~~CONFIDENTIAL~~

MASTER

LOS ALAMOS • NEW MEXICO

RECEIVED BY THE

Quarterly Status Report on the

AEC RESEARCH AND DEVELOPMENT REPORT

RESTRICTED DATA DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Group 1 - Excluded from automatic downgrading and declassification

UTION OF THIS DOCUMENT IS LIMITED
Government Agencies and Their Contractors * EAS

~~CONFIDENTIAL~~

RESTRICTION OF THE SALE OF INFORMATION
To Government Agencies and Their Contractors + LAR

CONFIDENTIAL

Distributed: February 1971

LA-4625-MS
C-93b, ADVANCED CONCEPTS
FOR FUTURE APPLICATION--
CONVERSION DEVICES
M-3679 (64th Ed.)

LOS ALAMOS SCIENTIFIC LABORATORY
of the
University of California
LOS ALAMOS • NEW MEXICO

Classification cancelled (or changed to) **UNCLASSIFIED**
by authority of **DIV OF DECLASS. WASH, DC**
by **GG** TIC, date **10/26/72**

Quarterly Status Report on the
Space Electric Power R and D Program (U)
for the Period Ending January 31, 1971

LEGAL 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.

UNITED STATES
ATOMIC ENERGY COMMISSION
CONTRACT W-7405-ENG. 36

RESTRICTED DATA

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

This document contains restricted data as defined in the Atomic Energy Act of 1954. Its transmittal or the disclosure of its contents in any manner to an unauthorized person is prohibited.

Group 1 - Excluded from automatic downgrading and declassification

CONFIDENTIAL

DISTRIBUTION OF THIS DOCUMENT IS LIMITED
to Government Agencies and Their Contractors

CONFIDENTIAL

QUARTERLY STATUS REPORT ON THE
SPACE ELECTRIC POWER R AND D PROGRAM (U)
FOR THE PERIOD ENDING JANUARY 31, 1971.

SUMMARY

A heat-pipe-cooled reactor design using either UC or UN fuel was investigated. The main advantage of this system is an operating temperature that is high enough for the reactor to be used in conjunction with a Brayton-cycle turbine. Criticality studies show that the reactor diameter could be as small as ~ 8.5 in. at a core length of 13.0 in., which would result in a radiation shield of minimum weight.

Nine Mo-60 v/o UO_2 cermet fuel pins were fabricated and will be irradiation-tested in the Engineering Test Reactor (ETR). Emitters have been calibrated in the Omega West Reactor (OWR) by measuring their temperature as a function of reactor power and then performing a radiochemical fission analysis to determine the relation of fission-power density in the emitters to reactor power and thence to emitter temperature.

The 27 specimens of various insulator materials and seals which are undergoing irradiation tests in the EBR-II reactor have accumulated 80% of their desired neutron fluence.

Resistivity tests of several sheathed insulators are being conducted, both in-pile and out-of-pile. The samples are held at 750°C while a current of 100 Vdc is applied to the outer insulating layer. The resistivity of the unirradiated sheathed insulators increased for ~ 400 h until it equaled that of metallized ceramic insulators, whereas the resistivity of irradiated sheathed insulators slowly decreased. The tests are continuing.

CONFIDENTIAL

THERMIONIC POWER SYSTEMS

Reactor Heat Sources for Brayton Cycle Turbines

Introduction

Recent interest at Los Alamos Scientific Laboratory (LASL) in thermodynamic cycles other than thermionics for space power-supply applications has prompted the study of reactors as possible heat sources for Brayton-cycle turbines. These studies are aimed at designing reactors that would comply with the usual requirements for nuclear space power supplies, i.e.,

- They would be as small as possible to minimize shield weight;
- Their control requirements would be consistent with those for 4π shielding;
- They would use highly reliable, redundant systems; and
- They would incorporate provisions for extended reactor lifetimes, of the order of five years.

The results of these studies are presented in the following paragraphs.

