BNL 801 (PR-2)

HIGH-TEMPERATURE LIQUID-METAL TECHNOLOGY REVIEW

A Bimonthly Technical Progress Review

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

VOLUME 1 • NUMBER 2 • APRIL 1963

BROOKHAVEN NATIONAL LABORATORY
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FOREWORD

Since this is just the second issue of the High-Temperature Liquid-Metal Technology Review, it is deemed advisable to explain again its purpose and the manner in which it is prepared.

The purpose of the Review is to keep its readers up-to-date on technical developments in the fast-moving high-temperature liquid-metal field, particularly as they relate to the space power program, and as far as unclassified information is concerned. The Review will cover all phases of liquid metal technology pertinent to the space program, including materials development, corrosion, heat transfer, fluid dynamics, instrumentation, component development, physical properties, and power systems.

All research-and-development contractors working in the liquid-metal field, for the various Government agencies, have been asked to submit their reports and technical papers to Brookhaven for review. The reviews will then be collected and published on a bi-monthly basis. Those laboratories which regularly submit their reports for the Review will automatically receive copies, at the time of issuance.

The reviewing and abstracting of the organizational reports are done mainly by staff members of the Nuclear Engineering Department at Brookhaven.

Again, we repeat--any comments and suggestions for increasing the value of the Review will be most welcome.

Finally, the help of Judith Ridgeway in compiling and typing the Review and that of Jean Reynolds in editing it, is gratefully acknowledged.

O. E. Dwyer
Technical Editor

High-Temperature Liquid-Metal Technology Review

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TOPICAL REPORT NO. 17
MERCURY BOILING RESEARCH

Sponsor: Atomics International, A Division of North American Aviation, Inc.
Contractor: Thompson Ramo Wooldridge Inc., Cleveland, Ohio
Sub-Contract No.: N843FS-101221
Report No.: TRW Report No. ER-4833, NAA-SR-6309
Prepared By: R. G. Gido and A. Koestel
Report Date: October 1962

This report summarizes the Hg boiling research carried out as part of the development work for the SNAP II Power Conversion System.

Theoretical equations for boiling coefficients were obtained, based on a drop model for the forced convection boiling of Hg. The drops may contact the tube wall surface, ride on a vapor film, or both, depending on the radial force tending to hold the drops against the wall and the vapor repulsive force due to the evaporation. When the Hg is in contact with the wall, Eq. 7-16 of this report is used:

$$\frac{hD}{k_v} = \frac{1}{32} Nu_\delta^2 \left(\frac{k_f}{k_v}\right)^2 \left(\frac{D}{\delta_o}\right)^2 \frac{(1-x)^{1/3}}{x} \frac{\rho_v}{\rho_f}$$

When film forced convection boiling prevails, Eq. 7-17 is used:

$$\frac{hD}{k} = \frac{6^{1/3}}{4} \frac{(1-x)^{2/3}}{x^{1/3}} \frac{D}{\delta_o} \beta^{4/3} (\tan \alpha)^{2/3} \left(\frac{\rho_v}{\rho_f}\right)^{2/3} \left(\frac{DG_T}{\mu_v}\right)^{2/3} \left(\frac{h_{fv}\mu_v}{k_v \Delta T_m}\right)^{2/3}$$

The transitional equation for intermittent contact (Eq. 7-25) was obtained empirically as a result of the data of this report:

$$\frac{hD}{k_v} = C^4 (234) \left(\frac{k_v}{k_f}\right)^4 (1-x)^{4/3} x \left(\frac{\delta_o}{D}\right) (\tan \alpha \frac{DG_T}{\mu_v} \frac{h_{fv}\mu_v}{k_v \Delta T_m})^2$$

To determine which equation applies, checks must be made to determine which boiling regime exists. In the above equations,

δ_o = initial drop diameter,

$\beta = \frac{\text{Nu (actual)}}{\text{Nu (film-spheres)}}$,

α = swirl wire angle.

An experimental program was carried out to provide data on both heat transfer and pressure drop during vortex, once-through, forced convection boiling of Hg. The research rig was composed of a N_2-pressurized reservoir-accumulator Hg feed system, an electrically-heated forced convection boiler, a 30-in. test section, an air-cooled condenser, and a combination collecting pot-mass weighing system. The operating ranges for the tests were as follows:

1.	Max flow rate	4 lb/min
2.	Min flow rate	1.5 lb/min
3.	Max system pressure	500 psia
4.	Max boiler power	~15 kw
5.	Test section power	~2.8 kw
6.	Max test section or tube temperature level	~1400°F

All data were correlated according to the heat transfer theory. A sample comparison of the data and theory is shown in Fig. 1.

Analysis of the test section data also showed that a considerable improvement over a bare tube is obtained by using a swirl device. An approximate factor of three times the bare tube heat transfer was obtained. This effect depends on swirl device geometry, mass velocity, boiling regime, etc., however, and could be greater or smaller depending on the application. It was found that the rig boiler swirl wire influenced the test section data. This was particularly noticeable with the SN 3 test data which had a 0.028-in. swirl wire as compared to the 0.0625-in. swirl wire used in the boiler.

Pressure drop correlations are presented for all test sections except the SN 1 for which the pressure drop was too low for measurement. It is shown that the drop flow of Hg results in greater pressure drop than the annular two-phase flow more commonly experienced. The Hg drops offer more surface area and therefore increased drag on the vapor. It is further shown

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Fig. 1 in Review corresponds to Fig. 7-20 in report

that the wire swirl device resulted in less two-phase pressure drop effect than the bare tube. This is attributed to the wire shielding effect.

(J. C. Chen)

REVIEW NO. 14

QUARTERLY PROGRESS REPORT
ADVANCED NUCLEAR ELECTRIC POWER GENERATOR

Sponsor: National Aeronautics and Space Administration
Contractor: Pratt and Whitney Aircraft, East Hartford, Conn.
Contract No.: NASw-360
Report No.: PWA-2157 Volume II
Prepared By: P. Bolan, W. J. Lueckel
Report Date: October 1 through December 31, 1962

Thermionic Power Plant Analysis

The nuclear thermionic power plant has been analyzed to select a promising system in the one megawatt electric size range. A parametric analysis can use any of a variety of approaches and criteria. In this particular study, six types of power plant have been examined. Each incorporated clad UC-ZrC fuel acting as the emitter of the converter. System studies were conducted assuming that the quantity of ZrC diluent varied to maintain a constant fuel evaporation rate. As a result, an optimum emitter temperature was found for each evaporation rate and the optimum temperature for 0.002 in./yr fuel evaporation was 3200°F. Below this temperature, the power density and efficiency of the converters was lower. At higher temperatures, the increase in diluent reduced the fuel loading and a thicker neutron reflector was required. The six power plants were compared at an emitter temperature of 3200°F.

The six power plants studied were all conceptually similar except for changes in the reactor cooling fluid, the radiator fluid, and the radiator material. Li and NaK were used in both the reactor loops and radiator loops. Both Cb alloy and Be were analyzed as radiator materials. The Be radiator is restricted to 1400°F as a reasonable upper limit for this material. The Cb alloy is capable of about 2000°F. Also, the NaK systems were limited to 1850°F from pressure considerations.

Of the six power plants, the three with Li primary systems are most attractive. The power plant utilizing a Be radiator and Li secondary loops offers the lowest weight. However, another major criterion is the radiator area, and the Cb radiator is significantly superior in this respect. The NaK radiator fluid is interesting because it might allow a simpler starting system even though its radiator is larger. The choice between these three systems is not clear at this time because the importance of radiator area and the complications of starting are not established.

Fuel Element Temperature Analog Study

A study was made to determine the circumferential temperature distribution in a fuel element in the thermionic reactor, with the element within the equilateral triangular matrix in line contact with its neighbors, and with Li coolant flowing in the cusp-cornered triangular passages surrounding it. The solution was accomplished by utilizing the analogy between heat and electrical conduction, assuming the coolant to be completely stagnated in the corners of the triangular coolant passages. At a heat flux of 6.83×10^4 Btu/hr-ft^2 and Li coolant flow of 10 ft/sec at a temperature of 1250°F, a maximum circumferential temperature difference of about 41°F was calculated.

(M. Maresca)

REVIEW NO. 15

LOS ALAMOS SCIENTIFIC LABORATORY
QUARTERLY STATUS REPORT ON LAMPRE PROGRAM
FOR PERIOD ENDING FEBRUARY 20, 1963

Sponsor: U. S. Atomic Energy Commission
Contractor: Los Alamos Scientific Laboratory, Los Alamos, N.M.
Contract No.: W-7405-ENG. 36
Report No.: LAMS-2875
Report Date: March 1963

LAMPRE I accumulated an additional 29 Mwd of operation to give a total integrated power of 70.2 Mwd for Core II.

Metallographic examination of LAMPRE fuel capsules has continued since the leak of September 15, 1962 (see LAMS-2815). Two additional capsules (Nos. 1273 and 1290), removed from the core subsequent to the leak, have been examined. A conspicuous absence of intergranular penetration was observed for all areas of these irradiated fuel capsules except in the weld zone. All three capsules exhibited intergranular penetration of Pu fuel in the heat-affected zone of the closure weld. In addition, the capsules showed evidence of Na attack of the weld metal surface. Similar attack has been observed in Ta containing appreciable amounts of oxygen. Since these observations suggest oxygen contamination of the Ta during closure welding, extensive investigations have been initiated to improve welding procedures and to re-examine the effects of oxygen on Pu-fuel corrosion of Ta.

