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HIGH-TEMPERATURE LIQUID-METAL TECHNOLOGY REVIEW

A Bimonthly Technical Progress Review

PREPARED UNDER THE AUSPICES OF
DIVISION OF REACTOR DEVELOPMENT
SPECIAL TECHNOLOGY BRANCH, USAEC

VOLUME 3 • NUMBER 6 • DECEMBER 1965

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

BROOKHAVEN NATIONAL LABORATORY
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FOREWORD

The purpose of the High-Temperature Liquid-Metal Technology Review is to provide up-to-date information on the various research and development programs in the United States in the field of high-temperature liquid-metal technology. The method is to publish reviews prepared, for the most part, by members of the Nuclear Engineering Department of the Brookhaven National Laboratory on current topical and progress reports submitted by contracting organizations. When results and conclusions are reported, it is intended that the individual reviews become both summaries and critiques.

The organizations currently submitting reports are those operating under AEC, NASA, and Air Force contracts. A list of these organizations is given in the Appendix.

The Review covers all phases of high-temperature liquid-metal technology, including materials development, corrosion and mass transfer, heat transfer, fluid dynamics, instrumentation, purification, component development, physical properties, thermodynamics, chemical analysis, and power systems. This type of information is needed primarily in the development of power systems for space vehicles, but much of it is also very pertinent to the AEC's fast breeder development program. In the latter area, the coverage, starting in the next issue, will be more complete than in the past, reflecting the increased importance of this technology in the Commission's reactor development program.

Monthly progress reports, owing to the usually small amount of new information contained in them, do not always receive individual treatment. The information in two or more such reports is usually combined into a single review.

Whenever an author feels that his report was not adequately or correctly represented in the Review, we would like to hear from him and would be happy to publish his letter in the next issue, if he so wishes.

Those organizations which regularly submit reports for coverage in the Review automatically receive courtesy copies of it directly from Brookhaven on date of issuance. All other

organizations are required to follow the usual procedure of procuring them through the Clearinghouse for Federal Scientific and Technical Information, National Bureau of Standards, U.S. Department of Commerce, Springfield, Virginia.

This is the sixth and final issue of Volume 3 of the Review, and I would like to take this opportunity to express my thanks to the following members of the Nuclear Engineering Department at Brookhaven who have served faithfully as reviewers during 1965:

C. Auerbach	C. Klamut
J. C. Chen	L. Newman
J. J. Egan	G. Pancer
A. H. Fleitman	R. M. Powers
K. C. Hoffman	A. J. Romano
C. J. Hsu	J. Weeks
S. Kalish	

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

I would also like to thank Mr. Robert P. Brown and the members of the Brookhaven Graphic Arts Section for their loyal and expert services during the past year, Mrs. Judith Ridgeway for typing the Reviews, and Mrs. Jean Reynolds for editing them.

Finally, I would like to express again my thanks to the several organizations which submit reports for coverage in the Review. Their splendid cooperation is also very much appreciated.

O. E. Dwyer
Technical Editor

HIGH-TEMPERATURE LIQUID-METAL TECHNOLOGY REVIEW

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AN INVESTIGATION OF LIQUID-METAL HEAT TRANSFER
IN A COCURRENT-FLOW, DOUBLE-PIPE, HEAT EXCHANGER

Sponsor: U.S. Atomic Energy Commission
Contractor: Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois
Contract No.: W-31-109-eng-38
Report No.: ANL-7056
Report By: Richard L. Merriam
Report Date: June 1965
Previous Reviews: none

The results of both analytical and experimental investigation of liquid-metal heat transfer in a cocurrent-flow, double-pipe heat exchanger are reported.

The analytical study is essentially an extension of the previous analysis by Stein⁽¹⁾ who made a similar study for a narrow annular space. Stein's analysis is extended to heat-exchanger configurations with wide annular spaces by introducing the diameter ratio of the annulus as an additional parameter. Slug-flow and negligible eddy transport compared with molecular heat conduction are assumed. The slug-flow results are then extended to a higher Peclet number range by introducing the k^+ approximation technique developed by Stein. The main conclusions drawn from the analysis are (1) heat transfer coefficients considerably lower than those based upon the uniform surface temperature boundary condition can be obtained, (2) the heat transfer boundary conditions depend upon the operating conditions of the heat exchanger as defined by the four basic parameters, H (heat-capacity flow rate), K (fluid thermal resistance ratio), K_w (relative wall thermal resistance), and R (annular ratio), (3) the heat transfer coefficients vary along the length of the exchanger and can lead to higher heat-exchanger efficiencies than those calculated based on the assumption of uniform surface temperature, and (4) the narrow-annulus approximation of Stein yields sufficiently accurate estimates of the heat exchanger efficiency for annular ratios >0.7 or values of $K < 1.0$.

-
- (1) Stein, R. P., "Heat Transfer Coefficients in Liquid Metal Cocurrent Flow Double Pipe Heat Exchangers" presented at Third Annual High-Temperature Liquid Metal Heat-Transfer Technology Conference, September 4-6, 1963, Oak Ridge National Laboratory

For heat exchanger efficiencies >0.7 and with nearly equal heat-capacity flow rates in both channels, calculations using the traditional design equations based on uniform heat flux boundary condition yield approximately the same results as the present analysis.

The experimental investigation was carried out with various double-pipe heat exchanger test sections of different heat-transfer length. Mercury and pure nickel were chosen as the heat transfer fluid and the test section material, respectively. Fully developed over-all and individual-channel Nusselt numbers and heat-exchanger efficiencies were determined for various heat-exchanger operating conditions. A new technique was used to determine values of the fully developed over-all Nusselt number by measuring the outside wall-temperature distribution. Although successful determination of the fully developed heat transfer coefficients was limited to operation with an annular-side Peclet number of 100 for the various tube-side Peclet numbers, the experimental results showed general agreement with the present analysis. Prediction by traditional analysis, on the other hand, yielded significantly different results. The discrepancy between the experimental results and the present analysis was attributed to extraneous conduction effects which exist at the end of the test sections.

It is also pointed out that (1) in a cocurrent-flow double-pipe heat exchanger, the thermal-entry-length is a complicated function of the various heat-exchanger operating conditions, and should not be determined solely using the criterion based upon L/D_1 ratio, and (2) the assumption often made concerning the ratio of individual-channel heat transfer coefficients may be in error since the individual coefficients depend strongly upon the heat transfer boundary conditions.

(C. J. Hsu)

REVIEW NO. 428

A LIQUID-METAL HEAT-TRANSFER EXPERIMENT

Sponsor: U.S. Atomic Energy Commission

Contractor: Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois

Contract No.: W-31-109-eng-38

Report No.: ANL 7038

Report By: R. E. Holtz
Report Date: June 1965
Previous Reviews: None

The ultimate object of this work is to investigate thermal radiation heat transfer as a means of supplying high uniform heat fluxes. The experimental work was conducted on a small scale thermal-radiation-heated liquid-metal loop. NaK-78 was used as the heat transfer fluid.

