NAA-SR-12256
VOL I

COPY

MASTER

PROGRESS REPORT
SNAP SYSTEMS IMPROVEMENT PROGRAM
MERCURY-RANKINE PROGRAM
JULY-SEPTEMBER 1966
VOLUME I

AEC Research and Development Report

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.

DISCLAIMER

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

DISCLAIMER

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

LEGAL NOTICE

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

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

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

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

OPTI PRICES

H.C. \$ 3.00; MN. 65

NAA-SR-12256
VOL I
REACTOR TECHNOLOGY

PROGRESS REPORT
SNAP SYSTEMS IMPROVEMENT PROGRAM
MERCURY-RANKINE PROGRAM
JULY-SEPTEMBER 1966
VOLUME I

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

LEGAL NOTICE

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

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

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

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

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.
P.O. BOX 309 CANOGA PARK, CALIFORNIA

CONTRACT: AT(11-1)-GEN-8
ISSUED: JAN 15 1967

DISTRIBUTION

This report has been distributed according to the category "Reactor Technology" as given in the Standard Distribution for Unclassified Scientific and Technical Reports, TID-4500.

CONTENTS

	Page
I. Introduction	4
II. Summary	5
III. CRU Analysis	7
A. Shaft Bearing Dynamics Analog	7
1. Modifications to the Hydrostatic Forces	7
2. Shaft Dynamics	9
B. Rotor Digital Dynamic Study	9
1. Dynamic Response Based on Shaft Balance	10
2. Critical Speed as a Function of Bearing Mounting Stiffness	10
IV. Component Development	13
A. Instrumented Boiler Test	13
B. Pressure Regulator and Injection Tank	17
V. System Testing	18
VI. Supporting Research – Pool Boiler Test	19

FIGURES

1. Shaft Shape at 36,000 rpm with a Bearing Mounting Stiffness of 2×10^5 lb/in.	11
2. Shaft Shape at 36,000 rpm as a Function of Bearing Mounting Stiffness, K_B – 400°F BCEP Bearing Film Characteristics	11
3. CRU V Critical Speeds vs Bearing Mounting Stiffness	12
4. MRP Boiler Test Model 7-1A Boiler NaK Temperature Profile (Run No. 9)	16
5. MRP Boiler Test Model 7-1A Boiler NaK Temperature Profile (Run No. 15)	16
6. Mercury Pool Boiling Heat Transfer at $\cong 950^\circ\text{F}$ Saturation Temperature From Haynes-25 Heater No. 6 Surface	21

I. INTRODUCTION

The primary objective of the Mercury Rankine Program (MRP) is the development of a broadly based component and system test technology that may be utilized in a space flight application for reliable electric power generation of long duration. The MRP technology program is an outgrowth of the original SNAP 2 Flight Test Program. The development is directly applicable to utilization with either a reactor or isotope type power source. The components under development can be combined in two or more parallel 3 to 5 kwe power conversion subsystems (PCS) to provide a flexible electrical power source for space missions. Major components have all completed 90-day endurance testing as the first step toward the 10,000-hr endurance objective.

During the first portion of this quarter, efforts continued on system engineering, component feasibility, endurance and reliability improvement, and system test evaluation. Near the end of this report period, the AEC directed that the scope of the MRP be reduced to include only 10,000-hr endurance tests of two CRU-V units.

The accomplishments in system engineering, component development, system testing, and basic technology are reported in Volume I. The progress and accomplishments specifically made in the testing and development of the Combined Rotating Unit (CRU) and the boiler which are subcontracted to TRW, are reported in Volume II.

II. SUMMARY

The development efforts during this first quarter of FY 1967 were reduced to the activities specifically dealing with CRU development, boiler conditioning investigation, and minimal system engineering. Late in this reporting period, the AEC directed the phase-out of all work efforts on the MRP except for the planned operation of two 10,000-hr CRU V endurance tests. Cognizance of the TRW subcontract was transferred from AI to the AEC through execution of a novation agreement effective October 1, 1966.

