. The installation design problems associated with these connections have been reviewed with Sundstrand and a satisfactory layout evolved. Arrangements for the procurement of the turbine-generator-feed pump unit have been initiated.

2.0 ORGANIC FLUID EVALUATION TESTS

Organic fluid capsule decomposition test

The test has now accumulated a total of 6576 hr at the desired 600°F temperature. A temporary interruption in the main building power supply line resulted in a 5-minute down time on this test during September. Temperature changes during the period were less than 3°F.

Requests have been issued to fabricate additional capsules to replace those to be removed after approximately 7000 hr of operation. The

possibility of obtaining a more pure form of Dowtherm for these capsules is being investigated. Preliminary results from the analysis on new material received from the Dow Chemical Company indicates that it contains 25 to 50 ppm more impurities than the material presently in the capsules. The results also indicate that the capsule material and the material from Dow is more pure than the "Dowtherm" obtained by mixing the materials that have been purchased to produce the Dowtherm for the quarter-scale loop test. Further tests on these materials will be made.

One-quarter scale organic fluid decomposition test loop

Fabrication of the system components was largely completed during the quarter. The support stand for the condenser was completed and has been set in place.

One of the two pumps on order from Liquid Dynamics Corporation has been shipped and should be received during the first week of October. According to the vendor, the second pump was damaged during the water shakedown test and consequently shipment will be delayed several weeks. It appears that the flexible hose employed to connect the pump in the test facility and the suction side of the pump was accidentally "crimped." This condition was not noticed and the pump was run dry until the bearings and container can overheat.

Dose rate measurements in the boiler tubes of the 1/4-scale loop test have been completed. These measurements were made using thermoluminescent dosimetry at 4-in. intervals along the tubes. The dose rates with the inner tubes in place and without the inner tubes were measured. Figure 1 is a plot of the dose rates inside the inner tubes and Fig. 2 is a plot of the dose rates outside the inner tubes.

3.0 THERMOELECTRIC SYSTEM

Heat pipe tests

Efforts to determine the reasons for the disparity between the calculated and measured performance of the heat pipe continued. The heat pipe was evacuated and all of the potassium distilled off prior to flushing with clean potassium. The heat pipe was then completely filled with potassium, heated to 800°C (1472°F) for 66 hr, and drained. It was

ORNL DWG 71-12910

Fig. 1. Dose rate inside inner boiler tube.

ORNL DWG 71-12911

Fig. 2. Dose rate outside inner boiler tube.

refilled with potassium, again heated to 800°C for an additional 20 hr, and again drained. A working charge of seventy-five (75) grams of potassium was then distilled into the heat pipe and the fill tube sealed shut. These operations were carried out by the liquid metal group in the ORNL Metallurgy and Ceramics Division to assure the use of the best available techniques.

A preliminary performance test of the heat pipe indicated that the unit still exhibited an anomalous behavior when the condenser end of the heat pipe was positioned below the evaporator section.

A review of the analytical work discloses that the initial heat pipe performance calculations were prepared assuming a pore diameter in the wick of 20 μ m. In reviewing the background for this, it was found that the 20 μ m pore diameter was the best that Los Alamos had been able to achieve when the ORNL design was prepared, but that usually LASL obtained around 30 μ m diameter pores in the type of wick structure employed for the ORNL heat pipes. As a consequence, while the original analysis indicated that the 20 μ m pore size would permit operation of the heat pipe completely inverted, with the 30 μ m pore size the difference in elevation between the boiler and condenser could not exceed about 47 in. Thus, in the 69 in. heat pipe with which the tests have been conducted at ORNL, one could not get satisfactory operation of the heat pipe completely inverted even under ideal conditions. However, it should be possible with the 30 μ m pore size to get satisfactory operation with the heat pipe inclined at an angle of perhaps 30° from the horizontal with the boiler above the condenser.

