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HIGH-TEMPERATURE LIQUID-METAL TECHNOLOGY REVIEW

A Bimonthly Technical Progress Review

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

VOLUME 4 • NUMBER 2 • APRIL 1966

no 2, 4/66

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PRINTED IN USA
PRICE \$3.00

Available from the
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards
U.S. Department of Commerce
Springfield, Virginia

June 1966

650 copies

HIGH-TEMPERATURE LIQUID-METAL TECHNOLOGY REVIEW

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ALKALI METALS EVALUATION PROGRAM

Sponsor: U.S. Atomic Energy Commission
Contractor: Aerojet-General Nucleonics, San Ramon, Calif.
Contract No.: AT(04-3)-368
Report No.: AGN-8166
Report By: P. Y. Achener, E. E. Parr, and E. A. Melaika
Report Date: October 1965
Report Period: Quarterly Progress Report for the period
July 1 to Sept. 30, 1965
Previous Reviews: 82,94,143,144,212,213,214,229,
275,299,335,358,359,389,410,448

A short history of the Alkali-Metals Evaluation Program at AGN, which began in February 1959, is presented. The status of current work is then briefly outlined and is summarized below.

Condensing heat transfer and fluid flow studies of rubidium and cesium have been completed and will be reported in AGN-8162.

Work is currently under way on the thermodynamic and transport properties of Rb and Cs including PVT relationships, vapor thermal conductivity, liquid viscosity, vapor viscosity, and liquid specific heat, up to 2000°F for cesium.

Plans are also being made to carry out measurements on potassium. These include thermal conductivity of the vapor, PVT relationships, vapor specific heat, enthalpy (and entropy), and vapor viscosity.

Also, properties of all the alkali metals needed to design heat pipes and not now available with sufficient accuracy will be measured. These include latent heat of vaporization, vapor pressure, surface tension, contact angle between liquid and solid container material, liquid and vapor density, liquid and vapor viscosity, and liquid thermal conductivity.

(J. J. Egan)

APPLICATIONS OF ULTRASONIC ENERGY:
ULTRASONIC INSTRUMENTATION FOR NUCLEAR APPLICATIONS

Sponsor: U.S. Atomic Energy Commission

Contractor: Aeroprojects Incorporated, West Chester, Penna.

Contract Nos.: Report Nos. 24 and 25 -- AT(30-1)2910; No.
26 -- AT(30-1)-3622

Report Nos.: NYO-2910-12, NYO-2910-13, NYO-3622-1

Report Dates: NYO-2910-12--Oct. 1965; NYO-2910-13--Dec. 1965;
NYO-3622-1--Feb. 1966

Previous Reviews: none

The purpose of this program is to develop instruments for nuclear applications which make use of ultrasonic principles in their operation. A number of devices are being worked on and are in various stages of development.

1. Liquid-Level Probe. A new unit was designed, tested in water, and shipped to ORNL for installation in a MSRE fuel processing tank. The unit was installed and the tank charged with salt. The probe indicated a level within 1 in. of the calculated level based on the weight of salt charged. It appears that the development of this unit is complete.

2. Incipient Boiling Detector. Previous work has shown that the approach to incipient boiling can be detected by measuring the ultrasonic power required to produce cavitation in the liquid phase. For boiling-metal reactors the tendency to superheat can also be monitored in the same general way. Theoretically, the power required to produce cavitation drops to zero at boiling. In a real system, however, because of power losses in the acoustic system, the power required for cavitation goes to a minimum value at the boiling state.

The first unit was designed, fabricated, successfully tested in water, and shipped to ORNL for testing in a potassium pool-boiling capsule. Although cavitation was induced at 750°F, it was not possible to do so at 1800°F. It was finally concluded that the difficulty was due to an altering of the physical properties of the sensing plate and the transmission lines at 1800°F which caused a change in the resonant frequency of a portion of the system. Therefore a new system

was designed with type 316 SS (instead of type 304).. The new unit was fabricated and successfully tested in water. However, because of a change in the test capsule dimensions at ORNL, some modifications are necessary. When completed, the unit will be tested at ORNL in potassium at 1800°F.

3. Flowmeter. A flowmeter based on ultrasonic principles is proposed for use in liquid metal and fused salt systems. The principle of operation is based on the transmission of an ultrasonic signal from a probe, mounted in a suitable support, through the moving liquid. The signal is picked up by two receiving probes equidistant from the transmitter. By measuring the time interval between reception of the signal by the downstream and upstream receivers, the flow rate can be calculated.

A loop is being designed in which a prototype can be tested. Water will be circulated at 30 gpm in a 1½-in. test section. The time intervals to be measured are in the order of 10^{-7} sec. This time interval would appear as a space of 2.25 cm between pips on a scope with a horizontal sweep rate of 0.1 μ sec/cm. Smaller flow rates could also be measured with a built-in 10x sweep expander.

It is not clear to this reviewer what the advantages are of this instrument over an e.m. flowmeter or a pressure-drop device.

(S. Kalish)

REVIEW NO. 466

ANNUAL TECHNICAL SUMMARY REPORT
SNAP 50/SPUR CONTRACT

Sponsor: U. S. Air Force
Contractor: AiResearch Manufacturing Co., Phoenix, Arizona
Contract No.: AF33(615)-2289
Report No.: APS-5153-R2
Report By: Engineering Staff and approved by R. D. Gruntz
Period Ending: December 31, 1965
Report Date: January 1, 1966
Previous Reviews: 312, 313, 336, 361, 411, 412, 450

Heat Transfer

Mock-up experiments with Freon are still in progress. The purpose is to study flow patterns in both boilers and condensers, with the aid of high-speed motion pictures taken through transparent walls.

On the basis of this work, it was concluded that wire helix inserts are preferred to twisted tapes for throwing the liquid phase to the tube wall. The preferred pitch of the helical winding is equal to twice the tube i.d.

A serpentine tube design was investigated with this technique, and it was observed that there was a slight swirl pattern in the two-phase flow and a tendency for the liquid phase to stratify on the insides of the tube bends at high vapor qualities.

In the flow-visualization condensing work, both condensing Freon and steam have been studied to show the effects of tube inclination upon flow stability and pressure fluctuations.

In the boiler development work, the primary effort continues to be directed toward a C-shaped boiler with inserts to centrifuge the liquid phase toward the wall. Both analytical and experimental work are in progress. A reduced-capacity version of the original SNAP 50/SPUR boiler was tested, and since the results had already been presented in the previous quarterly progress report (see Review No. 449 in the previous issue), they will not be re-presented here.

In the development of a process for joining a wire helix to the inside wall of a tube, the following three types of joints were prepared and evaluated:

- (a) Wire plated with 0.002-in. nickel plus 0.003-in. palladium using the Dalic process. The wire was assembled into the L605 tube with a low-carbon (1010) steel mandrel. The assembly was given a diffusion treatment for 30 min at 2250°F in a vacuum of $\approx 10^{-4}$ mm.
- (b) Unplated wire, similarly assembled into a tube with a mandrel, and heated for 1 hr at 2200°F in a vacuum of $\approx 10^{-4}$ mm.

- (c) Wire wound around a copper mandrel, inserted into a tube, and resistance-welded at intervals.

The first two of these appear satisfactory even though the bonding is not completely continuous.

In the radiator analysis work, weight optimization studies resulted in selection of four-cylindrical-section radiator configurations for the original SNAP 50/SPUR reference design system. Each cylindrical section is divided into four subsections, each containing 250 0.015-ft-diam tubes, and each supplied by one U-configuration inlet and outlet manifold. The inlet manifold diameter was set at 0.1325 ft.

This report also describes work conducted in various areas on the SNAP 50/SPUR Nuclear Mechanical Power Unit. The ultimate objective is to develop a system capable of delivering 300 kW of electrical power with a design life of 10,000 hr.

Following is a summary of progress in the various technical areas.

1. Materials

Four fatigue tests on TZM bar stock specimens operated in a helium atmosphere at 1500°F were completed. Results are tabulated, and indicate a reduction in life with a reduction in peak stress that is unexplained.

Sixteen wear and friction tests of molybdenum, tungsten carbide, and titanium carbide bearing materials in liquid potassium at 500°F have been completed. Tabulated results as well as photomicrographs are presented.

2. Bearings

The objectives of the bearing development program are to develop journal and thrust bearings suitable for use in the test turbine for potassium aerodynamics tests, and to develop the analytical and test techniques necessary for general bearing design.

The development of suitable bearings for the test turbine involved initial screening tests of various bearing

configurations using oil and water as the lubricant, followed by further evaluation testing of the most promising configurations in potassium at 500°F. Screening and final evaluation testing was conducted on the turbodynamic bearing test rig. Bearing types originally screened included floating ring, hybrid, and pivoted-pad bearings. The three-pad pivoted pad journal bearing and the pivoted-pad thrust bearing were selected for further evaluation. Subsequent tests of these bearings, fabricated of tungsten carbide, lubricated with potassium at 500°F, proved them adequate for use in the test turbine. A discussion of the test program with tabulated results is included in the report.

The task of developing a general bearing analysis technique was approached by first developing a computer program for the basic case of the plain cylindrical bearing. This program was then extended to include partial areas, lobed, pressurized source and pivoted pad configurations, and the results were verified by actual tests. The program analyzes the hydrodynamic (both laminar and turbulent) and rotor dynamic performance, and can predict bearing instabilities and expected whirl patterns. Verification testing is conducted on the conventional fluids journal bearing test rig. Graphical representation of the computer analysis of cylindrical bearings, lobe bearings, hybrid and hydrostatic bearings and floating ring bearings are included in the report. A discussion of the extent and results of verification testings is included.

3. Seals

The performance of a 12-vaned hydrodynamic slinger seal of 1.889 in. nominal diameter operating against a water-air environment was investigated and its pressure coefficients experimentally determined. A seal similar to the above was successfully operated against a potassium liquid-vapor environment at 1000° to 1350°F, 15 to 20 psi pressure differential. A measured value of the power consumed by this seal operating at 24,000 rpm of 2 hp per seal agrees with the predicted value. The pressure coefficients of a 2-in.-diam smooth disc seal, operating completely submerged in water were measured for various clearances.