The heated section consisted of a 0.500 in. o.d. x 0.035-in. wall type 316 stainless steel tube containing the flowing NaK. The tube was surrounded by two half-cylindrically shaped tantalum elements which were electrically heated. Appropriately placed thermocouples were used to measure wall temperatures and inlet and outlet bulk temperatures. The loop was contained within an evacuated enclosure as a safety measure and also to extend the life of the tantalum heating elements.

The loop was operated for a total of 750 hr. The maximum fluid temperature was apparently 1400°F, although it appears that for the most part the temperature did not exceed 900°F. The first heater failed after 400 hr. Heat fluxes up to 62,000 Btu/hr-ft² had been obtained. Failure was due to expansion of the inside thermal radiation shield and subsequent shorting of power leads at the top of the heated section. It would seem that it is possible to design around this problem. The next two heating elements failed after 150 and 200 hr of operation. These heaters failed because of embrittlement of the tantalum. It is stated in the report that the tantalum used for making the latter two elements "appeared to be of an inferior quality for this application." It seems to this reviewer that a more quantitative investigation as to the cause of the premature failures would be useful.

The loop, with the thermal-radiation test section, was used to obtain single-phase heat transfer data for NaK flowing vertically upward in a tube. The data were compared to the predictions of Dwyer⁽²⁾ and the agreement was reasonably good. The interesting feature of the results was that they showed a significant jump in the heat transfer coefficient as the flow changed from laminar to turbulent. This is expected on the basis of theory, but was never before shown by experiment, to the reviewer's knowledge.

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(2) Dwyer, O. E., "Eddy Transport in Liquid-Metal Heat Transfer," A.I.Ch.E. J. 9, p. 261 (1963).

The development of a radiant heat source capable of supplying high uniform heat fluxes is important. It is pertinent to mention that, in a relatively straight-forward operation at BNL, a radiant furnace with Kanthal heating elements, in a non-inert atmosphere, was recently used to supply a heat flux of 90,000 Btu/hr-ft² to a boiling potassium test section at a temperature of $\approx$ 1500°F.

(O. E. Dwyer)

REVIEW NO. 429

ARGONNE NATIONAL LABORATORY
REACTOR DEVELOPMENT PROGRAM PROGRESS REPORT

Sponsor: U.S. Atomic Energy Commission

Contractor: Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois

Contract No.: W-31-109-eng-38

Report No.: ANL-7115

Report By: Coordinated by R. M. Adams and A. Glassner

Report Date: October 1965

Previous Reviews: 29, 30, 41, 42, 66, 67, 83, 117, 118, 141, 142, 169, 170,
202, 203, 240, 241, 244, 245, 246, 289, 296, 297, 318,
319, 337, 338, 362, 363, 391, 392, 414, 415

Development of Refractory-Metal Alloys for Service in Oxygen-Contaminated Na (p. 36)

Ten binary V alloys, prepared to insure homogeneity, were exposed to Na for one week. The Na, presumably in a static system, was held at 650°C and contained 40 to 45 ppm O. The observed weight losses are summarized in the following table.

<u>Nominal wt % of element in alloy</u>	<u>Weight loss, mg/cm²</u>
10 Aluminum	51.2
10 Copper	104.0
10 Chromium	61.4
20 Chromium	27.5
10 Iron	88.5
20 Iron	91.8
10 Nickel	93.8
20 Nickel	115.0
2 Silicon	82.5
20 Titanium (controls)	28.8, 28.4

The results substantiated earlier indications and showed that Al, Cr, and Ti are beneficial additions. Microexamination of the corroded samples to estimate oxygen penetration is not yet complete.

Ternary alloys of the series V - 40 Ti - x will be tested next.

Liquid-Metal Corrosion (p. 55)

Current effort is aimed at verifying the effect of polarizing current on the thickness of corrosion film previously observed. Five zirconium electrodes were exposed together overnight in oxygenated sodium at a central temperature of 580°C to form an electrode-surface corrosion film suitable for subsequent polarization experiments. Weight gains varied only $\pm 8\%$, a significant improvement over previous results. Individual samples of this group are being subjected separately to further exposure at 400°C (central), under either unpolarized or anodically polarized conditions. Polarization voltages of >100 mV have been achieved, throughout a test, across the corrosion film at 400°C with a surface current density of 10 mA/cm^2 . Voltage values are not yet predictable from sample to sample. The mechanism of film blemishing by sodium-moisture reaction product, i.e., whether film growth is generally inhibited, or the effect is more direct and localized to near the apparent, thin spot areas, has been questioned. Subsequent comparison of weight-gain data of zirconium samples with and without film spots supports the latter view. It is recognized, however, that absorption of hydrogen or oxygen impurity by the sample electrodes at 540°C may interfere with the resolution of the question by comparison of weight-gain data.

Oxidation of Solid Na (p. 56)

Solid Na may be cut, weighed, and otherwise handled in He containing 1 to 2 ppm each of H_2O and O_2 without developing a surface film in 15 to 20 min. However, at 100 ppm of H_2O , Na develops an obvious film almost immediately, while Li does not, even after an extended time of exposure.

Boiling Liquid-Metal Technology (p. 62)

Construction of the Cb - 1 Zr loop facility continues. It will be used to study heat transfer and two-phase flow for boiling Na at temperatures up to $2100^{\circ}F$. Fabrication of the circulating system is complete, but some instrumentation and vacuum chamber work remains to be done. Apparently it will be several weeks before the loop is ready for operation.

Electron-Bombardment Heater Experiment (p. 63)

The mechanical difficulties previously encountered with insulators and power leads appear to be solved with maximum lead flexibility commensurate with current capacity. Short-term operation of the heater has revealed a mismatch between the heater circuit and the high-voltage power-supply control. Modifications of the electron heater circuit, the cathode heater circuit, and the control input of the main power supply are in progress.

Liquid-Metal Heat Transfer in Double-Pipe Heat Exchanger (p. 63)

For studies under conditions of countercurrent turbulent flow, relatively minor revisions of the existing mercury heat exchanger loop--previously used for cocurrent flow experiments--were completed and others are being considered. Emphasis is directed to the use of new experimental techniques related to the generalized mathematical formulation described recently at the Conference on Application of High Temperature Instrumentation to Liquid-Metal Experiments held at ANL, September 1965. The proceedings of this conference are to be published as ANL-7100.