The factors which determine the heat pipe performance from a theoretical standpoint were reviewed together with the many tests that have been conducted in an effort to diagnose the marked loss in performance that occurs when the boiler is tilted to a level a bit above the condenser. It appears that the most probable source of the difficulty stems from surface chemistry effects on the capillary forces. A NASA review of these problems discloses that wide differences in surface tension have been found by different observers working with potassium. These differences appear to be caused by differences in the oxygen content (see Fig. 3.).

Fig. 3. Surface tension of potassium as a function of temperature.
(From Ref. 8)

However, an investigation of this problem is seriously handicapped by the absence of a good technique for determining the oxygen content of potassium; every laboratory that has tried to do this has run into difficulty. In general, for oxygen contents below about a 1000 ppm, the accuracy of the oxygen determination is rarely as good as plus or minus 50%, and it is substantially poorer than this for oxygen contents below 100 ppm. The problem is further aggravated if one attempts to extract a significant sample from the capillary structure of a heat pipe.

In view of the limited funds available and the fact that the work on the heat pipe has greatly exceeded the amount allocated in the program plan, and in view of the fact that discussions with personnel at LASL, JPL, and Westinghouse Astronuclear disclose that they have experienced similar unresolved difficulties, it was decided that the heat pipe should be returned to endurance testing. This course is now being followed.

Thermoelectric module

3M repaired the leak in the seal weld between the stainless steel end bell and the nickel sleeve by grinding out most of the material in the trepanned projection from the nickel sleeve and rewelding the stainless steel end bell to the nickel sleeve using an Inconel 82 filler rod. In addition, they welded in an additional Inco 600 end bell to close off the region between the end of the nickel sleeve and the outer stainless steel jacket. Figure 4 shows details of the repaired region.

3M initiated the comprehensive set of performance tests called for in their contract and completed these tests on July 29, 1971. Figures 5 and 6 compare 3M's experimental results with the predicted behavior of the thermoelectric generator for the beginning and end of life conditions. Figure 7 shows the voltage-current relationship of the generator as it is presently operating.

The experimental points in Figs. 5 and 6 are superimposed on a set of curves which were calculated for the module in the course of the design work. The difference between the performance given by the experimental points and the calculated performance apparently stems from a somewhat higher internal resistance in the unit which might be expected from the fact that, as a consequence of the difficulty with the sulfur embrittlement,

Fig. 4. Thermoelectric-heat pipe test module.

ORNL DWG 71-12914

Fig. 5. Heat pipe-thermoelectric module predicted I-V characteristics at BOL heat input.

Fig. 6. Heat pipe-thermoelectric module predicted I-V characteristics at EOL heat input.

ORNL DWG 71-12916

Fig. 7. Voltage and power as a function of current for the 3M thermoelectric generator-heat pipe assembly.

3M did not operate the unit at as high a temperature as planned during their run-in process in which the electrical bonds are affected. However, R. R. Dahlen at 3M was of the opinion that this bonding might improve with extended operation, and offered as evidence that they had observed some improvement in the module that they built and have been operating at 3M.

The thermoelectric module was received from 3M and installed in its test stand at ORNL. The system was started without incident on August 24, 1971, and operated satisfactorily throughout the balance of the quarter. Initially a maximum hot junction temperature of about 870°F was employed with a heat pipe temperature of 1000°F. This temperature level was maintained until the instrumentation necessary for determining open circuit voltages was calibrated and installed. At that time the power input was increased to bring the hot junction temperature to 1000°F.

The output of the thermoelectric generator is connected into the circuit shown in Fig. 8. Normally the generator is allowed to charge a bank of lead-acid batteries. Once a day a timer circuit closes a switch that allows the batteries to discharge into a resistance load. A shunt regulator is incorporated in the circuit to prevent overcharging the battery bank. (The shunt regulator will divert a portion of the generator output through the shunt load if the output voltage rises above a pre-selected level.)

When it is necessary to make a performance map of the generator, it is possible to switch the output from the battery bank to a variable load. Another switch in the circuit makes it possible to interrupt the current flow to obtain data from the generator under open circuit conditions. When the switch is activated the data logging system automatically begins recording the data.