Shielded Reactor and Heat Exchanger Concept

The reactor which appears to be most compatible with the objectives stated above has a relatively small fast-neutron-spectrum core that is reflected by BeO and cooled by heat pipes. Heat pipes are also included in several other system components; their use results in considerable design simplification, redundancy, and automation of operation.

The first reactor to be studied in detail is being designed to operate in the range of from 130 to 190 kw. It can be coupled with three Brayton-cycle turbines, each with a capacity of 10 to 15 kWe, to provide a space power supply of 30 to 45 kWe.

The shielded reactor and heat-exchanger concept is shown in Fig. 1. The reactor core and the reflector are enclosed in a heavy-metal γ -radiation shield which also provides containment for the reactor. The heat pipes, which transport heat from the reactor core, pass through a portion of the γ and neutron

Fig. 1. Shielded reactor and heat-exchanger concept designed as heat source for Brayton-cycle turbines.

CONFIDENTIAL

shield to a gallery section that contains the compact heat exchangers. The heat-pipe sections passing through the radiation shield are bent to prevent the formation of radiation streaming paths. The reactor is controlled by means of neutron-reflecting and moderating rods that are withdrawn through part of the shield. Scram control is provided by means of springs, which are stretched as the control rods are inserted into the reactor, and which can be released instantaneously in case of emergency. Heat pipes along the centers of the control rods transport the heat from the inserted portions of the rods to the withdrawn portions from where it is radiated to space.

The heat exchangers are of the fin-and-tube type. They are shielded against radiation in order to maintain acceptable activation levels of the turbine working fluid. The amount of shielding required for this purpose will depend primarily on the composition of the working fluid.

The materials and thicknesses of the radiation shields shown are essentially the same as those specified for the ZrH_x reactor that has been designed by Atomics International (AI) for manned space-base application.¹ Part of the LiH between the reactor and the gallery of the AI design has been replaced by BeO because of the high temperature of the heat pipes.

Portions of the reflector and of the shield are cooled by heat pipes which transport both the heat generated in, and the heat conducted to, these components to the surface of the shield. An amount of heat equal to the reactor decay heat immediately after shutdown is allowed to be conducted during normal operation to the shield surface by means of heat pipes in the reflector. This scheme provides for automatic disposal of reactor decay heat in case of emergency shutdowns.

Reactor Design

A cross-sectional view of one reactor design is shown in Fig. 2. This reactor is based on the assumption that the fuel consists of individually clad pieces of multiple hexagons, each of which encloses at least two heat pipes. There are 48 in-core heat pipes and 13 control rods in this design. The fuel may be either UN or UC. Properties, including

Fig. 2. Cross-sectional view of heat-pipe-cooled reactor.

uranium density, thermal conductivity, irradiation stability, and compatibility with other materials are essentially the same for both fuels. The in-core heat pipes are made of niobium and contain sodium as the working fluid. Niobium is also used as the fuel cladding. All calculations have been based on the assumption that all niobium surfaces in contact with the fuel must be protected by 5 mils of vapor-deposited tungsten. A thermal bond consisting of either lithium or helium will be included between the fuel and both the heat pipes and the fuel cladding. The core and the BeO reflector of the design shown in Fig. 2 are enclosed in a niobium vessel which may also contain a thermal bonding material such as helium and which, together with the fuel cladding, serves to doubly contain any evolved fission-product gases.

Although not restricted to this application, the operating conditions specified for the reactor and heat exchangers are consistent with the requirements of the 10 to 15-kWe Brayton-B power system being developed by NASA at the Lewis Research Center.²

Among the most important objectives is the design of a highly reliable, redundant system. Because heat-pipe cooling of the reactor provides part

CONFIDENTIAL

REF ID: A66000
CONFIDENTIAL

of the redundancy, random failures of in-core heat pipes must be taken into consideration. Two-dimensional calculations of temperature distributions for the worst cases of isolated heat-pipe failure are therefore being made for several possible core configurations. The maximum heat-transmission rate required per heat pipe (at 190 kW) during normal operation is 4.55 kW; in comparison, the heat-transmission capacity of the sodium heat pipes being considered is 14.5 kW. This excess heat-transmission capacity has been included in the design to provide a factor of safety and to ensure core cooling in case of heat-pipe failures.

