355
9-27-66

MASTER

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 3 • JUNE 1966

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.

under contract with the
UNITED STATES ATOMIC ENERGY COMMISSION

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

CFSTI, PRICES

H.C. \$ 2.00; MN .50

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 3 • JUNE 1966

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

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

August 1966

650 copies

HIGH-TEMPERATURE LIQUID-METAL TECHNOLOGY REVIEW

SUBJECT INDEX

(Arabic numerals used below refer to Review numbers)

- I. Physical Properties and Thermodynamics
486
- II. Fluid Dynamics
488, 489
- III. Heat Transfer
488, 489, 490, 491, 493, 503
- IV. Materials Development and Corrosion
488, 490, 491, 493, 494, 496, 501, 502, 504, 506, 508
- V. Instrumentation
487, 489, 491, 494, 495, 505
- VI. Component Development
488, 492, 493, 494, 497, 498, 503, 507
- VII. Systems Studies
492
- VIII. Chemistry and Chemical Analysis
490, 493, 499, 500, 505
- IX. Fabrication Techniques
494
- X. Safety
492, 493

**THIS PAGE
WAS INTENTIONALLY
LEFT BLANK**

TABLE OF CONTENTS

Review No.	Title	Page
486	ALKALI METALS EVALUATION PROGRAM, Aerojet-General Nucleonics, San Ramon, Calif., AGN-8177, Oct. 1 through Dec. 31, 1965	93
487	APPLICATIONS OF ULTRASONIC ENERGY: ULTRASONIC INSTRUMENTATION FOR NUCLEAR APPLICATIONS, Aero-projects Incorporated, West Chester, Penna., NYO-3622-2 and NYO-3622-3, April and June 1966	94
488	QUARTERLY TECHNICAL PROGRESS REPORT SNAP 50/SPUR CONTRACT, AiResearch Mfg. Co., Phoenix, Arizona, APS-5152-R6, April 18, 1966	96
489	PROCEEDINGS OF THE CONFERENCE ON APPLICATION OF HIGH TEMPERATURE INSTRUMENTATION TO LIQUID-METAL EXPERIMENTS, ANL-7100, Sept. 1965	99
490	ARGONNE NATIONAL LABORATORY REACTOR DEVELOPMENT PROGRAM PROGRESS REPORT, Argonne National Laboratory, Argonne, Ill., ANL-7204, April 1966	101
491	ARGONNE NATIONAL LABORATORY REACTOR DEVELOPMENT PROGRAM PROGRESS REPORT, Argonne National Laboratory, Argonne, Ill., ANL-7219, May 1966	104
492	SGR DEVELOPMENT PROGRAM QUARTERLY PROGRESS REPORT, Atomics International, AI-66-1, January 1966	106
493	QUARTERLY TECHNICAL PROGRESS REPORT AEC UNCLASSIFIED PROGRAMS, Atomics International, NAA-SR-11900, June 1966	107
494	SODIUM-HEATED STEAM GENERATOR DEVELOPMENT, The Babcock & Wilcox Co., BAW-1280-34, BAW-1280-36, Jan. 15 and April 8, 1966	111
495	PRESSURE MEASURING SYSTEMS FOR CLOSED CYCLE LIQUID METAL FACILITIES, Consolidated Controls Corp., Bethel, Conn., NASA CR-54960, April 8, 1966	113

TABLE OF CONTENTS

Review No.	Title	Page
496	SODIUM MASS TRANSFER: XXI, 1964 TEST RUN REPORTS, General Electric Co., San Jose, Calif., GEAP-4837, October 1965	113
497	TWO-STAGE POTASSIUM TEST TURBINE, General Electric, Cincinnati, Ohio, NASA-CR-54897, November 24, 1965	115
498	TWO-STAGE POTASSIUM TEST TURBINE, General Electric, Cincinnati, Ohio, NASA-CR-54917, January 10, 1966	116
499	REPORT ON ADVANCED REACTOR TECHNOLOGY (ART), Los Alamos Scientific Laboratory, Los Alamos, New Mexico, LA-3524-MS, Quarter ending April 30, 1966	117
500	DEVELOPMENT OF TECHNIQUES FOR MEASUREMENT OF IMPURITIES IN SODIUM, MSA Research Corp., Evans City, Penna., MSAR 66-72, April 25, 1966	119
501	EFFECT OF HIGH TEMPERATURE SODIUM ON AUSTENITIC AND FERRITIC STEELS, MSA Research Corp., Evans City, Penna., 66-71, April 25, 1966	120
502	ACCELERATED CAVITATION DAMAGE OF STEELS AND SUPER-ALLOYS IN LIQUID METALS, NASA, Lewis Research Center, Cleveland, Ohio, NASA-TN-D 3426, May 1966	122
503	SECOND QUARTERLY REPORT VAPOR-CHAMBER FIN STUDIES, Pratt & Whitney Aircraft, East Hartford, Conn., PWA-2773 and NASA CR-54922, January 1966	123
504	RESEARCH ON GAS PLATED REFRACTORY METAL COATINGS FOR LIQUID METAL COMPATIBILITY INVESTIGATION, San Fernando Laboratories, Pacoima, Calif., Fifth Quarterly Report, March 1966	124

TABLE OF CONTENTS

Review No.	Title	Page
505	UNITED NUCLEAR CORPORATION MONTHLY PROGRESS REPORT ON DEVELOPMENT OF A CARBON METER FOR SODIUM, United Nuclear Corporation, Elmsford, N.Y., Progress Letters Nos. 1, 2, 3, and 4, April, May, June, July 1966	125
506	COMPREHENSIVE CAVITATION DAMAGE DATA FOR WATER, MERCURY, AND LEAD-BISMUTH ALLOY INCLUDING CORRELATIONS WITH MATERIAL AND FLUID PROPERTIES, University of Michigan, Ann Arbor, Mich., 05031-4-T, May 1966	127
507	SNAP-50/SPUR GENERATOR DEVELOPMENT PROGRAM, Westinghouse Electric Corp., Lima, Ohio, WAED 66.30E, April 15, 1966	128
508	DEVELOPMENT AND EVALUATION OF MAGNETIC AND ELECTRICAL MATERIALS CAPABLE OF OPERATING IN THE 800° TO 1600°F TEMPERATURE RANGE, Westinghouse Electric Corp., Lima, Ohio, NASA-CR-54355, June 1965	130

	Appendix A -- Organizations Having Reports, as Indicated by Review Numbers, Covered in this and Previous Issues of the <u>Review</u>	137

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-8177
Report By: P. Y. Achener and E. D. Parr
Report Period: Quarterly Progress Report for the period Oct. 1
through Dec. 31, 1965
Previous Reviews: 82, 94, 143, 144, 212, 213, 214, 229, 275, 299, 335,
358, 359, 389, 410, 448, 464

This report describes progress made in several tasks concerned with the measurement of thermodynamic and transport properties of various alkali metals. Experimental results are reported on the following two tasks.

PVT Relationship

Three experiments for determining the PVT relationship of Cs were attempted during this period. One experiment (No. 18) was unsuccessful because of failure of the pressure measurement device. The other two (Nos. 19 and 20) were partially successful, and some of the results are shown in Figure 1. Experimentally measured pressures and temperatures are plotted for a given charge of Cs (0.6772 g) in the test capsule. It is seen that these data are in good agreement with results derived from NRL work.⁽¹⁾

Liquid Viscosity

The apparatus for the measurement of Cs liquid viscosity was first tested with water. The resultant data for water, when compared to values reported in the International Critical Tables, appears to the reviewer to have been approximated 10% too high. Nevertheless, experimental measurements were obtained for liquid Cs in the temperature range 63° to 449°C. The results are shown in Figure 2 compared with other values previously reported in the literature. These measured viscosities are

(1) C. T. Ewing et al., High-Temperature Properties of Cesium, NRL Report 6246, U.S. Naval Research Laboratory, 24 Sept. 1965.

seen to be $\approx 10\%$ lower than those reported by Andrade and Dobbs⁽²⁾ and $\approx 50\%$ lower than those reported by Lemmon.⁽³⁾ It appears that further experimental measurements will be required to resolve this disagreement and arrive at a final curve.

(J. C. Chen)

Figures 1 and 2 in the Review correspond to Figures 1 and 3, respectively, in the original report.

REVIEW NO. 487

APPLICATIONS OF ULTRASONIC ENERGY:
ULTRASONIC INSTRUMENTATION FOR NUCLEAR APPLICATIONS

Sponsor: U.S. Atomic Energy Commission
Contractor: Aeroprojects Incorporated, West Chester, Penna.
Contract No.: AT(30-1)-3622
Report Nos.: NYO-3622-2 and NYO-3622-3
Report Periods: Feb. 1, 1966 to March 31, 1966
April 1, 1966 to May 31, 1966
Report Dates: April and June 1966
Previous Reviews: 465

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

1. 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.

