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HIGH-TEMPERATURE LIQUID-METAL TECHNOLOGY REVIEW

A Bimonthly Technical Progress Review

PREPARED UNDER THE AUSPICES OF
DIVISION OF REACTOR DEVELOPMENT
ENGINEERING DEVELOPMENT BRANCH, USAEC

VOLUME 1 • NUMBER 6 • DECEMBER 1963

BROOKHAVEN NATIONAL LABORATORY
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UPTON, NEW YORK**

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FOREWORD

The High-Temperature Liquid-Metal Technology Review, sponsored by the Engineering Development Branch, U. S. Atomic Energy Commission, and published by the Brookhaven National Laboratory, is now one year old. This issue is the sixth and final of Volume 1.

During the past year, the issues have grown steadily in size and, we think, also in quality. The present issue of the Review has two innovations which we hope will increase its usefulness. First, along with each individual review, a list of all previous ones on the same project or program is given; and second, a listing of all reviews published to date, by organization, is given as an appendage.

I would like to repeat again, that ideas from our readers for further improvement of the Review are always welcome.

I would also like at this time to express my thanks to the following members of the Nuclear Engineering Department at Brookhaven who have served faithfully as reviewers during the past year:

J. C. Chen	C. Klamut
J. J. Egan	M. Maresca
A. H. Fleitman	J. Powell
K. C. Hoffman	A. J. Romano
C. Hsu	L. Topper
S. D. James	J. D. Van Norman
S. Kalish	J. Weeks

It is mainly through the capable and steadfast efforts of these scientists and engineers that the Review is made possible.

Finally, I express my appreciation to the several organizations which submit progress reports for coverage in the Review for their promptness and splendid cooperation.

O. E. Dwyer
Technical Editor

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HIGH-TEMPERATURE LIQUID-METAL TECHNOLOGY REVIEW

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SODIUM-HEATED STEAM GENERATOR DEVELOPMENT

Sponsor: U. S. Atomic Energy Commission
Contractor: The Babcock & Wilcox Company-Boiler Division,
Barberton, Ohio
Contract No.: AEC AT(11-1)-1280
B&W 610-0067
Report No.: Progress Report No. 5
Report By: P. B. Probert
Report Date: September 1963
Previous Reviews: 56, 61, 115, 116

The present objective of this project is no different from that summarized earlier in Review No. 115. This report gives detailed drawings of the large-scale steam generator, which at 100% load transfers 2.33×10^9 Btu/hr. Drawings of the shell, boiler bundle, and superheater, and three tables of design parameters are also given.

The design of the 30-Mw(t) prototype has been started. It will have twenty-seven 1-in.-o.d. tubes in the boiler bank and fifty-five 7/8-in. tubes in the superheater.

The following R/D work was carried out in support of the generator designs.

Carbon transfer and effect on material properties.

A loop is being designed to study C and mass transfer phenomena in a single-tube steam generator. The test conditions will simulate, as far as possible, those existing in the 30-Mw(t) and full-scale generator designs. The steam generator is a double-pipe heat exchanger with Na in the annular space.

Effect on heat transfer and two-phase flow of coiling tubes.

Experimental results are going to be obtained on the effect of curved tubes on (a) location of the point of DNB, (b) nucleate and film heat transfer rates, and (c) two-phase flow behavior. An existing boiling-heat-transfer rig will be used for this work, and the design work on the curved test section is in progress.

Sodium-water reaction.

Nothing new to report under this heading in addition to that given in Review No. 116. The work is just getting started.

Welding tubes to back side of tube sheet.

Nothing new since Review No. 115.

Radiographic inspection of back side of tube weld.

It is proposed to do this with a small x-ray source to be placed inside each tube. The x-radiation will be produced by a beta-emitter such as Pm-147 in conjunction with a heavy element. Exploratory work is now in progress.

Chemical simulation of sodium environment for leak testing.

Nothing new since Review No. 115.

(O. E. Dwyer)

REVIEW NO. 124

SODIUM-HEATED STEAM GENERATOR DEVELOPMENT

Sponsor: U. S. Atomic Energy Commission
Contractor: The Babcock & Wilcox Company-Boiler Division,
Barberton, Ohio
Contract No.: AEC AT(11-1)-1280
B&W 610-0067
Report No.: Progress Report No. 6
Report By: Paul Probert
Report Date: October 1963
Previous Reviews: 56, 61, 115, 116, 123

The previous monthly report is summarized above, and only those topics will be mentioned again here, which show significant advances in status.

Carbon transfer and effect on material properties.

Design of loop is completed, but detailed design of certain components is continuing. Long delivery items have been ordered.

Corrosion rates for Croloy 2 $\frac{1}{4}$ steel in products of a sodium-water reaction.

Work has started on the determination of corrosion rates in aqueous NaOH solution. Data have been obtained in a 24.2% solution at 140°, 170°, and 200°F at time intervals of $\frac{1}{2}$, 1, 3 $\frac{1}{2}$, and 7 hr. There was "reasonable progression of corrosion" of metal as temperature and exposure time are increased. No mention of the type of corrosion, or corrosion rates, was given.

Chemical simulation of sodium environment for leak testing.

Specimens of weld slag from Croloy 2 $\frac{1}{4}$ and type 316 SS have been prepared. Tests to determine the solubility of this slag in sulfamic acid, ethylene-diamine tetracetic acid (EDTA), and the tetrasodium salt of EDTA have been started.

(O. E. Dwyer)

REVIEW NO. 125

THE EXPERIMENTAL P-V-T PROPERTIES OF POTASSIUM TO 1150°C

Sponsor: National Aeronautics and Space Administration
Contractor: Battelle Memorial Institute, Columbus, Ohio
Contract No.: NAS 5-584
Report No. BATT-4673-T4
Report By: Joseph F. Walling and Alexis W. Lemmon, Jr.
Report Date: April 30, 1963
Previous Reviews: 37, 93

The results of experimental studies on the thermodynamic properties of potassium are presented. The main purpose of this work was to measure the P-V-T relationships of potassium vapor, and then utilize the knowledge, together with other relevant information, to construct a Mollier diagram.

Experimental measurements of the P-V-T properties were carried out in a fixed-volume apparatus. The general mode of operation was to hold the temperature of the system constant for a series of determinations, introduce or withdraw K by means of a calibrated mechanism, and measure the equilibrium pressure following each incremental change in the quantity of K. Data were taken in a series of runs at 850°, 950°, 1000°, 1050°, 1100°, and 1150°C. Deviation from ideality was expressed in terms of a "compressibility factor." The following virial-type equation was reported to best represent the results, with uncertainties in experimental compressibilities placed at 5 to 9%.

$$PV/nRT = 1 + B'P + C'P^2,$$

where

$$\log |B| = 8.9912 + 1.471 \times 10^3/T - 2.212 \log T$$

$$B' = \frac{-|B|}{82.057 T}$$

$$\log |C'| = -6.315 + 4.670 \times 10^3/T, \quad C' < 0$$

Corrections to the enthalpy and entropy of the gas were calculated in a straightforward fashion by using the equation of state and standard thermodynamic relationships. These corrections were used in conjunction with liquid-phase thermal data and vapor pressure data to compute enthalpies and entropies of liquid and vapor under a variety of conditions. These calculations are summarized and presented in the form of an enthalpy-entropy diagram.

The report describes the structure of the experimental apparatus, and the procedures of operation and data reduction. A table listing the enthalpy, entropy, specific heat, and specific vapor volume in the temperature range 1200°R to approximately 2600°R is given in the Appendix.

(C. Hsu)

THE THERMAL CONDUCTIVITY AND ELECTRICAL RESISTIVITY
OF LIQUID POTASSIUM AND THE ALLOY NIOBIUM-ZIRCONIUM

Sponsor: National Aeronautics and Space Administration
Contractor: Battelle Memorial Institute, Columbus, Ohio
Contract No.: NAS 5-584
Report No.: BATT-4673-T6
Report By: H. W. Deem and J. Matolich, Jr.
Report Date: April 30, 1963
Previous Reviews: 37, 93

An apparatus and method are described to measure simultaneously the thermal conductivity and electrical-resistivity values of liquid K. The method, a steady-state longitudinal-heat-flow method, consists of heating one end of a specimen, measuring the temperature gradient along the specimen, and determining the rate of heat flow through the specimen by means of a reference material of known thermal conductivity attached to one end of the specimen. Since the container and reference material was Nb-1 Zr alloy, its thermal conductivity was measured. The electrical resistivity values for liquid K and Nb-1 Zr alloy were also measured.

The thermal conductivity, k , of liquid K may be represented by either

$$k = 0.543 - 0.333 \times 10^{-3} t \quad (100^\circ \text{ to } 800^\circ\text{C}) \quad (1)$$

or

$$k = 0.438 - 2.22 \times 10^{-4} t + \frac{39.5}{t + 273.2} \quad (100^\circ \text{ to } 800^\circ\text{C}) \quad (2)$$

where

k = thermal conductivity, watt/(cm²) (C/cm)
 t = temperature, °C.

The standard deviation of the 50 points used is 0.014 watt/(cm²) (C/cm) for equation (1) and 0.011 watt/(cm²) (C/cm) for equation (2). The estimated experimental error is ±8%. Use of these equations outside the temperature limits is not advised.

Electrical-resistivity values for liquid K ranged from 15.4 microhm-cm at 100°C to 15.3 microhm-cm at 1175°C.

The thermal conductivity of the Nb-1 Zr alloy ranged from 0.474 to 0.634 watt/(cm²) (C/cm) between 100° and 1150°C, respectively. Electrical-resistivity values ranged from 19.5 microhm-cm at 100°C to 45.4 microhm-cm at 800°C.

(J. D. Van Norman)

REVIEW NO. 127

DESIGN AND EVALUATION OF AN INSTRUMENT
FOR MEASURING THE SPECIFIC HEAT OF POTASSIUM VAPOR

Sponsor: National Aeronautics and Space Administration
Contractor: Battelle Memorial Institute, Columbus, Ohio
Contract No.: NAS 5-584
Report No.: BATT-4673-T5
Report By: Joseph F. Walling, Harry K. Nuzum, Byung C. Kim,
and Alexis W. Lemmon, Jr.
Report Date: April 30, 1963
Previous Reviews: 37, 93

The report reviews efforts to evaluate various methods for the determination of specific heats of K vapor. The experimental methods evaluated were (a) velocity-of-sound method, (b) isentropic-expansion method, (c) heat-calorimeter method, and (d) flow-calorimeter method. An analytical method for calculating the vapor specific heat from an equation of state was also evaluated. It was concluded that the latter procedure promises the greatest precision and was the one selected.

(J. C. Chen)

REVIEW NO. 128

THE VAPOR PRESSURE AND HEAT OF VAPORIZATION
OF POTASSIUM FROM 480° TO 1150°C

Sponsor: National Aeronautics and Space Administration

Contractor: Battelle Memorial Institute, Columbus, Ohio
 Contract No.: NAS 5-584
 Report No.: BATT-4673-T3
 Report By: Joseph F. Walling, Harry K. Nuzum, and Alexis W. Lemmon, Jr.
 Report Date: April 30, 1963
 Previous Reviews: 37, 93

This report describes measurements and calculations of vapor pressure that define the maximum pressure obtainable in one- or two-phase K systems between 900° and 2100°F (480° and 1150°C, 753° and 1423°K). These data permit calculation of the heat of vaporization of K as a function of pressure and temperature which is necessary to construct the enthalpy-entropy diagram.

The K was purified by distillation to 35 to 40 ppm of O₂. After loading into the boiling tubes, this contamination had increased to ~100 ppm O₂. For use above 872°C, a boiling tube of Nb - 1% Zr was used. Below this temperature, type 304 SS was employed.

