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HIGH-TEMPERATURE LIQUID-METAL TECHNOLOGY REVIEW

A Bimonthly Technical Progress Review

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

VOLUME 4 • NUMBER 1 • FEBRUARY 1966

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FOREWORD

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

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

The Review covers all phases of high-temperature liquid-metal technology, including materials development, corrosion and mass transfer, heat transfer, fluid dynamics, instrumentation, purification, component development, physical properties, thermodynamics, chemical analysis, and power systems. This type of information is needed primarily in the development of power systems for space vehicles, but much of it is also very pertinent to the AEC's fast breeder development program.

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

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

Those organizations which regularly submit reports for coverage in the Review automatically receive courtesy copies of it directly from Brookhaven on date of issuance. All other organizations are required to follow the usual procedure of procuring them through the Clearinghouse for Federal Scientific and Technical Information, National Bureau of Standards, U.S. Department of Commerce, Springfield, Virginia.

O. E. Dwyer
Technical Editor

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HIGH-TEMPERATURE LIQUID-METAL TECHNOLOGY REVIEW

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ALKALI METALS EVALUATION PROGRAM

Forced Convection Condensing Heat
Transfer for Rubidium and Cesium

Sponsor: U.S. Atomic Energy Commission.
Contractor: Aerojet-General Nucleonics, San Ramon, Calif.
Contract No.: AT(04-3)-368
Report No.: AGN-8162
Report By: C. R. Fisher and J. H. Moskowitz
Report Date: January 1966
Previous Reviews: 82, 94, 143, 144, 212, 213, 214, 229, 275, 299, 335, 358,
359, 389, 410

The heat transfer characteristics of rubidium and cesium were investigated in forced convection condensation in a round tube in both vertical and horizontal orientations. The experiments were performed in a 316 SS loop with Ni test sections. Data were obtained at temperatures up to 1360°F. Mass flow rates ranged from 23,000 to 88,000 lb/hr-ft², and heat fluxes ranged from 15,000 to 120,000 Btu/hr-ft².

The report is in three main parts presenting first the description of the experimental apparatus, second the test procedure, and third the results. The final reduced data are presented in tabular form. Along with the results, the authors present a careful analysis of system errors and experimental uncertainties. From the error analysis and from the observed scatter of the measured data, the authors concluded that the imprecision in the temperature data was sufficiently large in relation to the observed temperature differences so that no trend in the condensing coefficient was observable as a function of vapor quality, condenser length, vapor side kinetic resistance, saturation pressure, or stratification. However, the ΔT data did exhibit a significant trend with heat fluxes as expected. These results are reproduced here in Figures 1 and 2. The authors obtained a rough estimate of the condensing coefficients by drawing the best-fit line through the origin. The coefficients which resulted range from $\approx 22,000$ to 39,000 Btu/hr-ft²-°F.

(J. C. Chen)

Figures 1 and 2 in the Review correspond to Figures 9 and 10, respectively, in the original report.

QUARTERLY TECHNICAL PROGRESS REPORT
SNAP-50/SPUR CONTRACT

Sponsor: U.S. Air Force, Wright Patterson Air Force Base, Ohio
Contractor: AiResearch Mfg. Co., Phoenix, Arizona
Contract No.: AF33(615)2289
Report No.: APS-5152-R5
Report Period: Quarter ending December 31, 1965
Report Date: January 18, 1966
Report By: Engineering Staff and approved by R. D. Gruntz
Previous Reviews: 12,64,88,102,103,150,151,152,173,243,312,313,
336,360,361,390,411,412

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

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

1. Materials. Fatigue tests have been conducted on TZM. Ten helium-filled specimens were tested and it appears that the 1500°F endurance limit of TZM is lower than that for Mo - 0.5% Ti. These tests will be continued and tests at 2000°F will be initiated.

Wear and friction tests have been completed at 500°F in liquid K on various cermets with columbium, molybdenum, and cobalt binders. Torque and weight loss data are contained in the report. These tests were conducted at 845 rpm with a static load of 45 lb for one hour.

2. Bearings. This section makes up a large part of the report. A conventional-fluid bearing test facility was constructed and is described. The purpose of this facility is to examine the performance and stability of various rotor, journal bearing, and thrust bearing configurations in water or oil to simulate the conditions in a potassium system. Tests in this facility are intended to verify the mathematical analysis of various bearing rotor configurations that are being studied. A discussion of the various bearings including cylindrical with circumferential feed groove, classical lobe type, tilted lobe

type, hybrid, and hydrostatic is included along with a summary of the analysis.

A potassium-turbine-driven bearing-test rig has been built and operated. This rig is described in the report and consists of a 24,000-rpm, single-stage, partial admission, impulse turbine that is supported by two fluid-film journal bearings and a double acting, fluid-film thrust bearing. The turbine is driven by 1350°F potassium vapor and the bearings are lubricated with 600°F liquid potassium. A 500-hr test on the pivoted pad-bearings was completed, and problems were encountered when an attempt was made to resume operation. The problems, as well as the results of inspection of the bearings are presented in the report in great detail. Upon post-test inspection, no wear was observed on the thrust bearing and its pads pivoted freely. There was evidence of potassium oxide in the system and it is thought that this is due to a leak which developed after the 500-hr run. A bearing support ring was loose and some wear was noted on one of the journal bearings. It was concluded that damage to the support ring and journal bearing was initiated by vibrations in the loop piping which caused the housing to vibrate in relation to the stable position of the rotor assembly.

3. Seals. The seal test rig was used to obtain pressure coefficient and torque data for a 3.0-in.-diam, smooth-disc, hydrodynamic seal operating completely submerged in water. Data were obtained for axial clearances from 0.010 to 0.070 in. at speeds of 16,000 to 24,000 rpm. The maximum power dissipation measured in the seal was 2.8 hp.

A molecular pump is being designed to operate between a bearing cavity slinger seal and a generator cavity where the cavity must be held below the 600°F potassium vapor pressure. Boundary pressures of 0.1 and 0.01 psia were used at the molecular pump discharge and at the generator cavity, respectively. A design computer program was completed and various pump geometries are presented in the report.

4. Turbine. Data from the air testing of the potassium turbine stage has been reduced, and the results indicate that the overall turbine stage performance is considerably below the previously published predicted performance. This is attributed to effects of the blade tip shroud design and possibly to low performance in the impulse root section of the rotor blade.

The potassium test turbine has been installed in the 32-MW test loop.