Construction on a core test facility is due to start in June. In this connection, information is given on the major components in the Na piping system. These include piping, intermediate heat exchanger, heat dumps, pumps, flowmeters, hot and cold traps, pressure transducers, Na level indicators, Na leak detector, Na smoke filters, core cover gas cleanup system, and instrumentation.

(O. E. Dwyer)

REVIEW NO. 16

PROCEEDINGS OF 1962 HIGH-TEMPERATURE LIQUID-METAL HEAT TRANSFER TECHNOLOGY MEETING

Sponsor: U. S. Atomic Energy Commission
Contractor: Brookhaven National Laboratory
Report No.: BNL 756 (C-35)
Report Date: May 1962

The purpose of the annual meetings on High-Temperature Liquid-Metal Heat Transfer is to provide an opportunity for workers in the field to describe their own work and to become familiar with the work of other researchers in the same field. This set of proceedings for the 1962 meeting probably represents the most current, comprehensive survey of research efforts throughout the country in the liquid-metal field.

Twenty-four unclassified papers describing work at nineteen different organizations are reproduced in the Proceedings, together with associated discussions. The list of titles and reporting organizations are as follows.

1. Development Problems of SNAP Reactor Systems - Compact Power Systems (SNAP).
   Division of Reactor Development, AEC

2. Alkali Metal Physical Properties Program at Pratt and Whitney Aircraft-CANAL.
   Pratt and Whitney Aircraft

3. Vapor Pressure of Alkali Metals, III. Rubidium, Cesium, and Sodium-Potassium Alloy (NaK) up to 100 Pounds per Square Inch.
   Columbia University

4. Current Status of the Research Program on the Engineering Properties of Potassium.
   Battelle Memorial Institute

5. Rubidium-Cesium Evaluation Program Thermodynamic Property Measurements.
   Aerojet-General Nucleonics

6. Summary of Sodium Boiling and Condensing Studies.
   Atomics International

7. Liquid Metal Boiling Studies at The University of Michigan.
   The University of Michigan

8. Pool Boiling of Sodium.
   University of Wisconsin

9. Alkali Metals Boiling and Condensing Investigations.
   General Electric Company

10. Liquid Metal Heat Transfer Test Programs.
    AiResearch Mfg. Co.

11. Forced-Convection Saturation Boiling of Potassium at Near-Atmospheric Pressure.
    Oak Ridge National Laboratory

12. Boiling Potassium Heat Transfer Project Loop Design and Development.
Brookhaven National Laboratory

13. Rubidium-Cesium Evaluation Program Heat Transfer and Fluid Flow Studies.
Aerojet-General Nucleonics

14. High Temperature Boiling Mercury Experiment.
Atomics International

15. Potassium-Mercury Amalgam Heat Transfer and Two-Phase Flow Investigation.
Allison Division, General Motors Corp.

16. Liquid Metal Research at NASA-Lewis Research Center.
NASA-Lewis Research Center

17. Experimental Determination of Over-all Heat Transfer Coefficients for Condensing Sodium.
Aeronautical Systems Division, Wright-Patterson AFB

18. Rubidium Heat Transfer Testing at Sundstrand Aviation-Denver.
Sundstrand

19. Boiling and Condensing Liquid Metal Loop.
Westinghouse Astronuclear Laboratory

20. Development of SNAP-2 Heat Transfer Components.
Atomics International

21. Design and Fabrication of a 2100°F Forced Convection Lithium Test Loop.
Martin Company

22. Geoscience Ltd. Progress Report on High-Temperature Liquid-Metal Heat Transfer for the AEC.
Geoscience Ltd.

23. Boiling Sodium Experimental Studies.
Argonne National Laboratory

24. Eddy Diffusivity Effect in Liquid-Metal Heat Transfer.
Brookhaven National Laboratory

(J. C. Chen)

REVIEW NO. 17

SUMMARY OF PROGRESS "IN-HOUSE" LIQUID METAL INVESTIGATIONS

Sponsor: National Aeronautics and Space Administration
Contractor: NASA-Lewis Research Center, 21000 Brookpark Road, Cleveland, Ohio
Report By: NASA-Lewis Research Center Staff
Report Date: March 1963

This report summarizes the progress as of March 1963 on the following liquid metal investigations.

1. Two-Phase Loops

The study of expanding flow through a research nozzle in a Na loop has been completed. Data have been obtained over a temperature range to 1700°F. These are now in the computation and analysis stage. A new high temperature Cs loop is being designed for two-phase flow studies at 2500°R. The facility is expected to be in operation in early 1964.

2. Sodium Turbine Facility

This facility is in the final phases of installation. Facility checkout and "shake-down" tests are expected to begin in June 1963.

3. Pump Test Facility

A low pressure loop has been successfully operated with Na. At present, a research cavitating pump inlet stage is being installed in the loop. Cavitation experiments, using this pump, are expected to begin in April 1963. A high pressure loop has been received from the contractor and is in the final stage of installation.

4. Liquid Alkali Metal Heat Transfer

Construction of this facility is ≈50% complete. Full completion and initial "shake-down" tests are planned for December 1963.

5. Space Radiator and Condenser Facility

Installation of this facility is 95% complete. It is expected to be charged with K and undergo "shake-down" tests in June 1963.

6. Bearing and Seal Studies

Friction and wear properties of candidate coatings and potential base materials were screened in a reducing atmosphere (10% H_2 in N_2) at temperatures to 2000°F. Subsequently, selected materials of interest were run submerged in liquid Na to determine friction, wear, and surface failure properties. Initial experiments at 1000°F confirmed predictions of stability, based upon chemical thermodynamics; however, in the case of lithium fluoride, solubility of the compound in Na was observed. Data obtained in the reducing gas provided significant correlation with data obtained in Na.

Initial operation of a high temperature seal rig with liquid Na at 1000°F has begun. With this rig, seals may be studied at temperatures to 1600°F, speeds to 50,000 rpm, and pressures to 1000 psi. Presently, work is under way with face type sliding contact seals, employing cermet running faces and using bellows type secondary sealing. Relatively high leakage rates have been experienced and corrective measures are under consideration

Compatability of Hg with a polyphenyl ether is being determined at temperatures ranging to that associated with pyrolytic degradation of the ether (800°F). No degradation of either the Hg or ether was noted at temperatures to 400°F.

7. Mercury Programs

(a) The purpose of the MECA-WASP (Mercury Evaporation and Condensing Analysis Weightless Analysis Sounding Probe) program is to define the performance and dynamic stability characteristics of typical SNAP-8 Hg vapor condenser tube configurations under one-g and zero-g operating conditions. The current effort is directed toward the development of components for an experiment payload for the two-stage WASP rocket vehicle. Basically, the condensing experiment apparatus consists of a gas pressure operated Hg expulsion cylinder, a direct electrically heated Hg boiler, a vapor flowmeter, the condenser tube, and a pressure-regulated condensate receiver. The coolant side includes a heated NaK expulsion unit driven by a regulated gas supply, a flowmeter, a collector, and an overboard dump diffuser. The major problem on the Hg side of the system has been with the Hg boiler, but this has been solved by a design in which the Hg flow coil is used as a resistance heater.

In addition to development of a flight payload, experiments pertaining to two-phase condensing flow phenomena are being conducted by use of convectively-cooled metal and glass tubes in ground test facilities and under short-term zero-g conditions (10 to 12 sec) provided by an AJ-2 aircraft. Approximately 100 zero-g trajectories have been flown during 25 flights to develop piloting techniques and to obtain high-speed movies of Hg condensing flow characteristics. Data obtained from these flights are being analyzed.

(b) The purposes of the simulated SNAP-8 system program are to evaluate quasi-steady state and dynamic characteristics of the integrated SNAP-8 liquid metal loops, to develop an electric NaK heater for simulation of the SNAP-8 nuclear reactor, and to evaluate system operating problems.

Experimental equipment consists of a loop system incorporating the basic features of the SNAP-8 concept with regard to line sizes, component volumes and heat capacities, and heat fluxes. Although the initial configuration will not include any of the actual SNAP-8 components, provisions are being made in the loop design to allow incorporation of actual components as they become available. The reactor will be simulated by an electric NaK heater and an analog controller to simulate the nuclear behavior. The NaK loop will also include appropriate pumps, reservoirs, control valves, plugging indicators, dump system, etc. The Hg power loop will consist of a SNAP-8 type boiler, a variable orifice and heat exchanger turbine simulator, a compact condenser, a pump, and injection reservoir. Third loop components include an all-liquid NaK radiator (convectively cooled) and a recirculating pump. System components are being fabricated and instrumentation and auxiliary equipment are being procured.

8. Materials Support Programs

Handling and analytical techniques for K purification have been established for complete vacuum operation and are now routine. The capsule test program for evaluation of suitable materials for containment of alkali metals has been altered slightly. The temperature range of interest extends from 1800° to 2200°F. It is now planned to screen ≈14 refractory metal alloys. These consist of Cb and Ta alloys, and include Haynes Cb-752, Fansteel FS-85, Westinghouse B-33 and B-66, and Ta-10W. Oxygen content will be varied in both the alloys and in the K

test fluid. In the temperature range from 1600° to 1800°F, Fe, Ni, and Co-base alloys will be screened with K with varying oxygen content. Alloys of interest will then be screened with Rb and Cs.

(J. C. Chen)

REVIEW NO. 18

UNIVERSITY OF MICHIGAN MONTHLY PROGRESS REPORT FOR MARCH

Sponsor: U. S. Air Force
Contractor: University of Michigan
Contract No.: 33(616-8277
Report No.: 4526-15-P
Report By: R. E. Balzhiser, Project Director
Report Date: March 1963

During the past month the high flux nucleate pool boiler was charged with K and several successful runs were obtained. Two burnout points were obtained for K, one at subatmospheric pressure and the other at 1 atm. The unreduced data seem to agree with the predictions of Noyes. The second of these burnouts resulted in catastrophic failure of the tube.