4. Turbine

Air tests were conducted on the test turbine rig to determine turbine bearing and seal losses, generator bearing, seal and windage losses, and turbine performance when operated with air. Turbine bearing and seal losses were found to be proportional to the one-fifth power of the viscosity, the fluid density, and the cube of the speed. Total turbine performance was found to be less than predicted although the center 2/3 of the stage blading met predicted performance. This discrepancy was thought to be due to the effects of the blade tip shroud design and the low performance in the impulse root section of the rotor blade. A revision of the original performance calculations, to more nearly represent the actual turbine, resulted in reasonable correlation between predicted and test performance. Graphical representation of test results are presented.

The turbine test loop was operated with potassium in a boiling-condensing cycle, the turbine test unit having been replaced by a pipe elbow, and the vapor flow throttled with the turbine inlet valve. Test operation consisted of 100 hr at 1150° to 1200°F boiling temperature, 100 hr at 1250° to 1425°F, and 75 hr at 1500°F. Stability of the boiler was found to depend on maintaining the proper liquid level in the vapor drum.

Most of the analysis and design work on a full-scale potassium turbogenerator was directed toward a two-bearing unit. The unit has the radial gap homopolar inductor generator cradled between the two potassium journal bearings with three stages of the six-stage turbine overhung on each end, the entire unit being supported on one shaft. Potassium vapor passes through the first three stages on one end, through the crossover ducts around the generator, and then through the remaining three stages. Among the advantages of this design are: elimination of the coupling which would exist between separate turbine and generator, resulting smaller unit size, minimum number of power consuming bearings and seals, maximum dynamic stability and markedly reduced thermal expansion problems. The generator development is under the cognizance of the Westinghouse Electric Corp. The aerodynamic design of the turbine is complete. The selected operating conditions are: at turbine inlet, $t = 2060^{\circ}\text{R}$, $p = 39.09$ psia, flow = 1.0 lb/sec; at turbine exhaust, $t = 1600^{\circ}\text{R}$, $p = 3.23$ psia. Various performance characteristics of the turbine are presented.

Discussions of the turbine thermal analysis, critical speed and bearing load analysis, and stress analysis are included.

(O. E. Dwyer and P. Bezler)

REVIEW NO. 467

EROSION PROPERTIES OF SELECTED TURBINE
MATERIALS IN WATER AND POTASSIUM

Sponsor: U. S. Air Force

Contractor: AiResearch Manufacturing Co., a Division of the
Garrett Corp., Phoenix, Ariz.

Contract Nos.: AF33(657)-8954, AF33(657)-10922, AF33(615)-
1551 [BPSN: 4(6399-675A)], and AF33(615)-
2289 [BPSN: 5(6399-657) 63409124]

Report No.: AFAPL-TR-65-130

Report By: E. A. Kovacevich

Report Date: January 1966

Previous Reviews: 12,64,88,102,103,150,151,152,173,243,312,
313,336,360,361,390,411,412,449,450

Various materials were qualitatively screened in a test apparatus designed for elevated-temperature liquid-potassium erosion studies. Tests were conducted with ambient temperature water and 1400°F liquid K. Of the ten alloys tested in K, the Mo-base alloys were superior in erosion resistance to the Cb and Ta-base alloys.

The design conditions of the test facility were such that three series of tests with K were achieved. The first consisted of duplicating the conditions of the water test (run previous to the K tests), except that the impact temperature varied for the duration of the test from 1000° to 1400°F. There was no measurable erosion on the test materials in this run; the materials were Stellite 6B, Rene 41, Mo + 0.5 Ti, and TZM.

A second K erosion test series with the same specimens used in the first K test was performed; the test duration was 50 hr. A summary of the test results is as follows:

Impact velocity, 212 ft/sec

Liquid K temperature, 1400°F

K flow rate, 4.9 gpm

Weight loss of specimens:

Rene 41, 0.0013 g

Stellite 6B, 0.0007 g

Mo + 0.5 Ti, 0.0007 g

Mo + 0.5 Ti + 0.08 Zr, 0.0008 g

A third test series was conducted when a review of the test facility showed the specimen-to-sump wall clearance differed in the initial K tests and that the greater clearance resulted in accelerated erosion of all specimens tested. The test duration was 25 hr. The results of this test series are shown below:

<u>Material</u>	<u>Weight loss, mg</u>
Mo + 0.5 Ti	0.8
Mo + 0.5 Ti + 0.08 Zr	1.0
Mo + 1.25 Ti + 0.15 Zr + 0.15 C	1.0
Stellite 6B	1.0
Rene 41	1.8
Cb + 15 W + 3 Zr + 0.1 C	35
Cb + 10 Ta + 2 Mo + 1 Zr	150
Ta + 8 W + 2 Hf	150
Cb + 1 Zr	200

This test apparatus and method of testing are not a valid process for obtaining quantitative erosion data for turbine application. Simulation of the actual environment experienced in turbine operation should be produced in the test facility.

(A. J. Romano)

REVIEW NO. 468

ARGONNE NATIONAL LABORATORY REACTOR
DEVELOPMENT PROGRAM PROGRESS REPORT

Sponsor: U.S. Atomic Energy Commission

Contractor: Argonne National Laboratory, Argonne, Ill.

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

Report No.: ANL-7176

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

Report Date: February 1966

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,
415,429,430,451,452

Fuel-Cladding Materials for Na-Cooled Reactors (p. 26)

Past screening tests had shown that V - 15% Ti - 7.5% Cr alloy had greatly improved creep resistance and somewhat improved sodium-corrosion resistance compared to the reference alloy V - 20% Ti. The report gives detailed information on the fabrication and preparation of the alloy specimens.

In conjunction with fabrication development, annealing characteristics of the V - 15 wt % Ti - 7.5 wt % Cr alloy (and a similar V - 15 wt % Ti - 5 wt % Cr alloy) have been studied. The change in hardness as a function of annealing temperature is shown in Figure 1. The increase in hardness observed for anneals at 1000°C and higher, especially at 1250°C, is thought to be due to a change in the nature and morphology of the precipitate. This has been observed in metallographic examination but requires further confirmation by other techniques.

The linear thermal expansion of V - 15% Ti - 7.5% Cr was determined on a specimen machined from a rod that had been annealed for 1 hr at 900°C in vacuum. It had a density of 5.88 g/cm³. Values of the mean coefficient of linear expansion are given below:

<u>Temperature range, °C</u>	<u>Mean coefficient of linear expansion, 10⁻⁶°C⁻¹</u>
0 to 250	9.30
0 to 500	9.83
0 to 750	10.42
0 to 1000	11.28 (extrapolated)

In corrosion studies, V - 20% Ti alloy was exposed to Na containing <5 ppm oxygen for periods up to 32 hr. The temperature was maintained at 600°C, and the test specimens were rotated at 5 rpm to promote access of oxygen to the

surface. The corrosion rate was found to be linear at 3×10^{-3} mg/(cm)²(hr). At 700°C, the rate was linear (8×10^{-3}) for the first 12 hr, and then was parabolic. At 750°C, the rate was linear up to 4 hr and parabolic after that. (See Review No. 452 in Vol. 4, p. 10.)

In other tests, exposure of alloys to 650°C Na containing 25 to 30 ppm O₂ for 7 days showed no significant corrosion effect from the addition of 1% Zr or 0.5% Y to the basic V - 20% Ti - 10% Cr alloy. Two 1-week exposures of V - 20% Ti in flowing Na at 650°C were carried out. In the first, the post-test O₂ analysis showed 20 to 28 ppm, the samples were badly roughened on the surface and eroded at the leading edges, and had lost about 100 μ per side. In the second test, the post-test oxygen content was 15 ppm, the surfaces were smooth, the leading edge of one sample was slightly eroded, and the samples lost only 10 to 18 μ per side.

Loop Evaluation After Long-Time, High-Temperature Exposure to Na (p. 41)

Pipe exposed to flowing Na on the inside at 1200°F for 2069 hr, at 1472°F for 4695 hr, and between 572° and 1200°F for 1000 hr was carefully examined. The loop had no cold or hot traps. At the end of this total period, the Na contained 77 ppm C and ≈2200 ppm O₂. The outside of the pipe was covered with insulation and thus exposed to air. In comparing the exposed pipe to the unexposed pipe, the conclusions were:

- a. a minor reduction in the room-temperature ultimate tensile strength (from 86.8 to 83.5 kpsi);
- b. an appreciable reduction in the room-temperature yield strength (from 45.7 to 35.2 kpsi);
- c. a minor reduction in room-temperature ductility (elongation dropped from 64 to 58%);
- d. significant microstructural change in the weld metal (partial transformation of delta ferrite to sigma);
- e. precipitation of carbides around the grain boundaries;
- f. chemical environmental reactions [both the inside and the outside surfaces were nitrided to a depth of about

0.001 in. The nitride phase was substantially harder than the matrix, Brinell 255 versus 180. The more heavily nitrided inner case (0.24%) initiated cracking of the wall in bend tests].

The report gives the concentration of metallic impurities in the Na in the loop at various times and locations. These results were consistent with the metallurgical observations summarized above.

Separation of Particulate Carbon From Na by Centrifugation (p. 43)

Initial results show that it is possible to separate particulate carbon in the submicron range from NaK at centrifugal forces corresponding to 35,000 g's. The work is continuing and if the method continues to show promise it will be extended to Na.

Lithium Corrosion Studies (p. 57)

Ti was tested in Li with Mo as the container. The temperature was 1200°C, and the exposure time, 7 days. The purpose was to follow the N₂ concentration in the Li, as well as determine the corrosion effects. A weight loss of 27.3 mg/cm² of Ti was observed, and the N₂ content of the Li fell from 50 to 15 ppm. A needle-like surface structure associated with high-microhardness measurements indicated some impurity diffusion had occurred. No significant surface change of the Mo capsule was observed after test.