Design of the full-scale turbogenerator is continuing. The stress analysis of the tie bolt is complete. The tie bolt is a hollow tube of Waspaloy and it is to be installed with a pre-stretch of .040 in. Its life is in excess of 10,000 hr and it has been calculated that there will still be sufficient tension in the bolt after 1000 hr so that the assembly would still be "locked-up" upon shutdown after 1000 hr. The necessary 10,000 creep data are not available; however, extrapolated data indicate that a shutdown and restart cycle at 10,000 hr is feasible.

Heat Transfer

Some further results are reported on the operation of the 19-tube K boiler. These include overall heat transfer coefficients and flow distribution results. The boiler is made of Haynes-25 alloy. The tube bundle has a triangular arrangement of the tubes and is C-shaped. The nominal design conditions for the boiler were:

Potassium Side

Flow, 12 lb/min

Inlet liquid temperature, 1100°F

Exit saturation temperature, 1600°F maximum

Exit quality, 100%

Sodium Side

Inlet temperature, 1800°F, maximum

Inlet-to-outlet temperature drop, 100°F

Average Boiling Heat Flux

160,000 Btu/hr-ft²

In the course of the boiler test, two separate sets of data were taken. The latter showed less scatter and are believed to be more accurate because they were taken under improved operating conditions. The results are shown in Figure 3 and from them the following conclusions were drawn:

- a. Operation of the boiler was stable at all times in the sense that the output flow and pressure did not fluctuate or vary appreciably with time.

- b. Initiation of boiling was easy being consistently achieved smoothly and with only a few degrees of liquid superheat.
- c. Substantial degrees of exit vapor superheat were readily obtained.
- d. Heat-transfer performance agreed closely with predicted values in the operating range of maximum interest; that is, 100-plus percent exit quality at high temperature, high flow, and high average heat flux.

In the figure, it will be noted that the overall coefficient generally increased with increase in exit quality up to 100%. This is contradictory to theory and practice and is a problem for further investigation. The results appear all the more anomalous when it is realized that the shell temperature profile during a given run indicated that at high qualities the coefficient decreased with increase in quality. Moreover, the definition of the "overall coefficient" as used in the figures is not given. It is assumed that the Na flow was countercurrent to the K.

During operation of the boiler the pressure drop across it was much lower than was predicted. It was later found that there was substantial K flow around the orifice plugs, and that uneven distribution of flow through the tubes resulted. In spite of this, however, the boiler performed quite satisfactorily.

After 300 hr of operation, various parts of the boiler were subjected to thorough metallurgical investigation. The results were:

- a. No deterioration of the Haynes-25 material in contact with sodium or potassium was noted.
- b. Pitting of nickel plating occurred at the sodium inlet plenum.
- c. Diffusion bonding of tapes in tubes was achieved although the degree of bonding varied from tube to tube and along the length of each tube.
- d. Vibration of the unbonded portions of the tape against the tube wall occurred during operation as determined from burrs on the tape edges and wear bands on the tube wall.

Apparently all the boiler tubes had twisted tapes in them, but the amount of twist was not indicated in this report. The reviewers get the impression, however, that helically wound wire attached to the inner surface of the tubes is preferred if a satisfactory way of attaching it can be developed. The following methods have been tried to date:

- a. Diffusion bonding of bare L-605 to bare L-605.
- b. Diffusion bonding of nickel-plated L-605 wire to bare L-605.
- c. Thin film brazing followed by a diffusion heat treatment. The wires were plated with palladium, inserted in the tubes, and heated to a temperature at which a low melting alloy was formed between palladium and L-605. The temperature was then lowered and an attempt was made to diffuse the palladium away from the joint.

Each of these methods was evaluated, with and without the use of a steel supporting mandrel. None was satisfactory but it appears that with the use of low-carbon mandrels, rather than high-carbon mandrel as used up to now, a satisfactory technique can be developed. The best appearing joints were those brazed with the Pd-L-605 low-melting mixture.

(K. Hoffman and O. E. Dwyer)

Figure 3 in the Review corresponds to Figure 118 in the original report.

REVIEW NO. 450

SNAP-50/SPUR FREQUENCY CONVERTER
PRELIMINARY DESIGN AND SPECIFICATION

Sponsor: U.S. Air Force, Wright Patterson AFB, Ohio
Contractor: AiResearch Mfg. Company, Phoenix, Arizona
Contract No.: AF33(615)-2289
Report No.: AFAPL-TR-65-119
Report By: E. Haugen, L. C. Spender, et al.
Report Date: January 1966
Previous Reviews: 312, 313, 361, 411, 412

This program involves equipment to convert the primary 3200-cps power from the SNAP-50/SPUR power system to 200- and 400-cps power for supplying up to 40 kW of motor load.

A bidirectional, half-wave, "blanking" type cycloconverter with three-phase output was selected. Design analyses and specifications for this system are contained in the report and appendices.

Special effort was devoted to the study of the high frequency operating conditions and characteristics of the silicon controlled rectifiers (SCR's). There appear to be conflicting data in the literature on the radiation tolerance of the SCR's, and the report recommends that this be the subject of further study.

A full-scale circuit analysis and design of the converter was made. A breadboard model of all the various converter sub-circuits has been built, and testing is nearly complete.

(K. C. Hoffman)

REVIEW NO. 451

ARGONNE NATIONAL LABORATORY
REACTOR DEVELOPMENT PROGRAM PROGRESS REPORT

Sponsor: U.S. Atomic Energy Commission

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

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

Report No.: ANL-7132

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

Report Date: December 1964

Previous Reviews: 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

Properties of Vanadium-Base Alloys (p. 20)

The thermal conductivity of V - 20% Ti was measured in a comparative type of apparatus. Inconel and Armco standards were used. The results are shown below.

Thermal Conductivity of TV-20^a

Temp °C	Thermal Conductivity ^b W/cm-°C
100	0.153
200	0.192
300	0.220
400	0.241
500	0.257
600	0.271
700	0.283
800	0.296
900	0.306
1000	0.317
1100	0.33 ^c

^a Vanadium - 20 wt % Ti alloy

^b Probable accuracy, $\pm 10\%$

^c Extrapolated

As far as the uniaxial creep measurements are concerned, five V-base alloys have been tested thus far and the results are shown in Figure 4. The lower the Ti/Cr ratio, the lower is the minimum strain rate. The arithmetic mean bulk moduli of the same five alloys have been calculated and are shown plotted against the creep rate in Figure 5 where it is seen that an increase in bulk modulus decidedly lowers the creep rate.

Preliminary evidence indicates that V - 20% Ti alloy exposed to Na containing ≈ 20 ppm O_2 has a significantly faster creep rate than unexposed alloy.