(O. E. Dwyer)

ARGONNE NATIONAL LABORATORY
REACTOR DEVELOPMENT PROGRAM PROGRESS REPORT

Sponsor: U.S. Atomic Energy Commission
 Contractor: Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois
 Contract No.: W-31-109-eng-38
 Report No.: ANL-7122
 Report By: Coordinated by R. M. Adams and A. Glassner
 Report Date: November 1965
 Previous Reviews: 29, 30, 41, 42, 66, 67, 83, 117, 118, 141, 142, 169, 170, 202, 203, 240, 241, 244, 245, 246, 289, 296, 297, 318, 319, 337, 338, 362, 363, 391, 392, 414, 415, 429

Development of Refractory-Metal Alloys for Service in Oxygen-Contaminated Na (p. 34)

V-Ti-Mo alloys, designed to improve the high-temperature mechanical properties of V-Ti, were corrosion tested in 650°C Na containing 30 ppm O. Some preliminary results are given below.

<u>Alloy, wt %</u>	<u>Weight loss, mg/cm²</u>	<u>External loss, u</u>
Controls V - 20 Ti	17.3	23
(annealed at 900°C)	20.9	23
V - 15 Ti - 7½ Mo	21.5	24
(annealed)		
V - 15 Ti - 7½ Mo	25.6	37
(50% cold work)		
V - 40 Ti - 10 Mo	8.9	10
(annealed)		
V - 40 Ti - 10 Mo	9.0	14
(50% cold work)		

Although quite a number of ternary alloys based on V-Ti have now been tested, none has offered an order-of-magnitude improvement in corrosion resistance as compared with the reference V - 20 wt % Ti binary. Because of the film retention properties shown by V-Cr binary alloys, ternary alloys have been made with chromium as the major addition to the vanadium. The best alloy thus far has shown an order-of-magnitude improvement over the reference alloy V - 20 wt % Ti, as shown

by the following results, which were obtained with Na containing 20 to 30 ppm O.

Alloy, wt %	External loss,	$\Delta w/cm^2$,
	<u>μ</u>	<u>mg/cm²</u>
V - 20 Cr - 5 Al	8	-20.7
V - 25 Cr - 5 Al	3	-15.8
V - 30 Cr - 5 Al	- 2	- 6.0
V - 20 Cr - 10 Al	3	- 1.8
V - 20 Ti (reference)	23	-20.9

Liquid-Metal Corrosion (p. 50)

In the continuing polarization studies, five sample electrode rods of unalloyed Zr were prefilmed in overnight exposures at 850°C in oxygenated Na (see Review No. 428 above). A portion of the surface of each of four of these samples was then exposed to highly oxygenated sodium at 400°C overnight in the polarization cell, either without external polarization (two samples) or with 10 mA/cm² (surface average) of anodic current (two samples). The samples gained 0.55 mg/cm² (average) during the prefilming step and changed weight <20 μ g/cm² (average over immersed surface) in the 400°C step. The latter weight changes were not significant.

Determination of O in Li (p. 51)

Since a reliable method for determining O in Li is not yet available, an attempt is being made to adapt the technique used for the determination of oxygen in sodium. The method involves the distillation of lithium under vacuum, solution of the residue, and titration against standard acid. A higher distillation temperature will be required for lithium than for sodium. The nickel crucible is replaced by one made of Armco iron. In order to protect the quartz portion of the apparatus, a molybdenum-covered quartz liner is added. With these modifications completed, analyses for oxygen can be expected soon.

Boiling Liquid-Metal Technology (p. 56)

Construction of the Cb - 1 Zr loop facility is continuing (see Review No. 429 above).

Electron-Bombardment Heater Experiment (p. 63)

It has not been possible, so far, to operate the experimental electron-bombardment heater for extended time periods. In an attempt to overcome this problem, several factors which

contribute to the life of an electron-bombardment-type heater are being investigated and improved. These factors are quality of vacuum, system cleanliness, and heater geometry. Several small leaks in the system have been detected and eliminated. All metal surfaces within the vacuum system are being wire-brushed and cleaned with Oakite 31, and the Al_2O_3 insulators are being sanded and cleaned. These precautions should help to improve the vacuum capability and reduce contamination.

Liquid-Metal Heat Transfer in Double-Pipe Heat Exchanger (p. 57)

Revision of the Hg loop and its instrumentation is continuing (see review NO. 429 above).

(O. E. Dwyer)

REVIEW NO. 431

EMPIRE STATE ATOMIC DEVELOPMENT ASSOCIATES, INC.
SGR DEVELOPMENT PROGRAM QUARTERLY PROGRESS REPORT

Sponsor: Empire State Atomic Development Assoc., Inc.
Contractor: Atomics International, A Division of North American Aviation, Inc., Canoga Park, Calif.
Report No.: AI-65-219
Report By: R. E. Douglas, J. R. Lewis, and D. T. Eggen
Report Period: July-September 1965
Report Issued: October 30, 1965
Previous Reviews: 301,365,395

The objective of this program is to develop information pertinent to the construction of a large sodium graphite reactor (SGR). Task I is to perform engineering-scale experiments of sodium-water reactions on a mock-up of the Model Steam Generator, while Task II is to examine components from the SRE sodium system to determine mechanical, chemical, and metallographical effects on materials exposed to sodium for a long time.

Task I

Eight tests have been completed in which water between 2650 psi (455°F) and 2770 psi (472°F) was reacted with Na between 900° and 922°F in the reaction test rig. Results from these tests indicated that the Na-water reaction from a single

tube can be contained; that structural damage will be localized, and that properties of a damaging pressure wave to other equipment in the plant will not occur. It was also demonstrated that pressures from the Na-water reaction can be adequately relieved. These results, although qualitative, have shown that other parameters must be evaluated in order to arrive at an analytical basis for modular steam generator design. Future tests will evaluate the effect of water leak rate, rupture location, and the effects of water or steam pressure.

Task II

This portion of the program has been completed and a final report is being prepared.

Results of the examination of the SRE components revealed no evidence of cracking or erosion in the primary, secondary, or sodium service systems. Materials at the liquid vapor interface and at high-Na velocity locations were structurally unaffected. A carburized layer found on hot-leg components and a layer having a high dislocation structure found on cold-leg components are reported to be of no concern to the integrity of the plant heat transfer system. The general conclusion is drawn that, even considering the most severe material changes observed in the SRE heat exchange system, large sodium systems operating under conditions similar to the SRE can be expected to have a reliable life adequate for power plant applications.

Although no details are presented, it is stated that materials data on erosion and corrosion obtained from test loops are extrapolable to large sodium systems.

(C. Klamut)

REVIEW NO. 432

SODIUM LEVEL DETECTORS IN THE ENRICO FERMI ATOMIC POWER PLANT

Sponsor: U.S. Atomic Energy Commission
Contractor: Atomic Power Development Associates, Inc., 1911
First Street, Detroit, Michigan
Contract No.: At(11-1)-865, Proj. Agreement No. 15
Report No.: APDA-300

Report By: G. H. Reicks
Report Date: November 30, 1965
Previous Reviews: none

The purpose of this report is to make available to reactor designers and engineers the experience that has been gained in the design and selection of sodium level detectors for the Enrico Fermi Atomic Power Plant. This is one in a series of reports that deals with a specific component, system, or technical aspect of the Fermi Reactor Project. Unfortunately, no reference is given for other reports which may have been written.