The system is being operated with a vacuum in the shield can around the heaters and the lower portion of the heat pipe in an attempt to remove an accumulation of hydrogen from the interior of the heat pipe. Apparently 3M did not completely remove the moisture from the thermal insulation before they brought the system to operating temperature. The presence of the hydrogen in the heat pipe is manifested by a non-uniform axial temperature distribution evident from the thermocouples mounted along the length of the module as indicated in Fig. 9. There is a 150°F difference between

Fig. 8. Thermoelectric generator external connections.

Fig. 9. Thermocouple locations for the heat pipe-thermoelectric generator assembly.

two points (thermocouples No. 7 and 8 of Fig. 9) respectively $5\frac{1}{8}$ in. and $4\frac{5}{8}$ in. from the upper end of the nickel sleeve. The difference in temperature decreases as the system temperature is increased. (This behavior would be expected from the presence of a noncondensable gas in the heat pipe condenser.) Figure 10 is a plot of this temperature difference as a function of the potassium vapor in the heat pipe. As the test progresses, new data will be plotted on this figure in an effort to tell whether or not the hydrogen in the heat pipe is being removed.

Two performance maps at hot junction temperatures of 1000 and 1055°F (at 8 amps) were completed and are shown in Figs. 11 and 12. Note that the performance is not as good as that found in the tests at 3M (see Figs. 5 and 6), probably as a consequence of the adverse effects of shipping on the contact resistances between the many elements in the assembly.

Heat pipe-thermoelectric module test program

The primary purpose of the Heat Pipe-Thermoelectric Module Test Program is to demonstrate the long term operability of the Heat Pipe-Thermoelectric Module assembly. The troubles encountered with the assembly at the 3M Company have prompted us to propose a somewhat more conservative test program than originally conceived.

The system will be operated in a vertical position with a potassium vapor temperature of 1050°F. (This temperature will be measured when the current output of the generator is eight amperes. The vapor temperature will vary above or below this value as the current output of the generator varies.)

The output of the generator will be connected to a bank of lead acid storage batteries. Once a day a timer circuit will connect a dissipative load across the battery bank. This will allow the batteries to discharge and will cause a limited thermal cycle to occur within the generator. This method of loading is intended to be typical of the service the system would encounter in the field.

The parameters listed in Table 1 will be logged on an hourly basis for the duration of the test. Once a week an open circuit test will be made to obtain the instantaneous open circuit voltage. This will allow us to calculate the internal resistance of the generator. Once a month

Fig. 10. Temperature gradient along nickel sleeve as a function of heat pipe vapor temperature.

Fig. 11. Heat pipe and thermoelectric module parameters as a function of thermoelectric module output current.

Fig. 12. Heat pipe and thermoelectric module parameters as a function of thermoelectric module output current.

Table 1. Tabulation of parameters to be recorded hourly during the life test of the heat pipe-thermoelectric generator.
(Refer to Fig. 9 for thermocouple locations)

Parameter	Location	Remarks
Temperature	Point No. 1	Heat pipe evaporator
Temperature	2	Heat pipe evaporator
Temperature	3	Heat pipe evaporator
Temperature	4	Heat pipe evaporator
Temperature	5	Heat pipe at entrance to TEM
Temperature	6	Heat pipe in thermowell inside TEM
Temperature	7	Nickel sleeve 0.625 in. from end
Temperature	8	Nickel sleeve 4.625 in. from end
Temperature	9	Heat pipe heater
Temperature	10	Calorimeter jacket
Temperature	11	Calorimeter jacket
Temperature	12	Not recorded
Temperature	13	Hot junction - couple 5-2
Temperature	14	Cold junction* - couple 5-2
Temperature	15	Inoperative
Temperature	16	Cold junction* - couple 5-7
Temperature	17	Inoperative
Temperature	18	Hot junction - couple 13-7
Temperature	19	Cold junction - couple 13-12
EMF		Generator output voltage
EMF		EMF across couples 13-7 to 13-12
EMF		EMF across couples 5-2 to 5-7
EMF		EMF across couple 5-2
EMF		EMF across couple 5-7
EMF		EMF across P leg of couple 13-7
EMF		EMF across N leg of couple 13-7
EMF		EMF across couple 13-7
Current		Generator output current