The film boiler is currently being operated with water as the fluid in both compartments in an effort to determine the significance of edge effects. These studies are once again under way after having been delayed by a Ta heater failure. The agravic portion of the program has not yet reached the operational stage. Construction of the apparatus is expected to be completed within the next reporting period and the initial data should follow very soon.

The liquid metal loop and associated instrumentation has been installed and the charging process is currently under way. K will be circulated in the primary loop initially to familiarize operating personnel with loop characteristics. The Na loop should be charged later this week and operation should commence some time during the first week of April.

(Authors)

REVIEW NO. 19

FOURTH QUARTERLY PROGRESS REPORT:
INVESTIGATION OF LIQUID METAL BOILING HEAT TRANSFER

Sponsor: U. S. Air Force
Contractor: The University of Michigan, Ann Arbor, Mich.
Contract No.: AF(33(616)-8277-Item IIa
Report No.: 04526-14-P
Report Date: February 1963

This report summarizes the progress realized in the period from August 1962 to February 1963. The over-all project is divided into the following programs.

1. Pool Boiling Studies

Fabrication of the experimental apparatus, which was described in the previous progress report, was completed during this report period. Preliminary testing of the equipment and instrumentation using water as the boiling liquid, was completed in mid-January. A number of nucleate boiling runs using water at pressures in the range 1 atm to 150 psig, and with fluxes up to one-half million Btu/(hr)(ft^2) were performed. The data compared well with the water data obtained by R. E. Lyons who also obtained data from an electrically heated 3/8-in.-diam tube.

K was charged to the vessel in late January. The equipment was checked out and a preliminary boiling run attempted. During the heat-up, the last boiling tube thermocouple failed. Upon removal of the lower head (of the outer protection vessel) it was discovered that the thermocouple sheath had shorted out against the boiling tube bus bar.

2. Film Boiling Studies

This phase of the project is concerned with the film boiling of liquid metals. Specifically, K will be studied between 1400° and 1800°F when boiling above a 1-in. diam horizontal plate.

The two previous quarterly reports have outlined in general terms the apparatus to be used. The assembly of the experimental system is essentially complete and is currently being checked out and evaluated using water in place of K. These runs are intended to assess the feasibility of obtaining film boiling by the two

techniques described earlier as well as provide some information on the significance of edge effects under these conditions. The latter evaluation will be made by comparing the results with those of Hosler and Westwater. Liquid metal data should be taken during the month of April.

3. Forced Circulation Studies

MSA Research Corporation recently completed the construction of the loop and it was installed on February 14. The loop is installed on a 7 1/2 by 7 1/2 by 12-1/2-ft steel framework to which hinged sheet steel plates are attached, enclosing the loop on all faces except the top. The electric and pneumatic lines are brought out to a terminal box. The necessary connections from the control panel to the loop are being made and the equipment checked out. A flow schematic is shown in Fig. 2.

4. Two-Phase Flow Studies

It appears that the main objective of this program is to investigate possible fluid-dynamic problems that could arise in the operation of the forced circulation loop discussed above. In considering the operation of the test loop, it seemed likely that instability problems might arise due to the merging of three two-phase streams from the preheaters and also because of the rather abrupt reduction in flow cross section in the funnelling section. In order to predict whether instabilities might occur, a series of air-water experiments was performed at room temperature in a Plexiglas mock-up of the loop's preheater, merging, and funnelling sections.

Considering again the operation of the test loop, the upper operating limits in terms of quality and liquid flow rate through the pump could be set by the occurrence of sonic choking rather than by the heat input rate. In order to better estimate the loop's operating limits, a prediction was made of the conditions under which critical flow might occur. The details of this work were presented in the August 1962 Monthly Progress Report.

5. Study of Boiling in Agravic Fields

The agravic studies have been set back by a series of delays in the design and construction stages. It is expected that construction will be completed within three to four weeks

and that operation will begin shortly after that. It is hoped that data from the initial runs will be available for the draft copy of the report to be prepared in late May.

6. Analytical Studies of the Transition and Film Boiling Regimes

The analysis of Zuber and Berensen has been used to predict film boiling curves for Rb, K, Na, and Li. Sample results for K are plotted in Fig. 3. Physical property data were obtained from Weatherford's report. The following equations were used to calculate the minimum flux at the ΔT corresponding to the minimum flux:

$$q_{min} = 0.156\ L\ \rho_v \left[\frac{g_c \sigma\ g\ (\rho_\ell - \rho_v)}{(\rho_\ell + \rho_v)^2}\right]^{1/4}$$

$$\Delta T_{min} = 0.262\ \frac{L\ \rho_v}{k_v} \left[\frac{\mu_v^2\ \sigma^3 g_c^3}{g(\rho_\ell + \rho_v)^4 (\rho_\ell - \rho_v)}\right]$$

(J. C. Chen)

Figs. 2 and 3 in the Review correspond to Fig. 7 and 14 respectively in report.

REVIEW NO. 20

LOS ALAMOS SCIENTIFIC LABORATORY
LAMPRE I FINAL DESIGN STATUS REPORT

Sponsor: U. S. Atomic Energy Commission
Contractor: Los Alamos Scientific Laboratory, Los Alamos, N.M.
Contract No.: W-7405-ENG.36
Report No.: LA 2833
Report By: K Division Personnel
Report Date: March 1963

LAMPRE I is the first reactor built by the Los Alamos Scientific Laboratory in its continuing program of developing fuels for advanced fast-breeder reactor applications. The core

of the reactor is an array of Ta capsules containing Pu-Fe alloy fuel. Of the 199 core locations, approximately 140 central ones are occupied by these fuel capsules, and the remaining locations are occupied by SS reflector pins.

Coolant Na enters the vessel and flows down through the 3/8-in. annulus formed between the vessel and a flow divider. At the bottom of the flow divider is a turn-around plenum where the coolant stream reverses to flow up through the bottom reflector, into another plenum, and then through a locator plate assembly into the core, where, after flowing past the fuel capsules and reflector pins, it flows through the top reflector region and into the outlet plenum. From this point it flows out of the vessel.

The report covers the design of the entire reactor system. The coolant system is described, with detailed information on such components as piping, em pumps, finned Na-to-air heat exchanger, Zr hot traps, dump tank, cold trap, instrumentation, and disposal system for contaminated Na.

(O. E. Dwyer)

REVIEW NO. 21

THERMOPHYSICAL PROPERTIES OF RUBIDIUM

Sponsor: Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio
Contractor: MSA Research Corporation, Callery, Penna.
Contract No.: AF 33(657)-7659
Report No.: ASD-TDR-63-133
Report Date: February 1963

This report covers the first year's work of this contract, is 70 pages long, and contains 120 references.

The vapor pressure of Rb was measured by the boiling point technique from 0.04 to 14.59 atm abs. The boiler and reflux column of the apparatus were constructed of Haynes alloy #25, a ductile Co-base alloy which proved resistant to Rb attack at high temperature. Thus the measurements extend the previous work of Bonilla from 7.5 to 14.6 atm. The agreement between the two sets of results is generally within 3.5%. The equation

$$\log_{10} P_{atm} = \frac{-7,005.20}{T°R} + 4.04369$$

represents the data.

The density of Rb was determined dilatometrically from 150° to 2000°F. The dilatometer was constructed of Haynes alloy #25 and its volume calibrated with Hg at room temperature. For higher temperatures, corrections were applied based on the coefficient of linear expansion of the Haynes alloy #25. The miniscus level was determined by x-ray photographs. The results are given by

$$\rho \text{ g/cc} = 1.55643 - 0.00026511\ [t(°F)] - \frac{6.26779}{t°F}$$

and are compared with previous results of other workers.

The specific heat at constant pressure of liquid Rb was determined with a copper block calorimeter from 260° to 2000°F and was 0.0880 Btu/lb/°F. Additional measurements are planned to possibly improve the precision and accuracy. The heat content, $H_T^\circ - H_{298}^\circ$, as well as the derived entropy and free energy function for Rb, are tabulated.

Work is presently under way to obtain PVT data on Rb vapor. Two approaches to this problem are being pursued and both are described.

Future experiments planned for liquid Rb include the viscosity using a hollow oscillating cylinder technique, the electrical conductivity, and the thermal conductivity.

Techniques found useful for the chemical analysis of Rb are presented. Analysis for metallic impurities, nitrogen, carbon, and oxygen were carried out, and the precision and accuracy of the results are discussed.

Measurements on some thermophysical properties of Rb vapor, although not planned in the immediate future, are considered. These include determination of the vapor species, thermal conductivity, viscosity, specific heat, and latent heat of vaporization.

(J. J. Egan)

REVIEW NO. 22

EVALUATION OF AS-55 AND OTHER HIGH STRENGTH COLUMBIUM ALLOYS FOR ALKALI METAL CONTAINMENT

Sponsor: National Aeronautics and Space Administration
Contractor: General Electric Company, Cinn., Ohio
Contract No.: NAS 3-2140
Report Date: Covering period Feb. 25, 1963 to March 25, 1963

Sheet tensile tests at room temperature and 2000°F on AS-55 and D-43 Cb-base alloys were completed. Sheet bend tests with a 0.0156-bend radius were performed at -100°F on both of the preceeding alloys. Rupture specimens and bead-on-sheet weld bend specimens have been prepared for test at -100°F. Capsules of both alloys were successfully die formed from sheet in a brake press and TIG welded in purified He. Two AS-55 and two Cb-1 Zr alloy K reflux capsules have been under test for 3900 hr at 2000°F. As-received MSA K was hottrapped in Ti pots for 200 hr at 1300°F. Analyses performed by the Zr gettering technique and Hg amalgamation method show 406 to 426 ppm O and 141 to 219 ppm O, respectively. Procedures for the transfer of hot trapped K in vacuum from the hot trap container directly into capsules were checked out in a trial run.