A similar experiment was carried out with the addition of 1.5 at. % Si to the Li. The weight loss of Ti was slightly reduced to 23.3 g/cm² over the same 7-day period. The nitrogen content of post-test lithium was 25 ppm (initial nitrogen content was the same as in the previous test). Microhardness measurements indicated no surface irregularities on the Ti. However, an unidentified, rather brittle layer developed on the inner surface of the Mo.

It is expected that selected additives may have profound effects on the corrosion of materials in high-temperature Li. Exploration of these systems will be continued.

Boiling Liquid-Metal Technology (p. 62)

A Cb - 1 Zr loop is being built to investigate heat transfer and two-phase flow characteristics of boiling Na to a temperature of 2100°F which is equivalent to a pressure of 8 atm. Among the variables to be investigated are boiling heat flux and temperature difference up to the critical heat flux, boiling and adiabatic two-phase pressure drop, vapor volume fraction, and parameters affecting boiling stability. The construction of this facility is almost complete, and check-out of components and instrumentation is in progress.

In the electron-bombardment heater development work, further tests have shown that the 200-kW, high-voltage power supply is not adequate for use with electron-bombardment heating for long time periods at lower power levels. Modifications of the present power supply which will enable operation from 0.5 to 200 kW are now being examined. Also, a filter system is being designed to eliminate a high-voltage arcing problem in the power supply, caused by dust buildup on components located within the power supply.

(O. E. Dwyer)

Figure 1 in the Review corresponds to Figure 18 in the original report.

REVIEW NO. 469

ARGONNE NATIONAL LABORATORY REACTOR
DEVELOPMENT PROGRAM PROGRESS REPORT

Sponsor: U.S. Atomic Energy Commission

Contractor: Argonne National Laboratory, Argonne, Ill.

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

Report No.: ANL-7193

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

Report Date: March 1966

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,
415,429,430,451,452,468

Fuel-Cladding Materials for Na-Cooled Reactors (p. 22)

The thermal expansion of annealed V - 5 wt % Ti - 15 wt % Cr was determined between 25° and 960°C. The dilation specimen was taken from rolled sheet material (parallel to rolling direction) after a 1-hr anneal at 900°C in vacuum. Specimen density was 6.16 g cm⁻³. The values for the mean coefficient of linear expansion are given below.

<u>Temperature range, °C</u>	<u>Mean linear expansion coefficient, 10⁻⁶ °C⁻¹</u>
0 to 250	9.72
0 to 500	10.42
0 to 750	10.95
0 to 960	11.45
0 to 1000	11.55 (extrapolated)

In the continuing corrosion studies, samples of V - 20% Ti were exposed to Na at 650°C for periods varying up to 32 hr. The O₂ content of the Na was measured as 3.8 ppm. The samples were rotated at 50 rpm. The corrosion rate was parabolic at a value of 6.2 x 10⁻⁴ mg²/(cm)⁴(hr). This compares with 30 x 10⁻⁴ found previously in a similar test where the O₂ content was 7.5 ppm and the rotational speed 5 rpm. The higher rate is believed to be due to the higher O₂ content, the velocity effect being relatively insignificant.

In further studies to determine the effect of O₂ content, samples of V - 20% Ti were exposed to static Na held at 650°C and containing about 15 ppm O₂. The results are shown below.

<u>Time, days</u>	<u>Sample change per surface</u>	
	<u>External loss,</u>	<u>Internal penetration,</u>
	<u>μ</u>	<u>μ</u>
7.0	10	38 to 42
14.0	20	49 to 55
21.1	41	45 to 58
28.1	52	44 to 57
35.1	62	45 to 60
42.1	83	50 to 65

The oxygen level was chosen based on a single analysis of EBR-II sodium at 13 ppm. The V - 20 wt % Ti formed a relatively constant hardened zone after the first week. A plot of the

total penetration vs. time gave a slope of $\approx 2.4 \mu/\text{day}$ (assuming linear kinetics) and an intercept on the penetration axis of $\approx 30 \mu$. If the total penetrations in one week are compared at various oxygen levels (48 to 52 μ at 15 ppm, 67 to 62 μ at 20 to 25 ppm, and 86 to 92 μ at 45 to 50 ppm), it is obvious that the alloy is extremely sensitive to oxygen concentration.

Boiling Liquid-Metal Technology (p. 73)

The construction and check-out of the Nb - 1% Zr loop facility continued during the month (see previous review).

The work to develop a satisfactory electron bombardment heater continued. Modifications to the power supply have shown that high-voltage arcing caused by dust collection can be prevented by installing an air filter in the inlet air cooling duct. It was also found that replacement of the saturable reactor by powerstats provided the required control for the heater voltage. Further tests of the experimental heater are now under way.

(O. E. Dwyer)

REVIEW NO. 470

QUARTERLY TECHNICAL PROGRESS REPORT ON AEC-SPONSORED ACTIVITIES

Sponsor: U. S. Atomic Energy Commission
Contractor: Atomic Power Development Associates, Inc.,
1911 First Street, Detroit, Mich.
Contract No.: AT(11-1)-865
Report No.: APDA-182
Report By: APDA Personnel
Report Date: October - December 1965
Previous Reviews: 36, 65, 106, 133, 172, 211, 238, 239, 247, 276,
320, 321, 322, 340, 364, 393, 394, 416, 433

Progress on the following liquid-metal projects is included in this report.

Sodium Water Reaction

In support of the AEC's sodium-heated steam generator development program, a project has been established to investigate the effect on tube wastage caused by a small leak of water into sodium. In this report period, a test facility designated Rig 10 was checked out and the first tests were initiated. Also, the bench-test apparatus for corrosion by hot caustic was fabricated, erected, and used in five experimental runs. In these tests, hot caustic is squirted onto a 2½ Cr - Mo steel. Results are to be presented in the next progress report.

Sodium Technology Loop

This loop is used to measure response of in-line meters to concentration changes in various contaminants in sodium. In this report period, a statistical analysis was performed on the data from the rho-meters and oxygen meters resulting from measured injections of sodium monoxide. It was determined that the variance prior to and following the injections were of the same order of magnitude as the signal changes. Therefore, quantitative response could not be reported with any degree of confidence. Attempts are now being made to improve the control of loop variables such as temperature, sodium impurity levels, and sodium flow rates.

A hydrogen meter for in-line use was assembled. Two types of sensor coils, a platinum-plated nickel coil and a nickel-plated platinum coil, were evaluated to determine their operating characteristics as a function of temperature and hydrogen concentration.

Under-Sodium Scanner

To obtain high resolution of images of submerged objects in under-sodium ultrasonic scanning systems, three types of transducers (focusing transducers with zirconium lenses, horn-type transducers, and line-and-cone transducers) have been designed for a frequency range of 1 to 10 Mc/sec for various work distances in 600°F sodium. Since zirconium, zinc, and lead provide a good acoustic impedance match for the piezoelectric ceramic, zirconium, which has a suitable index of refraction in sodium, was chosen as the lens material and zinc or lead was used as the absorbing layer to reduce the effect

of multiple reflection. From the engineering analyses of horn-type and line-and-cone transducers, it is expected that sharp radiation beams will be obtained and that the suppression of minor lobes will be achieved.

(J. C. Chen)

REVIEW NO. 471

LIQUID METAL VAPOR QUALITY METER

Sponsor: U.S. Atomic Energy Commission
Contractor: The Bendix Corporation, Research Laboratories
Division, Southfield, Mich.
Contract No.: AT(04-3)-636
Report Nos.: 3285, 3314, 3368 -- Monthly Progress Reports 2,
3, and 4
Reports By: Prepared by H. W. Schwartz and approved by
G. T. Burton and L. B. Taplin
Report Dates: January, February, and March 1966
Previous Reviews: none

This is a new project, the over-all objective of which is to establish the feasibility of, and to demonstrate the use of, a fluid-state delay line oscillator to measure the quality of a liquid metal vapor. The delay line oscillator utilizes a bistable fluid amplifier with output ports connected by delay lines to the control ports. Self-oscillation occurs with pressure pulses created in each leg of the delay lines as the power jet oscillates between the two receiver ports. In a given configuration the frequency of oscillation depends upon the sonic velocity which in turn is dependent upon the density of the fluid. Hence, the frequency is a function of the quality.

It is stated that this type of delay line oscillator sensor has produced satisfactory results when used as a steam quality meter. This reviewer knows of no steam installation or experimental program where this type of device is used. Apparently the results referred to are "in-house" unreported experimental results.

Typical requirements for such a metal vapor quality meter for nuclear power systems were established as follows:

Fluid, potassium
Pressure, 7 to 115 psia
Temperature, 1250° to 1900°F
Quality, 85 to 100%
Operational life, 10,000 hr

Although the primary task is the quality meter development, there are two secondary tasks concerned with experimental evaluations. These are

1. To modify an existing liquid-metal test loop to provide controlled adjustment of quality.
2. To develop a frequency sensor and transducer capable of detecting the pressure pulsations in the delay lines of the oscillator, and to transduce the pneumatic signal to an electric signal for display and recording purposes.

The following paragraphs summarize the progress made during the report period.

A combination spray injection nozzle with a venturi was chosen as the means of varying the quality of the metal (potassium) vapor. This combination is known as an "attemperator." The unit was designed, fabricated, and installed in the modified test loop. A second flowmeter was also installed to measure the flow rate to the attemperator. This is required for determination of the vapor quality entering the delay line oscillator. This method of quality determination assumes knowledge of the quality of the vapor delivered from the boiler. No mention, however, is made of this point.

The delay line oscillator was designed and fabricated. The delay lines are 5.74 in. The purchase of a dynamic pressure transducer for frequency measurement and recording had been under consideration. However, because of excessive cost, it was decided to modify an existing transducer. The unit chosen is of quartz and it is to be connected to the delay line oscillator with small diameter tubing. Provision is made to maintain the transducer under 500°F, which is its maximum operating temperature.