*Cold junction temperature measurements are influenced by current flow. Therefore, meaningful cold junction temperatures can only be taken during the open circuit tests.

the system will be tilted to within 10° of the horizontal and allowed to come to equilibrium. A complete set of readings will be taken and the system will be returned to the vertical position. At the conclusion of the test another performance map (similar to Fig. 11) will be made to compare the performance characteristics of the generator with those it displayed at the beginning of the test.

At the conclusion of the thermal mapping studies on the full-scale heat block, a full set of heat pipes will be installed in the heat block. The forces required to insert and withdraw the heat pipes will be determined. The results of these tests will determine what provisions must be made before the heat pipe-thermoelectric module assembly can be installed in the heat block for testing with the dummy heat pipe-module units.

After completion of the tests in the full-scale heat block-shield assembly the thermoelectric module will be reinstalled in the endurance test rig and the endurance test will be resumed.

4.0 THERMAL FUSE AND INSULATION

The meltdown test on the first aluminum alloy 1100 wire screen insulation has been completed. The results were disappointing - they do not provide a good basis for predicting the results with a full-scale unit. There was no sharply defined melting point, and all of the heater rod temperatures were greater than expected during the first part of the test. However, the temperatures near the midpoint dropped as the melting progressed. An examination of the partially melted screen after the test indicated that two factors contributed to the high temperatures. The first and most serious effect is that there was sufficient oxidation of the aluminum (probably because of the many weeks of thermal conductivity testing) so that during the meltdown a rather large quantity of oxide whiskers were formed. These whiskers were held in place by a 1/4-in-mesh stainless steel screen on which the aluminum screen was rolled. As the melting continued, it appears that the molten aluminum at the midpoint of the screen carried the oxide debris to the bottom where it was trapped by the stainless steel screen, thus forming an insulating layer. It should

be noted that the oxidation appeared on the inner screen layer that had been operated at temperatures up to about 950°F during the conductivity tests.

A contributing factor to the delayed melting in this test was the use of a 1/4-in-mesh stainless steel screen liner used to hold the mesh in place. This would not be employed in a full-scale system and will be eliminated in the next test. The effect of the oxide is more serious. Assuming that undersea units are initially filled with an inert gas, one is still concerned with the possibility of water in-leakage. A small in-leakage of water into the pressure vessel would give a vapor pressure of 0.1 to 0.2 psia.

Analyses indicated that the thermal resistance of the wire screen insulation could be increased and the melt-down characteristics improved by interleaving a layer of aluminum foil between sets of layers of wire screen. To investigate this possibility some 0.002 in. thick aluminum foil was procured and a specimen of aluminum wire screen insulation containing aluminum foil sheets spaced eight layers of screen apart has been fabricated. The test assembly has been installed in the vacuum tank and testing will be performed in nitrogen. Preliminary tests indicate that the thermal conductivity is well below that of the wire screen alone.

A test was carried out to investigate the feasibility of using aluminum blocks between the fins of the heat block-shield assembly which can be melted to develop high capacity heat flow paths from the heat block-shield assembly to the pressure vessel. The test was run by using a 2 in. diameter slug of aluminum placed in a short vertical piece of 2 in. pipe with a side arm of 1 in. tubing approximately 3 1/2 in. long. The outboard end of the latter was placed against a tank of water to provide a heat sink similar to a pressure vessel. Electric heaters around the aluminum slug were supplied with power to give a rate of temperature rise of 70 - 100°F/hr which is equivalent to that to be expected if the heat removal from the heat block-shield assembly were stopped and all of the heat given off by the isotope fuel capsules went into raising the temperature of the shield. In view of the fact that, in the small unit with which the test was carried out, the heat of fusion of the aluminum makes the effective heat capacity of the aluminum very large compared to

the heat input required to raise the temperature at the above rate, the rate of heat input was increased when the aluminum reached its melting point and the temperature leveled off. Figure 13 shows the set-up.