(A. Fleitman)

REVIEW NO. 23

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

Sponsor: U. S. Atomic Energy Commission
Contractor: Geoscience Ltd., La Jolla-San Diego, Calif.
Contract No.: AT(04-3)-409
Report No.: GLR-13
Report By: H. F. Poppendiek, N. D. Greene, F. R. MacDonald, R. K. Livett
Report Date: December 1, 1962 to February 28, 1963

The liquid metal heat transfer system, which is shortly to be used to investigate fundamental boiling and condensing phenomena with Hg, was sufficiently completed so that preliminary non-boiling water heat transfer experiments were conducted. The purpose of these studies was to establish the

accuracy of the heat transfer instrumentation for the boiler test section, gain operating experience and transfer instrumentation for the boiler test section, gain operating experience, and obtain information on system integrity.

The flow rate range corresponded to Reynolds number variations from 1000 to 24,000. At high heater wire temperatures ($\approx$2000°F), nearly uniform heat fluxes of about 150,000 Btu/hr-ft^2 were readily attained with the variable axial heater element design. Heat balances indicated that about 94% of the electrical heater power was transferred to the test section coolant. Experimental heat transfer conductances were in satisfactory agreement with predicted values over a range of flow rates. Current studies include test section entrance and exit effects, and possible local scale deposits. A photograph of the boiler test section during operation (with shield removed) is shown in the report.

In the continuing analytical studies, a number of zero-gravity forced-flow saturation boiling models for the cases of linear and rotational flow have been calculated. There are some large differences in the results, depending upon the flow type postulated. Several flow types have been studied, the results from some of which show general agreement with boiling water measurements.

(O. E. Dwyer)

REVIEW NO. 24

RESEARCH IN THE FIELD OF LIQUID-METAL LUBRICATED BEARINGS

Sponsor: Aeronautical Systems Division, Air Force Systems Command
Contractor: Rocketdyne Division of North American Aviation, Inc., Canoga Park, Calif.
Contract No.: AF33(657)10553
Report No.: R-5086
Prepared By: Rocketdyne Engineering
Report Date: April 1, 1963

A 710.6-hr endurance test was conducted on a liquid K lubricated journal bearing. The bearing was a 1 in. diam by 1 in. long plain journal of titanium carbide with a radial clearance of 0.0016 in.

The test was made in the general purpose test rig which consists of an Ar-driven turbine and a K lubricating system. Previous difficulties with C and O contamination in the A compressor were avoided by using Teflon seal rings and bleeding A into the stuffing boxes. Problems with the support bearing and the K circulating pump interfered with the early stages of the endurance test.

The test bearing was operated at a speed of 28,000 rpm with K temperatures up to 950°F. The system was shut down and the shaft removed for inspection at 502.9 hr. Score marks were observed at each end of the shaft bearing surface; however, they were not deep enough to cause concern and it was concluded that the marks were made during startup or load change. At the conclusion of the 710.6-hr run the shaft bearing surface exhibited a worn area. It is believed that this damage occurred due to cocking of the shaft during a torque calibration.

Speed decay curves were obtained after 500 and 700 hr and will be used to obtain torque measurements. Analysis of the test data is under way and is to be presented in the next report.

In general it was concluded that a satisfactory range of operating conditions had been encompassed and that further testing should be concentrated in the area of whirl suppression bearings.

(K. Hoffman)

REVIEW NO. 25

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
PROGRESS REPORT
HEAT TRANSFER DURING FILM CONDENSATION OF A LIQUID METAL VAPOR

Sponsor: U. S. Atomic Energy Commission
Contractor: Massachusetts Institute of Technology, Cambridge 39 Mass.

Contract No.: AT(30-1)-2995
Submitted By: Suhas P. Sukhatme and approved by W. M. Rohsenow
Report Date: April 10, 1963

It had been expected earlier that the entire experimental apparatus would be constructed and assembled by the beginning of April. However, due to some unexpected delays in the machine shop, it now seems that the apparatus should be ready for preliminary runs in about one more month.

On the analytical side, a modification to the theory of film condensation is being considered. So far, all published theories have assumed that the liquid-vapor interface is at saturation temperature. It seems that this assumption is a rather poor one for the case of liquid metals.

Results of preliminary calculations suggest that the mass transfer resistance at the liquid-vapor interface (Schrage effect) can possibly account for the reduced condensing coefficients for liquid metals. The calculations show that this effect is insignificant for H_2O (which agrees with heat transfer measurements) but may be quite sizable for condensing Hg and very, very large for condensing Na. This appears to agree, at least in direction, with the meager data available for Hg and Na. We propose to continue this analytical study.

(Authors)

REVIEW NO. 26

TWO-STAGE POTASSIUM TEST TURBINE

Sponsor: National Aeronautics and Space Administration
Contractor: General Electric, Cinn., Ohio
Contractor No.: NAS 5-1143
Report No.: Quarterly Report No. 7
Report Date: For quarter ending Feb. 8, 1963

This contract calls for the design and fabrication of a two-stage test turbine suitable for operation in saturated potassium vapor at 1600°F. The test turbine consists of stages three and four of a five-stage 500-kw turbine and is to have a design flow capacity of 2.8 lb/sec.

The main objectives of this program are to study the effects of vapor wetness on performance, to demonstrate interstage condensate extraction, to study blade erosion with different blade materials, to study the phenomena of supersaturation and droplet formation, to establish correct K vapor properties of an improvement over G.E.'s calculated Mollier diagrams, and finally, to establish accurate fluid flow design methods for K turbines operating in the wet vapor region. The test turbine runs on oil-lubricated bearings. The test program anticipates 200 hr of performance testing, 1,000 hr of endurance testing under aggravated erosive conditions at 23,000 rpm.

Fluid Dynamic Testing

Initial testing of the flow nozzle with air has been completed. Static pressure distributions were obtained for several pressure levels; they agreed quite well with theoretical predictions. The effective flow area at each of the several wall static taps was also obtained.

A series of tests was conducted with steam as the working fluid. Static pressure distributions through the nozzle were obtained for different total pressures. Polystropic exponents as a function of axial distance were calculated. They indicate that condensation will occur further downstream as the pressure level is decreased.

To determine the effect of inlet quality on performance and turbine blade erosion, it is necessary to provide a spray nozzle for introducing liquid K into the near-saturated vapor coming from the boiler. At design conditions, the inlet quality to stage three is 91.6%. Exploratory tests were conducted using air-water mixtures in a 2-in.-diam pipe, and final nozzle design is shown. Plastic models were employed. On the basis of the air-water tests, it was concluded that a satisfactory spray nozzle design had been obtained for the projected tests of the two-stage turbine. The optimum location of the spray nozzle relative to the turbine inlet had also been established. No further air-water tests will be run.

Mechanical Testing

The turbine pretest facility has been completed and checked out. During the pretest, the K turbine is driven by a Barbour

Stockwell steam turbine to determine system critical speed, bearing and seal characteristics, and to obtain general system familiarization.

The bearing pretests have been completed and smooth rotor operation is experienced throughout the speed range up to 23,000 rpm. The temperature distribution within the bearing and the rotor critical speeds are presented in the report. Power consumption within the bearing and the over-all system has been determined.

Preliminary testing runs were made on the hydrodynamic seal. Modifications will be proven out in separate tests on a seal test rig.

Design engineering of the 3000-kw component test facility is nearly complete. The vaporizer tube bundle, furnace, dump tank, as well as some auxiliaries, have been installed.

Materials Support

Six samples of Astroloy were exposed to K for 1000 hr at 1500°F and will be mechanically tested. The tensile properties of Astroloy control specimens that were heated in air to 1500°F for 1000 hr are included in the report. Aging studies of F-48 and AS-30 columbium alloys have been started.

Preparation has begun for the testing of metal O-ring seals for K vapor containment.

The appendix to this report presents thermodynamic properties of supersaturated K vapor. The equilibrium constant, molecular weight, enthalpy, entropy, polytropic exponent, and acoustic velocity are tabulated for the temperature range 1000° to 2100°R.

(O. E. Dwyer and K. Hoffman)

REVIEW NO. 27

ALKALI METALS BOILING AND CONDENSING INVESTIGATIONS VOLUME II. MATERIALS SUPPORT

Sponsor: National Aeronautics and Space Administration
Contractor: General Electric Missile and Space Division, Cinn., Ohio
Contract No.: NAS 5-681
Report No.: GE63FPD66
Report By: J. W. Semmel, Jr., W. R. Young and W. H. Kearns
Report Date: January 14, 1963

Results of tests to provide critical materials information required for the construction and operation of two high temperature boiling and condensing alkali metal heat transfer loops are reported. One loop rated at 300 kw, was fabricated from L605 (Haynes alloy #25), and the other, a 100-kw loop was fabricated from Cb-1 Zr. Summarized results of the investigations are as follows:

1. L605 was found to be reasonably stable in air, in combustion gas products, and in contact with several ceramic materials for operation at 1850°F for periods in excess of 1000 hr.

2. Vacuum melting or modification of the commercial heat treatment of L605 was not effective in reducing the aging-reduced room temperature ductility which occurs at operating temperatures. Moderately effective procedures were to heat the loop to about 1000°F during stand-by periods and from heating the loop to temperatures near 1850°F prior to cooling to room temperature. Although no problems were encountered in welding aged L605, some concern is expressed relative to making field repairs on the loop after it has been in service.