-
- (2) E. N. DaC. Andrade and E. R. Dobbs, The Viscosities of Liquid Lithium, Rubidium and Cesium, Proc. Roy. Soc. London, 211.2 (1952).
- (3) A. W. Lemmon et al., The Specific Heat, Thermal Conductivity and Viscosity of Liquid Cesium, p. 25, PATT-4673-T7, Battelle Memorial Institute, Feb. 29, 1964.

The modifications on the Incipient Boiling Detector, made necessary because of changes in test capsule dimensions at ORNL, were completed. The unit was returned to ORNL and successfully tested in a potassium test loop at temperatures ranging between 300° and 1200°F and at power levels between 0.6 and 60 W. Because of loop modifications, accurate calibration of the ultrasonic instrument could not be made. Future work will consist of calibration of the instrument by ORNL personnel. The reviewer notes that earlier reports indicated that the unit would be tested at 1800°F.

2. 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 test loop, in which a prototype flowmeter can be tested, has been assembled. The ultrasonic flowmeter array is now complete except for the transmitter-pulsing equipment and readout oscilloscope. It is anticipated that preliminary operation of the apparatus will take place during the next bimonthly period.

3. Ultrasonic Thermometry--Prior work established that there are two approaches that merit investigation: (a) the phase relation approach and (b) the frequency change approach.

In the phase relation approach two coupler rods are attached to a transducer. One rod is maintained at a fixed temperature and the other at the temperature being measured. The phase angle between the signals can be measured by means of a phase detector and can be related to the temperature being measured.

In the frequency change approach, a single transducer-probe penetrates the vessel where the temperature is being measured. It is found that a relationship exists between the resonant frequency and the probe temperature.

An instrument based on the phase-relation approach requires no calibration; the temperature is calculated from the phase

angle. On the other hand, an instrument based on the frequency change approach requires careful calibration. Current work appears to be centered on the frequency change approach.

(S. Kalish)

REVIEW NO. 488

QUARTERLY TECHNICAL PROGRESS REPORT
SNAP 50/SPUR CONTRACT

Sponsor: U.S. Air Force
Contractor: AiResearch Mfg. Co., Phoenix, Arizona
Contract No.: AF33(615)-2289
Report No.: APS-5152-R6
Report By: Engineering Staff and approved by R. D. Gruntz
Period Ending: March 31, 1966
Report Date: April 18, 1966
Previous Reviews: 12, 64, 88, 102, 103, 150, 151, 152, 173, 243, 312, 313,
336, 360, 361, 390, 411, 412, 449, 450, 466, 467

This report describes work conducted on the SNAP 50/SPUR Nuclear Mechanical Power Unit.

Following is a summary of progress reported in the various technical areas:

1. Materials

Six wear and friction tests were conducted in 500°F liquid potassium. Results indicate that the K-94 material undergoes more wear than the K-96 material, and higher surface finishes result in lower running torques. Tabular results are presented.

Fatigue test results indicate that TZM has better fatigue resistance at 2000°F than at 1500°F, a result which is opposite to that obtained with Mo - 0.5 Ti. The testing machines are being recalibrated after which testing will be resumed.

2. Bearings

The development of computer bearing analysis techniques continued with the final check-out of the pivoted-pad dynamics program. Cases with free pivots and also cases with free pivots

and radial mount flexibility have been analyzed. Complete results will be reported in the next quarterly report.

The conventional-fluids test facility was utilized to conduct tests on two water-lubricated, plain, cylindrical bearing configurations, "A" and "B." Both bearings were the same size but bearing "A" was run with a radial clearance of 0.004 in. while bearing "B" was run with a radial clearance of 0.001 in. The tests were conducted to check the ability of the computer program to predict the half frequency whirl type instability. Graphical representations of analytical and test results for the bearing "A" configuration are presented and indicate good correlation. The bearing "B" tests were discontinued when a thermally induced seizure occurred.

The orifice and capillary-flow data for the hybrid and hydrostatic bearing program are presented in graphical form. The data indicate that, for a given diameter, the flow coefficient for either the orifice or capillary can be approximated by a constant over the pressure ranges investigated.

Efforts in the work horse bearing development program have been directed toward the preparations for a 2500-hr pivoted-pad potassium bearing endurance test to be conducted on the turbo-dynamic bearing rig. A detailed test description is contained in APS-5139-R.

3. Seals

Visual and high-speed photographic studies were made of 3-in. and 2.5-in. smooth rotor hydrodynamic seals. The results of these observations will be presented in a later report.

The 2-in. smooth disk rotor was operated with the 2-in. stator vanes through a range of axial positions, from 3000 to 24,000 rpm, and with a liquid/vapor interface-radius rotor-radius ratio varying from 0 to 0.9. All modes of operation were stable.

4. Turbine

The initial attempt to operate the test turbine in the potassium test loop was unsuccessful because of leakage of hot potassium and oil into the transition section between the turbine and generator. The reaction produced a carbon residue which contaminated the rear bearing cavity, parts of the test loop, and the argon buffer section of the front generator oil seal. Disassembly and inspection are in progress.

All engineering and design work on the full-scale turbine has been stopped, as this phase of the program has been terminated by the Air Force. In place of the full-scale turbine program, a multistage turbine erosion evaluation program, sponsored by the AEC, will be initiated. The objectives of this program will be to investigate turbine-blade erosion and aerodynamic performance by testing a 6-stage, Rankine cycle, space power-type turbine with both saturated steam and potassium vapor. A complete description of the program is contained in the report.

5. Heat Transfer

a. Boiling Stability Tests. Flow stability in multitube forced-convection boilers was studied with Freon as a stand-in for potassium. A typical flow-stability map is shown.

A theoretical flow-stability analysis is being prepared for a computer solution. The boiler tube is considered to consist of a preheating section, a wet-wall boiling section, a dry-wall boiling section, and an unheated exit section. System stability is examined by perturbing the tube wall temperature and determining the effect upon the time-dependent differential equations that describe the behavior of the system.

b. Condensing Experiments. Preliminary testing of the variable-attitude test condenser showed that it was easily operated in the downward position but inoperable in the horizontal and upward-flow positions because of flow maldistribution and slugging. This will be studied carefully in upcoming condenser experiments.

To achieve closer simulation of flow processes in an actual potassium condenser, the heat flux is being increased by changing the shell fluid to Freon 113 at 0°F and switching to cross flow on the shell side.

c. Boiling-Heat-Transfer Tests. A single-tube heat transfer test section is being built. It consists of two 20-in.-long copper tubes, with seven pressure taps along its length, and with thermocouples attached on the outside at 1-in. intervals. It will be heated by direct flow of alternating current through it. The purpose of the heat transfer tests is to see whether or not boiling Freon can be used as a stand-in for boiling potassium. The results will be compared with previous results obtained on a single-tube potassium boiler.

Preliminary design of a multitube Freon heat transfer section has been completed. It will be used to correlate boiler

performances when operating on potassium and when operating on Freon.

d. Multitube Potassium Boiler. Fabrication of the 12-tube Haynes-25 Na-heated potassium test boiler has been completed and it has been installed in the heat-transfer loop. The final system check out is under way, and testing is scheduled to start in April. Pressure-drop data were taken with water to confirm that the inlet orifice for each tube was not plugged. The results indicated that neither bypassing nor plugging of the orifices existed. Geminol N-P grounded thermocouples, sheathed in 1/4-in. Inconel tubing with MgO insulation, have been chosen for maximum life and stability. The boiler is C-shaped to accommodate thermal expansion, and thermocouples are installed with junctions about 1 in. apart along the outer bend of the shell. Pressure transducers are installed at the sodium inlet and outlet and at the potassium inlet and outlet.

(P. Bezler and O. E. Dwyer)

REVIEW NO. 489

PROCEEDINGS OF THE CONFERENCE ON APPLICATION
OF HIGH TEMPERATURE INSTRUMENTATION
TO LIQUID-METAL EXPERIMENTS

Sponsor: U.S. Atomic Energy Commission and the National Aeronautics and Space Administration

Report Date: Sept. 1965

Report No.: ANL-7100

Proceedings of Previous Conferences: Review No. 16--Brookhaven
National Laboratory
Review No. 298--Oak Ridge
National Laboratory

Thermodynamics and Heat Transfer Measurements

	<u>Page</u>
1. Heating Techniques for Liquid Metal Loops	9
2. Electrical Heater for Liquid Metals at Elevated Temperatures	23
3. Flow Instrumentation and Operating Experience in a Condensing Alkali Metals Test Loop	45

(cont.)