Apparently the combined effects of the low heating rate, the substantial heat of fusion of the aluminum, the flow inhibiting effects of aluminum oxide, and the absence of a really sharp melting point for the aluminum (even though commercially pure aluminum alloy was employed) led to slow melting of the aluminum block. Further, when the aluminum did melt, although it filled the passage between the simulated heat block-shield assembly and the pressure vessel wall with a relatively pore-free column of aluminum, the thermal bond between the end of the aluminum column and the water-cooled wall was quite poor. In view of this it is believed that an improved situation could be obtained if the pressure vessel wall were fitted with internal fins in the vicinity of the channel to be filled with aluminum, and if a diaphragm of commercially pure aluminum could be used to contain a somewhat lower melting point aluminum alloy until the aluminum slug had completely melted. If this were done, when the diaphragm melted a large quantity of molten aluminum could flow freely out through the channel to the wall to give a much sharper change in conditions. Fins on the water-cooled wall would increase the heat removal capacity of the slug. However, further tests along this line will be deferred pending results of the tests of the aluminum foil interspersed between layers of aluminum wire screen.

5.0 HEAT BLOCK-SHIELD DESIGN

The installation of the electrical and instrumentation equipment for the heat block-shield test is nearly complete. The heater cans have been completed and shipped. The heater cores have been completed. Assembly of the heaters should be completed by the second week in October. The heat shield sub-assembly, the instrument stand, and the sand box have been completed. The vacuum vessel for the insulation test is being fabricated and should be completed by October 15.

The completion of the heat block-shield has been delayed until the first week in October. This delay resulted from a broken 4-in. drill.

Fig. 13. Schematic of melt plug test.

6.0 FULL-SCALE ORGANIC RANKINE CYCLE SYSTEM TEST WITH A TURBINE-GENERATOR PUMP UNIT

A survey of all of the vendors and other organizations engaged in the development of small turbine- or engine-driven generators has been completed and a topical report prepared and submitted for review. This survey indicates that the Sundstrand unit is the most promising of the organic turbine-generators that have been under development in recent years. The Sundstrand unit has completed 3000 hr of testing, and the Sundstrand organization is continuing with the development of larger units in a cooperative effort with a number of natural gas organizations. In terms of test experience, the next most promising candidate is the Aerojet 6 kW(e) organic Rankine cycle turbine-generator unit which has completed 1000 hr of endurance testing. However, the organization responsible for this has been disbanded as a consequence of termination of the SNAP-8 mercury Rankine cycle development program. The Thermoelectron engine-generator development program has still not yielded any long endurance tests--the greatest amount of running time on any given unit has been only a few hundred hours. The Stratos organic turbine-generator development effort for Ft. Belvoir has been concluded without any appreciable amount of operation of the two units they built. The Stratos group has been disbanded. The Westinghouse effort to build an engine-generator unit using a Freon compressor running as an expander has been discontinued after a small amount of operation.

In view of the fact that the Sundstrand unit seems to be the most promising of any available, negotiations were initiated with Sundstrand for procurement of a turbine-generator unit. An installation drawing for the 6 kW(e) turbine-generator unit was obtained and several layout studies were prepared to determine how best to install the unit in the ORNL bread-board system. Some 13 connections must be made to the turbine-generator unit, and many qualifications and special considerations apply to these connections. The questions raised in connection with these connections have been resolved through discussions and correspondence with Sundstrand, and a satisfactory flow sheet together with a layout have been evolved. These are shown in Figs. 14 and 15. A set of design precepts for the layout is presented in Table 2.

Fig. 14. Flow diagram for full scale organic system.