3. Capsule and thermal convection loop tests showed L605 to have good corrosion resistance to K at 1850°F for about 1000 hr. Both carbon and nitrogen were essentially completely removed from the L605 by the K, however, the removal of these elements did not significantly reduce the rupture strength or room temperature ductility of the alloy. Cb-1 Zr hot traps were placed into the L605 loop to reduce the probability of obtaining areas high in interstitial content which could lead to embrittlement.

4. A L605 tube was successfully brazed to Mo-0.5 Ti tube using a tongue-in-groove joint design and vacuum brazing with H-33 (J-8400) at 2150°F. The joints showed promising resistance to failure by thermal cycling and corrosion resistance to K. Bi-metallic, Cb-1 Zr to type 316 SS tube joints were also made by using this procedure.

5. Tests on Stellites No. 6 and 12 for use as hard facing materials on valves showed them to be resistant to K at 1850°F for 250 hr; however, alloying element depletion and softening may reduce their wear resistance. At 1650°F and above, the alloys exhibited strong tendency to diffusion bond to each other.

6. Successful welds were made on 1-in. o.d. by 0.156-in. wall Cb-1 Zr tubing by the TIG process using both a vacuum-pumped, He-filled chamber and also in a He-purged plastic box which is more representative of field welding. Tests confirmed that aging at 1500°F embrittled weld material and that a post weld anneal for 1 hr at 2200°F prevented embrittlement upon subsequent aging at 1500°F.

7. Measurements of the total hemispherical emittances were made for grit blasted Cb-1 Zr and also for two ceramic-type coatings applied to Cb-1 Zr.

8. A preheater section was prepared by flame spraying alumina onto a Cb-1 Zr tube and then flame spraying a Mo helical heating element into the alumina. Although initial high temperature and thermal cycling tests on this element were successful, subsequent heaters of the same type made for the 100-kw loop boiler failed by cracking in the Mo. The failure has been tentatively attributed to variation in the Mo thickness.

9. Appended to the report is a very complete set of specifications for:

a) L605 forgings,
b) L605 tubing and pipe,
c) L605 sheet strip and plate,
d) L605 welding procedure,
e) L605 welder qualification,
f) Cb-1 Zr rod, bar, sheet, plate, and strip,
g) Cb-1 Zr seamless tubing, and
h) Cb-1 Zr welding procedure.

(C. J. Klamut)

REVIEW NO. 28

EXPERIMENTAL INVESTIGATION OF HEAT REJECTION PROBLEMS IN NUCLEAR SPACE POWER PLANTS

Sponsor: National Aeronautics and Space Administration
Contractor: Pratt & Whitney Aircraft, East Hartford, Conn.
Contract No.: NAS 3-2335
Report No.: PWA-2132
Report By: H. R. Kunz, H. L. Ornstein, S. S. Wyde & J. R. Hooper
Report Date: Sept. 1 through Nov. 30, 1962

This is the second quarterly progress report on the "Experimental Investigation of Heat Rejection Problems in Nuclear Space Power Plants." The program has three parts.

Experimental Evaluation of Hydrodynamic Losses in Manifolds Using Air and Water

Photographic studies and pressure-loss tests were conducted on four Plexiglas manifolds with single-branch tubes. Four different configurations were tested, but experimental data have so far been reduced and correlated for only one of them. On the basis of the results obtained thus far, the authors conclude that two-phase flow estimates of pressure losses are not greatly different from those of single-phase flow. Presumably, the work will be extended to cover multi-branch configuration, for the information from such work will be needed to arrive at criteria for providing good two-phase flow distribution in radiator condensers.

Experimental Condensing Flow Stability Studies

The purpose of this work is to study dynamic stability behavior in different header-condenser tube combinations with steam. The experimental rig was assembled with a single condensing tube as the test section during checkout. However, two manifold test sections are ready for testing, one made of metal, the other of glass. Each has three condensing tubes. The individual condenser tubes are cooled by individual water jackets. Behavior of the test section will be followed by variations in the pressure drops across the tubes and by temperature measurements, as well as by visual observation with the glass test section.

Space Power Plant Startup and Transient Operation Simulation

The purpose of this work is to carry out an experimental study of the startup and transient operating characteristics of a variety of simulated Rankine cycle space power plants utilizing single-phase and two-phase segmented radiator systems.

A test facility consisting of three loops has been built and some preliminary results have been obtained. A heater loop provides the heat supply for the water-steam Rankine loop, and a heat-sink loop circulating refrigerated trichlorethylene removes the heat from the condenser, or simulated radiator (see Fig. 4. Early runs were hampered by leaks in the condenser, but in spite of this, some illuminating observations were made.

Several simulated power plant startups were made using automatically-sequenced starting controls. Two forms of instability were observed during the starting transients. One, localized at the pump inlet, was caused by mixing the stream from the separator liquid return (which partially vaporizes at a valve in the line) with the subcooled liquid returning from the condenser. This was eliminated by exchanging heat between the two streams before mixing them. The other instability, and the more serious one, occurred whenever the accumulator fill line was connected at the pump outlet. It did not occur when the accumulator was connected at the pump inlet.

Fig. 5 shows the oscillations in boiler inlet temperatures and pressures. The test was stopped after about four minutes when the pump inlet temperature rose to the cavitation limit.

The advantages of placing the accumulator fill line before and after the pump are briefly discussed.

(O. E. Dwyer)

Fig. 4 and 5 in the Review correspond to Fig. 77 and 80 in the report.

REVIEW NO. 29

LOCAL PARAMETERS IN CO-CURRENT MERCURY-NITROGEN FLOW

Sponsor: U. S. Atomic Energy Commission
Contractor: Argonne National Laboratory, Argonne, Illinois
Contract No.: W-31-109-eng-38
Report No.: 7725
Report By: L. G. Neal
Report Date: January 1963

This report describes an experimental study of local, two-phase flow characteristics for mercury and nitrogen in the slug-flow regime. It is the first of a series that describes heat-transfer and fluid-flow studies performed at Argonne under a program sponsored jointly by the Associated Midwest Universities and the Argonne National Laboratory.

Two special measurement devices were developed in the course of this work. First, an electric probe, consisting of a needle insulated everywhere except at the tip, was used to obtain instantaneous measurements of local resistivity in the two-phase mixture. Time traces of the output signals were then analyzed to obtain values of the local gas fraction, bubble frequency, and bubble-size spectra. Second, a modified version of the pitot tube was used as an impact probe to measure the time average impulse pressure resulting from the fluid being diverted around the probe. This pressure was then related to the local liquid velocity.

From the results, the author arrived at the following conclusions:

1. The gas-fraction and liquid-velocity profiles in fully developed flow can be expressed by power-law relationships.

2. Entrance effects persist for about 20 tube diameters. In mercury-nitrogen flow, these are manifested by a large gas fraction at the wall, as well as large fluctuations of static pressure and a large phase-velocity ratio.

3. In mercury-nitrogen slug flow, the phase distribution is not important in determining the average phase-velocity ratio, and all slip is due to local slip.

4. The empirical result of Armand, that the ratio of cross-sectional average gas fraction to the gas volumetric flow fraction is a constant, is not valid for this study.

5. The gas slip velocity and the relative slip velocity are quantities which can be correlated reasonably accurately. For very large Reynolds numbers, as in this study ($Re>9000$), these quantities are independent of Reynolds number.

6. The bubble diameter and slug (both gas and liquid) length spectra can be represented as a cumulative distribution function. These show that a large proportion of bubbles have diameters less than the pipe diameter, but that most of the gas flow is carried by the slugs.

7. The basic flow structure of mercury-nitrogen flow is different from air-water flow as a result of the high surface energy of mercury; consequently, the theories derived from air-water flow cannot be used to predict flow variables for mercury systems.

8. The usual Taylor bubble does not appear. The gas slug rises up the wall, with the liquid pouring down the opposite wall. The slugs rotate as they rise, and very long gas slugs are spiral shaped.

9. The Griffith and Wallis slug-velocity correlation does not apply. A new correlation, using the same basis followed by Griffith and Wallis, was successfully made.

(J. C. Chen)

REVIEW NO. 30

ARGONNE NATIONAL LABORATORY
REACTOR DEVELOPMENT PROGRAM PROGRESS REPORT

Sponsor: U. S. Atomic Energy Commission
Contractor: Argonne National Laboratory, Argonne, Illinois
Contract No.: W-31-109-eng-38
Report No.: ANL-6705
Coordinated By: R. M. Adams and A. Glassner
Report Date: March 1963

Lightweight Alloy for Use With Mercury

The addition of Zr to Hg considerably reduces the attack on Ti at temperatures up to 538°C under static conditions. Recent tests have indicated that the corrosion of Ti can also be reduced by the addition of Ni to the Hg. Duplicate specimens tested in saturated Ni solutions at 538°C showed a uniform protective layer. No significant weight change occurred after 14 days of exposure.

Studies are under way to identify the nature of the layer observed on the surface of these specimens. The layer appears as a continuous single phase, 0.37 mil thick. No transition or diffusion zone has been observed between the layer and the base metal. Spectrographic analysis indicates that this layer is primarily composed of Ni and Ti along with a small amount of Hg. Efforts to identify the compound by x-ray diffraction technique were not successful.