There are two types of continuous level detectors installed in the Enrico Fermi Atomic Power Plant to measure sodium levels. One type is the Moore Special Model "15" bellows-type detector, and the other is the Taylor NaK-filled diaphragm detector. The Moore unit measures levels to ± 3 in. An advantage of these detectors is that they are capable of measuring levels with a cover gas pressure down to a full vacuum. The Taylor units have been found to be accurate to within $\pm 1\%$ of full-scale range; and their performance, based on operating experience at the Fermi plant, indicates that they are quite suitable for use in sodium because of their accuracy, small temperature shift, linearity, reproducibility, and low maintenance.

(S. Kalish)

REVIEW NO. 433

ATTENUATION MEASUREMENTS OF SOUND AND PERFORMANCE
OF ULTRASONIC TRANSDUCERS IN 600°F LIQUID SODIUM

Sponsor: U.S. Atomic Energy Commission
Contractor: Atomic Power Development Associates, Inc., 1911
First Street, Detroit, Michigan
Contract No.: AT(11-1)-865
Report No.: APDA-180
Report By: Shuh-Pan Ying and Clyde C. Scott
Report Date: December 15, 1965
Previous Reviews: 36, 65, 106, 133, 172, 211, 238, 239, 247, 276, 320, 321,
322, 340, 364, 393, 394, 416

The purpose of this work is to develop a system for "viewing" objects in opaque media, including liquid metals. Such a

system would locate objects in liquid sodium by means of sound waves and would be useful in the maintenance and fuel handling operations of nuclear reactors. However, the method is practical only if the liquid metal provides a reasonably low ultrasonic absorption and the operation of ultrasonic transducers is feasible at high temperatures.

Ultrasonic absorption in liquid sodium was measured in the temperature range 220° to 600°F with frequencies of 4 Mc/sec and 5 Mc/sec. At 600°F the data were lower for sodium than the corresponding value for water at 59°F. An ultrasonic pulse technique was used for these measurements. The necessary electronic equipment consisted of a transmitting transducer driven by a pulsed oscillator which was synchronized with the sweep of an oscilloscope by the trigger pulse from a pulse generator. The received signals were amplified and displayed on the oscilloscope. Further details are given in the report.

The ultrasonic transducers were found to operate satisfactorily in liquid sodium at temperatures up to 600°F. Piezoelectric discs, 0.5 in. in diam, were used in the transducers. The disc was separated from the sodium by acoustic windows of either beryllium or stainless steel. Three piezoelectric materials were used in the transducers. These were X-cut quartz, lead metaniobate, and lead zirconate-titanate (PZT-5). Of the three the PZT-5, which has a curie point of 690°F, operated most satisfactorily at 600°F.

The determination of ultrasonic attenuation in liquid sodium and the performance of ultrasonic transducers at high temperatures permit concepts for under-sodium scanning systems to be established. Details of these concepts are provided in a separate report. (1) However, a brief summary is also presented in this report.

Much effort in the design and operation of the sodium facility required for this work was directed towards the maintenance of the purity (especially oxygen contamination) of the sodium. This was felt to be necessary for good transmission of ultrasonic waves from the transducers into the liquid sodium. (It seems to this reviewer that it would be worthwhile to make similar measurements in a relatively dirty system. Perhaps this is planned. An undersodium viewing system, such as described in this report, might be used to help diagnose a failure

(1) Ying, S. P. and Scott, C. C., "Concepts for General-Purpose Under-Sodium Scanning Systems," APDA-179, Nov. 18, 1959.

in an operating facility, in which case the coolant sodium might be dirty.)

(S. Kalish)

REVIEW NO. 434

MATERIALS INVESTIGATION, SNAP 50/SPUR PROGRAM
Part III. Mass-Transfer of TZM by Potassium
in Boiling-Refluxing Capsules

Sponsor: Air Force Systems Command, Wright-Patterson Air Force Base, Ohio

Contractor: Battelle Memorial Institute, Columbus, Ohio, under contract to AiResearch Mfg. Company of Arizona

Contract No.: AF33(615)-2289

Report No.: APL TDR 64-116--Part III

Report By: E. M. Simons and J. F. Lagedrost

Report Date: May 1965

Previous Reviews: 390

The SNAP-50/SPUR power plant is designed to use TZM (Mo - 0.5 Ti - 0.08 Zr) as the structural material in the K-vapor turbine (the wheel and blades). Creep and stress-rupture studies carried out at Battelle with TZM in the 1600° to 2200°F range showed evidences of mass transfer when exposed to potassium. In view of these findings, a corrosion-mass transfer study was initiated utilizing refluxing capsules with controlled temperature gradients.

The purpose of the program was to study the effects of various system parameters on TZM mass transfer by potassium. The parameters of major interest were oxygen content of the potassium, temperature, temperature gradient, and exposure time. The ranges of variables were as follows:

1. Oxygen in K, 48 to 500 ppm
2. Liquid temperature, 1500° and 2040°F
3. Temperature gradient, up to 170°F/in.
4. Exposure time, 240 and 480 hr

The 6-in.-long, 3/8 x 1/4-in.-i.d. capsules were machined from bar stock, and the inside surface was honed to a <10 μ in. rms finish. The hot-trapped K (1300°F for 75 to 100 hr in contact with Zr - 30 Ti foil) was added to the capsules in a vacuum

dry box using a room temperature extrusion device. The tests were carried out in a bell jar which was evacuated to 2×10^{-6} mm Hg.

On the basis of the results described in the report, the following observations were made regarding the mass transfer of TZM by potassium in refluxing systems.

1. The amount of mass transfer was more sensitive to the oxygen concentration in the potassium than to any other variable, within the limits of the study.

2. The reactions leading to the mass transfer of molybdenum in these systems are:

and

where the primary reactions (1) and (3) are slightly favorable thermodynamically up to 2000°F and the secondary reactions are highly favorable.

3. Mass transfer was worse when the liquid temperature was above 1680°F (the freezing point of K_2MoO_4) and the vapor-zone wall temperature was below 1680°F than it was when the liquid and vapor zones were both above or below 1680°F.

4. The amount of mass transfer was relatively insensitive to temperature gradients, although the transferred material tended to deposit preferentially on the hot-test surfaces. This showed that simple solution precipitation processes were not responsible; rather, the mass transfer was a result of chemical reactions and diffusion processes.

5. Of special significance was the fact that the mass transfer was no worse after 480 hr than after 50 hr, which indicated that the chemical reactions leading to crystal deposition reaches an equilibrium or saturation condition in a relatively short time.