Fig. 15. Full-scale organic loop system layout.

Table 2. Design precepts for the full-scale organic system.

-
1. The system should be designed so that it can be hermetically sealed, yet readily accessible for maintenance, particularly during the initial shakedown tests.
  2. Use a containment shell having the same diameter as the pressure vessel of an operational unit to enclose the condenser and turbine-generator region. Provide a flanged joint between the upper and lower portions to permit access.
  3. Support the containment shell from the top and raise or lower the lower portion for access.
  4. Provide a pool of water over the top of the containment shell to simulate seawater cooling the condenser portion of the pressure vessel of an operational unit.
  5. Provide a side access port about 16 in. in diameter.
  6. The containment shell wall thickness should be $1/4$ in.
  7. The containment shell material should be 300 stainless steel to avoid trouble with rust.
  8. The condenser cone thickness should be $1/8$ in.
  9. Mount the regenerator in a well in the bottom of the condenser region with a seal weld at a flange under the regenerator.
  10. Use a cylindrical bellows between the turbine and the duct to the regenerator to avoid troubles with differential expansion.
  11. Use sleeves on penetrations through the containment shell.
  12. Use 2 in. of thermal insulation on outside of the containment shell with 1000 W of electric heaters on the outside of the tank and a simple 110 v plug connection to facilitate disconnecting it.
  13. Provide a $1/2$ in. pipe connection above the main flange of the containment shell for a vacuum pump. Mount a valve in this line just outside the vacuum tank.
  14. Use Viton A O-rings for sealing the vacuum tank flanges.
  15. Use the Sundstrand plumbing layout on the turbine-generator.
  16. Mount the turbine on two shear webs welded to the condenser cone. Use nickel-plated Unistrut to provide adjustment for alignment.

Table 2 (continued)

-
17. Use a large cold trap in the line from the Dowtherm system to the vacuum pump.
  18. Use an insulated hood over the boiler.
  19. Mount the boiler in the electrically heated heat block-shield assembly at one side of the containment shell. The condenser should be 4 ft above the boiler to provide sufficient static head for a bootstrap start.
  20. An electric motor driven auxiliary feed pump should be provided to assure sufficient boiler pressure for starting and to provide a lubricant supply under pressure to the bearings before starting the turbine.
  21. An auxiliary tank in the auxiliary feed pump system will be used for filling and draining the organic fluid system.
  22. It does not appear practicable to arrange for complete drainage of the organic fluid from all parts of the system, particularly the regenerative feed heater and the plumbing around the turbine. If need be, the system can be heated and the fluid distilled from these regions.
-

A number of points with regard to the turbine-generator installation in the ORNL system deserve amplification. In the first place, the turbine-generator unit employs numerous flanged joints which are not thoroughly leak tight. As a consequence, it will be necessary to enclose the turbine-generator unit within a containment shell which can be hermetically sealed. In view of the fact that numerous minor difficulties are anticipated during the shake-down of the system, the ORNL design employs what is in effect a large inverted bell jar to serve as a containment shell. The numerous connections between the turbine-generator unit and the rest of the system will all be enclosed within the containment shell, and Swagelok or similar fittings can be employed without affecting the hermetic seal. Small amounts of fluid that leak from these joints can drain to the bottom of the containment shell. The amount of this leakage is expected to be a trivial fraction of the system inventory. The main function of the containment shell will be to prevent air inleakage to the organic system. The organic system should be sufficiently leak-tight to permit shake-down testing with the lower part of the containment shell removed.

Sundstrand does not have cavitation performance data for the feed pump in their turbine-generator-pump unit. However, this pump impeller is very similar to one they have used in other systems and should have a cavitation specific speed of between 8,000 and 10,000. ORNL estimates indicate that some means of increasing the cavitation suppression head must be provided. As a consequence, it appears best to follow the practice used by Sundstrand in their recent test (and the practice used by ORNL in its space power plant work); namely, employ a jet pump to provide sufficient cavitation suppression head at the entrance to the centrifugal feed pump. The flow sheet proposed includes a jet pump of this type.