This reviewer feels that this is a well planned and executed effort for the development of an item of hardware for which there is a great need. However, for the worker involved with liquid metal technology who is not well versed in the principles upon which these devices operate, these reports are difficult to understand. Additional introductory material would be helpful.

(S. Kalish)

REVIEW NO. 472

BROOKHAVEN NATIONAL LABORATORY
NUCLEAR ENGINEERING DEPARTMENT ANNUAL REPORT

Sponsor: U. S. Atomic Energy Commission
Contractor: Associated Universities, Inc., Upton, N.Y.
Contract No.: AT-3-2GEN-16
Report No.: BNL 954 (S-68)
Report Date: December 31, 1965
Previous Reviews: 9,16,32,49,79,180,366

HEAT TRANSFER STUDIES

Boiling-K Heat Transfer Studies (p. 75)

Two series of experiments were carried out for the case of upward flow in an open round tube. The test conditions are given in the following table:

	<u>Series I</u>	<u>Series II</u>
Boiler diameter, in.	0.622	0.300
Mass flow velocity, lb/hr-ft ²	3 to 10 x 10 ⁵	4 to 8 x 10 ⁵
Vapor quality at test section, %	0.7 to 16.9	1.9 to 9.4
Max heat flux at test section, Btu/hr-ft ²	81,700	91,500
Boiling temperature, °F	1510 to 1650	1370 to 1515
Boiling pressure, psia	28 to 42	12.2 to 24.9

In the first series of experiments, 12 thermocouples were used to measure temperatures at various radial positions in the boiling test section wall, and three in-fluid thermocouples were located at the axis of the boiler to measure fluid

temperature. The use of all thermocouples at one axial position enabled the radial temperature profile to be determined with good precision. Results from the first series of tests indicated that for certain conditions of boiling two-phase flow the fluid core temperature was higher than the inside wall temperature. The measured single-phase Nusselt numbers were in good agreement with other recent data and theoretical predictions. The second series of experiments confirmed the results of the first. Apparently, for boiling two-phase flow of liquid metals, there can exist an inverse temperature profile in the fluid stream. (See Figure 2.) A theory has been proposed to explain this phenomenon, which indicates that while the effect may be negligible for ordinary fluids, it is important for liquid metals. (Please see next section.)

Analytical Study of Nonequilibrium Two-Phase Flow (p. 79)

This work was started to develop the theory of nonequilibrium two-phase flow, following the concepts introduced in the boiling potassium experimental program described above. The objective is to derive a theoretical expression for the inverse temperature profile in a two-phase liquid-metal stream by analyzing the process of simultaneous heat and mass transfer in the vapor core with axially varying saturation temperatures. In the first part of the project, the problem was limited to the case of uniform velocity in the core, uniform vaporization, and a step change in saturation temperature. Figure 3 shows some typical normalized temperature profiles in the vapor core, for the case of $u_o = 10$ ft/sec, $x/r_o = 100$, and four different values of β . It is seen that for the same entrance velocity, higher vaporization rates (higher β) lead to higher centerline temperatures at a given axial position. This is attributable to the increase in average local velocity with increased mass addition by vaporization. The meanings of the symbols are:

- u_o = entrance velocity of vapor, ft/sec
- x = axial distance from entrance, ft
- r_o = radius of vapor core, ft
- $\beta = C_p \rho v_w r_o / k$
- C_p = specific heat of vapor
- ρ = density of vapor
- k = thermal conductivity of vapor
- v_w = radial velocity of vapor at r_o

T = local vapor temperature at r and x
 $T_0 = T$ at $x = 0$
 T_s = saturation temperature at x, r_0

Analytical Study of Heat Transfer to Liquid Metals Flowing In-Line Through Unbaffled Rod Bundles (p. 77)

"The boundary conditions were uniform heat flux and fully developed velocity and temperature profiles. Rod spacing was equilateral triangular with pitch:diameter ratios ranging from 1.100 to 1.375.

"A typical set of results is given in the following table for the case of $P/D = 1.200$, $Pe = 100$, and $Pr = 0.00735$. In the table, t_w = wall surface temperature at angle θ , $t_{w,30}$ = wall surface temperature $\theta = 30^\circ$, $\bar{t}_w$ = average surface wall temperature, t_b = bulk temperature of flowing stream, and h = Btu/hr-ft².

θ , degrees around circumference of rod from point of closest proximity to the next rod	$(t_w - t_{w,30}) / (\bar{t}_w - t_b)$	Local h
0	0.481	16000
1.875	0.479	16100
5.625	0.461	16546
9.375	0.404	17650
13.125	0.285	19328
16.875	0.1757	21580
20.625	0.0869	23844
24.375	0.0343	25420
28.125	0.00202	26500
30	0.00000	26750

"At low P/D spacings, i.e., in the range investigated, it was found that the relative circumferential temperature variation is essentially independent of heat flux and Peclet number. It depends primarily on the P/D ratio.

"The circumferential variation in the local heat transfer coefficient is very dependent on the P/D ratio. At $P/D = 1.375$, the coefficients were found to vary by a factor of ≈ 1.2 , at 1.200 by ≈ 1.7 , and 1.100 by ≈ 100 . Below $P/D \approx 1.3$, the rod-average heat transfer coefficient drops increasingly fast as the P/D ratio approaches 1.000."

Analytical Study of Heat Transfer to Liquid Metals Flowing in Eccentric Annuli (p. 78)

"The boundary conditions for this study were (a) heat transfer from the inner wall only, (b) constant circumferential inner wall temperature at a given axial position, (c) for a given angle on the circumference of the inner wall the heat flux is uniform with length, and (d) the velocity and temperature profiles are fully developed. The results are summarized below where $R = r_2/r_1$, $e =$ eccentricity, $\bar{\psi} = (\epsilon_H/\epsilon_M)_{av}$, $Pe =$ Peclet number, $Nu = (hD_e)/k =$ Nusselt number, and $Nu_o =$ Nusselt number for concentric case."

R	e	$\bar{\psi}Pe$	Nu	Nu/Nu_o
1.5	0.15	368	6.89	0.895
		1700	11.43	0.950
	0.30	368	5.91	0.767
		1700	9.61	0.798
		8000	19.23	0.737
	0.50	368	4.58	0.596
		1700	7.27	0.604
	0.70	368	3.47	0.451
		1700	6.24	0.518
		8000	14.43	0.553
2.5	0.30	1700	11.25	0.818
	0.70		7.13	0.519
4.0	0.30	1700	13.45	0.851
	0.70		8.17	0.517

Analysis of Liquid Metal Heat Transfer in Tubes With Radiant Cooling (p. 79)

An analytical study was carried out to determine the heat transfer characteristics of liquid metals flowing through tubes which are radiantly cooled. This problem arises in nuclear power systems for space applications where the ultimate heat sink is a radiator. The wall heat flux is prescribed as being proportional to the fourth power of the local wall temperature. The results show that the local heat flux diminishes sharply in the initial length of a tube.

Heat Transfer to NaK in Cross Flow Through a Bundle of Circular Rods (p. 76)

"Local and rod-average heat transfer coefficients were determined for 90° cross flow of NaK through a 63-rod bundle ($\frac{1}{2}$ -in.-o.d. rods, 7 across and 9 deep). The rods were 7 in. long and spaced in an equilateral triangular array where the pitch:diameter ratio was 1.75. There were 8 instrumented test rods distributed throughout the bundle.

"Some typical results, for a rod in the interior of the bundle, are shown in Figure 4, where they are compared with the results of previous investigators. Curve A-A represents the results of Subbotin et al. (1) for Hg, where (a) only the test rod was heated, and (b) where the test rod and adjacent rods were heated. It was found that heating adjacent rods had a negligible effect on the average coefficient. Curve B-B represents the experimental results of Borishansky et al. (2) for Na, where the test rod and adjacent rods were heated. Curve C-C is based upon the experimental results of Rickard et al. (3) for Hg, where only the test rod was heated. Curve D-D represents the theoretical curve derived by Hsu (4).

"It is seen that at the lower Peclet range there is a distinct difference in the average heat transfer coefficient, depending on whether only the test rod is heated or whether all the rods are heated."

CORROSION STUDIES

The corrosion behavior of boiling Hg, boiling alkali metals, and a liquid Na-Li alloy are being studied in capsules, natural circulation loops, and forced circulation loops. Maximum temperatures of test for the various liquid metals are: Hg, 760°C; alkali metals, 1316°C; Na-Li, 650°C.

- (1) V.I.Subbotin, V.E.Minashin, and E.I.Deniskin. Teplofizika Vysokikh Temperatur 1, 238 (1963).
- (2) V.M.Borishansky, A.A.Andreevsky, and V.B.Zhinkina. Atomnaya Energiya 13, 269 (1962).
- (3) C.L.Rickard, O.F.Dwyer, and D.Dropkin. Trans. Am. Soc. Mech. Engr. 80, 646 (1958).
- (4) C.J.Hsu, Intern. J. Heat Mass Transfer 7, 431 (1964).

Mercury Studies

Materials studied in natural-convection boiling loops include Ta, Nb - 1 Zr, and 2½ Cr - 1 Mo steel. The corrosion-inhibition effects of small additions of Ti or Zr to Hg contained in 2½ Cr - 1 Mo steel systems were evaluated and found to substantially decrease boiler corrosion in 5000-hr long tests.

A Ta loop containing 190 g of Hg boiling at 640°C (500 psia) and vapor superheated to 745°C was shut down after 19,975 hr of operation. It was contained in a vacuum chamber held at 2×10^{-6} torr. Metallographic examination of the loop after test showed that the inside surface was similar to the "as-received" standard, having shallow grooves 15 μ in depth (maximum). Analysis of the Hg inventory of the loop showed 64 μ g Ta and 60 μ g Mg (13 mg Mg were added at the start of the test).