Boiling Liquid-Metal Technology (p. 42)

A Cb - 1 Zr loop is being 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 eight atm. Among the variables to be investigated are boiling heat flux and temperature difference up to the critical heat flux occurrence, boiling and adiabatic two-phase pressure drop, vapor volume fraction, and boiling stability parameters. The construction of this facility is almost complete.

In the electron-bombardment heater development work, improvements in the heater have resulted in longer times of electron emission. Additional modifications to the system are expected to extend emission time to useful levels.

Liquid-Metal Heat Transfer in Double-Pipe Heat Exchanger (p. 43)

It is shown that under certain conditions countercurrent heat exchangers designed by use of uniform-heat-flux, fully developed coefficients yield exchanger lengths which are much longer than those given by an improved design method. The results are preliminary and further confirmatory information will be obtained.

Nature of Carbon in Sodium (p. 47)

In an attempt to measure possible stable organic compounds in Na, Na samples were extracted with n-nonane. The extracts were filtered and examined spectrophotometrically using n-nonane in the reference cell. No absorption was found between 2200 and 4000 Å.

In another procedure, sodium was dissolved in distilled water and the clear solution examined spectrophotometrically with dilute NaOH in the reference cell. No significant absorption was found in the ultraviolet and visible regions (2150 to 7000 Å), indicating that the Na did not contain any significant amount of stable, NaOH-soluble, aromatic compounds.

"Indirect information concerning the nature of carbonaceous species in sodium can be obtained by analysis of the products of sodium hydrolysis. The gases evolved on dissolution of U.S.I. sodium in water were absorbed on a liquid-nitrogen-cooled, silica gel trap and analyzed by gas chromatography. Methane (0.7 to 1.6 ppm equivalent carbon) was detected as an off-gas from the alkaline solution. The methane may have existed as such or as an organometallic compound in the sodium. When the alkaline solution was acidified, carbon dioxide (≈ 6 ppm equivalent carbon) was evolved. The carbon dioxide probably originated from Na_2CO_3 in the sodium. Acetylene, ethylene, and ethane were not detected as off-gases from either alkaline or acid solution; carbon monoxide will be determined in future experiments. A grey-white residue, partially soluble in dilute HCl, remained after the dissolution. The residue, after being collected on a fine-porosity quartz frit, was analyzed for total carbon and found to contain 14 ppm carbon based on the original sodium.

Summarizing, $\approx 55\%$ of the carbon in U.S.I. sodium has been accounted for by three different hydrolysis products.

Analyses for cyanide in the NaOH solution obtained by dissolution of U.S.I. sodium in water revealed < 1 ppm cyanide. Using the same analytical procedure, < 1 ppm cyanide was found in samples of sodium from the primary and secondary sodium coolant systems of the EBR-II."

(O. E. Dwyer)

Figures 4 and 5 in the Review correspond to Figures 5 and 6 in the original report.

REVIEW NO. 452

ARGONNE NATIONAL LABORATORY
REACTOR DEVELOPMENT PROGRAM PROGRESS REPORT

Sponsor: U.S. Atomic Energy Commission

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

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

Report No.: ANL-7152

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

Report Date: January 1966

Previous Reviews: 29, 30, 31, 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

Fuel-Cladding Materials for Na-Cooled Reactors

Creep tests were conducted on 0.5-mm-thick V - 20% Ti specimens that were previously exposed to flowing Na at 650°C which contained ≈ 20 ppm O_2 . The results are shown in Figure 6. Curve A refers to a specimen exposed to Na for seven days. Curve B refers to a control specimen which was vacuum encapsulated in Vycor and heated for seven days at 650°C . Curve C represents a 1.5-mm-thick specimen which was not exposed to Na. All specimens were in the 900°C recrystallized condition. It is concluded that short-time exposure materially decreases creep resistance under these conditions.

Samples of V - 20 wt % Ti have been exposed to sodium containing 3 to 5 ppm oxygen (measured by vacuum distillation) at temperatures of 700° and 750°C for periods of time up to 32 hr. Samples are rotated at about 5 rpm to insure access of oxygen to the surface. The oxidation at 750°C is parabolic with a parabolic rate constant $K_p = 43 \times 10^{-4} \text{ mg}^2/\text{cm}^4\text{-hr}$ for the 32-hr period of exposure.

At 700°C the process is linear for the first 12 hr and is followed by a transition to a parabolic loss for the balance of the exposure of 32 hr. The respective rate constants are: $K_l = 8 \times 10^{-3} \text{ mg}/\text{cm}^2\text{-hr}$ and $K_p = 13 \times 10^{-4} \text{ mg}^2/\text{cm}^4\text{-hr}$.

In further corrosion tests in oxygen-contaminated Na, a number of V alloys were prepared and exposed for seven days to 650°C-Na containing about 25 ppm O₂. The results are shown below.

<u>Alloy* wt %</u>	<u>External loss μ per side</u>
V - 20 Ti (reference)	33
V - 30 Ti - 10 Al	25
V - 20 Ti - 7½ Al	31
V - 20 Ti - 10 Al	27
V - 10 Ti - 10 Al	45
V - 10 Ti - 10 Al - 10 Cr	19

*Alloys (except V - 20 wt % Ti reference) exposed in the as-cast, machined, and etched condition. V - 20 Ti in the 900°C-1 hr annealed and etched condition.

The corrosion rate for V - 20% Cr - 10% Al obtained earlier on the same basis is only 3 μ, and an effort is being made to improve the fabricability of this alloy.

Samples of V - 15% Ti - 5% Cr were also exposed to Na under the same conditions. The results are shown below. It will be noticed that the heat treatments at higher temperature led to a significant reduction in the depth loss.

<u>Condition</u>	<u>External loss μ per side</u>
As rolled	40
Annealed at 700°C for 1 hr	31
Annealed at 900°C for 1 hr	31
Annealed at 1350°C for 1 hr	24
Annealed at 1500°C for 1 hr	13

Liquid-Metal Corrosion (p. 59)

Further exploratory experiments were carried out in studying the possibility of protecting Zr from corrosion in Na by prefilming and by polarization methods. When Zr electrodes prefilmed overnight in oxygenated Na at 580°C (see Review No. 429, Vol. 3, No. 6, Dec. 1965) were exposed at 400°C, additional weight changes were well within the variations due to handling and weighing errors.

Studies to improve polarization experiments at a Na temperature of 540°C continue.