The Sundstrand turbine-generator unit requires a surprisingly high turbine inlet pressure to provide sufficient break-away torque to start the rotor. ORNL experience and estimates indicate that it should be possible to get the Sundstrand unit to start with an initial turbine inlet pressure of only 1 or 2 psia, so that it should be possible to boot-strap the system on the static head available because of the difference in level between the condenser and the boiler. Sundstrand does not have any

experience with bootstrap starts and feels that it may be necessary to employ an auxiliary electrically driven pump to provide a lubricant supply to the bearings under pressure before attempting to start. Both the uncertainty with respect to the bootstrap start and the bearing lubricant requirements led to the decision to employ an auxiliary pump. The flow sheet for the system was worked out to minimize the number of penetrations through the containment shell and keep the auxiliary boiler feed pump outside the containment shell.

Sundstrand does not have a regenerative feed heater available for use at ORNL. Previous studies at ORNL had indicated that we might be able to employ a NaK-to-air radiator that was built under the ANP program but never used. The headers will have to be reworked to give a 6-pass or 12-pass configuration (instead of 2-pass) to suit it to the Sundstrand turbine requirements.

Blank Page

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. A. P. Fraas, Program Director, Isotope Kilowatt Program Quarterly Progress Report for Period Ending December 31, 1970, USAEC Report ORNL-TM-3292, Oak Ridge National Laboratory, February 1971.
6. A. P. Fraas, Program Director, Isotope Kilowatt Program Quarterly Progress Report for Period Ending March 31, 1971, USAEC Report ORNL-TM-3394, Oak Ridge National Laboratory, May 1971.
7. A. P. Fraas, Program Director, Isotope Kilowatt Program Quarterly Progress Report for Period Ending June 30, 1971, USAEC Report ORNL-TM-3491, Oak Ridge National Laboratory, August 1971.
8. H. H. Coe, Summary of Thermophysical Properties of Potassium, NASA TN D-3120, Lewis Research Center, December 1965.
9. J. W. Taylor, The Surface Energies of the Alkali Metals, Phil. Mag., Vol. 46, pp. 867-876, August 1955.
10. J. W. Cooke, Thermophysical Property Measurements of Alkali Liquid Metals, USAEC Report ORNL-3605, Vol. 1, pp. 66-87, Oak Ridge National Laboratory, 1964.

Blank Page

Internal Distribution

1. S. E. Beall	33. A. M. Perry
2. T. A. Butler	34. R. A. Robinson
3. W. B. Cottrell	35. M. W. Rosenthal
4. W. C. Cox	36. A. F. Rupp
5. F. L. Culler	37-46. G. Samuels
6. R. G. Donnelly	47. Myrtlelen R. Sheldon
7-16. A. P. Fraas	48. A. C. Schaffhauser
17. J. H. Frye, Jr.	49. M. J. Skinner
18. J. H. Gillette	50. A. M. Smith
19. A. G. Grindell	51. I. Spiewak
20. K. W. Haff	52. D. A. Sundberg
21. H. W. Hoffman	53. D. B. Trauger
22. R. S. Holcomb	54. J. J. Tudor
23. P. R. Kasten	55. A. M. Weinberg
24. M. E. Lackey	56. G. D. Whitman
25. E. Lamb	57. J. V. Wilson
26. M. E. LaVerne	58. H. C. Young
27. D. B. Lloyd	59. Biology Library
28. M. I. Lundin	60-61. Central Research Library
29. R. N. Lyon	62. Y-12 Document Reference Section
30. R. E. MacPherson	63-87. Laboratory Records Department
31. H. C. McCurdy	88. Laboratory Records Department (RC)
32. A. J. Miller	