6. Under most practical conditions, the presence of an inert gas mixed with the potassium vapor tends to inhibit mass transfer.

7. Although not conclusive, there was some evidence that a TZM specimen under stress would suffer more mass transfer than an unstressed specimen.

(A. J. Romano)

REVIEW NO. 435

PRESSURE MEASURING SYSTEMS FOR
CLOSED-CYCLE LIQUID-METAL FACILITIES

Sponsor: National Aeronautics and Space Administration
Contractor: Consolidated Controls Corporation, Bethel, Conn.
Contract No.: NAS 3-4170
Report No.: NASA CR- 54763; Sixth Quarterly Report
Report By: Anthony J. Cassano
Report Date: October 18, 1965
Previous Reviews: 250, 278, 323, 367, 397

The purpose of this program is to develop pressure transducer equipment suitable for use in high-temperature liquid-metal systems.

As mentioned in the last quarterly progress report (see HTLMTR Review No. 397), the use of tungsten heater wire in the encapsulated heater assembly led to difficulty because of failure of plasma sprayed joints. As a result, an attempt was made to use rhenium wire for both the heater and the external lead. This would replace the plasma sprayed joint with a welded joint. These attempts were not successful because of embrittlement and breakage problems. Next, a unit was made with W - 3 Re heater wire. This required a W - W Re/Re weld joint, which appeared to be sound. The unit is now undergoing initial bakeout.

Photomicrograph and x-ray microprobe techniques were used to analyze the metal ceramic joints which have recently undergone tests at 1800°F and up to 1000 psia internal argon pressure. Results indicated that joints fabricated by the technique previously described meet temperature (1800°F) and internal pressurization (160 psia) requirements.

The potassium compatibility testing was completed on the four single-convolution test capsules of C-129Y, FS-85, T-222, W-25Re alloy, and the one test capsule containing four representative electrical terminals. (See HTLMTR Review No. 278 for alloy compositions.) The tests consisted of five 100-hr cycles at 1800°F ($\approx$ 80 psia potassium vapor pressure). No leakage of potassium was observed during the test, and examination of the capsules after the test showed no sign of failure.

Design work has started on the transducer signal conditioning system. The signal levels are reasonable, and the required components are readily available. Detailed studies are being made, and initial models of system components are being fabricated.

A mock-up of a differential pressure transducer was fabricated. The results of the tests performed to evaluate the force-deflection characteristics were in very good agreement with the analytical results obtained during the last report period (see HTLMTR Review No. 397).

(S. Kalish)

REVIEW NO. 436

TWO-STAGE POTASSIUM TEST TURBINE

Sponsor: National Aeronautics and Space Administration
Contractor: General Electric, Missile and Space Division,
Cincinnati, Ohio
Contract No.: NAS 5-1143
Report No.: NASA-CR-54392
Report By: Edited by E. Schnetzer
Report Period: Nov. 8, 1964 thru Feb. 8, 1965
Previous Reviews: 11, 26, 72, 159, 189, 190, 220, 222, 256, 325, 368

The test turbine consists of stages three and four of a five-stage 500-kW turbine. During the report period the turbine operated on potassium vapor for 40 hr at inlet temperatures ranging from 1400° to 1580°F. Testing was interrupted at various times by potassium leaks in instrumentation lines which resulted in fire damage. The test was finally terminated by a leak in the upper boiler drum.

Inspection of the turbine after test revealed excessive erosion of the first stage and fire damage (caused by in-leakage of air) to the second stage stator vanes and tip seals. The turbine inlet region showed classic erosive damage, with the turbine blades striking the slower moving liquid droplets and throwing them back into the aft face of the nozzle vanes. It was significant that the erosive damage in the second stage was less than that in the first stage even though about 3% more moisture was present. This effect is attributed to the fact that the liquid is reduced to a finer mist in the first stage, thereby reducing the second stage impact forces. Also the fluid is somewhat cooler in the second stage.

Considerable data were collected during the run, and an off-design analysis is included in the report.

The turbine is being rebuilt and the test facility is being repaired so that testing may be resumed. The modifications that are being made to both the turbine and test facilities are discussed in detail in the report.

(K. C. Hoffman)

REVIEW NO. 437

SODIUM MASS TRANSFER: XII
1963 TEST RUN REPORTS
(July - December)

Sponsor: U.S. Atomic Energy Commission
Contractor: Atomic Power Equipment Department, General Electric
Company, San Jose, California
Contract No.: AT(04-3)-189
Report No.: GEAP-4439
Report By: R. W. Lockhart
Report Date: October 1964
Previous Reviews: 75, 100, 162, 187, 188, 192, 219, 251, 252, 253, 293, 347,
348

The objective of this program is to study the effects of several variables on the corrosion resistance of three selected alloys (type 316 SS, 2½ Cr - 1 Mo steel, and 5 Cr - ½ Mo - ½ Ti steel) to liquid Na.

This report gives complete operational details and results of corrosion sample examination for four runs completed in the report period. Operational conditions include specific temperature conditions, flow rates, impurity and corrosion product analysis, and a complete log of the runs. Sample analysis includes weight change data, metallography, surface composition changes, and carbon movement.

Test conditions for the four runs reported were

<u>Run No.</u>	<u>Hot leg material</u>	<u>Cold leg material</u>
1-6	Type 316 SS	Type 316 SS
3-9	Type 316 SS	2½ Cr - 1 Mo
4-7	Type 316 SS	5 Cr - ½ Mo - ½ Ti
6-6	5 Cr - ½ Mo - ½ Ti	5 Cr - ½ Mo - ½ Ti

<u>Run No.</u>	<u>T_{max}, °F</u>	<u>ΔT, °F</u>	<u>Flow, gpm</u>	<u>Oxygen level, ppm</u>	<u>Length of run, hr</u>
1-6	1200	506	0.61	50	2368
3-9	1096	295	0.69	10	2806
4-7	1097	495	0.40	13	2832
6-6	1201	309	0.40	12	2802

(C. Klamut)

REVIEW NO. 438

SODIUM MASS TRANSFER: XV BEHAVIOR OF SELECTED STEELS EXPOSED IN FLOWING SODIUM TEST LOOPS

Sponsor: U.S. Atomic Energy Commission

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

Contract No.: AT(04-3)-189

Report No.: GEAP-4831

Report By: M. C. Rowland, D. E. Plumlee, R. S. Young

Report Date: March 1965

Previous Reviews: 75,100,162,187,188,192,219,251,252,253,293,347,348,437

This report summarizes the results of a five-year program to study the corrosion behavior of materials in flowing Na up to 1200°F. Six forced-circulation loops were used to test type 316 SS, 2½ Cr - 1 Mo steel, and 5 Cr - ½ Mo - ½ Ti steels at two oxygen levels (12 and 50 ppm), at two levels of maximum temperature (1100° and 1200°F), and at two temperature differentials (250° and 500°F).