In a modified boiling-point experiment, the temperature at which the vapor pressure of K became equal to a fixed He pressure was determined by noting when the temperature-time behavior of a gently heated sample changed. Using the steel tube, at a fixed He pressure and rate of heating, boiling points were well-defined as points of abrupt change in slope of the temperature-time curves. With the Nb - 1% Zr tube, the slope of the temperature-time curves decreased gradually over an ~40°K-interval and the boiling points were taken from the points of intersection of the constant slopes before and after this interval. This procedure was justified empirically by showing that these points of intersection were independent of heating rate and met a number of other criteria for true boiling points.

When the data were analyzed by a conventional Third Law procedure, they could be represented between 757° and 1430°K (484° to 1157°C) by the relation

$$\begin{aligned} \log P = & \frac{-4794.3}{T} - 1.97108 \log T + 4.9800 \times 10^{-4} T - 1.0659 \times 10^{-7} T^2 \\ & + 10.1451 + \frac{1915.4}{T} \exp \left[-\frac{4338.9}{T} \right] + \frac{7.40 \times 10^4}{T} \exp \left[-\frac{1.056 \times 10^4}{T} \right] \end{aligned}$$

where P is in atmospheres. Standard deviation was ± 0.0097 in $\log P$.

Below 1200°K (927°C) agreement with the recent determination of Johnson et al. is good; agreement with the determinations of Makansi et al. is fair. The only other data which extend substantially above 927°C (Grachev and Kirilov) disagree badly. The calculated normal boiling point is 1034.5°K (761.3°C).

By using these data and the liquid-density data of Ewing in the Clapeyron equation, the heat of vaporization was found to vary from 19,530 cal/g-atom at 773°K (500°C) to 14,240 cal/g-atom at 1423°K (1150°C), with an estimated uncertainty of ± 100 cal/g-atom.

(S. D. James)

REVIEW NO. 129

THE SPECIFIC HEAT FROM 0° TO 1150°C
AND HEAT OF FUSION OF POTASSIUM

Sponsor: National Aeronautics and Space Administration
Contractor: Battelle Memorial Institute, Columbus, Ohio
Contract No.: NAS 5-584
Report No.: BATT-4673-T2
Report By: H. W. Deem, E. A. Eldridge, and C. F. Lucks
Report Date: August 31, 1962
Previous Reviews: 37, 93

The enthalpy and specific heat of K from 0° to 1150°C and its heat of fusion at 63.2°C were determined by means of data obtained with a Bunsen ice calorimeter. The K was contained in Nb - 1 Zr capsules for the measurements. Measured enthalpy values were corrected for the effect of K vapor above the liquid and for slight external oxidation of the capsules. The equations obtained for specific heats of K were

$$\begin{aligned}C_s (\text{solid}) &= 0.1705 + 0.4190 \times 10^{-3} t \quad (0^\circ \text{ to } 63.2^\circ \text{C}) \\C_s (\text{liquid}) &= 0.2004 - 0.8777 \times 10^{-4} t \\&\quad + 1.0970 \times 10^{-7} t^2 \quad (63.2^\circ \text{ to } 1150^\circ \text{C}),\end{aligned}$$

where

$$C_s = \text{cal g}^{-1}\text{C}^{-1}, \text{ and}$$
$$t = \text{temperature, } ^\circ\text{C}.$$

In the range 100° to 800°C, agreement between the specific heats measured here and those reported by Douglas et al.* agree to within ±6.4%.

The heat of fusion obtained in the present study, for K at 63.2°C, is 14.3 cal/g. This is in essential agreement with previously reported values.

(J. C. Chen)

REVIEW NO. 130

THE VISCOSITY OF SATURATED LIQUID POTASSIUM
FROM 70° TO 1150°C BY THE OSCILLATING-CYLINDER METHOD

Sponsor: National Aeronautics and Space Administration
Contractor: Battelle Memorial Institute, Columbus, Ohio
Contract No.: NAS 5-584
Report No.: BATT-4673-T1
Report By: Elton H. Hall and John M. Blocher, Jr.
Report Date: August 31, 1962
Previous Reviews: 37, 93

An oscillating-cylinder viscometer was designed, constructed, and used for the measurement of the viscosity of liquid K over the temperature range 70° to 1150°C. The previous upper limit was 700°C. The results are expressed by the following equations:

614° to 1158°R (154° to 698°F):

$$\log \eta = \frac{516.8}{T} - 0.7073,$$

*Douglas, T. B., Ball, A. F., Ginnings, D. C., and Davis, W. D., "Heat Capacity of Potassium and Three Sodium-Potassium Alloys Between 0° and 800°C, the Triple Point and Heat of Fusion of Potassium," J. Am. Chem. Soc. 74, 2472-8 (1952).

1158° to 2560°R (698° to 2100°F):

$$\log \eta = \frac{737.5}{T} - 0.8979.$$

The viscosity, η , is in lb/ft-hr, and T is in °R.

The results tended to fall between the extremes of previously reported values. The maximum error was estimated to be about 5%, and the probable error not greater than 2.5%. The results obeyed the Andrade equation up to 370°C.

(O. E. Dwyer)

REVIEW NO. 131

ENGINEERING PROPERTIES OF POTASSIUM AND CESIUM
Twelfth Quarterly Report-July 1 to Sept. 30, 1963

Sponsor: National Aeronautics and Space Administration
Contractor: Battelle Memorial Institute, Columbus, Ohio
Contract No.: NAS 5-584
Report No.: BATT-4673-Q-12
Report By: Alexis W. Lemmon, Jr.
Report Date: October 30, 1963
Previous Reviews: 37, 93

The report covers the period July 1, 1963 through September 30, 1963, and briefly outlines the status of the following measurements which are currently under way: thermal conductivity of potassium vapor, preparation and analysis of Cs, specific heat of liquid Cs, thermal conductivity of liquid Cs, and the viscosity of liquid Cs.

(J. J. Egan)

CAVITATION DAMAGE IN LIQUID METALS

Sponsor: National Aeronautics and Space Administration
Contractor: Hydronautics, Inc., Laurel, Maryland
Contract No.: NASr 105
Report No.: 235-6
Report By: H. Preiser, C. Couchman, and A. Thiruvengadam
Report Date: Progress Report for July 2 to October 2, 1963
Previous Reviews: 107

The current work is oriented towards analysis of the effects of specific test variables on cavitation damage. Al specimens ranging from 3/8 to 7/8-in. diam exposed to distilled water in the magnetostriction device exhibited a constant weight loss per unit area, thereby providing means of correlating the damage rate on different sized specimens.

Pure Fe (Ferrovac E) and Ti (TMCA, 100A) were exposed to Na at temperatures of 400° to 700°F in the inert-atmosphere magnetostriction apparatus. The specimens exhibited the same characteristic damage phases that were observed on Al samples in tap water: a very short period during which no damage took place (incubation zone), a period of rapid increase in damage rate (accumulation zone), a period of decreasing damage rate (attenuation zone), and a period of constant damage rate (steady-state zone). The maximum rate of weight loss for Ti was 0.67 mg/min compared to 2.7 mg/min for Fe under nearly constant conditions of amplitude, frequency, and temperature. This maximum was reached after a much longer accumulation time for Ti and the steady-state zone weight loss after 700 min of test was 0.26 mg/min for Ti vs. 0.68 mg/min for Fe.

Preliminary studies have been conducted on the effects of variation of amplitude and temperature on damage rate and the role of surface corrosion fatigue during the damage incubation period. The magnetostriction device appears to be suitable for obtaining S-N fatigue curves at high frequencies.

The new refractory-metals dry box is being fabricated and is scheduled for delivery in January 1964.

(K. C. Hoffman)

REVIEW NO. 133

SODIUM RESISTIVITY METER LOOP
SUMMARY REPORT FOR OCTOBER AND NOVEMBER 1963

Sponsor: U. S. Atomic Energy Commission
Contractor: Atomic Power Development Associates, Inc., Detroit, Mich.
Contract No.: AT(11-1)-865, Project No. 3
Report By: Patrick Hanniford, Contract Administrator
Report Date: October and November 1963
Previous Reviews: 36, 65, 106, 133

These two monthly reports describe progress on an experimental program to evaluate in-line meters for the determination of contamination levels in Na systems. Attention has been concentrated on the Blake resistivity meter and on a variable-orifice plugging meter.

The reports describe test runs with Na_2CO_3 and Na_2O contamination introduced by means of "tea bags," and with CO , CO_2 , and CH_4 contamination introduced by direct gas injection. Typical response behaviors of the meters are presented by graphical calibration curves for Na_2CO_3 , Na_2O , and CO_2 .

(J. C. Chen)

REVIEW NO. 134

15-kw SOLAR MECHANICAL ENGINE

Sponsor: U. S. Air Force
Contractor: Sundstrand Aviation, Denver, Colorado
Contract No.: AF 33(616)-7128
Report No.: CDRD-63:5035 - Quarterly Progress Report No. 12
Report By: K. E. Nichols, Project Engineer
Report Date: December 1963
Previous Reviews: 34, 63, 108

The system elements and design objectives of the 15-kw Solar Mechanical Engine have been reported in prior High-Temperature Liquid-Metal Technology Review reports (e.g.,

Vol. 1, No. 5, October 1963, p. 37). The work during this reporting period was all directed toward the energy collection subsystem (mirror, heat receiver, and orientation system) and the special test equipment necessary for monitoring. Information pertaining to liquid metal technology has been screened for presentation in this review, while omitting information on mirror fabrication techniques and orientation system design and analytical techniques.

In August, the small-scale heat receiver with the Rb flow loop was mounted on the 10-ft mirror and testing started. A leak developed in the energy divider. Dye penetrant tests revealed three cracks about 1/16 in. from the leading edge near a circular seam weld. The reflective face was warped and discolored over a large part of the surface. The failure of the energy divider was caused by thermal stresses resulting from localized boiling of Rb and consequent hot spots. Boiling within the energy divider is ascribed to a reduction in the reflectivity of the Inconel face during the test so that the absorbed solar energy exceeded the cooling capacity of the design.

An investigation was initiated to find a coating for the energy divider having a high reflectivity and a high resistance to corrosion. Based on existing data, either Au, Ag, Cr, or Al would provide good reflective qualities and resistance to a gaseous environment.

(M. W. Maresca)

REVIEW NO. 135

CAVITATION DAMAGE IN MERCURY AND WATER
IN A CAVITATING VENTURI AND OTHER COMPONENTS

Sponsor: National Aeronautics and Space Administration
Contractor: University of Michigan, Ann Arbor, Michigan
Contract No.: NSG-39-60
Report No.: 03424-9-T
Report By: F. G. Hammitt et al.
Report Date: September 1963
Previous Reviews: 43, 71

A series of cavitation damage tests was conducted in a cavitating venturi, using cold water and Hg as test fluids, with a variety of structural materials including austenitic stainless steel, carbon steel, Al, Cb - 1% Zr, and Plexiglas. This report covers the entire investigation to September 1963 and includes a description of the test facility and the analytical techniques used to evaluate the test data. Cavitation damage data in terms of weight loss, and observations related to the type of damage, its characteristics, and probable mechanisms as a function of flow, material parameters, and exposure time are presented. Among the major conclusions reached are the following:

1. The damage produced by Hg and water is of a similar kind, the principal difference being that individual blows produced by collapsing Hg bubbles are more intense than those obtained in water. Thus Hg damage is more often of the single blow crater type while water damage is of the multiblow fatigue type.
2. Under similar flow conditions the volume of metal loss in cavitating Hg is about 100 times that in cavitating water.
3. The damage obtained on the test specimens is similar in kind to that obtained on flow components such as pump impellers and valves.
4. The effect of throat velocity on damage rate is not as great as that found by previous investigators, using other types of equipment.
5. Preliminary comparison of volume loss with mechanical properties of the test material indicate that the best correlation is with strain energy to failure. However, the scatter of individual points is very large and the gross discrepancy indicated by Plexiglas in water appears to show that other parameters are required, probably involving a coupling between fluid and material parameters.