Thermodynamics and Heat Transfer Measurements

	<u>Page</u>
4. Heat Transfer and Pressure Drop Measurements for High Temperature Boiling Potassium in Forced Convection	53
5. Measurements of Forced Convection Condensing Potassium Heat Transfer	97
6. Development of Efflux Measuring Device for Performance Evaluation of Potassium Vapor Turbine	127
7. Pressure Transducer for Liquid Metal Applications	165

Quality and Void Fraction Measurements

8. Forced Convection Boiling Sodium Studies at Low Pressure	189
9. X-ray Measurement of Void Dynamics in Boiling Liquid Metals	195
10. Instrumentation for Two-Phase Metallic Flows	217
11. An Accurate One-Shot Gamma Attenuation Technique for Measuring Void Fractions	247
12. Development of Alkali Metal Quality Meter	271

Bearing Film Measurements

13. Liquid-Metal Lubricated Bearing Instrumentation	291
14. Development of Performance-Measuring Instrumentation for a Liquid-Metal Turbine-Driven Bearing Test Rig	307
15. Approaches to the Measurement of the Steady State and Dynamic Performance Characteristics of Liquid-Metal Lubricated Bearings	331

Liquid Level and Impurity Measurements

16. Liquid-Metal Level Detector and Indicator	367
17. Experiences and Developments in Instrumentation for Liquid Metal Experiments	379
18. Impurity and Liquid Level Measurements for the Faret Loop	413
19. The Liquid Metal Oxygen Meter	427
20. An Inert Gas Purity Tester	443

(cont.)

Liquid Level and Impurity Measurements

21.	Instrumentation for Evaluating Cavitation Damage Resistance and High Frequency Fatigue of Refractory Alloys in High Temperature Liquid Alkali Metals	455

Heat Transfer

22.	A Method for the Determination of Local Heat Fluxes in Liquid Metal Heat Exchangers	483
23.	Existence of Nonequilibrium, Inverse Temperature Profile in Boiling Two Phase Flow	499
24.	Experimental Studies of Boiling of Sodium and Condensing of Potassium	513
25.	Superheat with Boiling Alkali Metals	515
26.	Pressure Drop with Forced-Convection Boiling of Potassium	535
27.	Sodium Boiling Heat Transfer and Hydrodynamics	549
28.	Recent Developments in Heat Transfer and Development of the Mercury Boiler for the SNAP-8 System	573
29.	X-Ray Movie Film Report of Flow Patterns in a Once-Through Forced Circulation NaK Heated Mercury Boiler	633
30.	High Temperature Liquid Metal Instrumentation at Atomics International for: (1) The SNAP 10A Flight System, (2) Boiler Conditioning Experiments and Mercury Vapor Quality Measurement for Mercury Rankine Systems	641

REVIEW NO. 490

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-7204
Report Coordinated By: R. M. Adams and M. Weber
Report Date: April 1966

Previous Reviews: 29,30,41,42,66,67,83,117,118,141,142,169,170,203,240,241,244,245,246,289,296,297,318,319,337,338,362,363,391,392,414,415,429,430,451,452,468,469

Fuel-Cladding Materials for Na-Cooled Reactors (p. 14)

The creep rate of V - 20% Ti has been determined as a function of annealing temperature. Tensile specimens were annealed for 1 hr at temperatures ranging from 700°C to 1500°C and then creep-tested in vacuum at 650°C and 30 kg/mm² stress. The short-time creep behavior varied considerably with annealing temperature, the 700°C anneal resulting in the highest minimum creep rate and the shortest rupture life, and the 1500°C anneal resulting in the lowest minimum creep rate and longest rupture life. No numbers were given. The improvement in creep rate with increase in annealing temperature is believed to be due, in part, to precipitation hardening.

Pre-exposure of V - 20% Ti to flowing Na containing 20 ppm O₂ lowers its creep resistance. A set of creep tests conducted in vacuum at 650°C and 15 kg/mm² stress showed that (a) the time to 11% creep strain was 180 hr for a specimen exposed to the Na while under stress, (b) it was 470 hr for a specimen exposed to Na while under no stress, and (c) it was 700 hr for a control specimen. The tests will be repeated with Na containing <10 ppm O₂, which is closer to actual power-reactor conditions.

The linear thermal expansion of V - 40% Ti was measured in the temperature range 25° to 1000°C. The results are given below.

Temperature range, °C	Mean linear-expansion coefficient, 10 ⁻⁶ °C ⁻¹
25 to 250	9.23
25 to 500	9.77
25 to 750	10.30
25 to 1000	10.85 (extrapolated)

Development of Refractory-Metal Alloys for Service in Oxygen-Contaminated Na (p. 24)

In further corrosion testing of V - 20% Ti alloy, test specimens have been exposed to flowing Na at 650°C which contained 10 ppm O₂. Weight gains of 0.43, 0.50, and 0.57 mg/cm² were observed after exposure times of 7, 17, and 28 days, respectively. These tests were the first to show weight gains in cold-trapped equipment.

Segregation of Carbon in Na (p. 31)

A considerable fraction of the C in reactor-grade Na is particulate. A zone-melting experiment was performed on a sample of Na containing ≈ 30 ppm total C. The experiment was carried out in a vertical quartz tube about 2 ft long. After 240 heating cycles, it was found that most of the C was contained in the Na residue adhering to the tube wall. The free Na in the middle and bottom sections of the tube contained less C than any sodium previously analyzed, 3 to 4 ppm.

Polarization Studies in Liquid-Na Environment (p. 47)

Three techniques of providing electrical insulation for portions of Zr sample electrodes exposed to Na vapor in liquid-Na polarization studies have been tried. Electrode samples carrying (a) a grown zirconia layer, (b) a jet-sprayed coating of alumina, and (c) a grown oxide layer covered by an alumina coating were exposed for periods of up to three days in Na at 540°C . All were sufficiently adherent, but the alumina coating without the underlying layer of zirconia was less adherent than that applied to the grown oxide. Electrical leakage through the dual coating was substantial but appeared to be satisfactory for future polarization experiments. It was found that grown zirconia layers of sufficient thickness to prevent significant electrical leakage produced small distortions in the specimen shape.

Boiling Liquid-Metal Technology (p. 59)

A Cb - 1 Zr loop has been built to investigate the heat transfer and two-phase flow characteristics of boiling sodium to a temperature of 2100°F , equivalent to a pressure of ≈ 8 atm. Among the variables to be investigated are boiling heat flux and temperature difference up to the critical flux occurrence, boiling and adiabatic two-phase pressure losses, vapor volume fraction, and boiling stability parameters. The system is ready for sodium filling.

An electron-bombardment heater is under development for eventual use in the above loop. The present design incorporates a 0.030-in.-diam thoriated-tungsten cathode inside a 3/4-in.-diam pipe. The pipe is immersed in a pool of Na and fluxes in excess of 10^5 Btu/hr-ft² have been obtained. Testing is continuing with emphasis on cathode behavior and durability.

Liquid-Metal Heat Transfer in Double-Pipe Heat Exchangers (p. 60)

Analytical studies were continued for the case of counter-current turbulent flow to show the effects of the various design and operating parameters on the local heat transfer coefficient and exchange efficiency. It has been shown that various formulations of the Nunge-Gill calculational procedure for laminar-flow problems give fairly accurate values of the heat-exchanger efficiency only within a very limited range of operating conditions. On the other hand, a newly developed procedure for turbulent flows gives accurate values of the efficiency for all operating conditions.

(O. E. Dwyer)

REVIEW NO. 491

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-7219

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

Report Date: May 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, 469, 490

Development of Refractory-Metal Alloys for Service in Oxygen-Contaminated Na (p. 14)

Dynamic corrosion tests of annealed V - 20% Ti and V - 15% Ti - 7.5% Cr were conducted in flowing Na under the following conditions: 650°C, 6.1 m/sec, and 10 to 12 ppm O₂. After 53 days of exposure, the V - 20% Ti samples showed no external change (except for a slight brown color), and the weight-gain results could be expressed by the equation

$$W = 0.278 t^{0.278}$$

where W equals the weight gain expressed in mg/cm², and t the time in days. The weight gains of the V - 15% Ti - 7.5% Cr samples were only about 60% those of the V - 20% Ti samples.

A number of alloys prepared in sheet form were exposed for seven days to 650°C sodium containing about 15 ppm oxygen. The data are shown in the first of the following tables. A test of levitation-melted alloy cylinders under the same conditions was completed to fill in missing data for the V-Cr-Al system. The results are shown in the second of the following tables.

<u>Corrosion of Vanadium-Base Alloys in Sodium at 650°C</u>		<u>Experimental Castings Exposed to Sodium at 650°C</u>	
Alloy, wt %	W, mg/cm ²	Alloy, wt %	W, mg/cm ²
V - 5 Cr, as rolled	9.1	V - 30 Cr - 5 Al	4.0
V - 10 Cr, as rolled	9.3	V - 30 Cr - 7.5 Al	1.8
V - 15 Ti - 7.5 Cr - 1 Y, annealed*	14.6	V - 40 Cr	1.6
V - 40 Ti - 5 Cr annealed*	9.3	V - 40 Cr - 10 Al	0.2
V - 40 Ti - 10 Cr, annealed	9.3	V - 20 Ti, annealed sheet	8.4
V - 20 Ti, annealed	9.7		

*Annealed 1 hr in vacuum at 900°C

Effect of Flow and Cooling Rates on a Plugging Meter (p. 27)

During a 6-month period, the oxygen content of a sodium loop varied between 3 and 37 ppm; the flow rate in the side (plugging) loop varied between 0.256 and 0.112 gpm; the period of cooling from the time the valve was closed to plugging temperature varied from 6 to 39 min; the temperature of the main loop to which the plugging loop was attached varied from 399° to 642°F. Data were taken to determine if these variables had any effect on the plugging-meter analyses of oxygen content of the sodium.