Significant observations made in this study were as follows.

A. Corrosion and Mass Transfer

The empirical equation shown below relates the weight changes measured with the operating variables under study. The equation for hot-leg corrosion is given as

$$R = V^{0.884} O_x^{1.156} \left[\exp 12.845 - \frac{23,827}{T + 460} - 0.00676 (L/D_i) + \frac{2.26}{t + 1} \right],$$

and for cold-leg deposition the equation is given as

$$R = O_x^{0.94} \exp \left\{ [22,61 - 0.038 \Delta T] - \left[\frac{31,980 - 55.24 \Delta T}{T + 460} \right] - [0.0032 (L/D_i) + \frac{0.92}{t + 1}] \right\},$$

where

- R = steady state removal or deposition of metal, mg/cm²/mo,
- ΔT = maximum sample holder temperature minus minimum sample holder temperature, °F,
- O_x = oxygen level in sodium, ppm
- V = sodium velocity, ft/sec,
- T = sample temperature, °F,
- L/D_i = downstream factor (number of diameters a sample is downstream in an isothermal region), and
- t = month's exposure.

B. Compositional Changes

Chromium, nickel, and manganese were selectively removed from hot-leg samples in runs having low oxygen in the Na. This produced ferrite layers on type 316 SS samples exposed to

temperatures of $>1000^{\circ}\text{F}$. A change in the corrosion mechanism occurred in high-oxygen runs, i.e., a loss of Fe occurred.

C. Carbon Transfer

Significant carbon transfer occurred only in those loops containing $2\frac{1}{4}$ Cr - 1 Mo steel. All bimetallic loops having type 316 SS in the hot leg and $2\frac{1}{4}$ Cr showed carbon transfer. At temperatures of $>1000^{\circ}\text{F}$ the $2\frac{1}{4}$ Cr - 1 Mo steel in the cold leg lost 60 to 70% of its carbon in 2800 hr, while the type 316 SS in the hot leg increased $2\frac{1}{2}$ times in gross carbon content. A $2\frac{1}{4}$ Cr - 1 Mo monometallic loop showed decarburization in both the hot and cold legs.

D. Long-Time Exposure Effects on Loop Components

Intergranular attack to a depth of 7 mils was detected in the hot-to-cold leg piping. This intergranular attack in the cross-over area was not observed on short term specimens exposed in the same area. (Reviewer's comment: One explanation for this cross-over attack is presented in another report.¹)

(C. Klamut)

REVIEW NO. 439

SODIUM MASS TRANSFER: XVI THE SELECTIVE CORROSION COMPONENT OF STEEL EXPOSED TO FLOWING SODIUM

Sponsor: U.S. Atomic Energy Commission

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

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

Report No.: GEAP 4832

Report By: E. G. Brush

Report Date: March 1965

Previous Reviews: 75, 100, 162, 107, 108, 192, 219, 251, 252, 253, 293, 347,
348, 437, 438

- (1) Comprelli, F. A., Hetzler, F. J., and Young, R. S., "Observations Concerning Localized Corrosion in Pumped Sodium Loops," Trans. Am. Nucl. Soc. 8, 411 (1965).

In this report a detailed, mathematical analysis is presented of the sodium corrosion data in the G.E. San Jose loop program. The corrosion of type 316 stainless steel in 1100° and 1200°F isothermal sections of heat transfer systems containing Na with 12 ppm O is described as a partially selective process. Mathematical equations are then set up describing the diffusion of each of the elements present in stainless steel in terms of their selective and nonselective corrosion rate components. Under these conditions iron behaves nobly, molybdenum is neutral, and chromium, nickel, and manganese behave actively; "noble," "neutral," and "active" in this sense refer to the selective leaching of a given species under the experimental conditions. After an initial period of time, during which selective leaching occurs, corrosion continues at a "linear" rate, i.e., the surface concentrations of atoms have changed to a point at which their corrosion rates have become equal. Equations are derived that permit one to estimate the average extent of compositional change in the steel, and the corresponding time to reach equilibrium.

This is one of the most careful and thorough mathematical and phenomenological treatments of liquid metal corrosion to have appeared in recent years. It is, however, only an initial step since it does not treat variations with sodium chemistry and fluid flow. It also characterizes corrosion from small samples, the behavior of which may not correspond with the corrosion behavior of piping.

(J. R. Weeks)

REVIEW NO. 440

SODIUM MASS TRANSFER: XX
1964 CORROSION SAMPLE DATA

Sponsor: U.S. Atomic Energy Commission

Contractor: Atomic Power Equipment Department, General Electric
Company, San Jose, Calif.

Contract No.: AT(04-3)-189

Report No.: GEAP-4836

Report Compiled By: J. E. Pohl

Report Date: May 1965

Previous Reviews: 75, 100, 162, 187, 188, 192, 219, 251, 252, 253, 293, 347,
348, 437, 438, 439

Six forced-circulation loops are being run to determine the corrosion rates of various materials (type 316 SS, 2½ Cr - 1 Mo, and 5 Cr steel) in liquid sodium at temperatures to 1200°F.

This report is a compilation of test data for about 700 samples exposed in the six loops during 1964.

Detailed information on temperature, time, flow rate, velocity, location in loop, hardness, weight changes, and corrosion rate is presented. Visual appearance after test and results of metallographic examination are also reported. No summaries or analyses of the data are presented.

The reader is referred to other reports for details of loop construction and loop operation.

(C. Klamut)

REVIEW NO. 441

QUARTERLY STATUS REPORT
ON ADVANCED REACTOR TECHNOLOGY (ART)

Sponsor: U.S. Atomic Energy Commission

Contractor: Los Alamos Scientific Laboratory of the University
of California, Los Alamos, New Mexico

Contract No.: W-7405-eng-36

Report No.: LA-3431-MS

Report Date: November 1965, for period ending Oct. 31, 1965

Previous Reviews: 2, 15, 20, 99, 155, 156, 201, 262, 279, 305, 327, 372, 400

Determination of O in Na (p. 39)

Several different O measuring devices were installed in one Na loop so they could readily be compared. Two O meters from United Nuclear Corporation (UNC) were installed on August 6, and the cell emf's were monitored through the remainder of this reporting period. The temperature coefficients of the cells were determined by varying the Na temperature while holding the O concentration constant. A value of 0.5 mV/°F, which is the value reported by UNC, was obtained. A rhometer was also installed and its temperature compensator was calibrated over the range 280° to 305°C. The optimum rhometer operating temperature is 294°±4°C with the temperature compensator set at

2.29×10^{-2} . A vacuum distillation Na sampler is also attached to the Na loop.