A small nickel corrosion loop is being built for isothermal flow of Na. It will circulate up to 1.5 liters/min, have a total inventory of about 5 liters, and operate at temperatures up to 650°C. Test samples will be distributed throughout the loop. Apparently it will be used to study corrosion inhibition by dissolved getters.

Boiling Liquid-Metal Technology (p. 63)

Construction of the Cb - 1 Zr experimental boiling heat transfer facility is continuing (see Review No. 451 above).

Electron-Bombardment Heater Experiment (p. 64)

The purpose of this experiment is to gain experience with electron-bombardment heating and to optimize the various mechanical factors involved in the construction of a high-heat-flux heater. It is planned to design and build an E.B. heater for eventual use in the Cb - 1 Zr loop mentioned above. Operation of the small prototype experiment continues. A number of modifications has recently been made to extend the heater operating periods and these are now being tested.

Heat Transfer in Double-Pipe Heat Exchangers (p. 65)

Both analytical and experimental studies are continuing on the problem of the design of both cocurrent and counter-current double-pipe heat exchangers by improved methods (see Review No. 451 above).

(O. E. Dwyer)

Figure 6 in the Review corresponds to Figure 22 in the original report.

REVIEW NO. 453

SODIUM HEATED STEAM GENERATOR DEVELOPMENT
FULL-SIZE STEAM GENERATOR

Sponsor: U.S. Atomic Energy Commission
Contractor: The Babcock and Wilcox Co., Barberton, Ohio
Contract No.: AT(11-1)-1280
Report No.: BW67-2, 2 Volumes and Addendum
Report Dates: Volumes 1 and 2 - July 1, 1964
Addendum - September 15, 1964
Previous Reviews: 56,61,115,116,123,124,163,194,195,237,248,
249,277,302,342,417

These reports constitute the Preliminary Design Report of the full-size [1000 MW(e) in three units] steam generator for use in a large reactor system. The unit is a helical coil type bundle, once-through steam generator. The boiler bundle is fabricated of Croloy 2-1/4, and is separate from the type 316 SS superheater bundle.

Volume 1 is a description of the plant steam cycle and steam generators. It includes copies of some of the arrangement drawings and a summary of the heat transfer data at full and part load. A cost estimate of the steam generator and reheaters is included. The estimated cost of this equipment to supply steam to produce 1000 MW(e) is $\$21.5 \times 10^6$ for the first plant and $\$18.6 \times 10^6$ for subsequent plants. This cost includes controls, inert gas system, feedwater heaters, freight, and erection.

Various areas requiring R&D work are outlined. A detailed description of these areas is contained in topical reports and progress reports.

Volume 2 summarizes the results of the ASME Code calculations, the steady-state stress analysis, and the transient temperature and stress analysis. Sample calculations of a typical steady-state and transient analysis are included.

The Addendum contains an analysis of the sodium-water reaction problem. The temperature and pressure conditions that would occur during a reaction were developed by APDA. The analysis of the steam generator to determine the effects of the reaction on the unit was done by Babcock and Wilcox. It was concluded that the full-size steam generator will withstand a credible number of tubes failing simultaneously without becoming a major hazard to nearby personnel and equipment.

(K. C. Hoffman)

REVIEW NO. 454

SODIUM-HEATED STEAM GENERATOR DEVELOPMENT
PROTOTYPE STEAM GENERATOR

Sponsor: U.S. Atomic Energy Commission
Contractor: The Babcock and Wilcox Co., Barberton, Ohio
Contract No.: AT(11-1)-1280
Report No.: BAW-1280-28, Vol. 1, 2, 3, and 4
Report By: J. G. Clark and J. E. Hocking
Report Date: November 15, 1965
Previous Reviews: 56, 61, 115, 116, 123, 124, 163, 194, 195, 237, 248,
249, 277, 302, 342, 417, 453

This report consists of four volumes and is the preliminary design report for the 30-MW(t) prototype sodium-heated steam generator. The prototype is sized for operation and test in the Sodium Components Test Installation at Atomics International.

Volume 1 contains a description of the steam generator, the heat transfer analysis at full and part load, and reduced copies of some of the arrangement drawings. The prototype is to model a steam generator [1000 MW(e) in three units] for a large power plant. The general concept is a once-through boiler

with a helical-coil tube bundle. The prototype models the temperature, pressure, flow, mechanical features, and stresses in the critical areas of the full-size unit.

Volume 2 summarizes the results of the ASME Code calculations, the steady-state stress analysis, the earthquake analysis, and the transient temperature and stress analysis. A sample calculation showing a typical steady-state and transient analysis is included.

Volume 3 deals with the problem of a sodium-water reaction and the analysis of its effect on the prototype unit. A model of the reaction kinetics was developed by APDA and was used to predict the pressure loading and temperature conditions which resulted from a reaction. This analysis is summarized in the report. Much of this volume deals with the full-size steam generator, since the pressure conditions which resulted from a reaction are similar to those that would exist in the prototype. The dynamic strength of the generator shell is determined by both the impulse--momentum and work--energy methods with similar results.

It is concluded that the full-size generator can withstand at least the simultaneous failure of 25 tubes in the worst location.

Analyses of critical areas other than the shell are summarized in the report, and sample calculations are included.

Volume 4 contains the design and fabrication specifications as well as the acceptance standards for welding, nondestructive tests, cleaning, hydrostatic test, and helium leak test.

(K. C. Hoffman)

REVIEW NO. 455

EFFECT OF HIGH TEMPERATURE SODIUM
ON AUSTENITIC AND FERRITIC STEELS
Mechanical Properties of Materials

Sponsor: U.S. Atomic Energy Commission
Contractor: MSA Research Corporation, Evans City, Penna.
Contract No.: AT(11-1)-1280

Report No.: MSAR 65-194; Topical Report No. 4
Report By: R. C. Andrews, K. R. Barker, R. C. Werner
Report Date: December 1965
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

This report summarizes tests run to determine the effects of high-carbon concentrations in Na at 1200°F on the mechanical properties of type-316 SS.

Rupture, yield, and tensile strengths of type-316 SS exposed in high carbon Na were found to increase. More important, however, was the occurrence of an almost total loss in ductility. In addition the impact strength was greatly reduced in a short period of time. Fatigue life of type-316 SS in this environment was comparable to that in air but much lower than that in low-oxygen Na. Examination of fractured tensile specimens indicated that carburized type-316 SS was notch-sensitive. Creep-rate curves obtained were very erratic and would have little meaning to the designer. The erratic behavior was attributed to the changing chemical composition of the specimen.