Within the limits of these experiments, variations in sodium flow, time of cooling, and sodium inlet temperature made no difference in the behavior of the plugging valve as a device for oxygen determination.

Boiling Liquid-Metal Technology (p. 49)

A power failure caused a small rupture in the Na hot trap on the Cb - 1% Zr test loop. It has been repaired, and the loop is about to be charged with Na (see previous review).

An electron-bombardment heater is being developed for eventual use in this same loop. About 150 hr of operation have been accumulated with the present 0.030-in.-diam thoriated-tungsten cathode. Heat fluxes of $>300,000$ Btu/hr-ft² have been obtained, with peak Na temperatures as high as 1350°F. Emission currents ranged up to 3.55 A and the cathode-to-anode voltage approached 7700 v.

(O. E. Dwyer)

REVIEW NO. 492

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-66-1
Report By: R. E. Douglas and W. J. Hallett
Report Period: October to December 1965
Report Date: January 1966
Previous Reviews: 301, 365, 395, 431

The principal objective of this program is to investigate the effects of a sodium-water reaction resulting from the sudden failure of a tube in a sodium-heated modular steam generator. A second objective is to study the relative effectiveness of pressure-relief devices, and the optimization of their number and location.

The final test under the C series test conditions and the four under the D series test conditions were performed during this report period. The test conditions were as follows:

1. Series C - water, 2780 psi at 470°F; sodium at 920°F.
2. Series D - water, 2650 to 2770 psi at 400° to 471°F; sodium at 674° to 691°F.

The test results to date are summarized in Table I.

For Test 4, Series C, a tube bundle of the same design as that used in previous tests except that the length was increased from 4 to 14 ft, was used. The results showed no significant change in peak pressure resulting from the impedance associated with the longer tube bundle.

The D series test conditions were identical to those of the C series except for the lower sodium temperature. The fourth test of the D series (4D) was performed for the purpose of comparing effects observed in using a rupture tube of different design with effects observed in test 3D in which the earlier rupture tube design was used. A comparison of the peak pressures for the two tests is given in Table I.

The test structure showed no sign of damage after the 13 tests. Tests performed with sodium temperatures of about 915°F resulted in peak pressures <1000 psi, whereas in tests in which the sodium temperature was about 675°F peak pressures were in the range 1000 to 3000 psi.

(A. J. Romano)

Table I in the Review corresponds to Table I in the original report.

REVIEW NO. 493

QUARTERLY TECHNICAL PROGRESS REPORT
AEC UNCLASSIFIED PROGRAMS

Sponsor: U.S. Atomic Energy Commission
Contractor: Atomics International, A Division of North American
Aviation, Inc., Canoga Park, Calif.
Contract No.: AT(11-1)-GEN-8
Report No.: NAA-SR-11900
Report By: H. A. Morewitz et al.
Report Period: January-March 1966
Report Date: June 1966
Previous Reviews: 33,92,341

This report contains summaries on a large number of individual projects. Each summary consists of the following five parts:

- I. Project Objectives
- II. Major Accomplishments in Fiscal 1966
- III. Progress During Report Period
- IV. Evaluation of Effort to Date
- V. Next Report Period Activities

The following projects are considered appropriate for listing in this issue of the Review, and the Project Objectives for each have been copied verbatim from the report.

Boiling Studies for Sodium Reactor Safety (p. 3)

"The general objective of this project is to develop basic information on two-phase flow and boiling required in the safety evaluation of sodium cooled reactors. This information is important because of the key role that sodium boiling plays in reactor dynamics, in fuel meltdown accidents, and in the ultimate shutdown mechanism of the reactor. Specific experimental objectives include the measurement of boiling heat transfer characteristics, two-phase pressure drop, void fractions, superheating, transient voiding rates and pressures in single channels, and hydrodynamic instabilities. Specific objectives of the theoretical study, in addition to any analyses required to support the experimental work, are the development of a digital computer code which will predict transient void fractions, flow rate, and heat transfer for single and multichannel sodium flow, and the incorporation of this code into a general reactor kinetics code."

Stability and Properties of Cladding and Structural Alloys in a High Temperature, Liquid Metal, Fast Neutron Environment (p. 9)

"The objective of this project is to provide sufficient, statistically significant data on the extent to which exposure to a sodium cooled fast reactor environment effects the physical and mechanical properties of cladding and structural alloys, to provide a basis for meaningful selection of materials and the understanding of phenomena required as a basis for interpretation of environmental effects, for projection to alternate designs, and for development of resistant alloys."

Coolant Chemistry (p. 11)

"The specific objectives of this task are to (a) define, prepare, and manage a loop source of stock sodium for the program; (b) develop sampling and transfer procedures for handling sodium without contamination; and (c) monitor composition of sodium and gas atmospheres in use on all tasks in this program, provide a management system for ensuring the use of proper procedures in sampling, transferring, and analyzing of sodium."

Mechanical Properties (p. 17)

"The specific objectives of this task are to determine the individual and combined effects of environment (sodium, air, helium, and vacuum), strain rate (10^{-7} to 10^{-3} /hr), stress condition (uniaxial and biaxial), and radiation on the creep, stress rupture, and fatigue characteristics of selected cladding alloys."

Operation and Maintenance of the Sodium Component Test Installation (p. 39)

"The project objective is to start up and operate the Sodium Component Test Installation (SCTI) in order to test, obtain data for, and evaluate the performance of prototype intermediate heat exchangers and steam generators."

Liquid Metals Information Center (p. 43)

"The project objective is to establish a Liquid Metals Information Center which will serve as a focal point for data on liquid metals technology, and which will provide special bibliographies, technical information, and state-of-the-art summaries to AEC-approved users. The objective for FY 1966 is to select, procure, evaluate, abstract, index, and store for machine retrieval all pertinent unclassified data on sodium and NaK published or declassified since January 1955. A major schedule objective is to have the Center fully operational by July 1, 1966."

Precision Mechanisms in Sodium (p. 47)

"The objective of this project is to prepare and publish a handbook of material characterization information and nonstandard design information required for design of mechanical elements to operate reliably in sodium/sodium-vapor to 1200°F; required is the information which will permit a designer to confidently employ combinations of those mechanical elements for such fast-reactor assemblies as fuel handling devices, control rod drives, and fuel hold-down mechanisms, which will operate in the sodium/sodium-vapor environment."

Mechanisms in Sodium (p. 63)

"The objective of this project is to obtain information regarding application of certain selected materials, surface treatments, and mechanisms in high temperature sodium liquid and vapor. Data will be useful for the design of components such as control elements, handling equipment, shield plug, and variable orifices needed for sodium cooled reactors."

Sodium Chemistry (p. 127)

"The objective of this project is to advance the understanding of the chemistry of liquid sodium as a solvent for metals and nonmetals through study of (a) the equilibrium solubility and the rate of solution of selected metals and nonmetals in liquid sodium, as a function of temperature, using the highest purity materials available to minimize the perturbations caused by unwanted side reactions; (b) the nature of solute entities and their interactions in liquid sodium, from which thermodynamic properties of the solutions may be deduced; and (c) the analytical chemistry of solutes in liquid sodium at very low concentrations, in order that the data developed under (a) and (b) (above) may have the greatest possible reliability."

Fission Product Retention by Reactor Coolants (p. 139)

"The general objective of the project is to determine the ability of reactor coolants to retain specific fission products released to the coolant stream as a result of fuel cladding failure or fuel meltdown. Specific objectives of the project are: (a) determination of the ability of sodium to retain radioactive iodine as a function of such parameters as sodium temperature, elapsed time from incident, sodium-to-fuel and sodium-to-gas volume ratios and geometric relationships, condition of released iodine; and (b) determination of the ability of boiling sodium and sodium in the vapor phase to retain radioactive fission products."

Characterization of Sodium Fires and Fission Product Release (p. 151)

"The general objective of this project is to develop experimental information and analytical methods which characterize the release and transport of effluents and energy generated during a primary-coolant-sodium accident. The source of energy generation may be from the escaping coolant (by rapid thermal energy transfer) and/or subsequent combustion of the sodium coolant. The effluents are sodium (some as Na-24) or its oxide in particulate form and selected fission products, available as potentially serious dispersions of radioactivity. The information to be developed is required for the design and safeguards analysis of economical, sodium-cooled fast reactors."

SODIUM-HEATED STEAM GENERATOR DEVELOPMENT

Sponsor: U. S. Atomic Energy Commission
Contractor: The Babcock & Wilcox Co., Boiler Division, Bar-
berton, Ohio
Contract No.: AT(11-1)-1280
Report Nos.: BAW-1280-34
BAW-1280-36
Report Periods: Oct.-Dec. 1965
Jan.-March 1966
Report Dates: Jan. 15, and
April 8, 1966
Reports By: Paul Probert
Previous Reviews: 56, 61, 115, 116, 123, 124, 163, 194, 195, 237, 248, 249,
277, 302, 342, 417, 453, 454

The objective of this program is to develop a large sodium-heated steam generator of improved design. The preliminary design of a full-size steam generator [1000 MW(e) in three units] has been completed. The preliminary design of a 30-MW(t) prototype steam generator has also been completed, and detailed design is in progress. Fabrication of the prototype, which will eventually be tested in the Sodium Components Test Installation (SCTI) at AI, is about 48% complete.