The O concentration in the Na loop was changed by raising the cold trap temperature from 125° to 175°C , and the response of the measuring devices was observed. According to the vacuum distillation results, the O concentration changed from 3 to about 12 ppm. The rhometer indicated a change from 3 to about 18 ppm. (This change assumes a rhometer sensitivity of 0.0068% change in resistivity per 1 ppm change in O concentration.) The emf of one O meter changed by 40 mV whereas the emf of the other meter changed by 51 mV.

For the O meters, the change in emf (E) is related to change in O concentration (C) by the equation

$$\ln \frac{C_1}{C_2} = K(E_1 - E_2).$$

With a value of $K = -36.1$, the calculated emf changes were equivalent to increases from 3 to 13 ppm O in one case and 3 to 21 ppm in the other. These preliminary results indicate that the values of K for the two meters are different. The K value for one meter is at the lower limit of the range reported by UNC, and for the other meter it is approximately at the upper limit of this range.

The use of high-energy photon activation is being investigated as a means of determining O concentration in Na. This technique offers the promise of being suitable for accurate O measurements in the 1-ppm range. A Na sample containing ≈ 1 wt % K and 1200 ppm O was prepared for irradiation in the LASL betatron. The object of this experiment was to determine if O activity from the (γ, n) reaction could be detected in the presence of a large fraction of K interference. Preliminary results indicate that the K interference can be readily discriminated by either data processing or electronic techniques.

An extruder which is capable of removing an irradiated Na sample from a Ni tube in <5 sec after γ irradiation has been designed and fabricated. Its purpose is to prepare the Na sample for counting as quickly after irradiation as possible since the O activity has a 2-min half-life.

Fission Product Removal From Na (p. 42)

Tests were run to determine the ability of graphite to absorb Cs-137 from Na. Layers of 10 to 20-mesh spectrographic

grade graphite were contacted with Na containing 1 mC of Cs-137 at temperatures of 200°, 250°, and 300°. It was found that the Cs-137 concentration in or adsorbed on the graphite was at least two orders of magnitude greater than that in the Na. Both the removal rate and the extent of removal increased significantly with temperature. It was further found that, in the temperature range studied, stainless steel was also a getter for the Cs-137, but not such an effective one as the graphite.

Viscosity of Cs Vapor (p. 61)

The viscosity of Cs vapor was determined by a transpiration technique in the 800° to 2000°K temperature range. In the temperature interval 800° to 1400°K, the results were represented by the relation:

$$\mu = 1.5 \times 10^{-4} (T/1000)^{1.7} \text{ poise,}$$

where T is in °K.

(For recent information on other physical properties of cesium, see Review No. 420 in HTLMTR, Volume 3, No. 5. October 1965.)

(O. E. Dwyer)

REVIEW NO. 442

RESEARCH ON GAS PLATED REFRACTORY METAL COATINGS FOR LIQUID METAL COMPATIBILITY INVESTIGATION

Sponsor: Wright-Patterson Air Force Base, Ohio

Contractor: San Fernando Laboratories, 10258 Norris Avenue,
Pacoima, Calif.

Contract No.: AF33(615)-2226

Report No.: Third Quarterly Report - May 1 through July 1, 1965

Report By: Richard B. Kaplan and Fred A. Glaski

Report Date: August 1965

Previous Reviews: 382

Studies are under way to develop methods for coating the inside surface of a SS condenser-radiator and subassemblies with Cb - 1 Zr by vapor deposition of CbCl_5 and ZrCl_4 .

Efforts to reduce oxygen and carbon in Cb deposits were continued. To date, the best results have been obtained with the use of a Vycor chlorinator without any graphite or glass sieve supports and high-purity Cb metal feed.

Experiments on deposition of Cb - 1 Zr indicate the desirability of maintaining a minimum specimen temperature of 1800°F. The technique consists of an initial CbCl_5 deposition to effect a diffusion bond followed by a 30% CbCl_5 - 70% ZrCl_4 mixture. Previous work indicated that there was Zr depletion midway through the deposit. An attempt was made to remedy this by using a 100% excess charge of Zr in the chlorinator, but postexamination indicated that gas channeling occurred, i.e., nonhomogeneous deposition was obtained. Three experiments will be attempted in the next quarter to eliminate this. They are (1) increasing the $\text{ZrCl}_4:\text{CbCl}_5$ ratio to 80:20, (2) mixing large Zr metal shavings or sponge with the fine pellet feed to disperse the channels, and (3) employing a vibrator system on the chlorinator to continually fill the channels as they form.

A number of specimens were tested for Vickers diamond point hardness, using a 300-g weight. Results indicate that at the deposit-substrate interface, hardness is as high as 180 kg/mm² were found; and in the bulk of the plate, 135 to 165 kg/mm². Qualitative bend tests of the as-deposited structure have not indicated any tendency toward cracking or delamination. The results of forthcoming tensile and bend tests are expected to provide a better determination of the substrate-bond-plate structure.

(A. H. Fleitman)

REVIEW NO. 443

FUNDAMENTAL INVESTIGATION OF
LIQUID-METAL LUBRICATED JOURNAL BEARINGS

Sponsor: U.S. Atomic Energy Commission
Contractor: Southwest Research Institute, San Antonio, Texas
Contract No.: AT(11-1)-1228
Report No.: SwRI-1228-8-16
Report By: R. A. Burton, Y. C. Hsu, H. J. Carper
Report Period: August 1, 1965 through October 3, 1965
Report Date: November 1, 1965
Previous Reviews: 271, 307, 334, 383, 424

This report summarizes progress in experimental measurements with a large-scale turbulent film (air) apparatus, and in the analytical prediction of turbulent film bearing behavior. The analytical approach to continuous turbulent films, developed previously, is used to provide estimates of performance of very short, full bearings. There are indications that the stability problem of the turbulent film bearing with large displacement may be somewhat different from that of laminar film bearings. Experiments on tilted pads without end leakage have been carried out and compare well with the theory. Data are reported for the pressure distribution in stepped pads and are found to differ considerably from what would have been expected on the basis of laminar flow theory. An analysis of steady and fluctuating velocity profiles near a blockage placed in the annulus of the test apparatus is presented.

Computer techniques are described in the report, whereby the analytical technique developed can be applied to finite bearings of arbitrary film thickness distribution and length-to-width ratio.

(K. C. Hoffman)

REVIEW NO. 444

ON THE DETAILED FLOW STRUCTURE AND THE
CORRESPONDING DAMAGE TO TEST SPECIMENS IN
A CAVITATING VENTURI

Sponsor: National Aeronautics and Space Administration
Contractor: University of Michigan, Ann Arbor, Michigan
Contract No.: NASA Grant Nsg-39-60

Report No.: 03424-16-T; Technical Report No. 16

Report By: M. John Robinson

Report Date: August 1965

Previous Reviews: 43,44,71,135,136,177,178,218,231,232,272,308,
309,310,356,357,385,386,387,407,408

This report summarizes the results of cavitation damage tests in both the water and mercury cavitating venturi systems. Damage phenomena were studied at liquid velocities up to 199 ft/sec.