In compliance with the above guidance, AI's activities were reduced to (1) continued bearing analysis — as it is related to the bearing-shaft dynamic analog computer study, (2) dismantling of MRP test facilities, and (3) writing and issuance of several final MRP reports.

During the quarter, two CRU V's were on test, accumulating a total of 841 hr. The total CRU V test time is now 21,196 hr and combined CRU IVM and CRU V time is 30,321 hr.

The CRU V-5C unit accumulated a total of 4,767 hr, the last 4,185 hr being continuous. At that time, a failure in the plant electric power supply caused a test cell shutdown. Prior to the shutdown, the CRU operation was very stable. Since the 5,000-hr objective had essentially been accomplished, it was decided that the unit should be removed from the test cell for post test disassembly and examination. All critical components were in excellent condition and capable of additional endurance operation.

The CRU V-1D, with the redesigned turbine bearing, completed the planned test series which included 683 hr of operation and 15 startups. All test objectives were accomplished and the new turbine bearing design is capable of being incorporated into all future units without change. All other critical components were in excellent condition.

The rebuild of the CRU V-3E unit, which incorporated a modified alternator bearing lube feed design, was in final assembly when the planned test objectives were revised to include 10,000-hr endurance. It was decided to disassemble the unit to (1) better document the initial hardware conditions, (2) remove the capacitance probes, and (3) convert the module plumbing to HS-25. These activities

will delay the -3E testing until early December. The -3E turbine mounting concept had been revised to include an additional axial load (applied by the locking washer) to the first stage wheel, thus partially insuring that the -3E turbine wheel will not move with respect to the shaft.

The continued satisfactory performance of the basic CRU V machinery in all environments, promises successful achievement of a reliable 10,000-hr service objective. The CRU V-5C test and disassembly results testify to the suitability of the design for long term endurance. The parametric testing of the CRU V-4D and -1D units over a wide range of operational variations shows the existence of a wide safe operating margin for properly assembled machinery.

The CRU V analog bearing-shaft dynamics computer model was amended to simulate a symetrically loaded one-bearing system. The shaft dynamic equations were modified to include shaft bending. The hydrostatic bearing force was changed to include the effect of,

- 1) Journal speed on bearing clearance impedance
- 2) Mercury inertia in the orifices
- 3) Hydrodynamic and squeeze film pressures on the hydrostatic pressure drop through the clearance.

The digital program was concluded with a critical speed analysis of the CRU V shaft as a function of mounting stiffness, and with a reassessment of shaft balancing. Both analyses made use of new 400°F BCEP bearing characteristic data.

Testing of the Model 7-1A boiler, modified to permit measurement and control of the individual flow rates, was carried on up to late September 1966. During the testing, the boiler was only partially conditioned. Initially it was determined that one tube was fully deconditioned, two tubes were partially conditioned and one tube was fully conditioned. Testing was terminated prior to a full parametric survey of both conditioned and deconditioned operation. The mercury pool boiling effort was also terminated prior to completion of the investigation which covered all planned Haynes-25 wetting-dewetting characteristics. Tests with a special heater indicated that no instabilities due to the presence of liquid superheat should occur in mercury boilers.

The results of the previously completed system tests were documented and reported. The system test facilities are scheduled to be dismantled.

III. CRU ANALYSIS

A. SHAFT BEARING DYNAMICS ANALOG

At the end of the last quarter it was recognized that the bearing-forces-analog model contained certain shortcomings which would have to be corrected in order that the analog be representative of CRU V and component test fixture shaft-bearing performance. In particular, the shaft dynamics had to be modified to account for shaft bending, and the hydrostatic bearing forces had to be modified to account for speed dependence and for mercury inertia in the bearing orifices. The inertia effect is considered to be important in determining the bearing damping characteristics. Therefore, in the last quarter the necessary analysis was completed to account for these effects, and at the present time the analog computer is being programmed. In the next quarter verification of the analog model should be completed as well as some parametric bearing analysis using the model.