A number of methods are available for the determination of oxygen with reasonable accuracy in concentrations above 100 ppm, none of the existing methods have high precision in the concentration range from 10 to 100 ppm, and none is of value below 10 ppm. One of the methods which is being explored for the analysis of oxygen is an activation method which involves the conversion of oxygen in the Na to F^{18} by reaction of the oxygen with tritons. In this method, a small amount of Li ($\approx$0.1%) is alloyed with the Na and the tritons are produced *in situ* by the $Li^6(n,T)He^4$ reaction. The utility of the method depends upon the production of a Li-Na alloy in which the Li is uniformly dispersed throughout the alloy and in which the oxygen is not excessively segregated. Preliminary studies are under way to develop a method whereby Li-Na alloys possessing the requisite properties can be produced.

(Authors)

REVIEW NO. 31

UNIVERSITY OF MICHIGAN
MONTHLY PROGRESS REPORT FOR APRIL 1963

Sponsor: U. S. Air Force
Contractor: University of Michigan
Contract No.: 33(616)-8277
Report No.: 4526-14P
Report By: R. E. Balzhiser, Project Director
Report Date: April 1963

All phases of the program have reached the operational stage with the exception of the agravic Hg boiling studies. It is expected that data will be obtained in this phase of the program in late June or early July.

During the past month high flux pool boiling data with K have been obtained. The boiling curve has been determined for several pressures and burnout values obtained at pressures from several millimeters of Hg to 1 atm. A copy of the data plotted in such a way as to compare the results with those of Noyes for Na boiling from a surface of a tube and with the theoretical correlations of Zuber, Rohsenow, and Kutateladze was transmitted to ASD during a recent visit.

Both the film boiler and the forced circulation loop are now ready for operation. Initial attempts with the film boiler were intended to evaluate edge effects using water as the boiling fluid. Difficulties prevented operation as anticipated and this portion of the study has been temporarily set aside; it is planned to begin operation as intended with K and Na as soon as the equipment can be made leak tight.

The liquid metal loop has been charged with K and Na, and K was successfully circulated for a short period of time before plugging necessitated a shutdown and subsequent removal of the pump from the system. All components, including instrumentation, appeared to be functioning properly, and it is hoped that following a carefully prepared flushing and charging procedure, sustained circulation can be achieved. The Na natural circulation system was not tested due to the premature shutdown of the K cycle.

(Authors)

REVIEW NO. 32

PROGRESS REPORT
NUCLEAR ENGINEERING DEPARTMENT

Sponsor: U. S. Atomic Energy Commission
Contractor: Brookhaven National Laboratory
Report No.: BNL 759(S-62)
Report By: W. E. Winsche and F. T. Miles
Dates Covered: May 1 to August 31, 1962

Heat Transfer Studies

After several months of de-bugging the test section of a NaK heat transfer loop, it now appears that good, reproducible data can be obtained on it. In this study, heat transfer coefficients are being measured on the central rod of a 19-rod unbaffled rod bundle for in-line, turbulent flow. The trouble has been that the local coefficients around the circumference of the rod varied when the rod was rotated, indicating that the requirement of symmetry had not been met.

In an analytical study of heat transfer to liquid metals flowing in an eccentric annulus, heat transfer coefficients, as a function of angle, have been obtained for eccentricities of 30 and 70% at Peclet numbers 367, 1700, and 8000. They were obtained under the conditions of $r_2/r_1=1.50$, constant heat flux, and fully established flow.

A short study was carried out to obtain a solution for the temperature distribution in a fluid flowing in an eccentric annulus with a slug-flow velocity profile. This would enable one to arrive at an approximate Nusselt number for the case of liquid metals flowing through such a channel under conditions of fully established turbulent flow. To give an indication of the eccentricity effect, when the eccentricity is increased from 0 to 50%, the slug-flow Nusselt number decreases 33%. The decrease in the actual heat transfer coefficient would always be less than this, but would approach it at low flow rates.

In another study, the effect of rod misalignment in slug-flow heat transfer in rod bundles has been determined. A solution was obtained for a triangular array with one rod displaced in a direction normal to the line of centers of two adjacent rods. To give an indication of the effect, a displacement 50%

of maximum would reduce the slug-flow Nusselt number for the rod by 29%. This would correspond to a reduction in the actual heat transfer coefficient of about 20% at a Peclet number of 1000.

Materials

This report summarizes the progress made on Hg and Na corrosion studies during the indicated period. The container materials being tested with Hg are carbon steel, 2 1/4 Cr-1 Mo steel, Haynes alloy #25 (L-605), Cb-1 Zr, and Ta. The Na corrosion studies are being carried out with Cb-1 Zr.

Twelve (12) natural circulation boiling Hg loops have been under test and an additional seven (7) loops are in preparation. Scheduled runs were completed on six (6) of the former loops (4 each carbon steel, 1 each Haynes alloy #25, and 1 each 2 1/4 Cr-1 Mo steel) and these have been examined metallographically. The temperature range for boiling in these loops was 1000°-1100°F. Three others (Cb-1 Zr, Ta, and carbon steel) are still under test while the remaining three (2 each of 2 1/4 Cr-1 Mo steel and 1 each of carbon steel) were shut down prematurely.

The metallographic results of the carbon steel loops are summarized as follows:

1. Even with no inhibitor present (Zr or Ti), the maximum corrosion noted was <1 mil.

2. The greatest penetrations occurred in the hottest area of the superheater in the Zr-inhibited and in the uninhibited loops.

3. Vapor deposits of Fe were found above the boiler liquid level in the Ti-inhibited loop which operated at 1100°F boiling and in the uninhibited loop. The Haynes alloy #25 loop underwent considerably more corrosion than carbon steel (~2 mils) in the vapor and condensing areas. No corrosion occurred in the liquid portion of this loop and a Co-rich deposit was found above the boiler while a Ni-rich deposit was found above the condenser. The 2 1/4 Cr-1 Mo steel loop (1000°F boiling) was only slightly attacked.

A total of 5661 hr of operation have been accumulated on a Cb-1 Zr loop boiling at 1200°F.

X-ray diffraction investigation of a carbon steel control tab (which was removed from a loop having been pretreated by liquid Hg containing Zr and Mg at about 1150°F for 500 hr) revealed the presence of a ZrN film at the surface.

A series of capsule experiments to study film formation and corrosion inhibiting effects of Zr and Ti pretreatment of low carbon steel and Haynes alloy #25 is in progress. Films stripped (by using liquid bromine-methanol) from a previous set of carbon steel specimens have been identified by electron diffraction studies as TiN and ZrN.

Sodium Corrosion Studies

Three Cb-1 Zr reflux capsules containing inserts of Cb, Ta, and Mo have been operated at 2200°F for 4750 hr. A scheduled 5000-hr run at 2200°F has been completed on six other Cb-1 Zr capsules and these will be examined metallographically. Preliminary hardness tests indicate the Cb-1 Zr was considerably softer after test (R_B84 to R_B18) respectively.

A Cb-1 Zr natural convection boiling loop was operated at 2000°F boiling for 610 hr. At this time the Pt/Pt-10% Rh thermocouples opened and were subsequently replaced by W/W-26% Re. The loop was not affected and will be restarted shortly.

Thermocouple evaluation tests are being carried out at high temperature and high vacuum to determine the relative merits of Chromel-Alumel, Pt/Pt-10% Rh, W/W-26% Re, and W/Ir. Chromel-Alumel cannot be operated at 2200°F for over 250 hr due to severe evaporation at a vacuum of 2×10^{-6} torr. Both W/Ir and W/W-26% Re appear satisfactory in all tests except for evidence of embrittlement after test. Pt/Pt-10% Rh undergoes a continuous drop in millivolt output which is attributed to the evaporation and/or migration of Rh in the hot junction. Ta-sheathed W/W-26% Re thermocouples are also being tested.

A large natural convection boiling Na loop which will achieve high velocities has been fabricated, and the heaters, thermocouples, etc., will be installed. The boiler temperature will be 2000°F with a maximum liquid velocity of 3.5 ft/sec and vapor velocity of 115 ft/sec.

A pumped Cb-1 Zr high velocity loop is also planned. The pump will be a General Electric spiral induction pump with a Cb-1 Zr pump cell.

(O. E. Dwyer and A. J. Romano)

REVIEW NO. 33

PROGRESS REPORT ON SHELL-SIDE HEAT TRANSFER STUDIES

Sponsor: U. S. Atomic Energy Commission
Contractor: Atomics International, Canoga Park, Calif.
Contract No.: AT(11-1)-GEN-8
Report No.: Letter No. 12
Prepared By: D. T. Eggen and addressed to Mr. T. A. Nemzek of the Chicago Operations Office)
Report Date: October 16, 1962 to February 20, 1963

This is a very short informal report and many aspects of the program are not discussed. The purpose of the work, which falls under the Advanced Sodium-Cooled Reactor Program, is to carry out engineering-scale studies on the subject of shell-and-tube exchangers. Experimental models of many different designs will be tested.

During the report period, 30 runs were carried out with Basic Unit 12, the design of which was not given in the present report. The data are being reduced and the results will be reported later.

An important feature of the program is that transparent, scale models of the heat exchangers to be tested are first studied for their flow characteristics with water, using dye-injection techniques.