Tabs of types 316 SS and 304 SS and 2-1/4 Cr - 1 Mo steel were exposed to the high-carbon Na. Types 316 SS and 304 SS initially carburized at the same rate; however, after a few days, the carburization rate of type 316 SS declined more rapidly than that of type 304 SS. Carbon pickup by the stainless steels occurred on the surface but the 2-1/4 Cr - 1 Mo steel showed a uniform increase. Carbide residues analyzed from each alloy showed that for equivalent carbon levels the carbon-rich M_7C_3 phase was more predominant in type 304 SS, while the $M_{23}C_6$ phase existed in the type-316 SS. Sigma phase was not detected in any of the type-316 SS specimens exposed to high-carbon Na. Microprobe analyses of types 316 SS and 304 SS carburized for 2000 hr showed depletion of Cr and Ni to a depth of $<6 \mu$. There was some indication that stress may enhance carburization of stainless steel.

(C. Klamut)

EFFECT OF HIGH TEMPERATURE SODIUM
ON AUSTENITIC AND FERRITIC STEELS
Mechanical Properties of Materials

Sponsor: U.S. Atomic Energy Commission
Contractor: MSA Research Corporation, Evans City, Penna.
Contract No.: AT(11-1)-765
Report No.: MSAR 66-09; Quarterly Progress Report ending Dec. 1965
Report By: R. C. Andrews, K. R. Barker, R. C. Werner
Report Date: January 17, 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

The objectives of this program are to determine the effects of Na, and the effects of contaminants in Na, on the tensile, creep, creep-rupture, fatigue, and impact properties of types 316 and 304 SS and 2-1/4 Cr - 1 Mo steel.

All testing of type-316 SS and 2-1/4 Cr - 1 Mo steel has been completed, and reports have been issued or are in preparation. The three major studies currently under way are (1) the effects of 200°F, high-oxygen (300 ppm) Na on the mechanical properties of type-304 SS, (2) the effects of 1200°F, high-carbon Na on type 304 SS, and (3) the development of an extensometer to measure creep rate of specimens exposed to 1200°F Na.

Type-304 SS Exposed at 1200°F in High-Oxygen Na: Currently three creep, two creep-rupture, and fatigue tests are under way. Some data have been obtained from the creep-rupture and high-cyclic-strain fatigue tests; however, since the tests in air have not been completed, these data have not been evaluated.

Examination of tabs exposed to this environment exhibit sodium chromite on the surface. Thin tabs exposed for short times show erratic weight changes, while thick tabs show slight weight gains. Carbon transfer in this test is not as extensive as that encountered in Test 5 (1200°F high-oxygen Na, but with type-316 SS). Carbon is usually lost in the 60-mil tabs, and where C pickup is observed, it is usually <100 ppm.

Type-304 SS Exposed at 1200°F in High-Carbon Na: The status of this test is essentially the same as that above. Creep-rupture and fatigue data are presented but no evaluation was

made because of the unavailability of the air and He environment test data.

The results on thin tabs exposed to this environment thus far (<500 hr) show considerable scatter. The formation of ferrite and a shift from fine to coarse carbide are reported. This was observed on both types-304 and 316 SS in previous tests in high-C Na. It was found that thin tabs exposed for 1053 and 160 hr have carbon contents of about 2.3%, indicating that saturation takes place rapidly. The microstructure, however, shows more ferrite and coarse carbides after the longer exposure, indicating that transformations are much slower than the carbon pickup. It is suggested by the authors that since these transformations are very slow, a deterioration in mechanical properties could occur (after long times at temperature) to stainless steels exposed for short times to sodium which has had a high carbon excursion. These carburized samples are to be run in the test loops under He cover for thousands of hours to determine if these changes in microstructure continue.

Extensiometer Development: Tests of the extensiometer in air have been initiated. Calibration at room temperature and a test at 1000°F were completed. However, when tested at 1200°F an erratic behavior was noted, and complete electrical failure of the sealed linear variable differential transformer was experienced on cooling to room temperature. Examination of the transformer showed failure of the lead wire-to-transducer connection. A second transducer failed in the same manner. The units have been returned to the manufacturer for redesign.

(C. Klamut)

REVIEW NO. 457

DEVELOPMENT OF TECHNIQUES FOR MEASUREMENT
OF IMPURITIES IN SODIUM

Sponsor: U.S. Atomic Energy Commission
Contractor: MSA Research Corporation, Evans City, Penna.
Contract No.: AT(11-1)-765
Report No.: MSAR 66-10
Report By: S. J. Rodgers and R. C. Andrews
Report Date: January 1966
Previous Reviews: 375, 402, 422

The areas of investigation have been curtailed by elimination of the development of in-stream techniques and all but three of the laboratory techniques. Exploration of whether changes in surface tension can be used as a measure of oxygen impurity is being continued. A bubble method employing argon pressure was chosen as the means of measuring the surface tension. Preliminary tests with potassium were previously performed. During this period the apparatus was modified and recharged with sodium. Decomposition of sodium by naphthalene dissolved in tetrahydroform and subsequent separation of the oxide by filtration was also attempted as a means of determining the amount of oxygen impurity. This organic solvent extraction method yielded one reasonably low result for oxygen, but subsequent analyses were very high, apparently because of filtering difficulties. New experiments are getting under way which involve high vacuum sodium distillation under total reflux conditions with collection of the evolved gases and subsequent analysis by mass spectrometry.

(L. Newman)

REVIEW NO. 458

REFRACTORY METAL PROTECTIVE COATINGS
FOR LONG TERM APPLICATIONS

Sponsor: U.S. Atomic Energy Commission
Contractor: Pratt and Whitney Aircraft, CANEL Division, Middletown, Conn.
Contract No.: AT(30-1)-2789
Report No.: PWAC-499
Report By: L. Friedrich, N. S. Bornstein, and E. C. Hirakis
Report Date: September 1965
Previous Reviews: 14,48

The objective of the program was to develop a reliable, long-time, intermediate-temperature (650° to 1100°C), thermally and mechanically stable coating for refractory metals, particularly Cb-base alloys. Sn-Al base coatings afford protection for times in excess of 2500 hr at 650°C in air but have a reliable lifetime of only 200 hr at 1100°C. To improve performance of the Sn-Al coating at 1100°C, a diffusion barrier of columbium silicide was investigated in an effort to enhance the integrity of the Sn-Al layer which is more resistant to oxidation when it is uncontaminated with Cb.