1. Modifications to the Hydrostatic Forces

In the old model the hydrostatic forces were calculated for zero speed and on a static basis. This ignored the dependence of the forces on journal speed, as evident in actual bearing test data, and it ignored the dynamic effects. That is, the hydrostatic forces are influenced by the hydrodynamic and squeeze film pressure profiles within the clearance and by inertia forces on the mercury caused by the time varying mercury flow rate through each orifice. All of these effects are caused by the dynamics of the journal motion.

According to previously derived equations,* the hydrostatic force is dependent on the three pad pressures within the bearing. All of the effects mentioned above manifest themselves in determining these pad pressures so that the modifications are in the form of a more accurate determination of the pad pressures. Thus, if the hydrostatic force is,

$$F = f(P_{HS_1}, P_{HS_2}, P_{HS_3} \dots P_{HS_i}) \quad \dots (1)$$

where P_{HS_i} are the pad pressures. The pad pressures are,

*J. H. Bick, "An Analog Computer Study of the MRP Combined Rotating Unit Shaft Bearing System," NAA-SR-11943, Equations 80, 81, 85, and 86, July 15, 1966.

$$\begin{aligned}
P_{HS_1} &+ \frac{(1 - \epsilon \cos \theta)^3}{K'w} \left\{ \frac{Z_u^2 (1 - \epsilon \cos \theta)^3}{K'w} P_{HS_1}^{2g(w)} \right. \\
&\quad \left. + Lg(w)P_{HS_1} [g(w) - 1] \frac{dP_{HS_1}}{dt} \right\} \\
&= P_{sup} - P_H(\epsilon, \theta, w) - P_{sq}(\epsilon, \theta, \dot{\epsilon})
\end{aligned}$$

$$P_{HS_2} = f_1(\theta + 120^\circ); P_{HS_3} = f_1(\theta - 120^\circ) \quad \dots (2)$$

In other words, P_{HS_2} and P_{HS_3} are the same functions as P_{HS_1} except they are shifted by $\pm 120^\circ$. P_{sq} is the average squeeze film back pressure seen by the pad. In these equations the speed dependence is accounted for by the functions $K'(w)$ and $g(w)$. The eccentricity ratio is (ϵ) , and (θ) measures the instantaneous angle between the bearing line of centers and a line between one pad and the bearing center. The static orifice impedance is Z_o and the inertial inductance is (L) . That is,

$$Z_o^2 = \frac{\Delta P_s}{W}; L = \frac{\Delta P_i}{dw/dt}$$

where,

ΔP_s = the static pressure drop across the orifice

ΔP_i = the inertial pressure drop across the orifice

W = the weight flow through the orifice

P_{sup} = the bearing supply pressure

P_H = the average hydrodynamic back pressure seen by the pad.

The three components of Equation 2 will be solved by the computer and fed into Equation 1 to get the instantaneous hydrostatic force.

Because Equation 1 and the describing equation for P_H are complicated functions of eccentricity ratio (ϵ) and position angle (θ) , a large amount of analog

computer equipment is necessary for the solution. Therefore, to hold the complexity of the analog to a minimum it has been decided to temporarily reduce the model to one bearing.

2. Shaft Dynamics

The original model consisted of two bearings and a stiff shaft. To improve the simulation of the actual component and CRU V bearing-shaft system, provision for shaft bending has been added to the model.

In all previous experience with the analog model, as well as with the actual component test configurations, no indication of a conical shaft mode has been observed with the conceivable loads expected. In addition, the component configuration is symmetrical so that no difference in the performance of the two bearings is to be expected. Therefore, since the derivation of the hydrostatic forces is quite complex it has been decided to temporarily reduce the dynamic model to a symmetrical system. Thus, one bearing and its equivalent loading from the shaft are to be represented. By eliminating one bearing from the model the complexity will be cut by more than half while at the same time maintaining the essentials of the analysis. Thus, since the actual component configuration is symmetrical, the new model with its more sophisticated hydrostatic representation and provision for shaft bending can be verified through correlation with the component data.