There is support work being done in several R&D areas. Following is a summary of progress in each of these areas:

1. Materials

A test loop simulating conditions and material proportions in the full-size generator was operated for 8000 hr. Microprobe examination of eight type 316 stainless steel superheater samples has been completed. Changes in composition, if any, are <5% the amount of each element and are confined to about 5 μ from the surface. Microprobe examination of Croloy 2-1/4 boiler sections indicates a surface pickup of nickel and chromium. The surface nickel content is >2.5% compared with <0.25% in the base metal. There is a surface layer 5 μ thick which is considerably different in composition from the base metal, but it is full of fine particles which make microprobe evaluation difficult.

2. Corrosion Rates for Croloy 2-1/4 in Products of a Sodium-Water Reaction

This project has been completed and reported in BAW-1280-30. The conclusions are summarized in the Progress Report for the period October to December 1965.

3. Procedure for Welding Tubes to the Back Side of the Tubesheet

This task involves the development of welding equipment and procedures for the crevice-free welding of tubes to the back side of the tubesheet by the TIG process with filler wire. A twenty-five-tube mock-up of the tube-to-tubesheet welds for 5/8 in.-o.d. x 0.076-in.-wall tubing was completed and sent to LASL for inspection with a special x-ray tube developed by LASL. Qualification welds have been made for the 7/8-in.-o.d. x 0.120-in.-wall stainless steel tubes. These welds were made using thick-walled tubes to simulate the tubesheet.

4. Preliminary Control and Instrumentation Studies

The control studies are directed toward the development of a mathematical model of the steam generators with an analogue computer. An open loop simulation has been written and it is hoped that this can be combined with the simulation written for the SCTI so that a system simulation of the prototype in the SCTI can be run prior to actual operation.

The instrumentation studies involve the development of strain gauges for use up to 1200°F in a sodium environment. The 900°F microdot half-bridge gauge has given the best results so far. This is a sheathed gauge and will be tested in sodium up to 1024°F. BLH high-temperature gauges have been calibrated at temperatures up to 1100°F. These gauges are not sheathed but will be suitable for strain measurements on the outside of the steam generator.

(K. C. Hoffman)

REVIEW NO. 495

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-54960
Report By: Anthony J. Cassano
Report Period: 8th Quarterly Report--Dec. 1, 1965 to Feb. 28, 1966
Report Date: April 8, 1966
Previous Reviews: 250,278,323,367,397,435,473

The purpose of this program is to develop pressure transducers to 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 of the differential instrument will be ± 5 psi.

The latest experimental results indicate that fabrication changes in the thermionic diode sensor have increased the expected operating life to >1000 hr. The final design for the absolute pressure instrument and the differential pressure instrument is well along. The design includes a double housing; there is an inner Nb - 1 Zr main housing to maintain the low pressure necessary for the successful operation of the thermionic sensor, and there is an outer Haynes alloy No. 25 shell to make the transducer usable on a liquid-metal test loop operating in air. Final drawings will be presented in the next quarterly report.

(S. Kalish)

REVIEW NO. 496

SODIUM MASS TRANSFER: XXI
1964 Test Run Reports

Sponsor: U.S. Atomic Energy Commission
Contractor: General Electric Co., Advanced Products Operation,
San Jose, Calif.

Contract No.: AT(04-3)-189, Project Agreement 15
Report No.: GEAP-4837
Compiled By: R. W. Lockhart
Report Date: October 1965
Previous Reviews: 347,348,437,438,439,440,474,475,477

The objective of this program is to study the effect of several variables affecting the corrosion resistance of three selected alloys (type 316 SS, 2-1/4 Cr - 1 Mo steel, and 5 Cr - 1/2 Mo - 1/2 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 information includes temperature conditions, flow rates, impurity and corrosion product analysis, and a complete log of the run. Sample data are included on weight change, metallography, surface composition changes, and carbon movement.

The reader is referred to other reports (i.e., GEAP 4836 and GEAP 4832) for an analysis and interpretation of the data presented in this report.

Test conditions for the four runs reported are presented in Table II.

Examination of test materials revealed the following significant results from the various runs.

Run 3-10. Preferential loss of iron from surface layers, as determined by x-ray fluorescence measurements, accompanied hot-leg-sample weight losses. Similar measurements on cold-leg samples which showed a weight gain, revealed an increase in concentration on the surface of the major constituents of type 316 stainless steel. These transfer effects were characteristic of all high-oxygen runs.

Run 4-8. Weight losses in the hot leg and gains in the cold leg were normal for this type of run; they were greater in magnitude than for the 1100° run, which is to be expected. No abnormal surface composition changes on corrosion samples were detected by x-ray fluorescence. No significant changes in the gross carbon content of the corrosion samples were observed.

Run 4-9. Hot-leg-sample weight losses were accompanied by a preferential loss of iron on the surface. Increase in surface chromium and nickel accompanied weight gains of the

cold-leg specimen. Cold-leg samples showed a decrease in thickness of the "disturbed layer" with decreasing temperature, i.e., 0.5 mil at 1000°F, 0.2 mil at 900°F, and essentially none at 600°F.

Run 5-6. Weight-change measurements followed the pattern of similar previous runs in that corrosion increased with increasing temperature. The magnitudes of the weight changes and compositional changes were small as would be expected from such a short test (701 hr).

Run 5-7. The magnitude and temperature dependence of the corrosion were normal for this type of run. However, the pattern of weight gains in this loop was different from that observed in other loops. Here, the maximum weight gains occurred on the last (coldest) rather than the first position (hottest) in the cold leg (compared to results of Run 4-9 described above).

Run 5-8. Weight-change measurements from this run clearly showed the effect of oxygen concentration in the Na. The weight losses measured on the samples at the hottest temperature (1102°F) from this run (15 ppm O) were only 1/4 those measured on samples at the same temperature in run 5-5 (50 ppm O).

Run 6-7. The low-temperature and low-oxygen conditions of this run produced relatively small weight changes and compositional variations in this run. Hot-leg samples showed weight losses and preferential loss of Cr at the surface. Cold-leg samples showed weight gains and increases in Cr content at the surface.

Included in this report is the paper entitled "Double Break Flow Patterns from Plugging Indicator Runs" by R. W. Lockhart. This paper presents a discussion of the "double flow break effect" observed during plugging meter runs made on the corrosion loops which were run for this program.

(C. Klamut)

REVIEW NO. 497

TWO-STAGE POTASSIUM TEST TURBINE

Sponsor: National Aeronautics and Space Administration
Contractor: General Electric, Missile & Space Div., Cincinnati,
Ohio

Contract No.: NAS 5-1143
Report No.: NASA-CR-54897
Report Edited By: E. Schnetzer
Report Period: May 8, 1965 through August 8, 1965
Report Date: November 24, 1965
Previous Reviews: 11, 26, 72, 159, 189, 190, 220, 222, 256, 325, 368,
436, 476

The test turbine consists of stages three and four of a five-stage 500-kW turbine. After the completion of tare testing, a successful performance test of the turbine was conducted. The turbine was operated on potassium vapor at 1450° and 1550°F, over a pressure ratio range of 1.4 to 4.4 and over a speed range of 15,400 to 21,850 rpm. Good agreement between predicted and test performance was obtained. The analysis of test data is included in the report.

Post-test inspection of the turbine revealed no evidence of blade erosion (blade material U-700); however, a metallic deposit had built up on the leading edges of stage one nozzle vanes and blading. Diffusion bonding between the turbine wheel curvic couplings was also noted. Analysis indicated that the deposit on the vanes were the same composition as material previously found in the upper boiler drum. It was therefore concluded that the material was dissolved in potassium droplets and was carried from the boiler to the turbine.

Preparations are under way for the turbine 2000-hr endurance test run. For this run light refractory metal blades will be mounted in the second-stage wheel, four of TZM and four of TZC. Additional static erosion specimens of TZM, TZC, and U-700 will be inserted in the second-stage tip seal. Anticipated operating conditions call for a potassium vapor temperature of 1500°F and a rotation speed of 18,250 rpm. This results in first- and second-stage wheel tip speeds of 703 and 768 ft/sec, respectively.

(P. Bezler)

REVIEW NO. 498

TWO-STAGE POTASSIUM TEST TURBINE

Sponsor: National Aeronautics and Space Administration
Contractor: General Electric, Missile & Space Div., Cincinnati,
Ohio

Contract No.: NAS 5-1143
Report No.: NASA-CR-54917
Report Edited By: E. Schnetzer
Report Period: August 8, 1965 through November 8, 1965
Report Date: January 10, 1966
Previous Reviews: 11, 26, 72, 159, 189, 190, 220, 222, 256, 325, 368, 436,
476, 497

The test turbine consists of stages three and four of a five-stage 500-kW turbine. Reassembly of the turbine following the performance test was completed, and the 2000-hr turbine endurance run was begun with 1000 hr of testing completed during this report period. Selected operating conditions for the test run are: inlet temperature, $1500 \pm 10^\circ\text{F}$; speed, $18,250 \pm 200$ rpm; exit temperature, $1240 \pm 10^\circ\text{F}$; and total-to-static pressure ratio across the turbine, 3.47. An inadvertent shutdown, resulting in damage to the pivoted pad bearings, occurred after 254 hr of operation; repairs were made and operations were resumed. Tabulated and plotted performance data are presented.