Sn-Si and Ca-Si slurry experiments were unsuccessful but a slurry mixture of 42 wt % Mg - 58 wt % Si in a lacquer vehicle was found to produce a uniform layer 0.0005 to 0.0006 in. thick of Mg_2Si over Cb_5Si_3 and Cb_5Si_2 after heating for 16 hr at 1200°C in Ar. This coating was chosen for the barrier silicide coating and designated as layer 1. Layer 2 consisted of a sprayed mixture of 53 Sn - 24 Cb - 10 Al - 7 Ti - 3 Cr - 1.5 LiF (in weight percents) followed by heating for 2 hr in 1066°C Ar. Layer 3 consisted of a slurry of 45 Sn - 30 Cr - 16 Al - 9 Ti heated for 2 hr in 1066°C Ar. This combined coating system was designated PWK-5.

A series of PWK-5 coated specimens was tested by exposing them to 650° and 1100°C air, and thermal cycling them five times a week. An additional series of specimens was exposed at temperatures from 538° to 1204°C , and their weight changes were continuously recorded for periods up to 5000 hr. Failure was defined as the first appearance of columbium oxide on a specimen. All failures were either at the edges or at a small area on the face of the specimen. There was no case of failure due to total degradation of the coating. A statistical analysis of the 1100°C data (80 specimens) using a Weibull distribution indicated that a PWK-5 coating on Cb - 1 Zr alloy resulted in a mean lifetime of 820-hr in 1100°C air (see Figure 7), and lifetime was limited by coating "wear out." An increase in the amount of silicide was found to significantly improve the lifetime. A similar analysis of 111 specimens at 650°C was performed. No failures occurred before 499 hr, and after 5000 hr of test 40% of the specimens had survived (see Figure 8).

Coating performance was also evaluated at 750° and 870°C with no failures at either temperature in 5000 hr. At 980°C (5 specimens) three failures occurred at 2640 hr and two failures at 2808 hr. No anomalous behavior was noted in these tests.

Virtually no oxygen penetration occurred in the base metal of specimens exposed for 900 hr in 1100°C air. Thermogravimetric data indicate that the oxidation process of coated specimens approximates a parabolic rate behavior.

Interactions between coating and base metal were studied on specimens exposed to 1100°C static air for periods up to 900 hr.

After 900 hr at 1100°C , penetration of the Cb_5Si_3 by Cb_3Sn_2 and other secondary phases occurred. Ultimate failure occurs when oxygen diffuses through the liquid tin phase path from the surface of the specimen to the base metal, which resulted in the formation of CbO , CbO_2 , and Cb_2O_5 .

Satisfactory coating of large Cb - 1 Zr components could not be achieved. The larger components require a longer time to melt the Mg, and lacquer decomposition and evaporation results in loss of the active ingredients by dust-off. Experiments with indium-silicon slurries (In having a lower melting point than Mg) showed that 1100°C oxidation tests gave improved performance, although eventual failure was determined by the same silicide-tin interaction as observed with the PWK-5 coating.

(A. H. Fleitman)

Figures 7 and 8 in the Review correspond to Figures 9 and 11 in the original report.

REVIEW NO. 459

THE COMPATIBILITY OF STRUCTURAL AND TURBO-MACHINERY
ALLOYS IN BOILING POTASSIUM

Sponsor: U.S. Atomic Energy Commission
Contractor: Pratt & Whitney Aircraft, CANEL, Middletown, Conn.
Contract No.: AT(30-1)-2789
Report No.: PWAC-501
Report By: S. S. Blecherman and J. Hodel
Report Date: October 1965
Previous Reviews: 14,48

The compatibility of candidate structural and turbo-machinery alloys with boiling potassium was studied with respect to the requirements of an advanced nuclear-Rankine space power plant. Four natural-circulation loops, each operated for 3000 hr at $\approx 1070^\circ\text{C}$ boiling, were tested. The loop materials were as follows:

- Loop #1 - Cb - 1 Zr with PWC-533 (Cb - 5 Mo - 3 Zr - 3 Ti - 0.1 C) inserts in boiler and condenser
- Loop #2 - PWC-533 throughout
- Loop #3 - Cb - 1 Zr with PWC-11 (Cb - 1 Zr - 0.1 C) inserts in boiler and condenser
- Loop #4 - Cb - 1 Zr with Mo - 0.5 Ti - 0.01 Zr inserts in boiler and condenser, and type 316 SS inserts in subcooler region.

The Cb - Zr - C alloys (PWC-533 and PWC-11) were unaltered in composition and strength by exposure to the K. The Cb-Zr alloys were not penetrated by stress-induced corrosion or by intergranular corrosion. The 1070°C condensate, however, did cause slight dissolution corrosion in the condenser regions.

The Mo - 0.5 Ti - 0.09 Zr alloy was compatible with wet K vapor at 1010°C, but a slight loss in elevated-temperature tensile strength was observed. The compatibility between 650°C type-316 SS and Cb - 1 Zr alloy in K was adequate to warrant further testing in a proposed forced-circulation loop.

(A. J. Romano)

REVIEW NO. 460

SUMMARY REPORT OF POTENTIAL LIQUID METAL
BEARING MATERIALS FOR SNAP-50/SPUR PUMPS

Sponsor: U.S. Atomic Energy Commission
Contractor: Pratt and Whitney Aircraft, CANEL, Middletown, Conn.
Contract No.: AT(30-1)-2789
Report No.: PWAC-468
Report By: M. J. Wallace
Report Date: November 1965
Previous Reviews: 14,48,148,175,380,406

Under this program the compatibility and wear characteristics of selected bearing materials were studied in lithium and NaK. This information was required to provide information for use in the SNAP-50/SPUR pump development program.

The compatibility of various materials in 1100°F lithium was studied in Cb - 1 Zr tilting capsules for durations up to 7000 hr. The wear behavior was evaluated with a rotating disc, static shoe assembly in lithium and NaK up to 1000°F.

The report contains an impressive amount of data for cermet, carbides, surface-treated refractory metals, and coated metals.

The following conclusions were contained in the report summary:

- a. The best compatibility and wear characteristics were exhibited by high density molybdenum-cemented carbides. Carburized Cb - 1 Zr alloy wear resistance was inconsistent, but under the best conditions was nearly equivalent to that of the cemented carbides. Plasma-jet sprayed coatings of tungsten carbide and WC-Co gave encouraging results in NaK, but additional development of the coating process appeared necessary to assume reliable control of adhesion and performance.
- b. Based on the test results, carburized cermets were recommended as the materials for use in fabricating full-size bearings to be tested under SNAP-50/SPUR pump bearing conditions.

(K. C. Hoffman).