B. ROTOR DIGITAL DYNAMIC STUDY

The final phase of studies with the digital rotor dynamic program was completed. The new 400°F BCEP bearing data were used to repeat a portion of the dynamic response studies to assess the effects of shaft balancing in conjunction with evaluating the effect of magnetic load orientation. A critical speed analysis of the CRU V shaft as a function of bearing mounting stiffness was performed.

Assessment of the effects of a loose first stage turbine wheel on CRU V shaft dynamics had been planned; but upon analysis, it was found that considerable re-programming would be required. Since the previous loose first stage turbine wheel design has been amended, the costs necessary to rewrite part of the digital program in order to evaluate a past anomaly would not be justified.

1. Dynamic Response Based on Shaft Balance

The worst case fabrication tolerances allowable by prints are $200\mu\text{in.}$ eccentricity on the shaft stubs and $400\mu\text{in.}$ on the alternator rotor. It was assumed that the stub and rotor eccentricities were 180° out of phase giving the worst possible case conducive to shaft bending. The CRU V shaft was then analyzed at 24,000, 30,000, 36,000, and 40,000 rpm for two cases.

Case 1 assumed that the shaft was under-balanced at 5700 rpm to a residual unbalance in the direction of rotor eccentricity of 0.0003 in.-oz at each rotor end plane. Case 2 assumed that the CRU V shaft was over-balanced at 5700 rpm to an unbalance value of 0.0003 in.-oz in the direction of shaft stub eccentricity. Characteristic shaft shapes and journal orbits were generated at each speed. Each case was analyzed for bearing mounting stiffnesses of 10^3 , 10^4 , 10^5 , 2×10^5 , and 10^{10} lb/in. using 400°F BCEP data based on infinitely stiff mounting, i.e. BCEP data were assumed to be just fluid film characteristics.

The actual CRU V strap mount is torqued down on Belleville washers at each of two hold-down bolts. Each Belleville washer deflects 8-mils with a force of 150-lb; and there are five washers in series at each location. Therefore, the reciprocal of deflection per inch, mounting stiffness in the up direction, is approximately 2×10^5 lb/in. deflection at each bearing.

Figure 1 shows the shaft shape at 36,000 rpm with a bearing mounting stiffness of 2×10^5 lb/in. Shaft A has a residual unbalance in the direction of rotor eccentricity of 0.0003 in.-oz at each rotor end plane. Shaft B is over-balanced 0.0003 in.-oz at each rotor end plane in direction of shaft stub eccentricity.

It can be seen that the differences in shaft shape as well as journal orbits are insignificant. The really significant characteristic that is readily apparent in both cases is the effect of bending in the shaft extension. The apparent orbits as perceived by capacitance probes will be at least a factor of two greater than the actual orbit experienced by the turbine bearing journal. These results are consistent with previous analyses.*

2. Critical Speed as a Function of Bearing Mounting Stiffness

Since the bearing housing hold-down straps are assembled cold and the Belleville washers deflect in the cold condition, there might be a change in

*"Flexible Shaft Dynamics," NAA-SR-11944, June 15, 1966 (Unc)

Figure 1. Shaft Shape at 36,000 rpm with a Bearing Mounting Stiffness of 2×10^5 lb/in.

Figure 2. Shaft Shape at 36,000 rpm as a Function of Bearing Mounting Stiffness, K_B - 400°F BCEP Bearing Film Characteristics