The inadvertent shutdown resulted when the turbine overspeed trip was accidentally energized during a routine calibration of the speed readout unit. With the trip energized, damage to the turbine pivoted pad bearings occurred when the valve supplying water to the turbine brake failed to open, and the turbine speed was consequently not immediately reduced. Replacement of the bearing was necessary, and modifications of the turbine oil system were made to incorporate a 20-sec supply oil accumulator.

An optical probe inspection of the turbine blading, made during the bearing overhaul, revealed no evidence of blade erosion, no evidence of a metal deposit buildup on the blading as had occurred during the performance test run, and no visible difference between the TZC, TZM, and U-700 buckets.

(P. Bezler)

REVIEW NO. 499

REPORT ON ADVANCED REACTOR TECHNOLOGY (ART)

Sponsor: U.S. Atomic Energy Commission
Contractor: Los Alamos Scientific Laboratory, Los Alamos, New Mexico

Contract No.: W-7405-eng-36
Report No.: LA-3524-MS
Report Period: Quarter ending April 30, 1966
Previous Reviews: 2, 15, 20, 99, 155, 156, 201, 262, 279, 305, 327, 372,
400, 441, 480

Solubility of Oxygen in Na (p. 50)

The solubility of oxygen in Na has been measured in the temperature range 125° to 300°C. The results are shown in Figure 3. A preliminary value at 185°C indicates agreement with the straight line drawn in the figure. Neither the method of analysis nor its estimated accuracy is given in the report.

Control of Fission Products in Liquid Na (p. 50)

Five grams of Pu - Co - Ce fuel, irradiated to a level of 10^{19} fissions in 1963, were placed in a forced-convection Na loop. The Na contacted the fuel at 600°C. A 5-in. section of tubing packed with stainless steel mesh was located in the cold leg, the temperature of which varied from 500° to 320° to 500°C over a 1510-hr period. The activity, due mostly to Cs^{137} , collected in the stainless-steel mesh. The results are shown in the following table:

Distribution of Cs^{137} in Isothermal Cold Leg

<u>Position</u>	<u>Observed Cs^{137} Activity, c/m</u>
Empty tube, 1/2 in. upstream from mesh	75
Front edge of mesh	11,000
1-1/2 in. inside mesh	4,200
3 in. inside mesh	3,000
4-1/2 in. inside mesh	1,650
Back edge of mesh	75

A simple method has thus been demonstrated for removal of fission product Cs (at least) from flowing Na.

Determination of Oxygen in Sodium by the (γ ,n) Technique (p. 52)

"A study has been undertaken of the use of high-energy photon activation as a means of O (and possibly C) determination in Na. It appears that O can be determined in Na at concentrations near 1 ppm and possibly lower by γ counting and spectrum analysis techniques. The White Sands Missile Range linear accelerator is being investigated as a source of the high-energy

γ flux required for this analytical technique. Measurements indicate that the flux is sensitive to electron current as well as to electron energy. Preliminary analysis of the results obtained so far indicates an estimated sensitivity of ≈ 1 cpm/ μ g of oxygen. This compares to a reported value of 10 cpm/ μ g of oxygen at 18 MeV."

(O. E. Dwyer)

Figure 3 in the Review corresponds to Figure 4 in the original report.

REVIEW NO. 500

DEVELOPMENT OF TECHNIQUES
FOR MEASUREMENT OF IMPURITIES IN SODIUM

Sponsor: U.S. Atomic Energy Commission
Contractor: MSA Research Corp., Evans City, Penna.
Contract No.: AT(11-1)-765
Report No.: MSAR 66-72
Report By: S. J. Rodgers and R. C. Andrews
Report Date: April 25, 1966
Previous Reviews: 375,402,422,457

"Redistribution of funding initially resulted in a partial cutback in these analytical studies and finally in a temporary work stoppage during this report period. No technical progress has been achieved since the previous quarterly report. (See Review No. 457.) Therefore, this report is issued only for the purpose of maintaining a continuity in reporting sequence. Background information has been included to provide the reader with information concerning the nature of the studies involved under this program. Additional funding has been received and the work will be reactivated."

(authors)

EFFECT OF HIGH TEMPERATURE SODIUM
ON AUSTENITIC AND FERRITIC STEELS

Sponsor: U.S. Atomic Energy Commission
Contractor: MSA Research Corp., Evans City, Penna.
Contract No.: AT(11-1)-765
Report No.: 66-71
Report By: R. C. Andrews and K. R. Barker
Report Date: April 25, 1966
Report Period: Jan. to March 1966
Previous Reviews: 53, 54, 55, 68, 69, 109, 110, 153, 154, 184, 185, 186,
204, 205, 207, 227, 264, 265, 266, 267, 280, 281, 306, 331,
332, 351, 376, 403, 421, 455, 456

Creep, creep-rupture, and fatigue tests on 304 SS are in progress in 1200°F high-oxygen (300 ppm) sodium (Test 6). Similar tests on 304 SS in high-carbon sodium at 1200°F (Test 7) are also in progress. Base line mechanical property data tests of 304 SS in air were initiated by the University of Michigan.

High-oxygen creep-rupture data to date show the following:

<u>Stress,</u> <u>psi</u>	<u>Rupture</u> <u>time, hr</u>	<u>Elonga-</u> <u>tion, %</u>	<u>Reduction</u> <u>of area, %</u>	<u>Min creep</u> <u>rate, hr</u>
25,000	41	35	26	0.5850
23,000	71	33	27	0.2390
21,000	230	27	23	0.0577
16,000	3370*			
14,000	3390*			

*In progress

Unstressed 304 SS specimens are being exposed for 4000 hr in 1200°F, 300 ppm oxygen and high-carbon Na. Other 304 SS specimens in a 1200°F helium environment will provide tests with identical thermal histories. Following exposure these specimens will be used in both tensile and creep rupture tests.

The results of creep rupture tests on as-received 304 SS in 1200°F high-carbon Na are shown below.

<u>Stress,</u> <u>psi</u>	<u>Rupture</u> <u>time, hr</u>	<u>Elonga-</u> <u>tion, %</u>	<u>Reduction</u> <u>of area, %</u>	<u>Min creep</u> <u>rate, hr</u>
26,000	48	31	31*	
26,000	59	50	39	0.3900
24,000	195	18	21	0.0206
22,000	390	22	16	0.0150
19,500	1037	16	13	0.0110
18,500	3661	13	9	0.0025
17,500	2600**			0.0027

*Failure at gauge mark

** In progress

Impact test blanks of 304 SS are being exposed at 1200°F for various time periods in both high-oxygen and high-carbon sodium and helium. These specimens are then tested in air at room temperature. Results to date on 0.098-in.-thick specimens show that the average impact strength drops from 18.1 to ≈2.5 ft-lb after 4000 hr of exposure to high-carbon Na. Similar tests after 1200°F helium exposure for 4000 hr show a reduction to 15.6 ft-lb. Under similar conditions, tests on 316 SS showed a less severe drop in impact strength.

Metallographic analyses of unstressed 304 SS monitoring tabs in high-oxygen and high-carbon Na indicate the same "behavior" as earlier 316 SS tabs did under similar conditions. The 304 SS tabs in either Na environment show a rapid carburization rate, a transition to a two-phase ferrite plus austenite matrix, and a change from $M_{23}C_6$ carbides to M_7C_3 .

Creep-rupture specimens tested up to 390 hr are characterized by intergranular surface cracking and ductile failure. In tests of >1000 hr the fracture is completely intergranular with little evidence of plastic deformation. These latter specimens have a ferrite network that completely encases the austenite grains and are characterized by a marked increase in carbon content of the steel.

An extensometer development program to increase the accuracy of creep measurements in Na is in progress. Two linear variable differential transformers are used. Calibration tests in air at room temperature, 400°, and 800°F proved satisfactory, but tests at 1200°F were not successful.

The chemistry program to determine the quantity of O, C, H, carbonate, and other contaminants in the loop cold traps was reactivated.

(A. Fleitman)

REVIEW NO. 502

ACCELERATED CAVITATION DAMAGE OF STEELS
AND SUPERALLOYS IN LIQUID METALS

Sponsor: National Aeronautics and Space Administration
Contractor: NASA, Lewis Research Center, Cleveland, Ohio
Report No.: NASA TN D-3426
Report By: S. G. Young and J. R. Johnston
Report Date: May 1966
Previous Reviews: 17,60,84,157,261,371

Vibratory cavitation tests were conducted on various materials in liquid sodium at 800°F and in mercury at 300°F. The frequency of vibration was 25 kc/sec with a total amplitude of 1.75 mils.