A Nb - 1 Zr loop containing Hg boiling at 760°C and vapor superheated to 870°C ruptured in a bend in the superheater region after 5712 hr of operation. After fabrication the entire loop had been annealed at 1200°C to remove all residual stresses. Metallographic examination showed intergranular corrosion in the failure area but no boiler or condenser attack occurred. A specimen from another bend in the superheater cracked when bent in a vise, whereas longitudinal specimens cut from the center of the superheater (not in a bend) and from the boiler inlet bent 180° without cracking. No deposition was found anywhere in this loop. These failures and earlier tests with Nb - 1 Zr bend specimens indicate that the alloy is susceptible to Hg stress corrosion cracking. The Hg vapor pressure of 1000 psia was equivalent to a hoop stress in the loop of ≈ 2500 psia. Experiments are in progress to determine the degree of susceptibility of Nb - Zr alloys to stress-corrosion cracking in Hg.

Three identical 2½ Cr - 1 Mo steel loops were operated with 593°C boiling Hg for about 5000 hr. The loops differed in that one contained Zr inhibitor, another Ti inhibitor, and the third was not inhibited. Metallographic examination of each loop is in progress. Preliminary results showed 20 to 25 μ intergranular corrosion in the boiler and condenser of the uninhibited loop but virtually no boiler corrosion was detectable in the Zr or Ti-inhibited loop. In addition, ≈ 1 g Fe deposit was found in the boiler and a ≈ 3 g Fe deposit in the condenser of the uninhibited loop. Very little Fe deposition was found in the loops containing Ti or Zr.

A pumped, boiling-Hg loop, fabricated of Nb - 1 Zr, is in preparation. Its specifications are:

Boiler temperature, 593°C
Superheater, 703°C
Condenser, 405°C
Flow rate, 91 kg/hr
Turbine blades, Ta - 9.5 W - 2.6 Hf alloy

The corrosion resistance of the blade materials will be determined at various vapor qualities and temperatures.

Alkali-Metal Studies

Studies are being carried out to evaluate refractory metals and alloys as container materials for liquid and boiling Na, Li, Cs, Rb, and K at temperatures up to 1315°C.

Nine Nb-base alloys were tested at 1266°C in boiling Na for 8000 hr. There was no corrosion detected in these capsules (7 of Nb - 1 Zr and 2 of Nb-W-Zr alloys).

The effect of oxygen contamination of Nb - 1 Zr was studied in six capsules containing purified Na operated at 1094°C for 10,000 hr. Metallographic examination showed 25 μ deep transgranular corrosion at the liquid-vapor interface of the four capsules in which the Nb - 1 Zr contained <1000 ppm oxygen. The two capsules in which the Nb - 1 Zr contained between 1000 and 2600 ppm oxygen underwent 100 μ deep, intergranular corrosion at the liquid-vapor interface. Deposits of ZrO₂ were found in all 6 capsules.

Metallographic examination of ten Nb - 1 Zr capsules containing Li, Na, K, Rb, or Cs at 1150°C showed no corrosion after 6000 hr.

Nickel leaching by K of several cermet tabs (K-601, K-801, K-151A, K-162B*) in Nb - 10 W - 1 Zr - 0.1 C capsules was observed after 322 hr at 1205°C. The test was shut down because of a rupture of a capsule. The refractory metal alloy was embrittled as a result of reaction with Ni.

*Kennametal Corp. designations.

Several high-strength alloys were tested as inserts and are now being tested as capsules. Results from the tab tests are given in Table 1. Materials and conditions for the capsule test are shown in Table 2. In addition, Li, Na, K, Rb, and Cs are being tested in Nb - 10 W - 1 Zr - 0.1 C capsules at 1205°C.

A Nb - 1 Zr, natural-convection loop was operated at 1095°C for 8007 hr without signs of corrosion.

Because of advantages gained by using Cs rather than Na as a working fluid, it was decided to modify a pumped, boiling Nb - 1Zr loop for Cs operation. Two parallel nozzle and blade simulator sections were fabricated. The blade materials are TZC and TZM. The operating conditions will be 895°C, 86% quality, and 780 ft/sec vapor velocity in the nozzle and blade sections.

A Na-Li alloy is of interest as a combined coolant-reactivity control fluid for fast reactors. In order to determine the relative corrosiveness of this alloy, Na-Li, Li and Na are being tested in types 321, 304, 316 and 410 stainless steel tilting capsules. The capsules have been in operation at a 650° - 500°C temperature differential for 4700 hr.

(O. E. Dwyer and A. Romano)

Figures 2, 3, and 4 in the Review correspond to Figures 26, 31, and 29, respectively, in the original report.

Tables 1 and 2 in the Review correspond to Tables 4 and 6, respectively, in the original report.

SEVENTH QUARTERLY REPORT
PRESSURE MEASURING SYSTEMS FOR
CLOSED CYCLE LIQUID METAL FACILITIES

Sponsor: National Aeronautics and Space Administration
Contractor: Consolidated Controls Corp., Bethel, Conn.
Contract No.: NAS 3-4170
Report No.: NASA CR-54899
Report By: Anthony J. Cassano
Report Date: January 25, 1966
Previous Reviews: 250,278,323,367,397,435

The purpose of this program is to develop pressure transducers which can be used in advanced power systems using liquid metals as the working and heat transfer media at elevated temperatures. It is planned that the absolute pressure instrument under development will operate at 1800°F with a full-scale range of 80 psia. The range for the differential instrument will be ± 5 psi.

During the report period, testing was done on transducer test units designated T-2, T-3, T-4, and T-5. Following bake-out in the vacuum test facility, units T-2 and T-3 underwent emitter activation. For T-2 the collector currents were found to be lower than expected. It is thought that this could be due to a deterioration of the emitter brought about by handling. When T-3 underwent emitter activation, a short circuit was found between the capsule and the emitter housing. The unit was disassembled, modified, and redesignated T-4. T-5 was identical to T-4, except that it had an FS-85 double convolution pressure capsule rather than a C-129Y pressure capsule (see Review No. 278 for alloy compositions). For T-4 the pressure output current curve is linear, although there is a strong dependence upon temperature. It was concluded that the temperature dependence is caused by thermal expansion effects leading to a variation in collector spacing. The data obtained from unit T-5 were erratic and were not presented. T-4 had been in operation for 1500 hr. The unit exhibited some loss in emission. The reason for this is being investigated.

Further work is reported on metal-ceramic seal development. The thermal cycling test was performed up to 1400°C on

a representative Nb - 1 Zr/Lucalox seal. Results provided further indication of the acceptability of the seal fabrication technique.

The transducer signal conditioning system was completed and is undergoing preliminary testing.

(S. Kalish)

REVIEW NO. 474

SODIUM MASS TRANSFER: VII
METHODS FOR DETERMINING IMPURITIES IN SODIUM SAMPLES

Sponsor: U. S. Atomic Energy Commission
Contractor: General Electric Vallecitos Atomic Laboratory,
San Jose, Calif.
Contract No.: AT(04-3)-189, PA 15
Report No.: GEAP-4178
Report By: W. W. Sabol and R. W. Lockhart
Report Date: September 1963
Previous Reviews: 75,100,162,187,188,192,219,251,252,253,
293,347,348,437,438,439,440

This report is a compilation and updating of analytical procedures, sampling methods, and special techniques (note report date of September 1963). They have been applied to sodium samples submitted for chemical analysis in connection with the sodium mass transfer program [USAEC Contract AT(04-3)-189, PA No. 15]. By application of these procedures, data have been generated to assist in the evaluation of mass transfer and corrosion mechanisms that are associated with loop operations described in GEAP-3725.

Wet chemical techniques were selected over emission spectrographic methods, on the basis of better sensitivity and accuracy. The table on the next page contains information pertinent to the analysis of a 40-g sample.

Sampling at 300°F into a thief-type sampler yielded mirror-bright sodium. The sampler consisted of a pre-evacuated

Pyrex glass tube with a bulb of about 50-cc capacity joined to a sealed capillary tube. The tube was preheated to 500°F and with a special holder pushed beneath the sodium surface, at which point the capillary tip was broken off and the sodium allowed to rise into the bulb. A portion of the sample was preserved for carbon analysis. A stock solution was made from the rest of the sample by an initial decomposition with methanol, followed by the addition of HCl and evaporation to dryness. The evaporation with HCl is repeated with a final dissolution in acidified H₂O.

Analysis of Elemental Impurities

<u>Element</u>	<u>Weight Na, g</u>	<u>Sensitivity, ppm</u>	<u>Typical assay, ppm</u>
Fe	2.0	0.06	2.0
Cr	2.0	0.04	1.0
Ni	2.0	0.13	2.0
Mn	4.0	0.16	1.5
Mo	2.0	0.30	0.5
Li	0.3	30	30
K	0.3	30	300
Cd	2.0	10	<15
C	10.0	5	35

Sodium was determined gravimetrically as NaCl. Spectrophotometric determinations were performed for Fe with o-phenanthroline, Cr with diphenylcarbazide, Ni with dimethylglyoxime, Mn as permanganate, and Mo as the thiocyanate complex. Li and K were determined by flame photometry, and Ca volumetrically with EDTA. An alternative method was also used for Ca based on the spectrophotometric measurement of naphthalhydroxamate which is released upon the dissolution of the Ca complex in EDTA. C was determined by dissolving the sodium in H₂O followed by oxidation to CO₂ with Van Slyke reagent. The CO₂ was finally measured by gas chromatography.

Radioactive coupons were nondestructively analyzed for Cr⁵¹, Fe⁵⁹, and Co⁶⁰. Upon dissolution of the coupons they employed conventional ion exchange was employed, and radiochemical separations for the determination of Cr⁵¹, Mn⁵⁴, Co⁶⁰, and Fe⁵⁹.

Samples of metal coupons, screens, and filters were inserted into the loop to study metal transport behavior and to

collect solid deposits. Liquid ammonia was selected to dissolve the sodium from the sample, in the hope that metallic oxides and other chemical forms would remain on the sample.