External Distribution

89. D. R. Bartz, Jet Propulsion Laboratory, NASA, 4800 Oak Grove Drive, Pasadena, California 91103
90. H. Bibb, Naval Facilities Engineering Command, Washington, D. C. 20390
91. Joe Clemente, Sundstrand Aviation, 1100 Connecticut Avenue, N.W., Washington, D. C. 20036
92. D. F. Cope RDT Site Office, ORNL
93. W. M. Crim, Jr., Research and Technology Department, Building 322, Ft. Belvoir, Virginia 22060
94. R. R. Dahlen, Advanced Engineering, 3M Company, Building 551, 2501 Walnut Street, Roseville, Minnesota 55113
95. R. V. Degner, Rocketdyne, 6633 Canoga Avenue, Canoga Park, California 91303
96. R. E. English, NASA, Lewis Research Center, Cleveland, Ohio 44135
97. E. E. Fowler, Division of Isotopes Development, AEC, Washington, D. C. 20545
98. N. C. Gibbon, Cryogenic Products Department, Linde Division, P. O. Box 44, Tonawanda, New York 14150

99. J. C. Graf, General Electric, Valley Forge, Pennsylvania 19481
- 100-104. W. D. Holloman, Division of Reactor Development and Technology, AEC, Washington, D. C. 20545
105. A. E. King, Westinghouse, Lima, Ohio 45801
106. M. Klein, Division of Reactor Development and Technology, AEC, Washington, D. C. 20545
107. W. W. Logvin, Aerojet Liquid Rocket Company, Department 2400, P. O. Box 13000, Sacramento, California 95813
108. J. J. Lynch, NASA Headquarters, Washington, D. C. 20546
109. S. V. Manson, NASA Headquarters, Washington, D. C. 20546
110. R. F. Mather, NASA, Lewis Research Center, Cleveland, Ohio 44135
111. W. Mathis, Westinghouse Astronuclear Laboratory, P. O. Box 10864, Pittsburgh, Pennsylvania 15236
112. T. A. McLaughlin, Isotopic Auxiliary Power Branch, AEC, Washington, D. C. 20545
113. R. E. Niggeman, Sundstrand Aviation, 4747 Harrison Avenue, Rockford, Illinois 61101
- 114-118. Nuclear Engineering Division, Naval Facilities Engineering Command, Washington, D. C. 20390
119. J. Pidkowitz, RDT Site Office, ORNL
120. A. A. Pietsch, AiResearch Manufacturing Company, 402 S. 36th Street, Phoenix, Arizona 85034
121. W. D. Pouchot, Westinghouse Astronuclear Laboratory, P. O. Box 10864, Pittsburgh, Pennsylvania 15236
122. C. R. Ross, Savannah River Laboratory, Aiken, S. C. 29801
123. G. W. Sherman, Aeronautical Space Power Division, Air Force Aeronautical Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio 45433
124. Anthony Stathoplos, Nuclear Technology Corporation, 116 Main Street, White Plains, New York 10600
125. B. Sternlicht, Mechanical Technology, Inc., 968 Albany-Shaker Road, Latham, New York 12110
126. D. Stewart, Battelle Northwest Laboratory, Richland, Washington 99352
127. P. Swenson, Jr., Swenson Research Inc., 5135 Richmond Road, Bedford Heights, Ohio 44146
128. J. E. Taylor, Thompson-Ramo-Wooldridge, 23555 Euclid Avenue, Cleveland, Ohio 44117
129. W. B. Taylor, Technical Director, U.S. Army Mobility Equipment Research and Development Center, Ft. Belvoir, Virginia 22060
130. T. F. Widmer, Thermo Electron Corporation, 85 First Avenue, Waltham, Massachusetts 02173
131. E. S. Wilson, Space Nuclear Systems, AEC, Germantown, Maryland 20767
- 132-133. Division of Technical Information Extension (DTIE)
134. Laboratory and University Division, ORO
- 135-137. Director, Division of Reactor Licensing, AEC-Wash.
- 138-139. Director, Division of Reactor Standards, AEC-Wash.
- 140-144. Executive Secretary, Advisory Committee on Reactor Safeguards, AEC-Wash.