The materials investigated included types 316 and 318 stainless steel, Sicromo 9M, Inconel 600, A-286, Hastelloy X, Haynes Alloy 25, Rene 41, and Stellite 6B. Materials were ranked according to volume loss, and the most resistant material in both fluids was Stellite 6B, while the least resistant was Sicromo 9M. Surface roughness measurements gave the same ranking of the materials.

Visual inspection of sodium pump impellers of types 316 and 318 stainless steel and Rene 41, after operation for 250 hr under cavitating conditions, indicated that the Rene 41 impeller had virtually no damage while both stainless steel impellers had regions of marked damage. This relative resistance of the various materials was confirmed by the vibratory tests.

Following is a brief summary of other major results:

1. Materials that were tested in both fluids ranked in the same order based on resistance to damage.

2. The damage to materials tested in mercury was consistently greater than that to materials tested in sodium. For example, after 4 hr the volume loss on Stellite 6B and Haynes 25 in mercury was about 4 to 5 times that encountered in sodium.

3. Metallographic examination during early stages of damage indicated that cavitation in sodium resulted in non-uniform damage to all materials, as evidenced by the delineation of twin and grain boundaries. Cavitation in mercury resulted in uniformly damaged surfaces with no apparent preferential attack except for Stellite 6B, where the carbides were more resistant than the matrix.

(K. C. Hoffman)

REVIEW NO. 503

SECOND QUARTERLY REPORT
VAPOR-CHAMBER FIN STUDIES

Sponsor: National Aeronautics and Space Administration
Contractor: Pratt & Whitney Aircraft, East Hartford, Conn.
Contract No.: NAS3-7622
Report No.: PWA-2773 and NASA CR-54922
Report By: L. S. Langston, A. Sherman, B. H. Hilton
Report Period: Sept. 1 to Nov. 30, 1965
Report Date: January 1966
Previous Reviews: 481

The purpose of this study is to explore and define the mechanism of heat transport in the vapor-chamber fin concept. A derivation of the vapor-chamber fin model and a simplified analysis of fin operation were presented in the first quarterly report (REVIEW NO. 481). Basically, a vaporizing fluid transports heat from the heated end of the fin to other surfaces of the fin where it condenses, and capillary action in a wick returns the condensate to the heated surface.

This second quarterly report deals with wicking and boiling studies. Some wicking materials were received for testing, and electrochemical machining was selected as a suitable method for cutting samples of the porous materials.

Capillary rise experiments, designed to provide a measure of the maximum pumping force that a wicking material can produce, were initiated. A relatively long time, on the order of days, is required for a liquid front in a sample to reach an equilibrium height. Some of the denser porous metal samples did not reach equilibrium within 20 days.

Preliminary data on friction factor for fluid flow through some of the wicking material were obtained using degassed water or Freon 113. The results thus far show that dissolved gases were probably the cause of time-dependent friction factors found by other investigators.

The apparatus for the wick boiling study was built and tested. Preliminary tests were run using a flat-plate sample. As yet, no porous samples have been tested.

(R. J. Parsick)

REVIEW NO. 504

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

Sponsor: U. S. Air Force
Contractor: San Fernando Laboratories, Pacoima, Calif.
Contract No.: AF33(615)-2226
Report No.: Fifth Quarterly Report
Report By: R. B. Kaplan and F. A. Glaski
Report Date: March 1966

This report describes the progress of a program to develop methods for coating the inside surface of stainless steel condenser radiator assemblies and subassemblies with Cb - 1 Zr by chemical vapor deposition techniques.

(1) Progress was reported on the vapor deposition ($\text{TaCl}_5 + \text{H}_2$) of Ta on 316 SS. Adherent bonds were not obtained unless a thin layer of columbium was first deposited on the 316 SS. Without a prior Cb deposit, separation of the Ta plate from the 316 SS always occurred after a cooling down period.

(2) Cb and Cb-Zr vapor deposition experiments on T-section tubing joints of 316 SS were successful. The best single surface preparation of a joint that assures adherence of a Cb deposit to 316 SS was found with a dilute HF etch. Surface preparation using hydrogen bakeouts with H_2 containing <3 ppm H_2O will be evaluated.

(3) Incremental plating of lengths of up to 5 ft of 316 SS tubing were studied. The best technique, although cumbersome, appears to be to heat the entire tube length to the $1050^\circ C$ plating temperature and successively cool 6-in. portions to $350^\circ C$. However, it is necessary to remove the reactant gases ($CbCl_5 + H_2$) prior to each cooling down period in order to eliminate buckling (due to hydrogen) of the plate. This plating technique could be utilized in operations designed to "weld" previously coated tubing sections into an integral condenser radiator assembly.

(4) The hydriding characteristics of Cb, Zr, and Cb - 1 Zr were studied. Cooling to room temperature of Cb - 1 Zr and Zr specimens which had been held in $600^\circ C$ H_2 for up to 65 min resulted in shattering of the specimens. The ductility of Cb - 1 Zr specimens could be totally restored if the specimens were vacuum annealed for 8 min at $1050^\circ C$ before cooling down. Pure Zr however, could not be totally dehydrided even if held in vacuum for 30 min.

(5) A 3-ft length of tubing was uniformly plated (0.002 to 0.003 in. thick) at a system pressure of -25 in. Hg and a $H_2:CbCl_5$ gas mixture ratio approaching stoichiometric. Tests on tube lengths up to 10 ft are planned.

(A. Fleitman)

REVIEW NO. 505

UNITED NUCLEAR CORPORATION MONTHLY PROGRESS REPORT
ON DEVELOPMENT OF A CARBON METER FOR SODIUM

Sponsor: U. S. Atomic Energy Commission
Contractor: United Nuclear Corporation, Elmsford, N.Y.
Contract No.: AT(30-1)-3665; UNC Project 2338
Report No.: Progress Letters Nos. 1, 2, 3, and 4
Report By: J. M. McKee

Report Dates: April, May, June, July 1966
Previous Reviews: none

"The objective of this program is to develop an on-line meter to measure carbon activity or concentration in sodium. The work will include:

1. Experimental measurements to obtain data needed for basic understanding and engineering design of the meter.
2. Design, construction, and evaluation of prototype meters.
3. Design and construction of operational instruments suitable for routine use during field trials.

Tests have shown that at 1400°F carbon will transfer from sodium to iron, diffuse through a thin wall, and react with dry hydrogen to form methane. The methane concentration thus produced in the hydrogen stream was shown to vary with the carbon activity in the sodium and to be readily measurable with a commercial flame ionization detector.

However, it was less than a tenth of the concentration predicted assuming that carbon diffusion through iron was the rate-limiting step. Metallography subsequently revealed a buildup in carbon content of the iron wall, showing that reaction of carbon with hydrogen was the rate-limiting step. Recently published work indicates that carbon could be removed from the iron much more rapidly by moist argon containing a little hydrogen. In this case, the carbon forms carbon monoxide and the hydrogen simply prevents oxidation of the iron. Although carbon monoxide cannot be detected as sensitively as methane, recent information now indicates that carbon monoxide can readily be catalytically converted to methane if necessary. Accordingly, evaluation of such gas mixtures as well as dry hydrogen was included in the test program.

The program was started late in February 1966. Three preliminary capsule tests were performed. These showed that both dry hydrogen and argon - 3% H₂O - 10% H₂ can remove carbon from iron more rapidly than carbon saturated sodium can supply it to iron at 1300°F. The gas analysis equipment needed for carbon flux measurements was selected and ordered. Two static sodium pots and their associated gas supply system

were designed. As of the end of June, fabrication and leak testing of these two pots for static tests were just completed."

(authors)

REVIEW NO. 506

COMPREHENSIVE CAVITATION DAMAGE DATA
FOR WATER, MERCURY, AND LEAD-BISMUTH
ALLOY INCLUDING CORRELATIONS WITH
MATERIAL AND FLUID PROPERTIES

Sponsor: National Science Foundation
Contractor: University of Michigan, Ann Arbor, Mich.
Contract No.: Grant G-22529
Report No.: 05031-4-T, Technical Report No. 4
Report Date: May 1966
Report By: R. Garcia, F. G. Hammitt, R. E. Nystrom
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, 484

Ultrasonic-induced cavitation studies have been conducted in lead-bismuth alloy at 500° and 1500°F, in mercury at 70° and 500°F, and in water at 70°F for a variety of materials including refractory alloys, steels, brasses, copper, nickel, and Plexiglas. Liquid metal exposure was limited to the steels and refractory alloys except for low temperature mercury tests with Plexiglas. The specimens were oscillated at about 20 kc/sec with a double amplitude of 0.002 in.

Following are the major conclusions reached as a result of this work.

1. The tantalum base alloys, T-111 and T-222, were the most cavitation resistant of the materials tested in lead-bismuth at 500° and 1500°F, in mercury at 500°F, and in water at 70°F. The stainless steels were the most resistant in mercury at 70°F.