(K. C. Hoffman)

CAVITATION DAMAGE AND PERFORMANCE RESEARCH FACILITIES

Sponsor: National Aeronautics and Space Administration
Contractor: University of Michigan, Ann Arbor, Michigan
Contract No.: NsG-39-60
Report No.: 03424-12-T
Report By: F. G. Hammitt
Report Date: October 1, 1963
Previous Reviews: 43, 71, 135

Facilities for the investigation of cavitation damage using a variety of fluids including high-temperature liquid metals have been developed.

A multiple cavitating venturi system (4 loops in parallel) has been utilized for water tests. This facility produces throat velocities up to 200 ft/sec. The damage specimens are thin flat plates $1/16 \times 5/8 \times 1/2$ in. with tapered ends and are inserted in suitable holders through the walls of the venturi with the smallest dimension normal to flow. Each venturi can hold three damage specimens.

A single loop cavitating venturi system capable of holding two specimens in the single venturi has been designed for use with water as well as various other fluids such as Hg and Pb-Bi at temperatures up to 1000°F. The maximum throat velocity attainable is about 100 ft/sec for water and 65 for heavy liquid metals.

An ultrasonic vibratory unit was selected for the study of liquid metals under temperature conditions applicable to advanced SNAP systems. A unit driven by a lead-zirconate transducer at frequencies up to 20 kc has been constructed for operation at temperatures up to 2000°F. Fabrication of periphery equipment for this facility is under way.

Techniques for studying damage effects have been developed. Flow regime examination techniques such as high-speed photography and gamma-ray densitometer measurements of void fraction are discussed.

(K. C. Hoffman)

SODIUM COLD TRAP STUDIES
Monthly Progress Report #8

Sponsor: U. S. Atomic Energy Commission
Contractor: Westinghouse Electric Corporation, Pittsburgh, Pa.
Contract No.: AT(30-1)-3186
Report No.: WCAP-4308
Report By: P. Cohen, Manager, Chemical Development
Report Date: Submitted November 19, 1963
Previous Reviews: 113, 114

Fabrication of the new mock-up trap, coring tools, and coring fixtures will be complete during the early part of November. The over-all trap size is 6 in. diam x 24 in. long. It is fabricated of schedule 5, 304 SS. The trap contains 2 rolls of York Demister Mesh, each 12 in. high and wrapped to a density of 15 lb/ft³. The mesh is laced with thin wires of different metals, in an established pattern, to determine relative mesh-sodium movement.

For the coring operations the trap will be filled with layers of sodium and sodium-containing oxides to determine the coring behavior between the sodium-mesh and the sodium-sodium oxide-mesh. It will be possible to remove 20 to 24 cores from the prototype.

Two double oscillating hole saws will be evaluated. In one tool the i.d. of the inner cutter is relieved 60 mils, and in the other 125 mils.

A review of the literature pertaining to the analytical chemistry of sodium was prepared and issued as document WCAP 4302.

The reviewer observes that these brief reports do not give the purpose, objectives, and plan of the work being reported.

(S. Kalish)

REVIEW NO. 138

SODIUM COLD TRAP STUDIES
Monthly Progress Report #9

Sponsor: U. S. Atomic Energy Commission
Contractor: Westinghouse Electric Corporation, Pittsburgh, Pa.
Contract No.: AT(30-1)-3186
Report No.: WCAP-4309
Report By: P. Cohen, Manager, Chemical Development
Report Date: Submitted December 19, 1963
Previous Reviews: 113, 114, 137

Fabrication of the new mock-up trap, coring tools, and coring fixture was completed. The mock-up was filled with sodium and sodium-sodium oxide layers. The sodium-sodium oxide mixture used was found to be extremely heterogeneous, containing essentially a layer of sodium and a layer of sodium oxide. Since it was anticipated that the mixture would be homogeneous, the planned filling procedure had to be modified.

The coring of the prototype trap was not successful, partly because the guide rails of the coring fixture were warped. After correction, difficulties were still encountered indicating that additional modifications are required.

Because of the results obtained, consideration of further scheduling is being deferred pending discussion with the A.E.C.

(S. Kalish)

REVIEW NO. 139

SODIUM PUMP DEVELOPMENT AND TEST FACILITY DESIGN

Sponsor: U. S. Atomic Energy Commission
Contractor: Westinghouse Atomic Power Dept., Pittsburgh, Pa.
Contract No.: AT(30-1)-3123
Report No.: WCAP-2539, Monthly Progress Report No. 11

Report By: C. C. Randall
Report Date: November 1963
Previous Reviews: 112

This very brief report has two things to say. First, the Phase I report, WCAP-2347, "Sodium Pump Development and Test Facility Design," was distributed, in addition to those on the contract distribution list, to a specified list of interested groups for review and discussion at a meeting on sodium pumps in December at the New York Operations Office. Second, the Phase II report, WCAP-2526, "Conceptual Design and Cost Estimate for Sodium Pump Test Facility," was completed and will be forwarded for approval following an internal review.

(K. C. Hoffman)

REVIEW NO. 140

SODIUM PUMP DEVELOPMENT AND TEST FACILITY DESIGN

Sponsor: U. S. Atomic Energy Commission
Contractor: Westinghouse Electric Corporation, Pittsburgh, Pa.
Contract No.: AT(30-1)-3123
Report No.: WCAP-2528
Report By: C. C. Randall, Project Engineer
Report Date: November 1963
Previous Reviews: 112, 139

The report "Survey of Sodium Technology," WCAP-2225, was distributed.

A draft of Appendix III to the Phase I report, WCAP-2347, relating to recent Na pump difficulties was completed. Portions relative to EBR II experience were reviewed by ANL. The entire report, including Appendix III, will be issued next month. The Phase II report covering test facility design and cost estimates will be submitted for approval next month.

These brief monthly reports simply say, in a very general way, what was done during the month; they contain no technical information.

(S. Kalish)

ARGONNE NATIONAL LABORATORY REACTOR DEVELOPMENT
PROGRAM PROGRESS REPORT FOR OCTOBER 1963

Sponsor: U. S. Atomic Energy Commission
Contractor: Argonne National Laboratory, Argonne, Illinois
Contract No.: W-31-109-eng-38
Report No.: ANL 6801
Report Coordinated By: R. M. Adams and A. Glassner
Report Date: November 1963
Previous Reviews: 29,30,41,42,66,67,117,118

Corrosion of Fuel Cladding Materials for Sodium-Cooled
Reactors (p. 13)

Five Nb-base alloys were exposed to flowing Na for 158 hr at 650°C. The average flow rate of the Na was 0.15 m/sec, and the oxygen concentration in the Na was 120 ppm, a rather high level.

The compositions of the five alloys were:

1. Nb - 5% Mo
2. Nb - 10% Ti - 5% Zr
3. Nb - 18% Ti - 4% V
4. Nb - 3% Mo - 9% Ti
5. Nb - 10% W - 2.5% Zr

Recrystallized and stress-relieved specimens of the above alloys were tested, but the metallographic analyses thereof are not yet completed. However, it was observed that the recrystallized specimens were more severely attacked and suffered greater intergranular attack.

Liquid-Metal Heat Transfer in Double-Pipe Heat Exchangers (p. 53)

Results of a theoretical study show that the heat transfer coefficients for liquid metals flowing in double-pipe heat exchangers can depart considerably from those which would obtain for either the case of uniform heat flux at the wall or the case of uniform wall temperature. A plot is given to illustrate this, where the two independent parameters are "heat capacity flow rate ratio" and "sum of thermal resistance ratios." Curves are given for both cocurrent and countercurrent cases. The

results will be of considerable interest to experimentalists and designers.

Natural-Convection Heat Transfer in Liquid Metals (p. 55)

Preliminary data have been obtained for both water and Hg flowing past a heated plate. The temperature gradients obtained with water agree with theoretical predictions, but those with Hg are flatter than predicted.

(O. E. Dwyer)

REVIEW NO. 142

ARGONNE NATIONAL LABORATORY REACTOR DEVELOPMENT
PROGRAM PROGRESS REPORT FOR NOVEMBER 1963

Sponsor: U. S. Atomic Energy Commission
Contractor: Argonne National Laboratory, Argonne, Illinois
Contract No.: W-31-109-eng-38
Report No.: ANL 6808
Report Coordinated By: R. M. Adams and A. Glassner
Report Date: December 1963
Previous Reviews: 29,30,41,42,66,67,117,118,141

Corrosion of Fuel Cladding Materials for Sodium-Cooled Reactors (p. 9)

See REVIEW NO. 141. The alloys tested, their pre-exposure heat treatments, and the weight loss results are given in the following table.

Alloy	Heat treatment temperature, °C, for 2 hr at 10 ⁻⁶ torr vacuum		Weight loss rate, mg/cm ² /mo	
	Stress- relieved	Recrystal- lized	Stress- relieved	Recrystal- lized
1. Nb - 5% Mo	800	1100	55.6	43.4
2. Nb - 10% Ti - 5% Zr	600	1100	17.1	80.7
3. Nb - 18% Ti - 4% V	600	1050	50.6	66.0
4. Nb - 3% Mo - 9% Ti	600	1100	72.8	63.7
5. Nb - 10% W - 2.5% Zr	950	1250	13.1	38.6

Microhardness measurements taken across the transverse section of the samples should have varying profiles, but there were no distinct differences between the hardness profiles of the stress-relieved and recrystallized samples.

An additional group of alloys was tested for 216 hr under the same conditions. These alloys and their weight-change results are summarized below:

Alloy	Weight loss rate, mg/cm ² /mo	
	Stress-relieved	Recrystallized
V - 10% Ti	3.23	2.76
V - 20% Ti	3.33	3.72
Nb	41.6	52.8

Heat-treatment temperatures were not given for this set of specimens.

Light Alloy Suitable for Use With Mercury at Elevated Temperature (p. 39)

A study of corrosion inhibition in the Ti-Hg system was carried out in a ½-in.-i.d. quartz thermal-convection loop. Maximum and minimum loop temperatures were 454° and 320°C, respectively, and the test lasted 90 days. Just enough pure Ni was added to the loop to give a concentration of 700 ppm in the Hg, which was about the saturation concentration at 320°C.

Visual examination of the exposed Ti specimens indicated that no corrosion had occurred in either the hot or cold leg. Surprisingly, Ni deposition on the hot leg samples appeared to be more than four times that on the cold leg sample.

(O. E. Dwyer)

REVIEW NO. 143

BIBLIOGRAPHY ON LIQUID METALS
TECHNOLOGY OF Hg, K, Na, AND NaK

Sponsor: National Aeronautics and Space Administration
Contractor: Aerojet-General Corporation, Azusa, California
Contract No.: NAS-5-417
Report No.: 2550
Report By: Dr. P. L. Studt, I. M. Rehn, J. T. Jouthas
Report Date: September 1963
Previous Reviews: none

This bibliography covers those subjects and topics in the field of liquid metals technology which are pertinent to the SNAP nuclear-reactor/Rankine-power-conversion systems. The scope of the work is indicated by the headings of the main sections, which are

1. Corrosion Fundamentals: SNAP-8 Materials
2. Containment Materials for Liquid Metal Systems
3. Liquid Metals (properties, heat transfer, purification, chemical analysis, solubilities)
4. Effect of Design and Fabrication Parameters on Corrosion by Liquid Metals
5. Effect of Loop Operation on Performance
6. Loop Components
7. Techniques of Corrosion Testing
8. Bibliographies - Reports of Proceedings and Symposiums - General Compendiums of Liquid Metals Technology
9. Index

The subject of heat transfer, not listed above, is covered under sections 3, 5, and 6.

The bibliography attempts to include references from both the United States and foreign countries, over the past two decades. The authors state that periodic supplements will be issued, so that users of the bibliography can be kept up-to-date. They also state that "a final report will be issued that will include a complete review of all abstracted articles and a compilation of significant data."

The subject matter is well organized and a descriptive sentence or two is included with each entry in the document, for the convenience of the user. It can serve as a very valuable document for engineers working in the liquid metal field, and for others as well.