Other considerations, in addition to maximum fuel temperature, may influence the final choices of fuel shape, thermal bonding material, and fuel cladding, e.g.,

- the disposition of fission-product gases that evolve from the fuel;
- the provision of in-core space to accommodate anticipated fuel swelling;
- the effects of fuel-element cladding failures, and
- the ease of fabricability, with particular attention to necessary dry-box operations.

The principal constituent of the control rods is BeO. Core reactivity is decreased by withdrawing the rods from niobium dry wells which extend throughout the length of the core. Each niobium dry well is protected on the inside by a carbon sleeve, and the control rods are enclosed in rhenium-clad niobium. This combination of materials was chosen because carbon and rhenium do not react in the temperature range at which the control rods will operate; thus, there will be no tendency for the control rods to gall or to stick to the structure. The small amount of heat generated in the control rods could probably be allowed to radiate to the surrounding structure; however, provisions have been made to transport this heat by means of heat pipes to radiating surfaces outside the reactor.

The dimensions and weights of the various reactor components are given in Table I.

Nuclear calculations were made for the reactor described above, assuming that either UC or UN fuel is used. Fuel densities assumed were 95% of

TABLE I. COMPONENT DIMENSIONS AND WEIGHTS FOR BRAYTON-CYCLE REACTOR

	Dimensions, in.
Equivalent cylindrical core diameter	8.42
Radial-reflector (BeO) diameter	12.42
Heavy-metal (Nb) vessel and γ-shield diameter	16.02
Core length	13.00
End-reflector (BeO) thickness	2.00
Overall reactor plus integral heavy-metal length	18.05
	Weights, kg
Core, including control rods	95.94
Reflector (BeO)	65.10
Heavy metal (Nb)	216.43

TABLE II. RESULTS OF REACTIVITY CALCULATIONS FOR BRAYTON-CYCLE REACTOR

	UC-Fueled Reactor	UN-Fueled Reactor
Cold, clean excess reactivity, β	5.37	5.32
Control margin, β	5.85	5.88

theoretical. Important results of these calculations are given in Table II. Total peak-to-average power-density ratios for the reactors indicated in this table are between 1.30 and 1.33.

Heat Exchangers

The heat-exchanger concept is presented schematically in Fig. 3. There are two rows of finned, reentrant tubes which extend through all three heat exchangers. The reactor heat pipes are inserted into these tubes. Either a gas or a metal thermal bond will be provided between the heat pipes and the heat-exchanger tubes. The turbine working fluid enters on the outer peripheries of the heat exchangers and flows radially toward the centers. The three gas systems are independent of each other. Failure of one or two of these systems will not affect the operation of the remaining one(s). To continue operation, it is only necessary to lower the total reactor power appropriately. Initial estimates indicate that the capacity of 16-in.-diam by ~2-in.-long heat exchangers will be adequate to transfer the required heat load.

CONFIDENTIAL

CONFIDENTIAL

Fig. 3. Compact heat-exchanger design for heat pipe cooled reactor.

Shielding and Total Weight

Detailed shielding analyses for specific missions will be required before accurate weight estimates can be made. The total weight of the system shown in Fig. 1 is ~ 5400 kg. This weight is, of course, critically dependent on the cone angle of the shield. If the cone angle is reduced from 35 to 21 deg, the system described would weigh ~ 4000 kg.

The shield weight is also dependent on the severity of the turbine working-fluid activation problem. If a turbine working fluid is chosen that is not activated by neutrons, the heat exchangers could be placed next to the reactor. Such an arrangement would significantly decrease the shield weight. The results of preliminary activation estimates based on the use of a mixture of 38 a/o helium and 62 a/o xenon indicate that the shield design discussed above is conservative.