2. All materials tested in mercury and lead-bismuth exhibited greater damage at the higher test temperature, with the exception of carbon steel which exhibited greater damage

in mercury at 70°F than at 500°F. This can be explained by the superior mechanical properties of carbon steel at the higher temperature.

3. Damage rates with mercury were 3 to 20 times greater than those for water. The damage noted in lead-bismuth and mercury at 500°F was comparable.

4. Comparison of cavitating venturi and vibration results shows a similar ranking of materials. The damage rates in the vibration tests are about three orders of magnitude greater than those in the venturi tests. Thus corrosive effects are of much less relative importance in the vibration tests.

5. Computer correlations of damage data with mechanical and fluid properties indicate that no simple single correlating equation applies to all the data. The best correlations generally include one or more of the energy-type mechanical properties, one or more of the strength-type properties, and one or more of the fluid coupling parameters. The energy-type properties are more predominant in the tests with high-density liquid metals, while the strength-type properties predominate in water tests.

(K. C. Hoffman)

REVIEW NO. 507

SNAP-50/SPUR GENERATOR DEVELOPMENT PROGRAM

Sponsor: U. S. Air Force, Wright-Patterson AFB, Ohio
Contractor: Westinghouse Electric Corp., Aerospace Electrical
Division, Lima, Ohio
Contract No.: AF33(615)-2326
Report No.: WAED 66.30E
Report By: Aerospace Electrical Division and approved
by R. W. Briggs and N. W. Bucci
Report Date: April 15, 1966
Previous Reviews: 111, 388, 426, 447, 485

The objective of this program is the continued development of the ac generator for the SNAP-50/SPUR power plant. Following is a summary of progress in each of the major development tasks:

1. Bore seal development: 2.5-in.-diam tubular bore seal specimens were loaded with potassium, and aging tests at 1100°F, planned for 1000-hr duration, are in progress. These specimens are made of high-purity alumina cylinders brazed to both ceramvar and Cb - 1 Zr end pieces with various zirconium- and titanium-base braze alloys. X-ray examination after 200 and 500 hr showed no evidence of leakage. Development work on 11.5-in.-diam assemblies is in progress. Explosive bonding techniques are being studied to provide a transition joint between a refractory metal that can be joined to the ceramic bore seal and a nonrefractory metal that can be joined to the frame of the generator.

2. Stator development: Assembly of the dummy stator is complete and electrical testing is scheduled. Some of the fabrication techniques are discussed. Thermal aging of two test statorettes under high vacuum and argon at 600°F is in progress, with 9340 hr accumulated in a 10,000-hr run.

3. Rotor development: Strain data are presented on a continuing test of four creep specimens of H-11 alloy steel rotor material.

Mechanical property tests of H-11 creep specimens exposed to potassium (and the metallic impurity and carbon analysis of the potassium used in the test) are reported. Metallographic examination of the specimens exposed to potassium indicates no attack.

4. Full-scale generator: Fabrication is proceeding and major accomplishments are discussed. The program to carry out analytical verification tests is outlined.

(K. C. Hoffman)

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 Corp., Aerospace Electrical Division, Lima, Ohio

Contract No.: NAS3-6465
Report No.: NASA-CR-54355
Report Period: March 1, 1965 to May 31, 1965
Report Date: June 1965
Previous Reviews: 446

The purpose of this program is to develop high-temperature electrical materials for application to advanced space electric power systems. The effort is divided into three areas as follows:

1. Development of a high-temperature magnetic material with satisfactory strength for rotor use.
2. Establishment of the feasibility of a high-temperature capacitor.
3. Development of a ceramic-to-metal bore seal that is compatible with alkali metals. Promising seals will be tested in potassium and lithium vapor at temperatures between 1000° and 1600°F for 2000 hr. Seal strength and vacuum tightness will be evaluated. A 4-in.-diam bore seal loaded with potassium will be incorporated in a stator design, and will be evaluated in a 5000-hr endurance test at temperatures in a high vacuum environment.

The chamber for alkali metal loading, electron beam welding, and the dual vacuum furnaces for capsule environment exposure were checked out. These facilities are described in the report.

Outgassing tests on alumina and beryllia ceramics have been completed.

The active-metal brazing study was initiated. Active metal brazing alloys which were received in the foil form were found to have higher oxygen content than in the powdered form. Beryllium, thorium, titanium, zirconium, yttrium, and vanadium in both pure metal form and alloys are being studied.

(K. C. Hoffman)

FIGURE 1. PVT DATA - CESIUM (EXPERIMENT 19)
(Review No. 486)

Figure 2
(Review No. 486)

Fig. 3. Solubility of O in Na at various temperatures.

(Review No. 499)

Table I

SUMMARY OF TEST RESULTS

Test	Na (°F)	H ₂ O (°F)	H ₂ O Pressure (psi)	Steam (°F)	Steam Pressure (psi)	H ₂ O Flow (lb/sec)	Pressure at Rupture (psi)	Pressure 5 ft Above (psi)	Pressure 5 ft Below (psi)	Time per 5 ft Above (msec)	Time per 5 ft Below (msec)	
0 ^a	—	—	—	1040	1500	—	—	—	—	—	—	Preliminary — steam only — no sodium pressure in test section. Reached 120 psi
1-A ^b	757	—	—	970	2060	—	—	—	—	—	—	Steam valve malfunction — no data
2-A	917	—	—	1038	2180	—	(800) ^c	400	365	0.6	0.6	Peak pressure exceeded range of instrument (ex- trapolated value)
1-B	920	480	2750	—	—	12	(1500) ^d	380	580	0.6	0.6	Pressure due to impact
2-B	900	455	2650	—	—	11	(—) ^e	347	335	—	—	Premature rupture of burst diaphragm (failed impact)
3-B	918	465	2740	—	—	11	(3410) ^f	160	481	—	—	(Impact) irregular pressure sequence
1-C	922	469	2760	—	—	12	(604) ^g	300	410	0.75	0.65	(Same instrument used for 3-B)
2-C	919	472	2770	—	—	12	(484) ^h	276	335	0.90	0.90	(Piezoelectric)
3-C	922	467	2690	—	—	11.5	915	485	(—) ⁱ	0.40	(—) ⁱ	
4-C ^j	920	470	2780	—	—	—	745	475	455	0.75	0.95	
1-D	676	471	2760	—	—	—	1850	(740) ^k	(170) ^k	0.25	0.27	
2-D	674	466	2770	—	—	—	2780 ^l	(—) ^j	(—) ^j	—	—	
3-D	691	426	2650	—	—	—	2160 ^m	123	318	0.40	0.33	
4-D	681	400	2650	—	—	—	1290 ^m	970	400	0.38	0.28	

a — Preliminary — Steam only — No sodium-pressure in test section
reached 120 psi

b — Steam valve malfunction — no data

c — Peak pressure exceeded range of instrument (extrapolated
value)

d — Pressure due to impact

e — Premature rupture of burst diaphragm (failed-impact)

f — (Impact) irregular pressure sequence

g — (same instrument used for 3-B)

h — Piezoelectric

i — Failed

j — 14-ft tube bundle

k — Followed by higher secondary peak pressures

l — 3-sec delay

m — Disc tube rupture

(Review No. 492)

Table II

<u>Run No.</u>	<u>Hot leg material</u>	<u>Cold leg material</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>
3-10	Type 316 SS	2¼ Cr - 1 Mo	1096	246	0.70	52	2827
4-8	Type 316 SS	5 Cr - ½ Mo - ½ Ti	1195	499	0.80	48	1407
4-9	Type 316 SS	5 Cr - ½ Mo - ½ Ti	1099	495	0.40	53	2805
5-6	2¼ Cr - 1 Mo	2¼ Cr - 1 Mo	1100	*	0.39	39	*
5-7	2¼ Cr - 1 Mo	2¼ Cr - 1 Mo	1200	**	0.40	**	771
5-8	2¼ Cr - 1 Mo	2¼ Cr - 1 Mo	1102	252	0.40	16	2821
6-7	5 Cr - ½ Mo - ½ Ti	5 Cr - ½ Mo - ½ Ti	1097	495	0.40	11	2802

*259°F first 431 hr, 601°F last 270 hr.

**500°F for 503 hr (49 ppm oxygen), 593°F for 268 hr (24 ppm oxygen).

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, 464,486	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. 465,487	Atomics International 33,92,301,341,365,395,431,492,493
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, 453,454,494
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, 412,449,450,466,467,488	Baldwin-Lima-Hamilton Corp. 57,122,147,174,208
Allegany Ballistics Lab., Hercules Powder Company 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, 469,489,490,491	Columbia University 73,344
	Consolidated Controls Corp. 250,278,323,367,397,435,473,495
	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,
496, 497, 498

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, 499

Massachusetts Institute of Tech.

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, 500, 501

NASA-Lewis Research Center

17, 60, 84, 157, 261, 371, 502

Oak Ridge National Laboratory

58, 90, 91, 95, 284, 298, 377, 378, 404,
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, 503

Rocketdyne (A Div of N. American
Aviation)

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

San Fernando Laboratory

382, 422, 504

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, 505

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, 506

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, 507, 508