High-speed photography was used to study the detailed flow structure of the cavitating fluid, and the analysis of these photographs is discussed in detail in the report.

An electrical probe technique was used to indicate fluid contact with the specimen surface. Wire conductors were installed with their ends flush with the specimen surface and insulated from the specimen. Data obtained by this technique indicate that the average contact time between fluid and surface never falls below about 50%, even when the specimen is completely immersed in a highly turbulent, cavitating flow regime. This does not apply to the nose of the specimen where a continuous void was formed under highly cavitating conditions. These data are of interest in MHD devices where both liquid and vapor phases are present.

Metallographic examination was made of the carbon steel, stainless steel, nickel alloy, and refractory alloy damage specimens. Profile data were obtained on damaged specimens and are discussed in detail in the report.

The following are the major conclusions reached.

1. From high-speed photographs it was observed that there were about 10^3 to 10^4 bubbles adjacent to the specimen surface per pit formed.
2. The damage inflicted was similar in the two systems. The symmetry of pits and the fact that they do not change if exposed to further cavitation is taken as evidence that they are caused by single blows.
3. The nonsymmetrical location of the rim around a crater lends support to the unsymmetrical bubble collapse theory where damage is caused by the resulting fluid jet. The size range (mostly <0.1 mils diam) confirms the belief that damage is produced in the very final stage of bubble collapse. Comparison of depth-to-diameter ratios from impact tests with the two fluids indicates that probable impact velocities of the mercury jet are about 600 ft/sec. The water velocity that would be necessary to create the same force is about 8000 ft/sec.
4. It was not possible to correlate damage data with any single mechanical property for all specimens.

(K. C. Hoffman)

ULTRASONIC-INDUCED CAVITATION STUDIES
IN LEAD-BISMUTH ALLOY AT ELEVATED TEMPERATURES

Sponsor: National Science Foundation
Contractor: University of Michigan, Ann Arbor, Michigan
Contract No.: NSF Grant G-22529
Report No.: Internal Report 05031-4-I
Report By: R. Garcia and F. G. Hammitt
Report Date: September 1965
Previous Reviews: 43,44,71,135,136,177,178,218,231,232,272,308,
309,310,356,357,385,386,387,407,408,444

The objectives of this program are the measurement of the relative cavitation resistance of several alloys to high-temperature liquid metals, and the study of applicable mechanical properties of materials tested so that a correlation can be established between material properties and damage resistance.

The tests were conducted in 70% Pb - 30% Bi alloy at 500° and 1500°F with a vibratory device utilizing a piezoelectric crystal transducer unit. Specimens were oscillated at 20 Kc/sec with a double amplitude of 2 mils. The materials tested were types 304 and 316 stainless steel, T-111 (Ta - 8 W - 2 Hf), T-222(a) (Ta - 9.5 W - 2.5 Hf - 0.05 C), Mo - $\frac{1}{2}$ Ti, and Cb - 1 Zr in two heat treat conditions.

At 500°F the tantalum alloys were most resistant, based on mean depth of penetration, although the Mo - $\frac{1}{2}$ Ti and the two stainless steels were nearly as good.

At 1500°F both tantalum alloys were still the best, followed by Mo - $\frac{1}{2}$ Ti, Cb - 1 Zr (cold worked), and 316 SS in that order. Cb - 1 Zr (annealed) and 304 SS were least resistant to cavitation.

Equations were developed which correlate the observed results with the ultimate tensile strength, 0.2% yield strength, hardness, and strain energy of the specimen material.

(K. C. Hoffman)

REVIEW NO. 446

DEVELOPMENT AND EVALUATION OF MAGNETIC AND
ELECTRICAL MATERIALS CAPABLE OF OPERATING
IN THE 800° TO 1600°F TEMPERATURE RANGE

Sponsor: National Aeronautics and Space Administration
Contractor: Westinghouse Electric Corporation, Aerospace
Electrical Division, Lima, Ohio
Contract No.: NAS3-6465
Report No.: NASA-CR-54354
Report By: Prepared by P. E. Kueser, et al., and approved by
N. W. Bucci, Jr.
Report Date: March 1965
Previous Reviews: none

Only a small portion of this work involves the use of liquid metals and therefore this review is limited to pp. 45-54 of the report.

Several active metal braze alloy seals (ceramic to metal) were evaluated in the presence of alkali metals at 1600°F. Thermalox 998 (99.8% BeO ceramic) joined to Cb - 1 Zr with a braze metal of composition Zr - 28 V - 16 Ti exhibited a modulus of rupture strength averaging 11,800 psi after exposure at 1600°F for 500 hr in K and similar strength after exposure at 1000°F for 500 hr in Li.

The future program will consist of evaluating (1) the joint microstructures by microhardness testing and electron microprobe analyses, (2) Y-Cb and Y-Be alloy systems as brazing metals, and (3) back-up seals for active-metal braze alloys such as pressure seals (diffusion bonding), metallizing seals, gradient seals, ion sputtering, and combinations of these seals.

(A. J. Romano)

REVIEW NO. 447

QUARTERLY TECHNICAL PROGRESS REPORT
SNAP-50/SPUR GENERATOR DEVELOPMENT PROGRAM

Sponsor: U.S. Air Force, Wright Patterson Air Force Base, Ohio
Contractor: Westinghouse Electric Corporation, Aerospace Electrical Division, Lima, Ohio

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The objective of this program is to develop a generator for a 300-kW(e) nuclear-dynamic space power system. The following is a summary of progress in the major development areas.

1. Generator bore seal development. Development work on the tubular ceramic-metal bore seal assembly was continued with the production of 2.5-in. diam test specimens. Various braze techniques were investigated for the attachment of the ceramic-to-metal parts. Braze specimens were prepared and exposed to 900°F potassium vapor for periods up to 10,000 hr. The results indicated that the special Ei-3 high-alumina ceramic is the most resistant to potassium vapor. The report also discusses the relative merits of different braze materials.
2. Stator development. The report contains welding specifications for welds between various combinations of Inconel, Haynes 25, stainless steel, and cupronickel. Also included are specifications for brazing Kovar, copper, and 15% zirconium-copper. Some evaluation of these joints is included.
3. Rotor development. Creep testing of premium quality H-11 alloy rotor material is in progress. Two potassium loaded creep specimens are in test. Assembly of the fluid dynamic test rig is proceeding.

Two test statorettes with flexible and pre-formed ceramic insulation are being tested at 900°F in 20 psia argon and 10^{-6} torr. Each statorette has been exposed for 5070 hr with no indication of material degradation.

4. Full-scale generator. Fabrication of two experimental generators is in progress.

(K. C. Hoffman)

APPENDIX A

Organizations Having Reports, as Indicated by Review Numbers, Covered in this and Previous Issues of the Review

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