REVIEW NO. 461

SNAP-50/SPUR FINAL SUMMARY REPORT
Coolants and Working Fluids

Sponsor: U.S. Atomic Energy Commission
Contractor: Pratt and Whitney Aircraft, CANEL, Middletown, Conn.
Contract No.: AT(30-1)-2789
Report Date: November 1965
Previous Reviews: 14,48,62

The SNAP-50/SPUR powerplant design was based on the use of lithium as a reactor coolant, potassium for the Rankine cycle working fluid, and eutectic NaK for the condenser coolant.

This report summarizes the work accomplished at PWAC to establish coolants and working fluid technology.

Analytical Chemistry

Trace metal contaminants in Li, K, and NaK (78K) were determined by spectrographic analyses of the carbonates which were prepared from the dissolution products of the materials. The methods used for these analyses are included in an appendix.

Two methods were applied to the determination of oxygen:

- a. The liquid ammonia method of Jaworowski, et al., for the determination of oxygen in lithium.
- b. The amalgamation procedure for oxygen in sodium, NaK, and potassium.

The authors felt that the determination of oxygen in alkali metals appears to be based upon reasonable assumptions and practices.

There are considerable uncertainties in the methods used for the determination of nitrogen and carbon in alkali metals. Nitrogen in lithium can be determined by measurement of the ammonia produced after hydrolysis and steam distillation. There is no recommended method for the analysis of the nitrogen content in other alkali metals. Experimental work at CANEL has shown that carbon can be recovered from lithium and sodium in several forms. Only those methods which determine total carbon have been validated to date, although it is expected that reliable methods for the determination of individual carbon species will be required for a complete understanding of any carbon transport phenomenon.

Handling and Purification

Descriptions are given of the procedures and equipment used and developed during this program for handling and purification of alkali metals. Specifically, safety practices, transfer equipment, purification methods, sampling methods, and decontamination procedures are reviewed.

Physical Properties

From a combination of literature sources and their own measurements, the authors have compiled graphs of "best available" physical properties for Li, K, and NaK. This report reproduces graphs for density, heat capacity, electrical resistivity, viscosity, vapor pressure, thermal conductivity, and He solubility in the liquid metals.

Corrosion Theory

As a result of corrosion tests carried out during the course of this program, the following conclusions and observations are put forth in the report:

For Cb - 1 Zr alloy with Li:

- a. Intergranular penetration by lithium occurs when oxygen concentrations in solid solution exceed 200 ppm.
- b. Zirconium, when added to pure columbium, is an effective oxygen stabilizing element which reacts to precipitate ZrO_2 . The precipitation reaction is accelerated by heating to 2200°F. This process was employed routinely for stabilizing welded material.
- c. Stabilized Cb - 1 Zr alloy can tolerate oxygen contamination up to 2:1 atom ratio with zirconium without incidence of lithium attack.

For PWC-11 alloy (Cb - 1 Zr - 0.1 C) with Li:

- a. A nominal 42% of available zirconium atoms were combined in the mixed (Cb-Zr)C phase. Only 58% remained as uncombined zirconium available to react directly with oxygen to form ZrO_2 . Thus, the oxygen tolerance would be reduced 42% if determined solely by interactions of zirconium and oxygen atoms.
- b. The reaction rate for removal of oxygen from solid solution was decreased in comparison to the behavior in Cb - 1 Zr alloy. This suggests that a different reaction may occur.
- c. The precipitated oxygen was almost completely extracted when exposed to lithium in contrast to partial removal from the ZrO_2 phase in Cb - 1 Zr alloy. It seems unlikely that the extraction behavior of oxygen would differ so greatly in alloys of nominally similar composition unless the oxygen containing phase differed.
- d. A duplex structure was evident in the carbide phase of oxygenated, stabilized PWC-11 alloy. The carbide phase evidently was not decomposed to ZrO_2 during the stabilizing heat treatment.

For Cb alloys with K and Na:

- a. The corrosion behavior of the Cb-Zr-O-Na system is qualitatively consistent with the model developed for the Cb-Zr-O-Li system. Intergranular penetration by

sodium occurs when oxygenated Cb - 1 Zr alloy is exposed in the "as-quenched" condition or when the O:Zr atom ratio exceeds two.

- b. The reactivity of sodium with oxygen contaminated Cb - 1 Zr alloy is significantly less than that of lithium.
- c. Based on the above, a getter element is probably required in columbium alloys to permit reliable operation in other alkali metal systems. Postweld heat treatments may also be beneficial in stabilizing the alloy to these alkali metals.

Long-Term Material Compatibility

The following "tentative" conclusions are reported as a result of compatibility loop tests:

- a. Columbium-zirconium alloys are capable of containing 2000°F boiling potassium without penetration attack or stress-induced corrosion. Potassium condensate causes slight dissolution corrosion, but evaluation of the significance of the effect requires testing under SNAP-50/SPUR flow conditions.
- b. Columbium-zirconium-carbon alloy compositions and strength are essentially unaltered by exposure to a 2000°F boiling potassium environment.
- c. Mo-TZM alloy appears to experience a slight reduction in elevated temperature tensile strength after exposure to wet potassium vapor at 1850°F.
- d. Compatibility between type-316 SS and Cb - 1 Zr alloy in boiling potassium at 1200°F was considered adequate to warrant further testing.

(J. C. Chen)

REVIEW NO. 462

PERFORMANCE EVALUATION OF HEAT EXCHANGERS
FOR SODIUM-COOLED REACTORS

Sponsor: U.S. Atomic Energy Commission
Contractor: United Nuclear Corp., White Plains, N.Y.
Contract No.: AT(11-1)-1452
Report No.: UNC-5135
Report By: R. H. Dischinger
Report Period: July 1, 1965 through Sept. 30, 1965
Report Date: October 20, 1965
Previous Reviews: none

United Nuclear Corporation has contracted to perform the evaluation of the thermal-hydraulic and structural performances of heat exchangers for sodium-cooled reactors. The evaluation will be made of 30-MW(t) model heat exchangers that are to be tested by Atomics International in the Sodium Components Test Installation (SCTI). An intermediate heat exchanger designed and manufactured by ALCO Products, Inc. and a steam generator designed by ALCO and manufactured by Baldwin-Lima-Hamilton are installed in the system and will be the first ones tested.

During this first report period United Nuclear reviewed reports, drawings, and other documents relating to the design, manufacturing, and test of the heat exchangers. Some time was also spent on familiarization with the test facility and the test program. Analytical techniques and computer codes were developed to digest the test data, and these were checked out against initial design information. Inconsistencies were uncovered in the heat exchanger design reports and these have been resolved.