(L. Newman)

REVIEW NO. 475

SODIUM MASS TRANSFER: XVII
THE DETERMINATION OF HYDROGEN
IN LOOP SODIUM AND COVER GASES

Sponsor: U. S. Atomic Energy Commission
Contractor: General Electric Vallecitos Atomic Laboratory,
San Jose, Calif.
Contract No.: AT(04-3)-189, PA 15
Report No.: GEAP-4833
Report By: D. Dutina and J. L. Simpson
Report Date: June 1965
Previous Reviews: 75,100,162,187,188,192,219,251,252,253,293,
347,348,437,438,439,440,474

A modified version of the diffusion gasometric technique has been set up for the measurement of hydrogen in sodium sampled from the mass transfer loops. A major innovation has been the use of gas chromatography, a specific method for the determination of hydrogen in place of the nonspecific manometric techniques used previously. The sensitivity of the technique is about 1 ppm when a 5-g sample of sodium is used, and the precision at this level is $\approx \pm 0.7$ ppm.

The method has been applied to the analysis of sodium sampled from the mass transfer loops. Hydrogen was found in the loop sodium in concentrations of about 5 ppm, but no correlation was found with the multi-break phenomena observed in plugging indicator runs performed on the loops.

The method of sampling and analyzing the argon cover gas for impurities is presented. Hydrogen, nitrogen, and an occasional trace of carbon-containing gases have been found.

Additional work is required to define the means by which the atmospheric contaminants are introduced and to eliminate them. There is also need for improving the sensitivity for the determination of the volatile carbon species.

(L. Newman)

REVIEW NO. 476

TWO-STAGE POTASSIUM TEST TURBINE

Sponsor: National Aeronautics and Space Administration
Contractor: General Electric, Missile & Space Division,
Cincinnati, Ohio
Contract No.: NAS 5-1143
Report No.: NASA-CR-54643
Report By: Edited by E. Schnetzer
Report Period: February 8, 1965 through May 8, 1965
Previous Reviews: 11,26,72,159,189,190,220,
222,256,325,368,436

The test turbine consists of stages three and four of a five-stage 500-kW turbine. During the report period, the turbine overhaul and facility modifications, begun during the last period, were completed. Calibration tests of both the Bullet Nose Annulus flowmeter and the tare testing apparatus were conducted, followed by a performance run of the test turbine on potassium vapor at 1450°F. Termination of the performance run became necessary after 18.8 hr of operation, when an excessive rise in the bearing housing temperatures was noted. The bearing housing was disassembled and repaired.

Disassembly and inspection of the bearing housing after test revealed a leak in the hydrodynamic seal of the potassium supply tube, permitting flooding of the closed tube cavity of the bearing housing with potassium, and resulting in an increased conduction heat flow path to the bearing housing. Modifications of this tube run, as well as various argon supply tube runs which were found to be leaking, were made to provide greater tube flexibility under the effects of thermal expansion.

Compilations and analysis of the data collected during the performance run, as well as data collected during the calibration test runs, are included in the report.

(P. Bezler)

REVIEW NO. 477

SODIUM MASS TRANSFER: XIX
LONG-TERM EXPOSURE EFFECTS IN A BIMETALLIC
316 SS - 2½ Cr TEST LOOP

Sponsor: U. S. Atomic Energy Commission
Contractor: General Electric Co., APED, San Jose, Calif.
Contract No.: AT(04-3)-189
Report No.: GEAP-4835
Report By: M. C. Rowland, D. E. Plumlee, L. E. Pohl,
and R. W. Lockhart
Report Date: April 1965
Previous Reviews: 11,26,72,159,189,190,220,
222,256,325,368,436,476

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

This report presents details of the operational variables and results of sample analysis for two runs of Loop #2 which had the hot leg of the loop built of type 316 SS and the cold leg of 2½ Cr - 1 Mo steel.

Test conditions for the two runs reported were:

Run No.	T max, °F	ΔT, °F	Flow, gpm	Oxygen level, ppm	Length of run, hr
2-5	1210	510	0.69	11	19,792
2-6	1213	511	0.69	11	1,400

Operational conditions reported include temperature, flow rates, impurity and corrosion product analysis, and a complete

log of the run. Sample analyses consist of weight change data, metallography, surface composition changes, and carbon movement.

The behavior of materials in these two runs was similar to that observed previously, i.e., selective transport of Cr and Ni and normal carburization-decarburization reactions between the hot and cold legs of the loop. The rapid initial corrosion rate (steady-state rate reached after ≈ 1400 hr) and linearity of the steady-state corrosion rate observed in previous test runs were verified. Also, the validity of an empirical model which was obtained from previous weight change data was checked by the long-term data obtained from Run 2-5 (20,000 hr).

(C. Klamut)

REVIEW NO. 478

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,
Ohio 45215
Contract No.: NAS 3-2528
Report No.: NASA-CR-54890
Report By: Edited by D. R. Ferguson and F. E. Tippets
Report Period: July 1, 1965 through September 30, 1965
Report Date: October 1965
Previous Reviews: 3,27,158,221,254,255,291,
292,324,345,398,418

Work on this program is distributed among three forced-convection liquid-metal loops, as discussed below.

300-kW Project

All data obtained with the 300-kW loop have been reduced and reported in previous progress reports. Analysis and treatment of these data are reported to be nearly finished. In this report the authors present the following empirical

correlation for critical heat flux values obtained from the 300-kW loop data.

$$q_c = 10^6 \frac{(1 + a_R)^{\frac{1}{4}}}{1 + 2\left(\frac{x_c}{1-x_c}\right)} \text{ Btu/(hr-ft}^2\text{)},$$

where x_c = quality at the critical heat flux point, and a_R = radial acceleration developed by inserts expressed in g's. Approximately two-thirds of the data were correlated within $\pm 30\%$ by this empirical equation.

100-kW Project

This report presents some boiling heat transfer coefficients reduced from data taken on a 3/4-in.-diam boiler with helical insert. The reported local heat transfer coefficients are of the order of 3000 to 8000 Btu/hr/ft²/°F, and show very little variation with vapor quality in the range 10 to 85%. An anomaly was found in that these heat transfer coefficients taken with helical inserts are lower than corresponding data taken in a plain tube with no insert.

50-kW Project

All condensing test data obtained with this facility have been reduced and reported. An analysis was presented which attempts to correct the condensing heat transfer coefficients by taking into account the radial pressure gradient generated by the helical insert. The authors report that this correction brings the helical flow data into agreement with results of linear flow measurements. A comparison is also presented of measured and estimated potassium fluid temperatures along the length of the condenser. Some results are reproduced here in Figure 5 which shows the experimental curve, a curve calculated from an analytical model, and an assumed linear profile. Substantial deviations between experimental values and the assumed linear profile are evident.

(J. C. Chen)

Figure 5 in the Review corresponds to Figure 19A in the original report.

ANNUAL TECHNICAL REPORT
HIGH ACCELERATION FIELD HEAT TRANSFER
FOR AUXILIARY SPACE NUCLEAR POWER SYSTEMS

Sponsor: U. S. Atomic Energy Commission
Contractor: Geoscience Limited, Solana Beach, Calif.
Contract No.: AT(04-3)-409
Report No.: GLR-41 and SAN-409-28
Report By: H. F. Poppendiek, N. D. Greene, C. M. Sabin,
L. V. Feigenbutz, G. Mouritzen, P. E. Schwartz,
D. J. Connelly, and W. A. Morton
Report Period: September 1, 1964 through August 31, 1965
Previous Reviews: 8,23,165,166,225,258,326,349,369,399

Some of the work presented here has been published previously in topical and quarterly reports (see reviews listed above).

Forced-Flow Boiling

Analyses are presented on (1) forced-flow boiling heat transfer in tubes with liquid layers at the walls, (2) fog-flow heat transfer in tubes, (3) single-phase heat transfer for helical flow in tubes, (4) momentum transfer in tubes with twisted dividers, and (5) slug flow normalization for helical flow.

Experimentally, heat transfer measurements were made for forced-convection boiling of potassium. A schematic of the loop is reproduced here in Figure 6. The test boiler is a 7-ft-long straight section of Haynes 25 alloy tubing containing a tantalum twisted divider with a pitch-to-diameter ratio of 4.4. Tube diameter is not given in the report but from a photograph it would appear to be of the order of $\frac{1}{4}$ in. Direct joule heating of the tube wall is utilized, and temperature measurements are made by means of thermocouples attached to the o.d. of the boiler tube. Twelve boiling runs were completed at qualities up to 100% vapor and with superheat, and heat fluxes of 8000 to 16,000 Btu/hr-ft². Boiling heat transfer coefficients reduced from the data are reproduced here in Figure 7. The authors point out in their discussion that such forced-convection boiling phenomena are not easily correlated. One reason for this difficulty, as proposed by

the authors, is that forced-convection boiling is essentially an entrance region process, in which local processes depend upon the upstream conditions as well as local conditions. However, the authors feel that the analytical models proposed in this report can be used as bounds for most of the important processes found in a boiler.

Droplet Vaporization

An induction heated apparatus was used to obtain over 100 vaporization lifetime measurements for potassium on a variety of surfaces. A cylindrical billet of the test surface material was mounted in a stainless steel chamber, and heated by water-cooled induction coils. During the experiments, approximately atmospheric pressure within the container was maintained with argon. Lifetime measurements were made by visual observation of the droplet size as a function of time. From the observations the authors feel that four distinct regimes of behavior can be identified. Type 1 behavior is characterized by high-frequency, low-displacement oscillation in the shape of the potassium droplet; Type 2, by high-frequency vertical oscillation of the droplet with a displacement of about five diameters; Type 3, by a very high elevation oscillation, as much as $\frac{1}{2}$ in. This behavior occurs most often with drops which are $< 1/16$ in. in diameter. Type 4 behavior is characterized by a shiny oblate floating quietly on a layer of vapor.