(O. E. Dwyer)

REVIEW NO. 144

RUBIDIUM/CESIUM EVALUATION PROGRAM

Sponsor: U. S. Atomic Energy Commission
Contractor: Aerojet-General Nucleonics, San Ramon, California
Contract No.: AT(04-3)-368
Report No.: 8096 - Quarterly Progress Report for July 1
to September 30, 1963
Report By: C. R. Fisher, Task A, and P. Y. Achener, Task B
Report Date: October 18, 1963
Previous Reviews: 94

The work performed in this report period involved the operation of a forced-convection-boiling Cs loop for heat transfer and fluid flow studies, and the design of an apparatus for measurement of the P-V-T relationships for Rb and Cs.

The same loop* previously used with Rb, was operated with Cs over the temperature range 1347° to 1798°F. A plot of the measured nucleate-boiling heat transfer coefficients is presented

*High-Temperature Liquid-Metal Technology Review, Vol. 1, No. 5, Rev. No. 82, p. 6, October 1963.

in Figure 1. It should be borne in mind that these data encompass a wide range of flow rates and qualities (90 to 400 lb/hr and 1 to 76 wt % respectively).

The boiling data shown in Figure 1 exhibit a relatively small degree of scatter. This is somewhat surprising in view of the wide range of variables covered and the fairly large degree of scatter found in single-phase heat transfer data obtained on this same loop. As the authors point out, the treatment presented in this report is only preliminary and detailed understanding may come with further analysis.

The loop was also operated to obtain measurements of departure from nucleate boiling. The report presents a tabulation of operating conditions at which DNB occurred.

The design of a constant-volume apparatus for P-V-T measurements was described in detail in the second part of the report. The capsule is to be constructed of Cb - 1% Zr, with a pressure diaphragm of the same material. It is planned to obtain measurements up to 2000°F.

(J. C. Chen)

Figure 1 in the Review corresponds to Figure 1 in the original report.

REVIEW NO. 145

LIQUID METAL HEAT TRANSFER AND TWO-PHASE FLOW
Allison Progress Report

Sponsor: U. S. Air Force
Contractor: General Motors, Allison Division, Indianapolis,
Indiana
Contract No.: AF 33(657)-9106 and AF 33(657)-7026
Report No.: Progress Report From January to July 1963
Report By: C. R. Smith
Report Date: November 1963
Previous Reviews: 96

The Allison liquid-metal program is directed toward development of a thermally-regenerative liquid-metal cell. The work described in this progress report, covering the first six months of 1963, includes studies of boiling heat transfer, two-phase flow, and materials of containment. Much of this work has been reported previously* so that it will be reviewed only briefly here.

A forced-convection-boiling loop was operated with K-Hg amalgams for heat transfer and two-phase flow studies. Both subcooled and net boiling results are reported. In the case of subcooled boiling, the authors point out that the data exhibited considerable scatter and no correlation was obtained. The reviewer notes that surprisingly high superheats, up to 600°F, are reported for the boiling amalgams - as compared to a maximum of ~100°F usually found for alkali metals. Pressure drop and void-fraction measurements are also reported.

The materials work involved operation of natural-convection-boiling loops for mass transfer studies and feasibility studies of vapor deposition of refractory metals. The 304 SS mass transfer loops showed most extensive corrosion in the vapor region, probably caused by Hg reflux.

(J. C. Chen)

REVIEW NO. 146

INVESTIGATION OF LIQUID METAL
BOILING HEAT TRANSFER

Sponsor: U. S. Air Force
Contractor: The University of Michigan, Ann Arbor, Michigan
Contract No.: AF 33(657)-11548
Report No.: 05750-6-P
Report By: Richard E. Balzhiser, Project Director, et al.
Report Date: November 1963
Previous Reviews: 18, 19, 31, 45, 46, 70, 87, 120

*High-Temperature Liquid-Metal Technology Review, Vol. 1, No. 5, Rev. No. 96, p. 25, October 1963.

This program, being carried out in the Liquid Metals Laboratory of the Department of Chemical and Metallurgical Engineering, is a multiobjective investigation of boiling liquid metals involving pool boiling, film boiling, convective boiling, two-phase flow, and agravic boiling. The following progress on various phases of the investigation is reported.

The high-flux nucleate pool boiler has been cleaned of K and recharged with water in an attempt to obtain burnout data which might be compared with existing data for other geometries. Two burnouts were experienced accidentally and neither yielded accurate values. One more attempt will be made before charging Na.

Recalibration of thermocouples used in the film boiler has revealed substantial drift. The results presented in the preliminary draft of the Final Report on the original contract will be modified. Efforts to stabilize and calibrate the microthermocouples prior to rerunning the K are continuing.

The forced-circulation loop was operated intermittently during October to obtain further pressure-drop data. The measured frictional pressure drops were significantly lower than those predicted by the Lockhart-Martinelli procedure. The reviewer notes that there appears to be a consistent trend for two-phase pressure drops with liquid metals to fall below values calculated by the usual correlations. This same trend has been reported for K (AiResearch) and for Rb (AGN). The loop has now been drained to initiate necessary repairs to the test section and pre-heaters (see High-Temperature Liquid-Metal Technology Review, Vol. 1, No. 4, p. 25).

Agravic studies have progressed to the equipment checkout stage. Operation is anticipated in the next quarter.

(J. C. Chen)

SODIUM COMPONENTS DESIGN PROGRAM

Sponsor: U. S. Atomic Energy Commission
Contractor: Baldwin-Lima-Hamilton Corp., Eddystone, Pa.
Contract No.: AT(11-1)-1213
Report No.: Progress Report for October and November 1963
Report By: R. B. Abderhalden
Report Date: November and December 1963
Previous Reviews: 57, 122

1. Steam Generator

A dimensional check of tube sheet holes was conducted with an Elliot three-point ball gauge. Numerous holes were found to be outside the tolerance, requiring repair in some cases.

Problems were encountered in the baffle and guide-ring holes. Some baffle holes were oversized and were improperly located. New baffle material has been ordered and the complete baffle nest will be stacked and gun-drilled. Holes in the guide ring that were improperly located will be repaired by drilling oversize holes in the proper location and inserting a ferrule.

Other manufacturing problems have been encountered and solved with either design changes or repair.

Tube-to-tube sheet joint welder qualification samples have been remachined to comply with drawings. Welder training is continuing, and problems have developed with root pass cracking.

2. High-Pressure High-Temperature Test Loop

Due to problems in the feedwater heater and superheater, the design has been modified to utilize direct resistance heating of the tubing by supplying power to the center portion of the heater and grounding both ends. The loop was operated at design temperature and pressure at a reduced flow rate. Modifications are being made to reach the design flow.

(K. C. Hoffman)

INVESTIGATION OF CAVITATION DAMAGE
OF MECHANICAL PUMP IMPELLERS OPERATING
IN LIQUID METAL SPACE POWER LOOPS

Sponsor: National Aeronautics and Space Administration
Contractor: Pratt & Whitney Aircraft Divison, UAC, CANEL,
Middletown, Conn.
Contract No.: NAS 3-2541
Report No.: CNLM-5202
Report By: R. Kulp and J. Altieri
Report Date: Quarterly Progress Report No. 1, June 26, 1963
to September 30, 1963
Previous Reviews: none

In a Rankine space power plant, it is desirable to minimize the radiator area by reducing the amount of subcooling in the condenser. Subcooling reduces the NPSH available at pump suction and may cause the pump to operate with some degree of cavitation. The objective of this investigation is to determine the extent of damage to an impeller operating with a known degree of cavitation in 1400°F K for 1000 hr. A mixed-flow type impeller was selected for test. This impeller exhibited superior values of suction specific speed in the earlier water test program. The K cavitation damage tests will be conducted at 6375 rpm and 700 gpm. The impeller will develop a head of 222 ft under these conditions which is in the neighborhood of current space power plant requirements.

Design modifications were made to an existing turbopump for high-temperature liquid metal operation. The impeller was completed and tested in the Impeller Water Test Stand developing a 200-ft head at 700 gpm, 6375 rpm. Construction work has started on the Water Pump Test Stand and modifications to the Liquid-Metal Test Stand have begun.

(K. C. Hoffman)

EXPERIMENTAL INVESTIGATION OF HEAT REJECTION PROBLEMS
IN NUCLEAR SPACE POWERPLANTS - VOLS. 1, 2, AND 3

Sponsor: National Aeronautics and Space Administration
Contractor: Pratt & Whitney Aircraft, Division of United Aircraft Corp., East Hartford, Conn.
Contract No.: NAS 3-2335
Report No.: 2227, Vols. 1, 2, and 3
Reports By: Vol. 1: Experimental Evaluation of Hydrodynamic Losses in Manifolds, H. L. Ornstein
Vol. 2: Condensing Flow Stability Studies, S. S. Wyde, Sr.
Vol. 3: Space Powerplant Startup and Transient Operation Simulation, J. R. Hooper, Sr.
Report Date: June 1, 1962 through May 31, 1963
Previous Reviews: 28, 47

This report, covering a year's work, describes results of an experimental investigation of heat rejection problems in nuclear space powerplants. The report is in three parts, Vols. 1, 2, and 3.

Vol. 1 - Measurement of pressure loss and flow distribution pertinent to the design of manifolds for direct-condensing radiators.

Two-phase flow experiments were conducted using air-water mixtures in order to obtain data concerning pressure loss and flow distribution in radiators of direct condensing Rankine cycle space powerplants. The areas of study were the inlet manifold pressure drops, the manifold-to-branch pressure losses, and two-phase distribution of the flow among the branch tubes.

Fourteen different branch tube inlet configurations were evaluated using single branch tubes. Two of these inlet configurations were also tested in multibranch arrangements using four in-line tubes. The effect of manifold taper was also investigated. The flow in the inlet manifold was vertically downward and the branches were horizontal except for two which were at a 30-degree angle with the manifold. Manifold inlet water flow was varied from 0 to 15% by weight of the inlet air flow. Other variables were inlet manifold Mach number (0.1 to 0.4), pressure level (25 to 35 psia), manifold two-phase flow

pattern (mist and annular), and branch-to-manifold air velocity ratio (0.25 to 3.8).

The static pressure drops in the manifold in the region of a branch tube and manifold-to-branch total pressure losses were correlated in dimensionless form useful for design calculations. At a given air flow, the effect of two-phase flow was found to be only slight on the manifold stream pressure drops but resulted in an increase in the branch inlet losses. Both of these effects were found to be insensitive to the manifold two-phase flow patterns. A comparison of branch inlet pressure losses for inlets that did not protrude into the manifold indicated that these losses could be greatly reduced by rounding the inlet corner. For inlets that protruded into the manifold, branch inlet pressure losses were increased and manifold stream pressure drops were reduced as branch protrusion decreased.

The distribution of the air between the four branches was found to be virtually unaffected by the presence of liquid and the manifold two-phase flow pattern. The liquid distribution between multiple branches, however, was found to be strongly dependent upon the two-phase flow pattern in the manifold. Greater uniformity of liquid flow distribution between multiple branches was found possible at some flow conditions by the introduction of swirl into the flow in the manifold. A tapered manifold which provided good air flow distribution into four rounded inlet branch tubes perpendicular to the manifold also gave good water flow distribution for an annular two-phase flow pattern upstream of the swirl generating device. This combination is thought to be the best of those tested when the factors of pressure loss, flow distribution, and fabrication are considered.

Vol. 2 - Study of the stability of condensing flow in parallel passages.

Two test configurations with parallel tubes connected to common manifolds were fabricated. One configuration consisted of metal manifolds connected by three glass tubes, each with a concentric glass cooling jacket. This configuration permitted visual observation of the condensing flow within the branches. However, the low thermal conductivity of the glass limited the heat extraction rate. The other configuration consisted of three metal tubes with concentric metal cooling

jackets mounted between two metal manifolds, thereby enabling higher heat extraction rates. The inlet manifold contained glass view ports in order to observe the flow in the branch inlets.