mounting stiffness upon heating up to operating temperature. For launching a CRU V while operating, consideration of a lower value mounting stiffness to partially isolate launch vibrations from shaft dynamics may be desirable. Therefore, the CRU V shaft-bearing system critical speed was assessed as a function of bearing mounting stiffness. Figure 2 shows shaft shape and displacement at the designated bearing mounting stiffness values of K_B . It is evident that although the centrifugal force load due to orbiting of the CG must increase as K_B is increased due to increased rotor orbit radius, the increase in combined bearing stiffness keeps the deflection in the bearings nearly constant. Deflection hardly varies at the turbine bearing and only increases slightly at the alternator bearing. Part of this constancy is due to the fact that 36,000 rpm is above the second critical speed at $K_B < \text{about } 3 \times 10^4$, and below the second critical but above the first critical speed at $K_B > 3 \times 10^4$ lb/in. This is shown in Figure 3 where critical speed is plotted versus bearing mounting stiffness, K_B . At about 3×10^4 K_B , the shaft will exhibit the conical characteristic of the second natural frequency. For instance in Figure 2, at $K_B = 10^3$ and 10^4 , the turbine bearing journal orbit is approximately twice that of the alternator bearing journal. As K_B is increased to very large values the alternator bearing journal orbit becomes approximately equal to that of the turbine bearing journal.

Figure 3. CRU V Critical Speeds vs Bearing Mounting Stiffness

IV. COMPONENT DEVELOPMENT

A. INSTRUMENTED BOILER TEST

The multitube boiler test program was initiated for the purpose of studying, by experimental means, the general performance and boiler conditioning characteristics of a parallel tube mercury boiler. The study was to be made under steady state conditions of NaK to mercury heat transfer.

The primary objective of the program was the measurement of the effect of both the mercury and NaK side boiler operating parameters on boiler overall performance, boiler conditioning and parallel tube stability. Secondary objectives were to include the measurement of the performance of the individual tubes, both when conditioned and deconditioned, and the determination of the influence of several potential contaminants on boiler conditioning. Some of the contaminants considered were argon, air, water, and oil.

The program as originally planned provided for a NaK shell thermocouple calibration and a boiler heat loss determination followed by a boiler checkout and conditioning operation. Initially a 100-hr endurance test for verification of stable conditioning had been established. Subsequently comprehensive boiler performance mapping was to be performed, with all four tubes in operation. The parallel tube effects studies, in which the tubes would be operated separately and in groups at various combinations of mercury flow rate, were to follow the mapping operations. As part of the parallel tube effects studies, some of the tubes were to be deconditioned by passivating them with a 50% solution of nitric acid. In the final phase, the tests to evaluate several potential deconditioning agents were to be performed. As mentioned, these tests were to include the injection of argon, air, water, and oil into the boiler tubes of the inlet section.

In view of the pending termination of the MRP, it was decided to immediately go into the parametric performance mapping. The decision to eliminate the boiler conditioning and 100-hr endurance runs was based upon the fact that, within the remaining time, a portion of both the conditioned and deconditioned special tests could be accomplished, both separately and in combination. The existence of a deconditioned tube in combination with at least one, and possibly

three, conditioned tubes made it possible to immediately accomplish the parallel tube effects testing.

Results and Accomplishments

The preliminary and checkout operations of the boiler were accomplished during the last weeks of the preceding quarter. Testing in accordance with the test plan was begun almost simultaneously with the start of the report quarter. During the first two weeks of the quarter the calibration operations, consisting of the calibration of the boiler NaK shell thermocouples and the determination of the boiler heat losses, were completed.

The calibration profiles showed that all of the thermocouples on the shell were within $\pm 6^{\circ}\text{F}$ of the norm and that all but a few were within $\pm 2^{\circ}\text{F}$ of the norm. Of the thermocouples distributed over the coiled length of the mercury tubes, all were within $\pm 4^{\circ}\text{F}$ of the norm.

The boiler NaK heat losses were determined for NaK temperatures ranging from 1050 to 1150 $^{\circ}\text{F}$. The heat loss was calculated from the steady state NaK flow rate and differential temperatures. The calculated results showed the boiler NaK heat loss to vary from 0.9 to 1.3 kw for mean NaK temperatures ranging from 1050 to 1150 $^{\circ}\text{F}$.