Liquid Metal Condensation

The authors present an analysis for heat transfer during liquid metal condensation on a vertical wall. Their postulate is that the difference that had been observed between measured and theoretical condensing coefficients for liquid metals can be explained by an interface resistance between the solid wall and the liquid condensate film. Most other workers in the field have sought the explanation for this difference in either interfacial resistance between vapor and condensate film or in the mass transfer resistance of the vapor phase. The present authors conclude that in terms of their postulate a liquid/solid contact resistance of the magnitude of 10^{-3} to 10^{-4} hr/ft²/°F/Btu would be required to bring measured coefficients into agreement with theoretical

values. Contact resistances of this magnitude could occur with one-tenth of a mil of gas film or several tenths of a mil of corrosion product layer.

(J. C. Chen)

Figures 6 and 7 in the Review correspond to Figures 2-13 and 2-20, respectively, in the original report.

REVIEW NO. 480

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-3482-MS
Report Date: February 1966; for period ending January 31, 1966
Previous Reviews: 2,15,20,99,155,156,201,262
279,305,327,372,400,441

Control of Fission Products in Molten Sodium (p. 38)

A method is being sought for the continuous removal of fission products from a Na coolant stream, and attention has been focused on Cs¹³⁷. In static tests, granular graphite, Ni mesh, and stainless steel mesh have been evaluated as getters. Graphite is an irreversible getter. It becomes effective at about 200°C, with the rate of reaction increasing rapidly with increase in temperature. The Ni screen is most effective at 150°C with gradual release of activity as the temperature is further increased. The stainless steel screen is most effective at 250°C. The adsorption of Cs¹³⁷ on both the Ni and stainless steel is very reversible, making it quite possible to base a gettering process upon them.

Variation of Plugging Temperature With Cooling Rate (p. 39)

Preliminary results indicate that at a constant oxygen

concentration, the plugging temperature will vary depending upon the rate at which the Na is cooled -- the greater the rate, the lower the plugging temperature. No numbers were given.

Determination of Trace Amounts of Oxygen in Sodium (p. 40)

A method for determining 1 to 10 ppm to a precision of ± 0.5 ppm has been developed. It is based on the quantitative separation of metallic Na from O-containing impurities by vacuum distillation. The nonvolatile residue is dissolved in dilute HCl and analyzed with a flame spectrophotometer for Na. By assuming that the distillation residue is Na_2O , an indirect determination can be made of the O concentration. To estimate the reliability of the procedure, samples were prepared by adding controlled quantities of O, as H_2O , to Na metal. Analysis of these samples showed that recovery of added O was quantitative.

Comparison of Methods of Measuring Oxygen in Sodium (p. 40)

"A Blake resistivity meter, two United Nuclear O meters, and a vacuum distillation Na sampler were installed on a forced-convection, cold-trapped Na loop. The resistivity meter was installed in the main flow circuit where it received 8 gpm, and the O meters and the distillation sampler were installed on a bypass line which received 1 gpm Na flow. Results obtained by the distillation technique described above were taken as standard, and the other instruments were calibrated with respect to them for the O concentrations in the test loop ranging from 2 to 30 ppm.

"The equation

$$E = 1.047 - 0.0274 \ln C$$

describes the calibration curve for O meter TP-20, and

$$E = 1.094 - 0.0332 \ln C$$

for meter TP-22; where E = meter emf in volts, and C = O concentration in ppm. At any given emf, the O concentration was subject to an error of $\pm 30\%$.

"The calibration of the resistivity meter indicated that the response was 0.0058% change in resistivity per ppm change in O concentration. The resistivity meter readings were subject to an error of $\approx \pm 2.5$ ppm O."

(O. E. Dwyer)

REVIEW NO. 481

VAPOR-CHAMBER FIN STUDIES

Sponsor: National Aeronautics and Space Administration
Contractor: Pratt & Whitney Aircraft, East Hartford, Conn.
Contract No.: NAS3-7622
Report No.: NASA CR-54882, PWA-2698
Report Period: May 28 to August 28, 1965
Report Date: September 1965
Report By: L. Langston and H. R. Kunz
Previous Reviews: none

This study involves the application of a heat pipe to the radiator of a Rankine-cycle space power plant. The heat pipe would be, effectively, a high conductivity fin and is referred to as a "vapor-chamber fin." The fin is in the form of a long, closed container in which vaporization and condensation of a fluid takes place. The vaporizing fluid transports heat from the heated end of the fin to outer surfaces of the fin where it condenses, resulting in a nearly constant surface temperature container. The condensate is returned to the heated surface by capillary action in a wick lining on the inside of the container.

This report includes the derivation of a model and a simplified analysis of fin operation.

The two key factors in the operation of the fin seem to be the heat flux at which apparent film boiling occurs in the wick at the evaporator section and the maximum liquid flow rate that the capillary pump (wick) can provide to the evaporator section.

An experimental program to obtain data on the permeability, capillary rise, and boiling in wicks is outlined in great detail. Metal screens, fibrous structures and sintered materials will be considered. Various fluids are also evaluated and water appears to be the preferred test fluid.

Permeability will be determined by measuring the pressure drop as a function of liquid flow rate through the wick specimens. Capillary rise will be evaluated by measuring the maximum static height that a liquid will rise in a wick. Boiling tests will determine the maximum heat flux that can be applied to liquid-filled wicks before film boiling is observed. The boiling test apparatus is designed for heat fluxes as high as 500,000 Btu/hr-ft². A detailed description of the apparatus to be used in each of these tests is contained in the report.

(K. C. Hoffman)

REVIEW NO. 482

SOLUBILITY OF REFRACTORY METALS
IN LITHIUM AND POTASSIUM

Sponsor: U. S. Atomic Energy Commission

Contractor: Pratt & Whitney Aircraft, Division of United Aircraft Corporation, Middletown, Conn.

Contract No.: AT(30-1)-2789

Report No.: TIM-850

Report By: R. E. Cleary, S. S. Blecherman, and J. E. Corliss

Report Date: October 1965

Previous Reviews: 14,48,62,458,459,461

The solubilities of Mo and Cb were determined in Li to 1320°C and in K to 1205°C by using an inverted capsule technique. The solubility of Mo in purified Li and K is <1 ppm at temperatures up to 1320° and 1205°C, respectively; a preliminary test showed that 5.4 ppm Mo is soluble in Li at 1540°C. Additions of O and N to Li have no effect on the Mo solubility. The solubility of Mo in K increases with the O content of the K; this increase is the same when O is added as KO₂, K₂CO₃, or KNO₃. The O/Mo atomic ratio in the K decreases with increasing

O content from ≈ 10 at 500 ppm O to ≈ 4 at 1.0% O. A crystalline product was isolated from the K-O-Mo system and identified as K_2MoO_4 .

Data on the Cb solubilities scatter more widely than those on the Mo solubilities. The Cb-Li results show no reproducible trend with O or N in the Li; they can be approximated by the equation $\log_{10}(\text{at. \% Cb}) = 4.77 - 1094/T (^{\circ}K)$, although the data scatter about the line of this equation by approximately a factor of ± 4 to 5. The solubility of Cb in K appears to have little identifiable dependence upon T or O additions up to 3000 ppm as KO_2 , K_2CO_3 , or KNO_3 . The addition of 5000 ppm O as KO_2 , however, greatly increases the apparent solubility of Cb in K.

Studies of the solubility of Zr in Li suggested that some volatile form of Zr was deposited on the upper receiver cup, but the program was terminated before the phenomenon could be investigated.

Detailed specifications are listed for the metals and inert gases, and the analytical procedures are described in detail.

(J. R. Weeks).

REVIEW NO. 483

PERFORMANCE EVALUATION OF HEAT
EXCHANGERS FOR SODIUM-COOLED REACTORS

Sponsor: U. S. Atomic Energy Commission
Contractor: United Nuclear Corp., White Plains, N.Y.
Contract No.: AT(11-1)-1452
Report No.: UNC-5142
Report Period: October 1, 1965 through December 31, 1965
Report Date: January 20, 1966
Report By: R. H. Dischinger
Previous Reviews: 462

United Nuclear Corp. has contracted to perform the thermal-hydraulic and structural performance evaluation of 30-MW(t) model heat exchangers that are to be tested in the Sodium Components Test Installation (SCTI). An intermediate Na-to-Na heat exchanger designed and manufactured by ALCO Products, Inc., and a steam generator designed by ALCO and manufactured by Baldwin-Lima-Hamilton (BLH), are installed in the system and will be the first units tested. Future tests of steam generators built by Atomics International (AI) and Babcock & Wilcox (B&W) are planned.

Test data will be furnished to United Nuclear Corp. for processing and analysis. The observed performance will be compared with predictions.

During this report period, procedures were developed for structural evaluation of the tubesheet regions, sine-wave tubes, and the shell and barrel discontinuities on the ALCO/BLH units. These procedures were applied to an analysis of the design and, in general, the agreement was very good. The techniques and assumptions made by ALCO were refined in many areas. The results of this analysis for assumed pressure conditions and thermal gradients are presented.

A preliminary review of the AI and B&W steam generators was started.

(K. C. Hoffman)

REVIEW NO. 484

ULTRASONIC-INDUCED CAVITATION
STUDIES IN MERCURY AND WATER

Sponsor: National Science Foundation
Contractor: University of Michigan, Ann Arbor, Mich.
Contract No.: Grant G-22529
Report No.: 05031-3-T
Report Date: December 1965
Report By: R. Garcia, R. E. Nystrom, and F. G. Hammitt
Previous Reviews: 43,44,71,135,136,177,178,218,231,232,
272,308,309,310,356,357,385,386,387,407,
408,444,445

Ultrasonic-induced cavitation studies have been conducted in mercury at 70° and 500°F and in water at 70°F on a variety of materials including refractory alloys, steels, brasses, and coppers. The test specimens are oscillated by a pair of lead-zirconate-titanate piezoelectric crystals at 20 kc/sec with a double amplitude of 2 mils. In mercury at 500°F, T-111 and T-222 tantalum alloys were most resistant to cavitation, followed by carbon steel, stainless steel, Mo - 0.5 Ti, and Cb - 1 Zr in that order. At 70°F, the stainless steels were most resistant, followed by the tantalum alloys, Mo - 0.5 Ti and Cb - 1 Zr.