A single metal condenser tube connecting two manifolds was used to establish a basic experimental curve of pressure difference in a tube as a function of condensing steam flow rate at constant cooling flow rate. Similar curves were obtained for three parallel metal tubes. The data showed that a total pressure rise could be obtained within the tube, but a static pressure loss always existed between header and collector due to larger-than-predicted pressure losses from the header to the tube inlet. Single-phase tests with air showed that tube inlet pressure losses compared favorably with calculated values. Therefore, the large losses in the condensing tests were not due to the geometry of the test section nor to instrumentation errors.

During the single tube tests, pressure fluctuations were observed on a pressure gauge upstream of the test section, indicating that a flow instability might be occurring in the test section. Therefore, a modified test section was installed in order to take high speed movies of the flow in the vicinity of the final liquid-vapor interface. These movies showed that slugging was taking place within the tube and causing pressure fluctuations. These movies also indicated that the flow rate was varying within the tube, causing alternating periods of calm and turbulence in the liquid layer of the condensing section. In order to investigate the effects of slugging, tests were performed to determine the amplitude and frequency of pressure fluctuation in both single metal tube and three metal tube arrangements. Effects of condensing flow rate, coolant flow rate, pressure level, and a compressible volume after the test section were investigated. In addition, tests were run with small orifices inserted inside each tube of the three tube configuration. The results showed that an increase in condensing flow caused a large increase in the amplitude of fluctuations, whereas a decrease in coolant flow caused small decrease in amplitude. The orifices did not prove advantageous nor did a compressible volume after the test section provide any improvement for eliminating the pressure fluctuations.

A three glass tube configuration was run to observe flow characteristics. This arrangement necessitated running at low condensing flow rates. A form of instability was observed in which the three interfaces underwent severe changes in location.

These pulses were sporadic with a fairly calm flow pattern in the intervening period. Movies taken of this phenomenon at five times normal speed did not reveal the exact nature of the flow. A test with the glass tubes tilted slightly downward did not produce these pulses. Small quantities of air were present in the test section during this testing with three glass tubes.

Vol. 3 - Study of the stability of a Rankine cycle during starting and transient operation.

Experiments were conducted on a nuclear Rankine cycle space powerplant simulator using water as the working fluid in order to determine suitable means for operating and controlling such powerplants during remotely initiated starts and during transients resulting from changes in operating conditions. This powerplant analog simulates many aspects of the operation of a space powerplant using liquid metal working fluids and rejecting heat by radiation, and thus provides an extremely useful tool for the study of the Rankine cycle during transient and starting conditions.

A two-loop powerplant system was used, consisting of an all-liquid heating loop supplied with heat by electrical Cal-rods simulating a nuclear reactor and a Rankine cycle loop having a simulated direct condensing radiator which rejected heat by convection to a liquid trichloroethylene stream. The facility was instrumented to study starting and transient behavior and was constructed so that a variety of starting control methods and component configurations could be tested.

All the starting tests were conducted with the Rankine loop initially evacuated and the working fluid supplied from a liquid accumulator. The pressure in the accumulator was held constant at the steady-state operating value in the loop at the point the accumulator was attached.

Attaching the accumulator at the power loop pump inlet resulted in a stable system and successful starts were made. However, attaching the accumulator at the power loop pump exit produced an unstable system during starting tests. The introduction of a pressure drop between the accumulator and the boiler was found to suppress this instability and tests were made to determine the pressure drop required for stability at different operating conditions. A successful start was then

made with the accumulator at the pump outlet when a sufficiently large pressure drop was introduced. This starting technique could eliminate the need for auxiliary power to start the system.

A series of starting tests were conducted to measure the individual effects of various parameters using an extremely simplified system with no separator at the boiler exit and with a steady-state boiler exit superheat of 10°F. In these tests the following factors were varied: 1) initial fill rate, 2) steady-state flow rate, 3) time of pump start, 4) radiators segmented or not on start, and 5) radiators orificed or not. The heating loop conditions, boiler steady-state inlet temperature, sink loop temperature, accumulator pressure and accumulator location at the pump inlet were held constant. All starts with the simplified starting control system were successful except one in which the fill rate was set at 10% of the steady-state flow rate. At this very low fill rate the loop greatly overfilled with liquid and as a result the radiator pressure limitations were exceeded.

(authors)

This very voluminous report contains many tables of data and results. It is also replete with many graphs, time charts, and photographs.

REVIEW NO. 150

MATERIALS INVESTIGATION SPUR PROGRAM

PART II. Creep-Rupture Properties of Mo + 0.5 wt% Ti

Sponsor: U. S. Air Force

Contractor: AiResearch Manufacturing Division, Phoenix, Ariz.,
A division of The Garrett Corporation

Contract No.: AF33(657)-8954

Report No.: ASD-TDR-63-270, Part II

Report By: E. A. Kovacevich, R. L. Salley

Report Date: November 1963

Previous Reviews: 102

The object of this study was to determine if Mo - $\frac{1}{2}$ wt% Ti alloy, a potential wheel and blade material for the potassium-vapor turbine in the SPUR power plant, would undergo accelerated creep in a potassium environment. Results on 10 specimens in K vapor and 5 in vacuum at temperatures of 1500°, 1800°, and 2000°F indicate that K vapor does not adversely affect Mo - $\frac{1}{2}$ wt% Ti creep properties. No evidence of K corrosive attack was noted in tests up to 500 hr at 2000°F.

Mo - $\frac{1}{2}$ wt% Ti material in two vacuum arc cast heats was hot rolled, stress-relieved for 1 hr at 1800°F and machined into $\frac{3}{4}$ -in.-diam bars. Tests conducted at 1500°F consisted of specimens containing 0.029% C and 0.53% Ti while the balance of the tests were on material containing 0.026% C and 0.47% Ti. Specimens tested at 1500°F were 0.188-in.-diam solid gauge section while those tested at 1800° and 2000°F were $\frac{1}{2}$ -in.-o.d., 0.375-in.-i.d. tubular specimens.

Special purity K containing 73 to 78 (± 10) ppm oxygen as determined by the Hg amalgamation technique was used. Test specimens at 1500°F were exposed to the vapor only while the remaining hollow specimens contained 0.9 cc of K seal welded into the hollow specimens. Heating of the latter tests were begun after evacuation of the test chamber to less than 5×10^{-4} torr.

Creep-rupture data for all temperatures is shown in Table II. The four 1500°F tests show little significant difference but do have rupture times longer than those extrapolated from data published by Climax Molybdenum Co. The plot of the stress vs. log of the minimum creep rate at 2000°F indicates that both helium and K vapor specimens lay on the same line and that lower stresses for the same creep rate occur in Climax molybdenum data. No difference was noted from the Climax data in the log minimum creep rate vs. stress for the 1800°F tests.

In tests 1 and 5 (see Table II) corrosion tabs were suspended from Mo wires in the K vapor space inside the creep pot. Results are shown in Table III.

(A. H. Fleitman)

Tables II and III in the Review correspond to Tables II and III in the original report.

MATERIALS INVESTIGATION, SPUR PROGRAM
PART III. Fatigue evaluation of Mo + 0.5 wt% Ti

Sponsor: U. S. Air Force
Contractor: AiResearch Manufacturing Division, Phoenix, Ariz.,
A division of The Garrett Corporation
Contract No.: AF33(657)-8954
Report No.: ASD-TDR-63-270, Part III
Report By: R. Salley and E. Kovacevich
Report Date: December 1963
Previous Reviews: 102, 150

Fatigue tests were conducted at 1500° and 2000°F in K vapor and in vacuum in order to determine whether a K vapor environment had any influence on fatigue characteristics of Mo - 0.5 wt% Ti alloy. The results of these tests indicate that the fatigue strength is reduced by a K vapor environment.

The test specimens were machined from vacuum arc-cast, hot-rolled, ground $\frac{3}{4}$ -in.-diam bar, stress-relieved at 1800°F for 1 hr. Analysis by weight percent shows 0.026 C, 0.004 Si, 0.002 Ni, 0.004 Fe, and 0.47 Ti.

Hollow, axial-loaded specimens were used for all tests. Specimens without K were tested with either a He-filled interior or an evacuated interior. K-filled specimens had a small charge of K sealed into the cavity so that, at temperature, the inner walls would be exposed to K vapor. The outer walls of all specimens were in a dynamic vacuum and were protected from reaction with atmospheric impurities by a wrapping of Ta foil. The K analyzed 78 and 73 ppm (± 10) oxygen.

All the tests were of the axial-load type and were conducted with a ratio of alternating to mean stress of $A = a/m = 0.95$. Data from the tests are summarized in Table I and are shown on S vs. log N coordinates in Figure 2. A significant decrease in fatigue life for the specimens tested in K vapor is apparent. At 1500°F the fatigue strength appears to be reduced from 67,500 psi in vacuum to 39,500 psi in K vapor for 10^8 cycles. At 2000°F, the reduction appears to be from approximately 47,000 psi to 37,000 psi for the same lifetime.

Metallographic studies on two specimens tested at 1500°F show no recrystallization but the K exposed specimen had more carbide and more cracks than a vacuum exposed specimen.

Specimens with a lifetime less than 1000 kilocycles showed plastic deformation and ductile fracture whereas the other specimens evidently failed because of fatigue since no plastic deformation was found and brittle fractures occurred.

(A. Fleitman)

Figure 2 in the Review corresponds to Figure 5 in original report. Table I in the Review corresponds to Table 1 in the original report.

REVIEW NO. 152

QUARTERLY PROGRESS REPORT - SPUR POWER SYSTEM

Sponsor: U. S. Air Force
Contractor: AiResearch Manufacturing Co., A Division of
The Garrett Corporation, Phoenix, Arizona
Contract No.: AF 33(657)-8954
Report No.: SY-5396-R6
Report Approved By: J. H. Dannan
Report Date: October 1963
Previous Reviews: 12,64,88,102,103,150,151

Creep-Rupture Properties of Mo - $\frac{1}{2}$ % Ti (p. 4)

Test work is completed, and a report will soon appear.

Fatigue Evaluation of Mo - $\frac{1}{2}$ % Ti (p. 5)

The test results at 1500° and 2000°F indicate that K vapor reduces the fatigue life. Metallographic examination of 1500°F specimens tested in vacuum and K vapor showed no evidence of recrystallization. There was also no significant difference between Vickers hardness readings. However, the K-exposed specimen had more C particles in it, and both radial and circumferential cracks were more evident. Results are shown in tables, graphs, and photomicrographs.

Cantilever Bending Fatigue of Cb - 1% Zr (p. 11)

Final results for tests in K at 800°F and in Li at 1600°F are presented in tabular and graphical forms.

Mass-Transfer Tests With Two-Phase Flow

Mechanical and electrical difficulties are reported. Loop is being prepared for purification cycle.

Bearing Tests (p. 16)

Mechanical problems with test rig are reported.

A 250-hr K-lubricated journal bearing test was completed. Bearing and journal materials were Mo - ½% Ti and K94 WC alloy,* respectively. Measurements taken before and after test indicated no wear. Bearing speeds and loads through test period are given, but not the temperature.

(O. E. Dwyer)

REVIEW NO. 153

EFFECT OF HIGH TEMPERATURE SODIUM
ON AUSTENITIC AND FERRITIC STEELS

Sponsor: U. S. Atomic Energy Commission
Contractor: MSA Research Corp., Callery, Pa.
Contract No.: AT(11-1)-765
Report No.: MSAR 63-161, Topical Report No. 1
Report By: R. C. Andrews et al.
Report Date: November 1963
Previous Reviews: 53, 54, 55, 68, 69, 109, 110

This report, Topical Report No. 1 - Test Facility Design and Operation Procedures, deals with the design criteria,

*Presumably tungsten carbide with 12% cobalt.

description and operating of the test facility. Type 316 SS and 2 $\frac{1}{4}$ Cr - 1 Mo alloy steel were chosen as the test specimens to be inserted into two identical but separate loops. The test facilities obtain creep, creep-to-rupture, and fatigue data in dynamic Na at temperatures of 1200°F for 316 SS and 1100°F for 2 $\frac{1}{4}$ Cr - 1 Mo steel specimens.