(O. E. Dwyer)

COMPARISON OF SN 3 TEST DATA WITH EQUATIONS 7-16, 7-17, 7-25

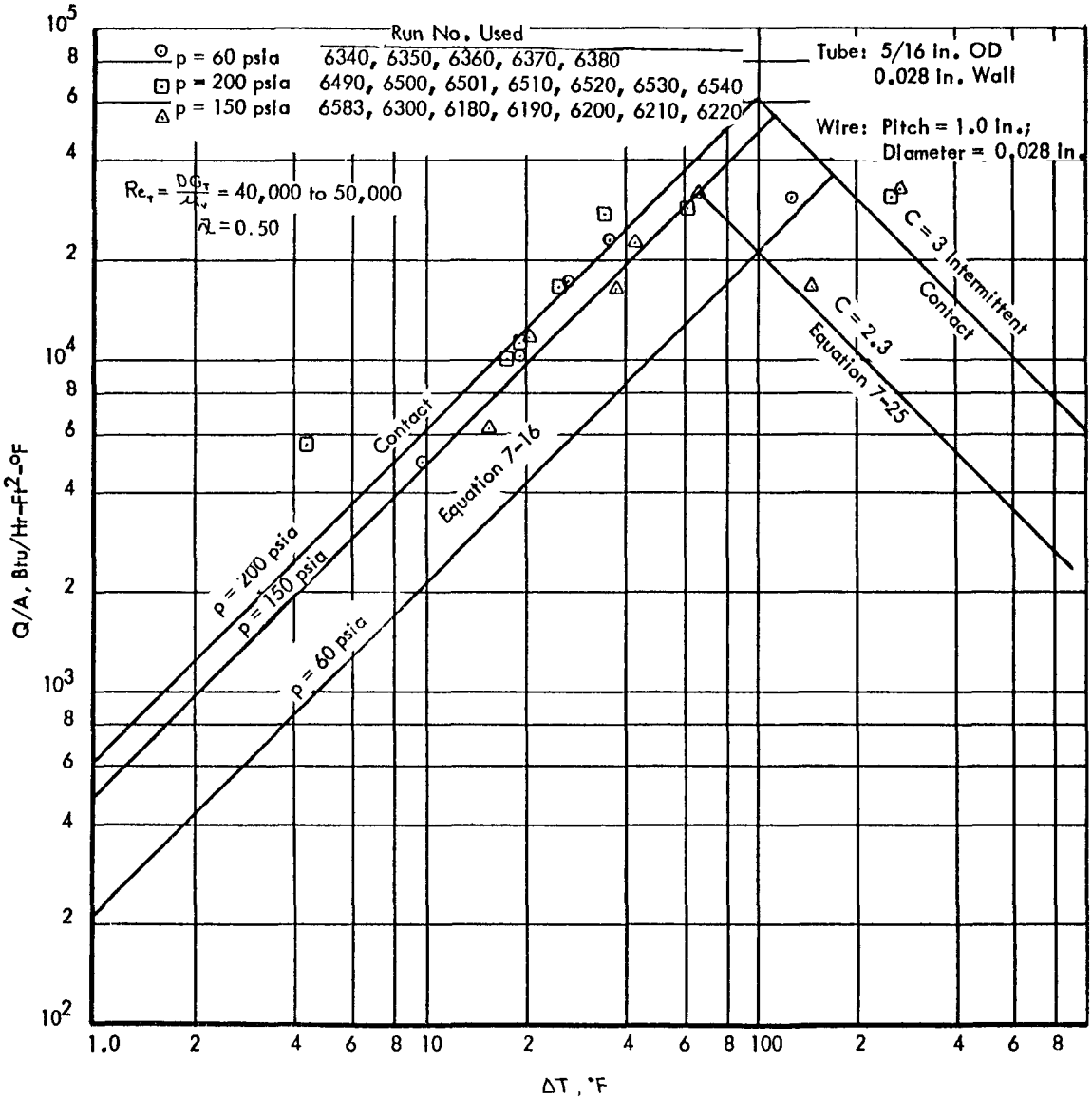
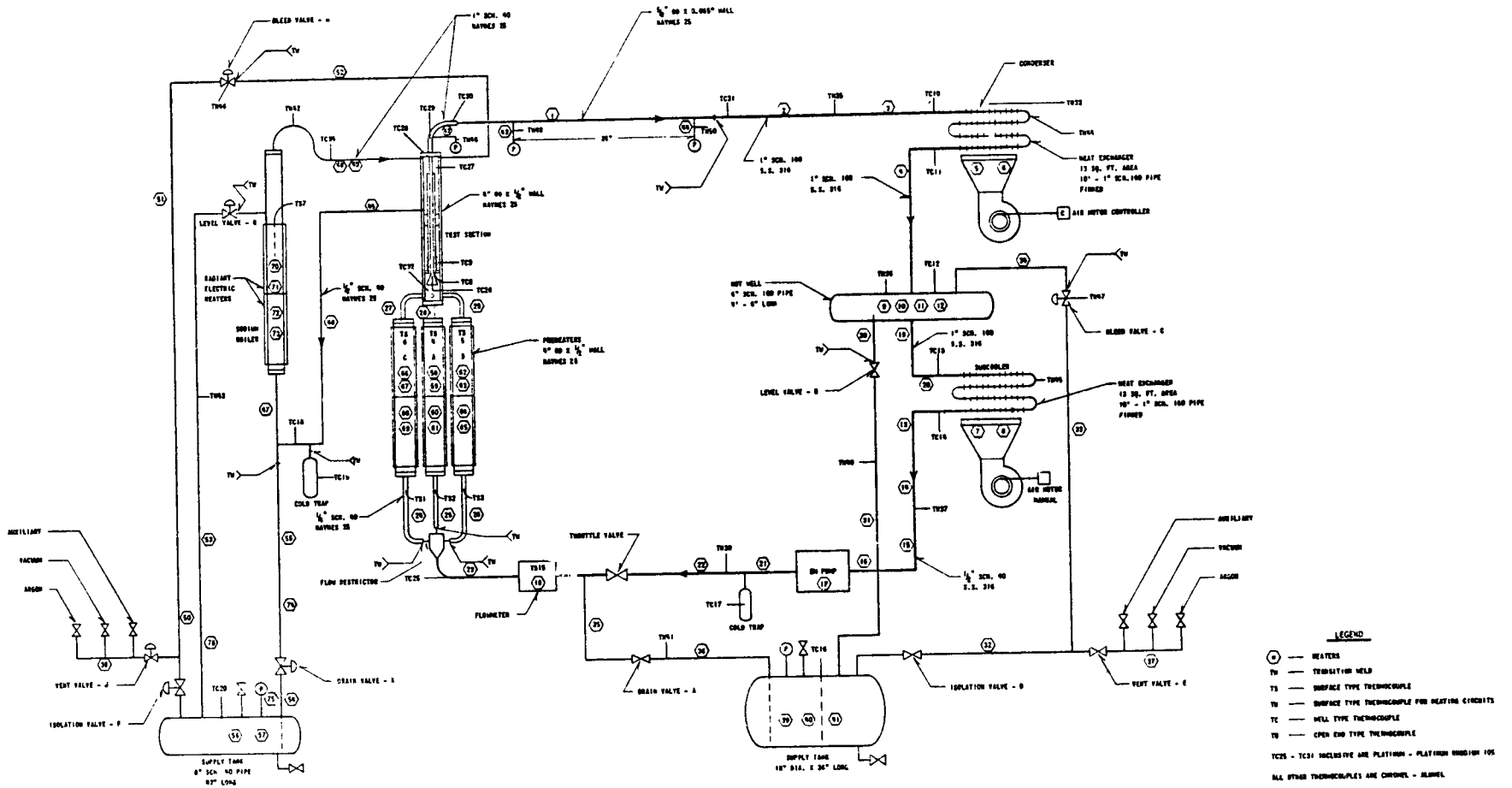