No single material property can be used to correlate the data and no single correlating equation can be applied.

Damage rates in the vibratory test exceed the cavitating venturi data by a factor of about 10^3 . In the vibratory tests, the damage rates in mercury at 70°F range from 3 to 20 times those obtained in water.

(K. C. Hoffman)

REVIEW NO. 485

SNAP-50/SPUR GENERATOR
DEVELOPMENT PROGRAM

Sponsor: U. S. Air Force, Wright Patterson AFB, Ohio
Contractor: Westinghouse Aerospace Electrical Div., Lima,
Ohio
Contract No.: AF 33(615)-2326
Report No.: WAED 66.01E
Report By: Aerospace Electrical Div. and approved by
R. W. Briggs and N. W. Bucci
Report Date: January 15, 1966
Previous Reviews: 111,388,426,447

The objective of this program is to continue the study, experimental, and development programs for the SNAP-50/SPUR ac generator and its controls.

The following is a summary of progress in each of the major development tasks:

1. Bore seal development. The problem in this area is to develop a reliable joint between the ceramic tube and the nonrefractory metal frame structure. As a result of difficulties encountered in producing a vacuum-tight brazed joint directly between the ceramic and nonrefractory metal, a decision was made to use a refractory metal as the transition material and join it to both the ceramic and nonrefractory frame structure. Satisfactory joints were obtained between alumina and Cb - 1 Zr using a zirconium base braze, Zr - 19 Cb - 6 Be. A sample of each of the test assemblies with both refractory and nonrefractory metal components was given a thermal cycle test before being loaded with potassium. Two cycles between room temperature and 1100°F were made without any damage to the assemblies.

2. Stator development. Fabrication of the dummy stator has progressed to insertion of stator coils.

The dummy field coil was completed. Mechanical failure of 0.031-in.-i.d. glass-fiber sleeving necessitated the use of glass-cloth tape for insulating thermocouples. While this material is satisfactory for completing the fabrication, it will not meet the lifetime requirements for a complete generator. Various alternative materials are being evaluated. The assembly of the lamination stack is discussed in the report.

Two test statorettes are undergoing thermal aging tests in vacuum and argon at 600°F.

3. Rotor development. Four creep specimens made from premium-quality H-11 alloy steel rotor material are continuing 10,000-hr tests. At 7601 hr, one specimen has undergone a 0.210% elongation under a stress of 130,000 psi at 600°F. Another specimen has shown a 0.187% elongation after 7000 hr under a stress of 8000 psi at 960°F.

Creep tests of 2500-hr duration have been completed on two potassium loaded specimens. One had an elongation of 0.0226% under a stress of 75,000 psi at 625°F, and the other an elongation of 0.1299% under a stress of 50,000 psi at 900°F.

Rotational tests were conducted at speeds up to 16,000 rpm to verify performance of the generator fluid components. An antifriction thrust bearing failed, and the test was terminated. Modifications are being made for operation up to 24,000 rpm. A very detailed description of the rotor cavity scavenge system, the molecular pumps for maintaining low cavity pressure, the rotor coolant system, and the liquid shaft seals is contained in the report.

4. Full-scale generator. Design revisions were made to accommodate the new bore seal joint design discussed above. Rough machining was completed on most of the major parts.

(K. C. Hoffman)

Figure 1. The change in hardness as a function of 1-hr anneals for V - 15 w/o Ti - 7.5 w/o Cr and V 15 w/o Ti - 5 w/o Cr

Review No. 468

Figure 2. Temperature profiles in boiling two-phase flow.

Review No. 472

Figure 3. Temperature profiles in nonequilibrium vapor core.

Review No. 472

Figure 4. Average Nusselt number for cross flow of NaK through a staggered rod bundle. A-A, Subbotin et al., ref. 1; B-B Borishansky et al., ref. 2; C-C, Rickard et al., ref. 3; D-D, Hsu, ref. 4.

Review No. 472

Figure 5. Comparison of Calculated and Experimental Dimensionless Temperature Distributions At 1100°F Inlet Temperature For Test Section No. 5, 50 KW Facility

Figure 6. Forced convection potassium boiling system:
Primary flow circuit and instrumentation.

Review No. 479

Figure 7. Measured potassium boiling heat transfer conductances for constant heat flux boundary condition.

Review No. 479

Table I

Results of Corrosion Test of High-Strength Alloy Inserts
in D-43 Capsules Containing Refluxing Na for 3000 hr at 1315°C

T, °C	Capsule No.	Material designation	Material composition, wt %	Corrosion results
1315	63	D-43	Cb-10 W-1 Zr-0.1 C	None
	64	TZM	Mo-0.5 Ti-0.06 Zr	None
	65	FS-85	Cb-28 Ta-10 W-1 Zr	Microcracks
	66	Ta-W	Ta-10 W	None
	67	T 111	Ta-8 W-2 Hf	Several pits

All capsules were heat-treated at 2200°F for 1 hr before being filled with Na

Review No. 472

Table II

Capsule Test No. 6, Alloys Tested in Refluxing Na ($T=1315^{\circ}\text{C}$)

Capsule No.	Material designation	Material composition, wt %	Material tested as
56	FS-85	Cb-28 Ta-10 W-1 Zr	Seam-weld tubing
57	T-111	Ta-8 W-2 Hf	Seamless tubing
58	D-43	Cb-10 W-1 Zr-0.1 C	Seamless tubing
59	X-34	Cb-5 W-3.5 Zr-0.1 C	Drilled rod
60	TZM	Mo-0.5 Ti-0.06 Zr	Drilled rod

Review No. 472

APPENDIX A

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

Aerojet-General Corporation 82,94,143,144,212,213,214,229, 275,299,335,358,359,389,410,448, 464	Atomic Power Development Assoc., Inc. 36,65,106,133,172,211,238,239, 247,276,320,321,322,340,364,393, 394,416,432,433,470
Aeroprojects, Inc. 465	Atomics International 33,92,301,341,365,395,431
Air Force Aero Propulsion Laboratory (Wright Patterson AFB) 300	The Babcock & Wilcox Co. 56,61,115,116,123,124,163,194, 195,237,248,249,277,302,342, 417,453, 454
AiResearch Mfg. Company (A Division of Garrett Corp.) 12,64,88,102,103,150,151,152,173, 243,312,313,336,360,361,390,411, 412,449,450,466,467	Baldwin-Lima-Hamilton Corp. 57,122,147,174,208
Allegany Ballistics Lab., Her- cules Powder Co. 259	Battelle Memorial Institute 37,93,125,126,127,128,129,130, 131,197,198,199,343,396,434
Allison Division, General Motors Corp. 96,145	Bendix Corp. 471
Ames Laboratory 314,315,316	Brookhaven National Laboratory 9,16,32,49,79,180,366,472
Argonne National Laboratory 29,30,41,42,66,67,83,117,118, 141,142,168,169,170,202,203, 240,241,244,245,246,289,296, 297,317,318,319,337,338,339, 362,363,391,392,413,414,415, 427,428,429,430,451,452,468, 469	Columbia University 73,344
	Consolidated Controls Corp. 250,278,323,367,397,435,473
	Electro-Optical Systems, Inc. 1,85
	Fairchild Stratos Corp., Stratos Div. 167

General Electric Company

3,11,22,26,27,50,51,52,72,73,
74,75,98,100,101,158,159,160,
161,162,187,188,189,190,191,
192,219,220,221,222,223,224,
233,234,235,251,252,253,254,
255,256,257,291,292,293,294,
295,303,304,324,325,345,346
347,348,368,398,418,436,437,
438,439,474,475,476,477,478

Geoscience Ltd.

8,23,165,166,225,258,326,349,
369,399,479

Hydronautics Inc.

107,132,164,260,370,419

Jet Propulsion Laboratory

80,97

Los Alamos Scientific Laboratory

2,15,20,99,155,156,201,262,279,
305,327,372,400,441,480

Massachusetts Institute of Technology

6,25,39,40,86,119,171,228,263,328

Mechanical Technology Inc.

329,373,374,401

MSA Research Corporation

21,53,54,55,68,69,81,89,109,110,
153,154,184,185,186,204,205,206,
207,227,264,265,266,267,280,281,
282,283,306,330,331,332,350,351,
375,376,402,403,420,421,422,455,
456,457

NASA-Lewis Research Center

17,60,84,157,261,371

Oak Ridge National Laboratory

58,90,91,95,284,298,377,378,384,
423

Pratt & Whitney Aircraft

14,28,47,48,62,148,149,175,285,
286,333,352,379,380,405,406,
458,459,460,461,481,482

Rocketdyne (A Division of North
American Aviation)

7,24,59,76,196,236,270,353,381

San Fernando Laboratory

382,422

Southwest Research Institute

38,271,307,334,383,424,443

Sundstrand Aviation

34,63,108,134,193,242,287

Tapco (A Division of Thompson
Ramo Wooldridge)

5,121

Thermo Electron Engineering Corp.
181

Thompson Ramo Wooldridge, Inc.
4,13

United Nuclear
78,290,462,483

U.S. Naval Research Laboratory
35,104,105,226,268,269,354,
463

University of Michigan

18,19,31,43,44,45,46,70,71,
87,120,135,136,146,176,177,
178,179,215,216,217,218,230,
231,232,272,288,308,309,310,
355,356,357,384,385,386,387,
407,408,409,425,444,445,484

University of Washington
200

Westinghouse Electric Corp.
10,111,112,113,114,137,138,
139,140,182,183,209,210,273,
274,311,388,426,446,447,485