The complete test program encompasses the following environmental tests:

- TEST 1 - SS specimens in 1200°F Na with 30 ppm oxygen under helium cover gas
- TEST 2 - Cr-Mo specimens in 1100°F Na with 30 ppm oxygen under helium cover gas
- TEST 3 - SS specimens in 1200°F Na with 30 ppm oxygen and saturated carbon under helium cover gas
- TEST 4 - Cr-Mo specimens in 1100°F Na with 200 to 300 ppm oxygen under helium cover gas
- TEST 5 - SS specimens in 1200°F Na with 30 ppm oxygen under nitrogen cover gas
- TEST 6 - Cr-Mo specimens in 1100°F Na with 30 ppm oxygen under nitrogen cover gas
- TEST 7 - SS specimens in 1200°F Na with 30 ppm oxygen and saturated carbon under nitrogen cover gas
- TEST 8 - Cr-Mo specimens in 1100°F Na with 30 ppm oxygen and saturated carbon under helium cover gas

The flowsheet of the test loop is shown in Figure 3.

The loop components, creep and creep-to-rupture units, and fatigue testing machines are described in detail in this report and these units would be difficult to describe adequately in an abstract of this nature. No technological data are given in this report but progress reports are presently available from MSAR in which physical properties data are presented.

(A. J. Romano)

Figure 3 in the Review corresponds to Figure 1 in the original report.

EFFECT OF 1200°F SODIUM
ON AUSTENITIC AND FERRITIC STEELS
(Physical Properties of Materials)

Sponsor: U. S. Atomic Energy Commission
Contractor: MSA Research Corporation, Callery, Pa.
Contract No.: AT(11-1)-765
Report No.: MSAR 63-156
Report By: R. C. Andrews et al.
Report Date: November 13, 1963
Previous Reviews: 53,54,55,68,69,109,110,153

A physical properties program is currently under way in which the possible effects of Na environments on the tensile, creep, creep-to-rupture, and fatigue properties of type 316 SS and 2½ Cr - 1 Mo alloy steel are being studied.

Test 3 - Type 316 SS in 1200°F, High Carbon Na

The operation of this test will be concluded during the next report period. Data will be available at that time.

Fatigue Test Results

The latest fatigue results on 2½ Cr - 1 Mo specimens run in Na and helium at the intermediate and high cyclic strain conditions are presented. The results obtained in this report period can be summarized as follows:

<u>Condition</u>	<u>Cyclic strain, %</u>	<u>Cycles to failure</u>	<u>Time at temp., hr</u>
High oxygen Na	0.969	9500	121.0
High oxygen Na	2.1	3150	70.5
High oxygen Na	2.1	1250	20.0
Helium	2.1	1545	22.0
Helium	2.1	1221	16.0

Creep-Rupture Results

The creep-rupture runs on 2½ Cr - 1 Mo steel specimens were completed and the results are presented. The results of the tests in high oxygen Na show a consistently shorter life than in low oxygen Na. This is attributed, however, to corrosion of the creep-rupture specimens.

Analytical Results

Results of the carbon analyses of the loop Na show the carbon content of the Na to be below saturation for low oxygen Na.

Results of a round robin carbon analysis are presented. An average value of 37 ppm was obtained.

Metallurgical Results

A $2\frac{1}{4}$ Cr - 1 Mo creep specimen which had been tested in helium revealed a heavy oxide type layer to be present. The layers on the specimens are thick enough (0.003 in.) to affect the creep properties of the specimens.

Several $2\frac{1}{4}$ Cr - 1 Mo steel specimens which were exposed to high oxygen Na were examined and revealed corrosion layers to be present on each. The depth of penetration increased with exposure time.

(A. Romano)

REVIEW NO. 155

STRUCTURAL MATERIALS IN LASL LIQUID SODIUM SYSTEMS

Sponsor: U. S. Atomic Energy Commission

Contractor: Los Alamos Scientific Laboratory, Los Alamos,
New Mexico

Report By: H. I. Bowers and W. E. Ferguson

Previous Reviews: none

A 2000-kw Sodium Test Facility was constructed and operated at a maximum Na temperature of 1200°F at the L.A.S.L. in support of the LAMPRE program. The flow diagram of the test facility is shown in Figure 4. The design, fabrication, and post-operative tests of the facility are discussed in the report.

The materials of construction are primarily the 300 series stainless steel; however, for special applications,

17-4 PH stainless steel and $1\frac{1}{4}$ Cr - $\frac{1}{2}$ Mo alloy steel were used. Since Ta and Ta alloys are used for fuel containment, the compatibility of these materials with Na was also studied.

In addition to the 2000-kw test facility results, operating experience with 17-4 PH stainless steel in the LAMPRE sodium system is presented.

Sodium Purity

Before being filled with Na, the system was outgassed at 500°F for about 9 days. The system was then purged with Na which was purified by passing through a cold trap held at 220°F. The plugging temperatures in the cold trap were monitored periodically at 220°F. The oxygen content at 220°F should be less than 10 ppm.

Fabrication

The system was of all-welded construction except for several flanged connections. Transition welds were made using Inco Rod "A" for filler material. A variety of nondestructive inspection techniques were used including dye penetrant, ultrasonic, radiographic, hydrostatic, and helium mass spectrometer leak test.

Stainless Steel and $1\frac{1}{4}$ Cr - $\frac{1}{2}$ Mo Alloy Steel

After approximately 18 months after initial startup, operation of the Na test facility was terminated and the equipment examined. Post-operative examination revealed, with two exceptions, little damage to structural materials. The following conclusions were presented:

1. Transition welds between stainless steel and $1\frac{1}{4}$ Cr - $\frac{1}{2}$ Mo steel are satisfactory in liquid Na at 500° to 950°F.
2. The use of type 316 SS as heat exchangers appears satisfactory but the use of $1\frac{1}{4}$ Cr - $\frac{1}{2}$ Mo alloy steel is not recommended due to poor weld quality.
3. A thermowell rupture appeared to be as a result of a flaw in the starting material.
4. Metallographic examination revealed decarburization and grain boundary carbide precipitation in several areas. These areas were not apparently affected structurally.
5. Cyclic temperature conditions in a type 304 L SS mixing tee apparently caused cracking due to thermal stress fatigue.

17-4 PH Stainless Steel in LAMPRE

The 17-4 PH stainless steel portions of the fuel capsules used in the LAMPRE reactor became overaged as a result of operation at 575° to 930°F in Na. The overaging is felt to be due entirely to temperature and that the liquid Na environment had no effect. The use of 17-4 PH stainless steel under similar temperature conditions is not recommended.

Tantalum Compatibility in Sodium

Tantalum compatibility in sodium was studied as follows:
(1) Ta corrosion rates in cold-trapped and Ta hot-trapped Na,
and (2) Ta and Zr corrosion in cold-trapped Na.

The results of these tests are as follows:

<u>Type test</u>	<u>Material</u>	<u>Temp., °F</u>	<u>Corrosion rates, mils/yr</u>
Cold-trapped	Ta	1075	None
		1220	~8
Hot-trapped	Ta	970	None
		1220	~ $\frac{1}{2}$

The results of the tests with Ta and Zr in cold-trapped Na show that Ta loses weight while Zr gains weight. The reason for this is that Zr forms an adherent oxide film while Ta forms a loose oxide film which then spalls off.

(A. Romano)

Figure 4 in the Review corresponds to Figure 1 in original paper.

REVIEW NO. 156

QUARTERLY STATUS REPORT ON LAMPRE PROGRAM

Sponsor: U. S. Atomic Energy Commission
Contractor: Los Alamos Scientific Laboratory, Los Alamos,
New Mexico
Contract No.: W-7405-eng-36

Report No.: LAMS-3021
Report Date: December 1963
Previous Reviews: 2,99

Liquid Metals Technology (p. 8)

A special loop is being operated for studying the effectiveness of various metals and alloys in removing dissolved oxygen from Na. Preliminary results show that Zr and Zr - 50% Ti increase in weight in Na with 15 to 20 ppm oxygen, in the temperature range 550° to 700°C, and flowing at 1 gpm. However, Ta, Ta - 10% W, and Nb decrease in weight, under the same conditions. Quantitative information will presumably come along later.

Core Test Facility (p. 11)

Information is given in the report on the design of such components as intermediate heat exchanger, heat dumps, EM pumps, EM flowmeters, and surge tanks for the Na system.

(O. E. Dwyer)

REVIEW NO. 157

COMMENTS ON "IN-HOUSE LIQUID METALS INVESTIGATION"

Sponsor: National Aeronautics and Space Administration
Contractor: Lewis Research Center, 21000 Brookpark Road,
Cleveland, Ohio
Prepared By: Ruth N. Weltmann
Report Date: December 31, 1963
Previous Reviews: 17,60,84

a. Two-Phase Flow Loop: As a result of the indicated condensate flow measurements obtained during the nozzle survey tests it was suspected that a substantial amount of liquid carry-over occurred in the liquid-vapor separator. The facility was therefore operated over a range of flow conditions and the condensate flow was measured with a weight tank that was devised for the purpose. The results of the weight tank tests indicated that there was not a substantial amount of liquid

carry-over in the separator as initially suspected. It is considered advisable, however, to modify the separator as this component was felt to be marginal. The nozzle tests will then be repeated with the modified separator.

b. Sodium Turbine Facility: The facility has been loaded with sodium and is undergoing checkout tests. The facility has generated vapor at design conditions for a period of 2 hr. Final modifications, adjustments, and minor repairs are now being made to the facility to ready it for the qualification test.

c. Pump Test Facilities:

(1) High-pressure sodium pump loop: A centrifugal pump was tested in this loop. After 6 hr the pump dynamic seal system failed due to a plugging of the dynamic seal rotor discharge pressure sensing line. Pump speed ranged from 1000 to 3500 rpm. Fluid temperature ranged from 650° to 1000°F. Pump flow rate varied from 470 to 280 gpm during the test. Five data points were recorded before the pump failed. The dynamic seal is now being redesigned.

(2) Low-pressure sodium pump loop: An all 316 SS axial flow rotor was tested in the low-pressure loop. Pump speed was held constant at 3550 rpm. Pump flow rate varied from 150 to 260 gpm. Pump head rise varied from 4 to 21 ft of Na. Fluid temperature varied from 1250° to 1500°F. Also, a multi-material axial flow rotor of the same hydrodynamic design as the above mentioned 316 SS rotor was tested. Performance parameters varied over the same limits mentioned above for the stainless steel rotor in generating the noncavitation and cavitation performance data of this rotor. Difficulties with cold-trapping and the plugging indicator system were experienced during both tests. Some changes are now being made in both systems before an endurance test of the multi-material rotor is attempted.

d. Accelerated Liquid Metal Cavitation Facility: A magneto-structive apparatus is being constructed to test materials for resistance to cavitation damage by liquid alkali metals. Relationships between material properties and cavitation damage are to be determined.

The design work for this facility has been completed and contracts for the equipment have been let. The facility should

be in operation during the early part of 1964.

e. Alkali Metal Heat Transfer Facility: Construction of this facility is approximately 80% complete.

f. Space Radiator and Condenser Facility: The installation of the facility with multi-tube K condenser and NaK coolant is complete. The facility has been operated with liquid flowing in all three loops (heater, test, and coolant) to evaluate the piping and component heat losses over a range of condenser inlet temperatures from 1200° to 1400°F. Modifications to the facility are being made to eliminate unsteady test loop flow that was encountered when two-phase operation was attempted.

g. 80-kw Cesium Loop: Design of a Cb - 1% Zr loop, to boil Cs at 2000°F, is 95% complete. Construction has been postponed because of late delivery of the Cb - 1% Zr. A stainless steel loop providing a boiling temperature up to 1600°F is now under construction.

h. Bearing and Seal Studies: Friction and wear tests on candidate bearing and seal materials are being made in liquid Na (500° to 1200°F) at sliding speeds between 500 and 4000 ft/min and at loads to 150,000 psi. The materials under study include metals, ceramics, cermets, and solid film coatings. A report on the initial work on coatings is in process.