(K. C. Hoffman)

REVIEW NO. 463

HIGH-TEMPERATURE PROPERTIES OF POTASSIUM
HIGH-TEMPERATURE PROPERTIES OF SODIUM
HIGH-TEMPERATURE PROPERTIES OF CESIUM

Sponsor: National Aeronautics and Space Administration
Contractor: U.S. Naval Research Laboratory, Washington, D.C.

Contract No.: NASA C-76320

Report Nos.: NRL-6233, NRL-6241, NRL-6246

Reports By: J. P. Stone, C. T. Ewing, J. R. Spann, E. W. Steinkuller, D. D. Williams, and R. R. Miller

Report Dates: September 1965

Previous Reviews: 35, 104, 105, 268, 269, 354

NRL-6233 is the final report on the work with potassium. Experiments include PVT studies, density measurements, vapor pressure measurements, and some specific heat measurements. The temperature range was 1400° to 2525°F. Thermodynamic properties, including the Mollier diagram, and the molecular constitution of the vapor were then calculated using the experimental results.

The design of a diaphragm null detector PVT apparatus is described. This apparatus was also used to measure vapor pressures of potassium. Also a high-pressure furnace used in the measurements is described. Liquid densities were determined with a columbium-1% zirconium pycnometer.

The results of PVT measurements are used to calculate the coefficients of the virial equation of state through the fourth virial. For potassium it was found that

$$\frac{p\tilde{V}}{Rt} = 1 + \frac{B}{\tilde{V}} + \frac{C}{\tilde{V}^2} + \frac{D}{\tilde{V}^3},$$

$$\text{with } \log |B| = -3.8787 + \frac{4890.7}{T} + \log T,$$

$$B < 0$$

$$\log |C| = 0.5873 + \frac{6385.7}{T},$$

$$C > 0$$

$$\log |D| = 1.4595 + \frac{7863.8}{T},$$

$$D < 0$$

where p is in atmospheres, T is in °R, and $\tilde{V}$ is the molal volume per formula weight of monomer.

With the use of these coefficients the enthalpy, entropy, and specific heat of the saturated and superheated vapor were calculated and tabulated for temperatures from 1400° to 2525°F.

Since the vapor polymerizes according to the general reaction $nK_1 = K_n$, the equilibrium constants for the dimer and tetramer formation (it was deduced that the trimer concentration was negligible) were calculated by using the raw PVT data. Results are also tabulated. The standard enthalpies of dimerization and tetramerization are also calculated. An equation of state using the above equilibrium constants (quasi-chemical equation of state) is deduced and compared with the virial equation.

The same program as reported above for potassium has been carried out for sodium and cesium, and is reported in NRL-6241 and NRL-6246, respectively.

(J. J. Egan)

FLOW RATE : 22,000 - 67,000 lb/hr-ft²
 SATURATION TEMPERATURE : 980 - 1350°F
 VAPOR QUALITY : 0.25 - 0.90

CESIUM - VERTICAL FLOW

FLOW RATE : 24,000 - 88,000 lb/hr-ft²
 SATURATION TEMPERATURE : 1020 - 1355°F
 VAPOR QUALITY : 0.15 - 0.85

RUBIDIUM - VERTICAL FLOW

FIGURE 1. FORCED CONVECTION CONDENSING HEAT TRANSFER DATA - VERTICAL FLOW

(Review No. 448)

FLOW RATE : 25,000 - 75,000 lb/hr-ft²
 SATURATION TEMPERATURE : 1040 - 1360°F
 VAPOR QUALITY : 0.15 - 0.85

RUBIDIUM - HORIZONTAL FLOW

FLOW RATE : 22,000 - 68,000 lb/hr-ft²
 SATURATION TEMPERATURE : 1030 - 1090°F
 VAPOR QUALITY : 0.21 - 0.89

CESIUM - HORIZONTAL FLOW

FIGURE 2. FORCED CONVECTION CONDENSING HEAT TRANSFER DATA - HORIZONTAL FLOW

(Review No. 448)

(Review No. 449)

Figure 3

NOTES
 GK - POTASSIUM MASS VELOCITY
 TSAT - POTASSIUM SATURATION TEMPERATURE
 AT SCALER EXIT
 SODIUM INLET-TO-OUTLET TEMPERATURE DROP
 10C 10F IN ALL CASES
 ● PRIMARY DATA POINTS
 ○ PRELIMINARY DATA POINTS

FIGURE
 19-TUBE POTASSIUM
 BOILER HEAT TRANSFER
 TEST RESULTS

Creep of Annealed V-Ti-Cr
Alloy Sheet Specimens
Tested at 15 kg/mm^2
Stress and 650°C

Figure 4
(Review No. 451)

Log Minimum Strain Rate versus Arithmetic
Mean Bulk Modulus for V-Ti-Cr Alloys
Annealed at 900°C for 1 hr and Tested
at 15 kg mm^{-2} Stress at 650°C in
 $< 1 \times 10^{-6}$ mm Hg Vacuum

Figure 5
(Review No. 451)

Effect of Sodium on V-20 w/o Ti.
See text for description of curves.
Figure 6

(Review No. 452)

RELIABILITY OF PWK-5 COATED Cb-1 Zr ALLOY IN 1100C AIR
(WEIBULL METHOD)

Figure 7
(Review No. 458)

RELIABILITY OF PWK-5 COATED Cb-1 Zr ALLOY IN 650C AIR

(WEIBULL METHOD)

Figure 8

(Review No. 458)

APPENDIX A

CORRECTION

The following statement dated February 24, 1966 was received from Mr. R. J. Beeley, Program Manager, Fast Reactor Program, Atomics International, relative to the Review.

Subject: Correction of a Reporting Error in BNL 953 (PR-16), "High Temperature Liquid Metal Technology Review," Volume 3, No. 4, August 1965

An error somehow crept into the reference publication which should probably be corrected. On p. 183 in the summary of the ESADA program, there is the following sentence: "Samples were taken from the hot trap inlet tube whose inside surface had been exposed to sodium containing about 1/4% carbon, and whose outside surface was exposed to sodium having a carbon content of 0.1%." This should be revised to read: "Samples taken from the inner surface of the hot trap inlet tube, which had been exposed to untrapped sodium, showed a surface carbon content of about 0.35%; the outside of this tube, which was exposed to the sodium returning from the hot trap, showed a carbon content of about 0.1%, indicating that the hot trap was effective in removing carbon." I believe this wording will clarify the situation.

APPENDIX B

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

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