Figure 1



FLOW SCHEMATIC, UNIVERSITY OF MICHIGAN BOILING LIQUID METAL LOOP

AK2246-28

Figure 2

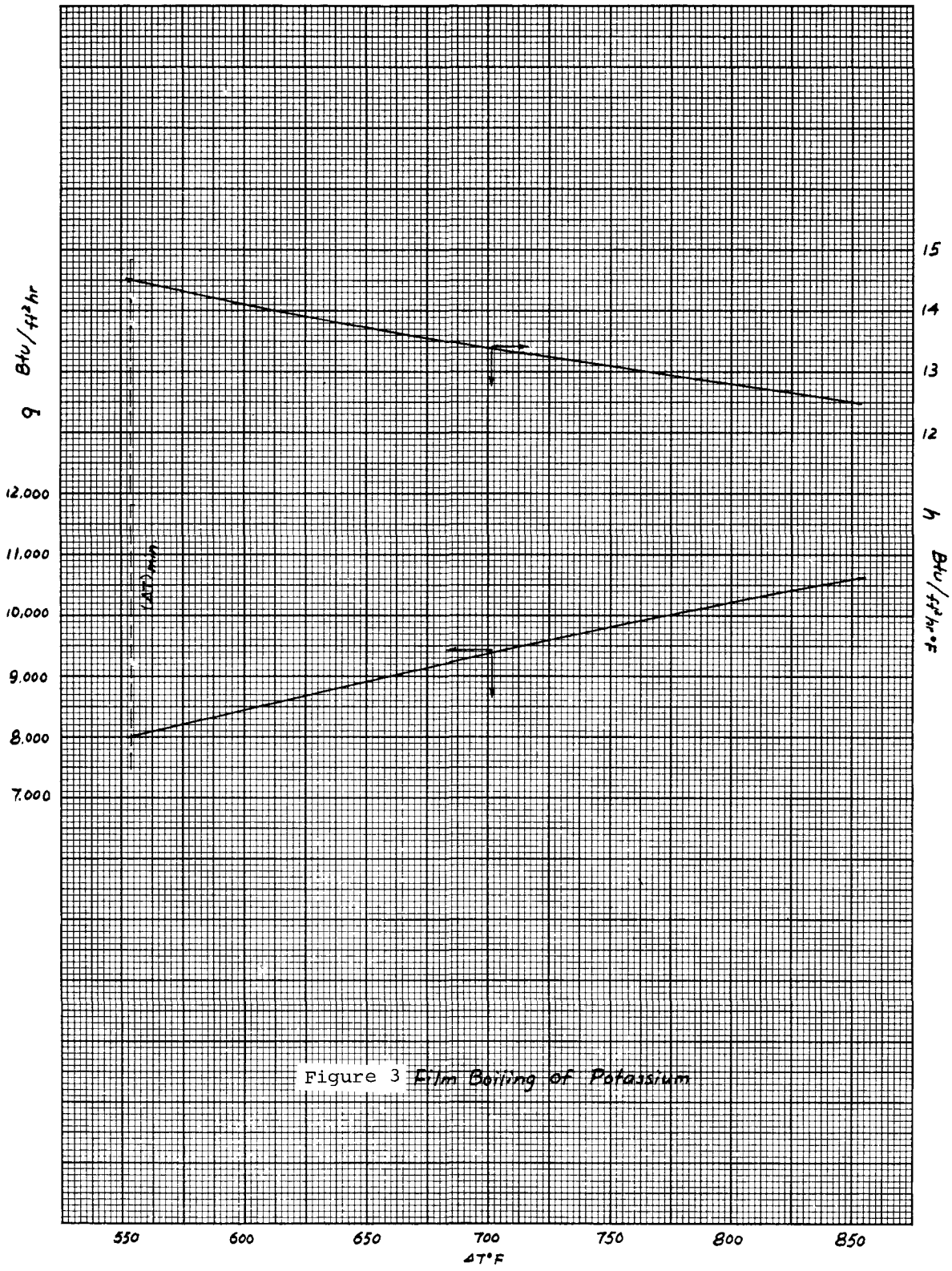


Figure 3 Film Boiling of Potassium

POWERPLANT ARRANGEMENT WITH SEGMENTED DIRECT RADIATOR - CONDENSER

FIRST CONFIGURATION

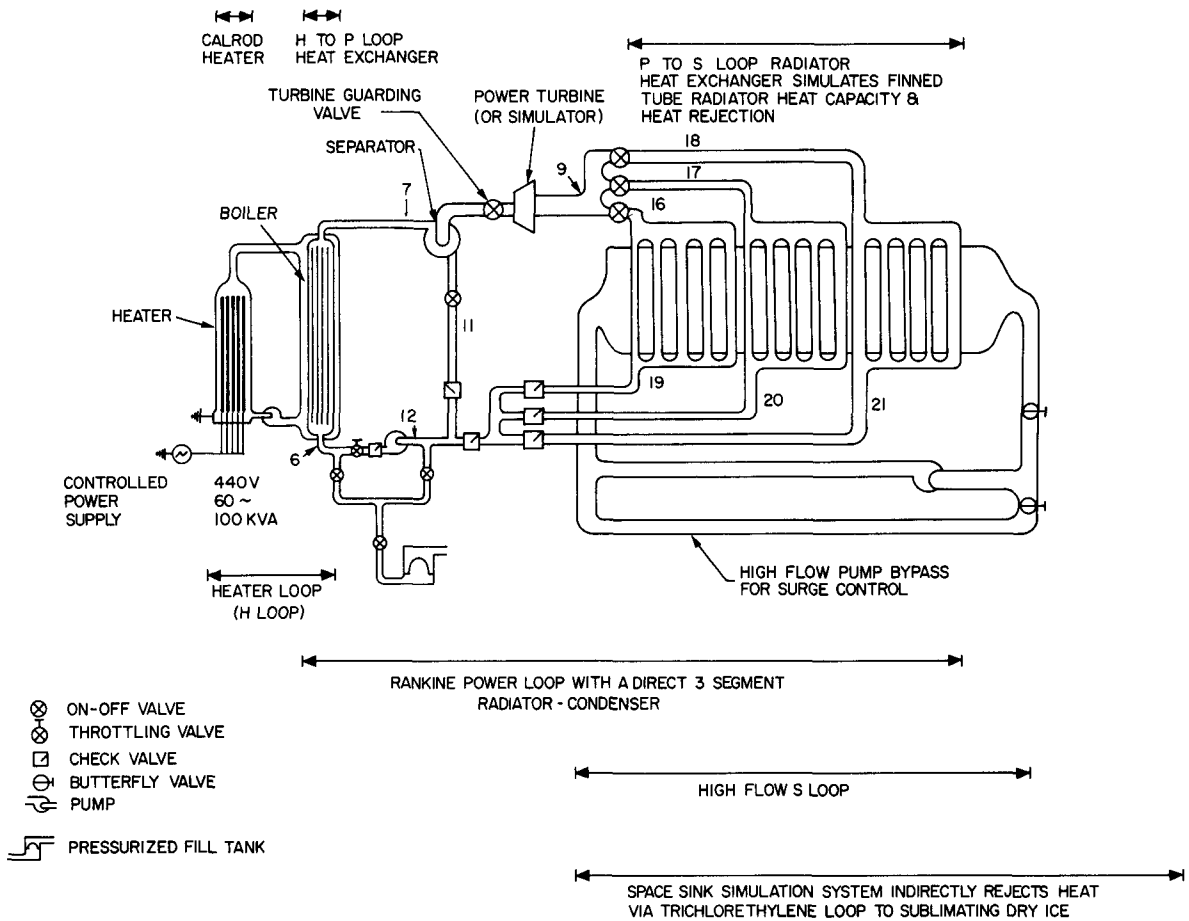


Figure 4

TEMPERATURES AND PRESSURES FROM INITIAL PORTION OF AN AUTOMATIC START

ACCUMULATOR FILL LINE TO PUMP OUTLET AT 160 PSIA
TURBINE SIMULATOR VALVE SET FOR DESIGN FLOW

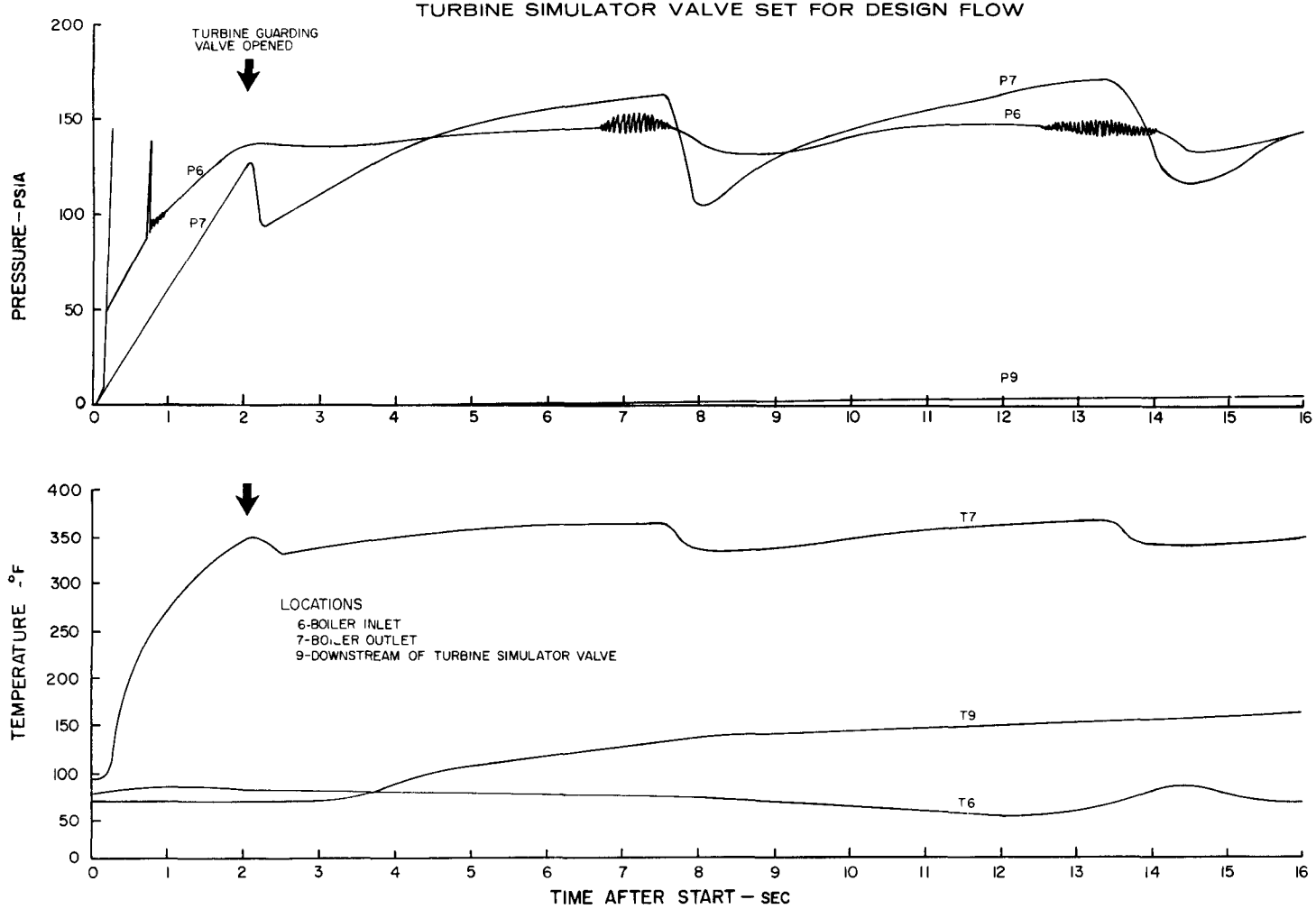


Figure 5