Face contact dynamic seal studies are continuing in liquid Na at 1000°F and 5000 ft/min. Various material combinations suggested by the friction and wear tests are being evaluated. Interface welding (and subsequent seal surface separation and increased leakage) continues to be a problem with metal and cermet sliding components.

Separate studies are being made on pressure balancing of the seal closing force and on pressure effects on the seal bellows.

A noncontact dynamic seal is under construction and is scheduled for testing in this seal program. The seal design reduces power consumption as compared with other dynamic types of fluid seals.

i. High-Speed Na-Lubricated Journal and Thrust Bearing Test: Preparations have begun to perform tests of Na-lubricated journal and thrust bearings at temperatures up to 1550°F and

rotational speeds up to 20,000 rpm. Barium bronze journal bearings, that were lubricated with S.A.E. No. 10 oil, have been used for initial facility shakedown tests. Water lubricant with a viscosity close to Na was used for additional shakedown tests. A transparent plastic pot permitted observation of lubricant flow.

Test rig modifications are in progress. Additional water-lubricated tests shall be performed before Na test is initiated.

j. Mercury Programs:

(1) MECA Project: Significant progress has been made in the buildup of test apparatus and in the acquisition of experimental data on Hg vapor condensing characteristics. A Hg-to-NaK heat transfer loop has been in operation for the investigation of over-all and local heat transfer coefficients, pressure drop, and stability characteristics of typical SNAP-8 condenser tube configurations. Results obtained to date indicate that, for dropwise condensation, the Hg side resistance to heat transfer is only 10 to 15% of the total resistance with 80 to 90% attributable to the combination of the NaK side and tube wall (depending upon tube wall thickness). The Hg side tube inlet pressure is quite sensitive to NaK flow rate and inlet temperature and also to interface position in the first half of the tube length. (Total length of the condenser tube was 50 in.) For thin-walled tapered tubes ($t = 0.020$ in.) choked flow was observed for vapor-liquid interface positions greater than 42 in. from the inlet. Choking was not evident in the thicker walled tubes (0.035 and 0.060 in.). Condensing characteristics of other tube configurations for both dropwise and filmwise flow conditions will be investigated.

The influence of gravitational forces on condensing flow regimes and pressure drop characteristics for dropwise condensation have been investigated for both constant diameter and tapered tubes with convective cooling in the A5-2 airplane. In brief, the data indicate that the two-phase pressure drops for both tube configurations were slightly greater (less than 0.5 psi) under zero-g than for one-g conditions. A report on this investigation is currently being prepared.

An experimental installation for the study of dynamic response characteristics of a condensing flow of Hg vapor to inlet and exit flow perturbations is being checked out. A

test installation for the study of filmwise condensation has been assembled and instrumented and is being checked out. A test installation for the study of filmwise condensation has been assembled and instrumented and is near operational status.

The subordinate influence of the Hg side heat transfer coefficient on the over-all heat transfer coefficient for dropwise condensation in the NaK-cooled condenser tube, obviates the requirement for the long-term zero-g WASP vehicle experiment. The buildup of the experimental payload is being deferred until ground and airplane experiments on filmwise condensing flow conditions provide an insight to the necessity of long-term zero-g experiments.

(2) Simulated SNAP-8 System: The test cell buildup and assembly of the simulated SNAP-8 system is in progress. Arrangements are also being made for acquisition of SNAP-8 components for later inclusion in the loop system. A flight type radiator is also being designed for projected investigation of system performance and dynamics in a large environmental test facility. Analog and digital studies of system dynamics are continuing. The digital representation of the complete system is operational and is periodically revised to incorporate latest design changes. The digital reactor simulation program is operational and is producing reliable results. An analog study of condenser dynamics is also under way to evaluate control requirements.

r. Materials Support Program: Highlights of the Lewis Research Center's liquid metal corrosion and related work will be included in the Proceedings of the Joint Fourth NASA-AEC Corrosion Meeting held on October 2 and 3, 1963, at Lewis. This will be issued as a NASA Technical Note.

Work is continuing on the evaluation of the Hg-amalgamation method with vacuum handling for analyzing O₂ in K. This is being compared with a vacuum distillation system for accuracy. The "Round-Robin" for O₂ analyses in K has not yet been completed.

Boiling reflux capsule corrosion testing is still continuing with K and Cb- and Ta-alloy tubing candidates. The data are still preliminary.

The two-phase pumped Hg-Haynes 25 corrosion loop has been operated successfully for 56 hr. Future runs for longer times are scheduled.

Other areas of work include a pumped two-phase refractory metal loop solubility studies of metallic elements in K, and test environmental effects on corrosion. These projects are still in their preliminary stages.

(Authors)

REVIEW NO. 158

ALKALI METALS BOILING AND CONDENSING INVESTIGATIONS

Sponsor: National Aeronautics and Space Administration
Contractor: General Electric, Space Power and Propulsion
Section, Missile and Space Division, Cincinnati 15,
Ohio
Contract No.: NAS 3-2528
Report No.: Quarterly Progress Report 4
Report By: Edity by J. Longo, Jr.
Report Date: July 25, 1963
Previous Reviews: 3,51

This program includes three forced-convection loop studies, a pool boiling study, and associated instrumentation and materials development projects. The reader is referred to HTLMT Review No. 51* for background information and descriptions of the experimental equipment. Progress in this report period is summarized below.

300-kw Loop

The double-tube boiler has been corrected for eccentricity, and the loop was operated with boiling K in the pressure range 25 to 75 psia. The report includes a tabulation of 100 data points. The authors state that "the local performance of the boiler can be inferred from the measurements currently available," i.e., from o.d. shell temperatures (on pipe outside of the hot Na) and from inlet and outlet temperatures of the boiling K. No graphical or analytical correlation of the heat transfer results is presented. Two-phase pressure drop

*High-Temperature Liquid-Metal Technology Review, 1, No. 3, Rev. No. 51, p. 23, June 1963.

data were obtained by measuring the ΔT_{sat} across an adiabatic section (a vertical condenser).

100-kw Loop

In this report period, the work on the 100-kw loop included a series of boiling Na runs and preparations for changing to tests with K. In the tests with Na, a twisted ribbon insert was used in the boiler. The results, plotted as boiling coefficient vs. quality, is reproduced here in Figure 5. In the opinion of the reviewer, it is worthwhile to compare this figure with Figure 5 in HTLMT Rev., Vol. 5, No. 1, which presents AiResearch's results for boiling K. The boiler geometry is approximately the same (i.e., twisted ribbon in tube), and yet both the shapes and absolute magnitudes of the resulting plots are quite different. It appears to the reviewer that this difference needs to be resolved. In general, the AiResearch results seem to be more precise, with markedly less scatter.

50-kw Loop

The 50-kw facility is used to obtain condensing data for alkali metals. Operation during this quarter was directed primarily at obtaining accurate thermocouple standardization and heat loss data. Two K leaks hindered this phase of the test program. A total of 14 liquid and 11 condensing runs were completed and the data from these runs presented. For these runs, the test section thermocouples were calibrated to a precision of approximately $\pm 1^\circ\text{F}$. Since the thermal driving force during liquid runs is only 1° to 7°F , the authors feel that this precision must be improved before accurate data can be obtained in this facility.

Pool Boiling Study

The pool boiling portion of the program is being carried out at Columbia University under the direction of Prof. C. F. Bonilla. During this report period, the assembly and installation of the pool boiling apparatus was completed. Calibration runs have been initiated and boiling operations are scheduled to begin in August 1963.

Instrumentation and Material Support

Modifications were made to the test sections of all heat

transfer facilities; instrumentation for the three facilities was connected to a single high-speed digital recorder for obtaining data. A program was initiated to increase the operating life of the boiler thermocouples in the 100-kw facility and preliminary results are presented.

The Cb - 1 Zr alloy, in-line hot trap from the 300-kw primary loop (Na) was removed and evaluated. It was found to be a very effective "getter" for oxygen in the Na loop. Other interstitial elements were gettered to a lesser extent. The metallurgical evaluation of S-1 alloy indicated that, unlike L-605 alloy, room temperature ductility was not affected by exposure at 1600°F for 1000 hr. The tensile and rupture properties of S-1 alloy, however, were lower than those of the L-605. The testing of a conductive heater design that employs a continuous layer of molybdenum-alumina composition was completed successfully. Steady-state and transient conditions were tested with He cooling of the inside diameter of the Cb-1 Zr tube.

(J. C. Chen)

Figure 5 in the Review corresponds to Figure 10a in the original report.

REVIEW NO. 159

TWO-STAGE POTASSIUM TEST TURBINE

Sponsor: National Aeronautics and Space Administration
Contractor: General Electric Co., Missile and Space Division, Cincinnati, Ohio
Contract No.: NAS 5-1143
Report No.: Quarterly Progress Report No. 9 for Quarter Ending August 8, 1963
Report Edited By: E. Schnetzer
Previous Reviews: 11,26,72

Bearing and seal pretesting has been completed. Modifications have been made to the oil, air, and water feed tubes running to and from the turbine sump and bearings. These tubes had been brazed into the housing and cracked during

the pretest operation due to embrittlement of the tube in the brazed area. New tubes were welded into place. This repair welding caused some distortion of the bearing housing requiring remachining of all critical dimensions. The forward Ni-plated labyrinth seal was replated where a rub had occurred during previous testing.

Despite early success with Ni-plated Inconel X "O" ring seals, problems have developed. Cracking and spalling of the Ni plate has been a primary cause of leakage. Remedial heat treatments are being employed to soften the Ni plate and improve the spring toughness of Inconel X. These "O" rings have also bonded to the flanges, presenting a problem in separating the seal. Stellite and Mo coatings were found to be effective in preventing this diffusion bonding.

Construction of the 3000-kw test facility and the scrubber system was completed and the furnace was dry-fired.

Potassium nozzle test data evaluation methods are being finalized. The objective of this test is to find the variation of polytropic exponent with temperature and quality and the variation of degree of supersaturation with inlet temperature and quality.

(K. C. Hoffman)

REVIEW NO. 160

ELECTROMAGNETIC ALKALI METAL
PUMP RESEARCH PROGRAM

Sponsor: National Aeronautics and Space Administration
Contractor: General Electric Co., Missile and Space Division, Cincinnati, Ohio
Contract No.: NAS 3-2543
Report No.: Quarterly Progress Report No. 1, June 27, 1963 to September 27, 1963
Report Edited By: J. P. Verkamp
Previous Reviews: none

This research program involves a study of electromagnetic pumps for application to space electric power plants. Although there is a weight penalty associated with this type of pump in comparison to centrifugal devices, the EM pump does offer a reliability advantage that is of interest to the space power program.

The research program will be divided into three phases:

Phase I is primarily analytical and will include an assessment of the theoretical feasibility of using EM pumps in space power systems. The basis for selection and design of EM pumps as well as a preliminary design and test program will be established.

Phase II is the experimental phase in which the detailed design, manufacture, and test of selected EM pumps will be accomplished. A suitable pump test installation will be designed and constructed.

Phase III is the evaluation phase involving an over-all evaluation of EM pump performance and limitations.

This report describes the design criteria for primary coolant, radiator circuit, and condensate boost pumps in a 1-Mw space power plant.

The performance characteristics and operating principles of conduction, induction, and rotating magnet type EM pumps in various geometries are presented.

(K. C. Hoffman)

REVIEW NO. 161

STUDY ON APPLICATION OF NUCLEAR ELECTRICAL POWER
TO MANNED ORBITING SPACE STATIONS

Phase I-Feasibility Studies and Parametric Data

Sponsor: National Aeronautics and Space Administration
Contractor: General Electric Co., Missile and Space Division,
Philadelphia, Pa.