References

1. L. M. Maki and E. J. Donovan, Jr., "Reference Zirconium Hydride Reactor," AI AEC 12715, June, 1969.
2. W. J. Brown, "Brayton-B Power System-A Progress Report," Proc. 4th Intersociety Energy Conv. Conf., Sept. 22-26, 1969, Washington, D.C. pp 652-658.

FUELED EMITTER DEVELOPMENT

Fuel Pin Development

Thermionic fuel pins now being made with a Mo-9 w/o W metal matrix contain 60 v/o Y_2O_3 -stabilized UO_2 . The fuel pins are machined from pressed-and-sintered material that has been stabilized at 1900°C for 100 h in argon. The pins are then coated with tungsten and are heat-treated at 1900°C for 24 h to bond the tungsten coating to the fuel-pin matrix. One Mo (TZM) alloy tack is positioned at each end of the fuel-pin assembly prior to the tungsten-coating process. The 10-mil-thick tungsten coating is then applied by chemical vapor deposition and holds these tacks in place. After coating and final heat treatment at 1900°C, the fuel pins are ground to a uniform diameter.

Nine fuel pins (Pins 4-075X through 4-083X) were completed and delivered for final surface-grinding operations; they will be used in reactor tests.

Sufficient material for about eight additional fuel pins is being prepared. The pins will be made from air-classified, 10%-enriched UO_2 powder. This will ensure the proper particle-size distribution to yield a fuel pin that is dimensionally stable after thermal cycling.

CONFIDENTIAL

DECLASSIFIED

CONFIDENTIAL

Emitter Calibration

In conjunction with the current ETR irradiation experiment, designed to test the long-term irradiation stability of the Mo-9 w/o W fuel-pin matrix material containing 60 v/o Y_2O_3 -stabilized UO_2 , a calibration of temperature versus fission-power density was obtained for the specific emitter configuration to be used in the tests. This course of action was chosen over that of using thermocouples to measure the temperature of every emitter in the test series because of cost considerations only.

The calibration procedure entails measuring the temperature of a typical emitter as a function of reactor power and then performing a radiochemical fission analysis to determine the relation of fission-power density in the emitter to reactor power and thence to emitter temperature. Subsequent fission-power density measurements for the fueled emitters in the long-term irradiation experiments yield an average temperature for the irradiation that is subject to correction for known effects occurring during irradiation and subject to error because of unknown effects.

The first part of the calibration experiment outlined above was completed, and measurements of fission density are currently under way. The measurement of emitter temperature versus reactor power was performed in the OWR. Three W/W26Re thermocouples were used to measure the temperature at the center of the emitter and at two locations near the periphery, i.e., at the axial midplane and near the support end. At the nominal operating temperature of 1670°C the heat loss from the emitter was about equally divided between radiation and conduction through neon gas at a pressure of 585 Torr in the 0.033-in. (cold) gap between the emitter and the collector.

When the emitter was first brought up to high temperature the temperature data points showed a tendency to drift. Therefore, only those points were used for the calibration curve which were obtained after the temperature had remained constant to within $\pm 5^\circ\text{C}$ at 1680°C for 3 h.

The peripheral temperatures measured at the axial midplane are compared in Fig. 4 with a

Fig. 4. Comparison of experimental and calculated dependence of fueled-emitter temperature on OWR power.

calculated curve. Obtaining this curve involved a neutronics calculation of fission power in the cermet versus the total power of the OWR plus a one-dimensional calculation of the axial surface-temperature distribution for the emitter as a function of the fission-power density generated in its interior. The latter calculation included the effects of gas conduction and radiation, and the radiative and conduction losses off the ends of the emitter.

It is not yet known whether the 12% discrepancy between the two curves is due to uncertainty in the neutronics calculation or to variation of the actual values from the assumed values of emissivity, gas conductance, and emitter-support conductance in the calculations of emitter temperature versus input power. This problem will be resolved by subsequent fission-density measurements.