Contract No.: NAS 3-4160

Report No.: 63SD865

Report Approved By: A. J. Arker, Program Manager, and
E. Ray, Manager, Advanced Nuclear Systems Engineering

Report Date: December 20, 1963

Previous Reviews: none

This 190-page report presents the results obtained during Phase I of a design study of the application of nuclear-electric power for manned orbiting space stations. The work of Phase I consisted mostly of a study of SNAP reactors, coupled to various power conversion schemes, from the standpoint of technical feasibility. SNAP-2 and SNAP-8 reactor types were evaluated in combination with Hg-Rankine, Brayton, thermoelectric, and steam-Rankine power conversion systems. In addition, isotope and advanced high-temperature reactors were considered in combination with a Brayton power plant cycle.

One attractive combination for a 35-kw(e) system is a SNAP-8 reactor with two independent Hg-Rankine loops with a total weight of about 9000 lb. Each loop would be capable of providing full power at rated temperatures and pressures.

The report contains several flow diagrams for the various schemes, giving temperatures, pressures, power consumptions, flow rates, and other pertinent information. Many tables and graphs are also included, giving such information as weights, efficiencies, radiator areas, and other calculated results.

(O. E. Dwyer)

REVIEW NO. 162

MASS TRANSFER INVESTIGATION IN LIQUID METAL SYSTEMS

Sponsor: U. S. Atomic Energy Commission

Contractor: General Electric Company Atomic Power Equipment
Dept., San Jose, California

Contract No.: AT(04-3)-189-Project Agreement #15

Report No.: Monthly Progress Letter #52
Report By: R. W. Lockhart
Report Date: November 8, 1963
Previous Reviews: 75,100

During this report period, operation of five of the six Na loops continued. The loop materials are as follows:

- #1 - 316 SS
- #2 - 316 SS and $2\frac{1}{4}$ Cr - 1 Mo steel
- #3 - same as #2
- #4 - 316 SS and 5 Cr - $\frac{1}{2}$ Mo steel
- #5 - $2\frac{1}{4}$ Cr - 1 Mo steel
- #6 - 5 Cr - $\frac{1}{2}$ Mo steel

Steel and Na samples were withdrawn and submitted for analysis from loops #2, 3, and 6. Analysis reports are not presented as yet.

Several steel and Na analysis reports are presented which cover previous runs. The loops involved are loops #1, 3, 4, and 6. The data may be summarized as follows:

- Loop #1 - After 1400 hr of operation at 1198° to 695°F temperature differential, data from loop #1 displayed high corrosion rates and high build-up of corrosion products on cold leg samples.
- Loop #3 - A 700-hr run showed lower corrosion rates in this loop and indicates that higher corrosion rates in previous runs seem to be a result of the higher oxygen content of Na. This loop operated at a 1099° to 848°F temperature differential.
- Loop #4 - The 2800-hr data indicated much lower corrosion rates than in previous runs. In this run the oxide level was lower and the $T_{\max}$ was lower.
- Loop #6 - After 700 hr of operation at a 1202° to 938°F temperature differential, the 5 Cr - $\frac{1}{2}$ Mo steel loop exhibited a normal corrosion pattern but somewhat higher than a previous run. Upon comparing the results of the present run with that of the previous run at a $T_{\max}$ of 1100°F but with a higher oxide content (46 vs. 13 ppm), the temperature effect seemed to outweigh the higher oxide level.

(A. J. Romano)

AN-80%

FIGURE 1. NUCLEATE BOILING HEAT TRANSFER DATA - CESIUM

Figure 2 RESULTS OF AXIAL LOAD FATIGUE TESTS ON Mo + 0.5 w/o Ti IN HELIUM-VACUUM ATMOSPHERE, OR POTASSIUM-VACUUM ATMOSPHERE AT 1500°F AND 2000°F

Figure 3 FLOW SHEET OF PHYSICAL PROPERTIES TEST LOOP

LEGEND

-FW- FEEDWATER

- S- STEAM

-Na- SODIUM

— — CONTROL VALVE

W = FLOW, LB PER HR

P = PRESSURE, PSIA

T = TEMPERATURE , F

H = ENTHALPY, BTU PER LB

Figure 4 Sodium flow diagram. 2000 kw Sodium Test Facility.

Figure 5 Sodium Boiling Heat Transfer Coefficient as a Function of Quality in 100 KW System (with twisted ribbon insert)

TABLE 1

AXIAL LOAD FATIGUE DATA FOR Mo + 0.5 w/o Ti
ALLOY AT 1500° AND 2000°F IN VACUUM OR HELIUM
AND IN POTASSIUM VAPOR (LOAD RATIO A = 0.95)

<u>Specimen Number</u>	<u>Maximum Stress, ksi</u>	<u>Lifetime, kilocycles</u>
<u>Helium or vacuum at 1500°F</u>		
7F*	100.0	Failed at startup
12F	80.0	7(1)
11F	77.5	24
8F*	77.5	120
13F	75.0	1,069(2)
14F	72.5	194
6F*	70.0	2,289
15F	70.0	> 3,567(3)
16F	67.5	36
17F	67.5	> 102,271(4)
9F*	47.5	> 92,650(4)
10F*	35.0	> 102,052(4)
<u>Potassium Vapor at 1500°F</u>		
2F	75.0	24
3F	70.0	6
4F	70.0	5
5F	65.0	2
26F	60.0	3
27F	55.0	3
28F	50.0	1
31F	45.0	204
30F	42.5	29
33F	40.0	45,071
<u>Vacuum at 2000°F</u>		
25F	57.4	45
24F	52.5	557
22F	50.0	230
<u>Potassium Vapor at 2000°F</u>		
39F	40.0	3,825
34F	35.0	> 23,212(5)
35F	31.5	> 1,360(6)

*Helium

- (1) Specimen did not fracture but was elongated 3/16 to 1/4 in. near center of test section.
- (2) Tarnished appearance indicated slightly contaminated atmosphere.
- (3) Exposed to room air at 3,567,000 cycles from sudden leak in system - test stopped.
- (4) Specimen did not fail.
- (5) Furnace failure at 23,212,000 cycles - test stopped.
- (6) Adapter ring broke - test stopped.

TABLE 2.
CREEP-RUPTURE DATA FOR Mo + 0.5 w/o Ti

Test	Specimen Type	Environment		Temperature °F	Stress psi	Rupture Time Hours	Elongation at Rupture, %	Reduction of Area at Rupture, % (a)	Minimum Creep Rate, %/hour	Time To Reach Indicated Deformation (hours)			Specimen Appearance After Test
		Internal	External							0.5	1.0	2.0	
1	Solid	-	Kv	1500 ±10	80,400	843.6	9.65	76.5	0.00436	0.25	2.1	45	Bright
2	Solid	-	Vac	1500 ±15	80,400	495.9	10.8	89.0	0.0090	0.29	2.5	53	Bright
3	Solid	-	Kv	1520 ⁻²⁰ ₊₅₅	80,400	104.6	6.85	89.4	0.0168	0.11	1.7	26	Bright
4	Solid	-	Vac	1500 ⁺⁵	80,400	93.0	7.10	73.2	0.0345	0.02	2.3	22	Momentary increase of pres. to 1×10^{-2} torr, black
5	Solid	-	Kv	1800 ⁺⁵ ₋₇	58,000	-	-	-	0.091	0.46	4.0	-	-
6	Hollow	He	Vac	2000	35,000	101.1	11.1	90+	0.017	5.0	28.3	71	Bright
7	Solid	-	Vac	2000	35,000	116.2	12.7	88.6	0.016	7.0	33	87.5	Bright
8	Hollow	Kv	Vac	2000	35,000	140.6	15.0	90+	0.016	10.5	40.5	89.5	Bright
9	Hollow	Kv	Vac	2000	48,000	9.2	16.0	90+	0.36	0.65	2.0	4.3	Bright
10	Hollow	Kv	Vac	2000	25,000	496.8	12.0	90+	0.0011	219.6	362	444	
11	Hollow	He	Vac	2000	25,000	310 (b)	12.3	90+	0.0015	112	233	280	Bright
12	Hollow	Kv	Vac	2000	25,000	488.3 (c)	4.3	90+	0.001	168.7	395	-	Bright
13	Hollow	Kv	Vac	1800	50,000	266.3	12.0	90+	0.010	2.1	27.4	112	Bright
14	Hollow	Kv	Vac	1800	55,000	153.4	11.7	90+	0.0235	2.6	19.5	62	Bright
15	Hollow	Kv	Vac	1800	60,000	30.9	9.9	90+	0.103	0.73	4.9	14.7	Bright

- (a) Impossible to make precise R. A. measurements on hollow specimen fractures.
- (b) This rupture time not reliable because the furnace failed twice during the test, and after the second failure (at 190 hours), the creep rate increased immediately.
- (c) Rupture occurred near the fillet.

TABLE 3.
CORROSION TABS FROM CREEP TESTS

Specimen	Material, w/o	Weight, g			Surface Roughness, μ in., rms	
		Before	After	Gain	Before	After
<u>Test 1. 867.3 Hr in 1500°F Potassium Vapor</u>						
1	Cb + 10 w/o Ti + 5 w/o Zr	0.6294	0.6314	0.0020	7-9	9-11
2	Cb + 4.33 w/o Zr	0.6550	0.6566	0.0016	7-10	7-10
3	Cb + 5 w/o Mo	0.1963	0.1975	0.0012	5-6	6-8
4	Cb + 10 w/o Ti + 5 w/o Mo	0.5286	0.5308	0.0022	6-7	7-9
5	Cb	0.5284	0.5297	0.0013	9-15	16-25
6	Cb + 2.37 w/o Cr	0.4987	0.5002	0.0015	7-10	7-9
7	Cb + 3.34 w/o Zr	0.5500	0.5517	0.0017	9-12	8-10
8	Cb + 1.56 w/o Zr + 1.09 w/o Cr	0.5486	0.5499	0.0013	7-10	8-10
9	Cb + 5.21 w/o V	1.0062	1.0531	0.0469	16-21	17-21
<u>Test 5. 137 Hr in 1700°-1800°F Potassium Vapor^(a)</u>						
10	Cb + 10 w/o Ti + 5 w/o Zr	0.5097	0.5116	0.0019	8-10	12-17
11	Cb + 4.33 w/o Zr	0.6113	0.6126	0.0013	6-9	10-16
12	Cb + 5 w/o Mo	0.2268	0.2246	-0.0022	6-7	30-45
13	Cb + 10 w/o Ti + 5 w/o Mo	0.4145	0.4171	0.0026	6-7	Badly scaled
14	Cb	0.5697	0.5547	-0.0150	8-10	28-30
15	Cb + 2.37 w/o Cr	0.3107	0.2968	-0.0139	7-8	18-25
16	Cb + 3.34 w/o Zr	0.4470	0.4509	0.0039	8-10	2-3
17	Cb + 1.56 w/o Zr + 1.09 w/o Cr	0.6970	0.7001	0.0031	8-10	12-15
18	Cb + 5.21 w/o V	0.7455	0.7485	0.0030	9-12	4-5

(a) All specimens except 16 and 18 had significant surface scale.

APPENDIX A

Organizations Having Reports, As Indicated By Review Numbers, Covered In This And Previous Issues Of The Review

Aerojet-General Nucleonics 82, 94, 144	General Electric Company 3, 11, 22, 26, 27, 50, 51, 72, 73, 74, 75, 98, 100, 101, 158, 159, 160, 161, 162, 163
Aerojet-General Corporation 143	Geoscience Ltd. 8, 23
AiResearch Manf. Company (A Div. of Garrett Corp.) 12, 64, 88, 102, 103, 150, 151, 152	Hydronautics, Inc. 107, 132
Allison Division, General Motors Corp. 96, 145	Jet Propulsion Laboratory 80, 97
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Tapco

(A Div. of Thompson Ramo Wooldridge)

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Thompson Ramo Wooldridge Inc.

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University of Michigan

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Westinghouse Electric Corporation

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