The test unit was disassembled in a hot cell, and the various components were found to be generally unchanged from their pretest appearance. In particular, there was no obvious change in the emissivity of the emitter and of the collector, which had been blackened to enhance the radiation transport from the emitter.

CONFIDENTIAL

CONFIDENTIAL

EBR-II ISOTHERMAL IRRADIATION TESTS

Irradiation of Ceramics and Ceramic-to-Metal Seals

As part of a continuing investigation of fast-neutron damage to ceramics and ceramic-to-metal seals, a second irradiation test capsule, K-2, has been placed in Position 7B3 of the EBR-II reactor. This unit contains 27 specimens, including yttria, three types of alumina (GE Lucalox, Coors AD 999, and Feldmuhle E-37), niobium and Nb-1%Zr/alumina seals (both brazed and autoclave-bonded), and a nickel/alumina seal. Two seal specimens and one ceramic specimen are being irradiated for the thermionics group of the Brown, Boveri, & Cie. laboratory, Heidelberg, West Germany.

The test unit is an isothermal irradiator set to run at a temperature of 750°C. The planned exposure ranges from 3 to 6×10^{21} nvt ($E_n > 0.1$ MeV). At present the unit has accumulated $\sim 80\%$ of the target fluence. Irradiation will presumably be completed in March 1971.

SHEATHED-INSULATOR DEVELOPMENT

Voltage-at-Temperature Tests of Sheathed Insulators

The combined effects of temperature, electrical stress, and neutron irradiation on sheathed insulators are being investigated. In these experiments 100 Vdc is applied continuously across gas-pressure-bonded tri-layers, the metal sheaths of which are made of Nb-1%Zr, whereas the insulators consist of either Wesgo Al 995 or GE Lucalox. The tests are designed to permit guard-ring measurements of the electrical resistance of each sheathed insulator under full test conditions. One series of tests is being made out-of-pile, another in the OWR. Both series of tests are intended to run for 10,000 h or until a drastic change occurs in the resistivities of the samples.

The following general statements can be made regarding the high-temperature (750°C) resistivities of the sheathed insulators; they are compared to the resistivities of unsheathed ceramics of the same type which had been metallized to ensure electrical contact:

- The resistivities of as-received gas-pressure-bonded sheathed insulators are one to two orders of magnitude lower than the resistivities of the metallized ceramics.
- The resistivities of metallized ceramic insulators decreased by less than an order of magnitude after long exposure to irradiation at high temperature.¹
- With 100 Vdc continuously applied across unirradiated sheathed insulators at 750°C, their resistivities increased for ~ 400 h, at which time they exceeded 10^{10} Ω -cm thus equaling the resistivities of the metallized ceramic insulators. No further significant changes occurred after an accumulated 1600 h under these test conditions. The test is continuing.
- With 100 Vdc continuously applied across irradiated sheathed insulators, their resistivities slowly decreased with time, but at a constantly decreasing rate. After 421 h of irradiation and an accumulation of 3.8×10^{19} nvt ($E_n > 0.1$ MeV) no apparent limit had been reached. At this point, the insulators retained sufficient resistivity, $> 10^6$ Ω -cm, to be of use in thermionic-reactor applications. The reactor was then shut down for two weeks of maintenance; after restart, the resistivity of both types of tri-layers was found to be very erratic and unpredictable. It is not yet certain whether this anomalous behavior is due to a failure of the sheathed insulators or to problems with the measuring circuits. The irradiation tests are continuing.

Reference

1. W. H. Reichelt, W. A. Ranken, C. V. Weaver, A. W. Blackstock, A. J. Patrick, M. C. Chaney, "Radiation Induced Damage to Ceramics in the EBR-II Reactor," Proc. Thermionic Conv. Spec. Conf., Miami Beach, Florida, Oct. 1970.

HEAT PIPE SYSTEMS

There is no report on Heat Pipe Systems this quarter and hence there is no unclassified section of the Space Electric Power R and D program.

CONFIDENTIAL
DECLASSIFIED