In mid-July test operations in accordance with the revised test plan were begun. However, during the initial operations the mercury system was shut down by a mercury pump power failure. The failure was identical to those experienced during the checkout operations in June. After the pump circuitry was re-examined it was determined that the pump failures were attributable to the overload thermal switches in the motor starter circuit breaker. The overload switch elements were replaced with elements having a higher rating and no further mercury pump failures were experienced.

Testing in accordance with the revised test plan was resumed, and by mid-August the performance of a deconditioned boiler tube was mapped over a range of boiler operating parameters. The nominal boiler tube operating parameters were as follows:

Mercury Flow Rate (lb/min)	5
Mercury Boiler Inlet Temperature (°F)	650
Mercury Boiler Outlet Pressure (psia)	120
NaK Flow Rate (lb/min)	24
NaK Boiler Inlet Temperature (°F)	1220

A boiler NaK profile was plotted for each parametric condition. The profiles plotted for the deconditioned tube test showed little change in characteristic shape for all of the test conditions. The curves were effectively a straight line between the boiler NaK inlet and outlet temperature. A typical example is shown in Figure 4.

During the "NaK Temperature Variations" and the "Mercury Inlet Temperature Variations" tests, tape recording equipment was arranged to make simultaneous recordings of the boiler vibrational output (noise) and the transient variations due to boiling on several of the boiler parameters. The boiling vibrations were recorded from accelerometers located at the boiler mercury inlet and outlet sections. The parametric transients were recorded from the tube inlet pressure, discharge pressure, discharge temperature, and liquid inlet flow rate transducers. A "noise" recording was made at each test condition.

The boiler was operated briefly at the nominal design conditions with all four tubes operating to provide data for the selection of a tube to be used for the conditioned tube performance mapping. During this operation it was observed that none of the tubes were operating in a fully conditioned mode, including the tube that was believed to have been conditioned. However, as seen in Figure 5, two of the tubes were still producing superheating vapor at 1200°F. The better of these two tubes was selected for the conditioned tube performance mapping and the mapping tests were begun.

The conditioned tube performance mapping was to be accomplished with the same tests as those specified for the deconditioned tube mapping. However, during the first group of mercury flow variations tests, deconditioned performance was indicated over most of the flow range. Termination of the test program prevented further parametric performance studies, and the causes for the deconditioning was not definitely defined. Possibly, minute traces of oil or other impurities from within the test cell — or residual from the boiler handling

Figure 4. MRP Boiler Test Model 7-1A
Boiler NaK Temperature Profile
(Run No. 9)

Figure 5. MRP Boiler Test Model 7-1A
Boiler NaK Temperature Profile
(Run No. 15)

after annealing — contributed to the deconditioning since complete cleanup of the test cell installation prior to test would not be accomplished.

B. PRESSURE REGULATOR AND INJECTION TANK

Because of the delay in the completion of the bellows assemblies, and insufficient funds for testing of the assemblies, the bellows purchase order was cancelled early in the report period.

V. SYSTEM TESTING

As reported previously, the PSM-3 testing program was terminated after completion of the 1F Phase. The performance of the CRU IVM units in the PSM-3 was reported during the quarter.* The report contains plots of the primary system and CRU data as a function of time through the test periods. Also presented are the methods used to correlate the CRU's performance with the data.

The three CRU IVM units (2B, 3B, and 4A) used in the PSM-3 system have been returned to TRW for post test examination.

In accordance with the current stated MRP objectives, the PSM systems are scheduled to be dismantled. Detail plans of action to accomplish the above are being formulated. In preparation for dismantling operations, the NaK and Hg systems have been drained.

*J. G. Le Blanc and F. W. Poucher, "MRP Integrated System Test (PSM-3)," NAA-SR-11945, June 1966 (Unc)

VI. SUPPORTING RESEARCH – POOL BOILER TEST

The objectives of the pool boiling tests are to:

- 1) Determine the effects of surface and system contaminations (to which MRP boilers are intentionally or unintentionally subjected) on pool boiling heat transfer, and, if possible, on degree of wetting.
- 2) Determine practicable methods for obtaining and maintaining adequate wetting, and for cleanup (reconditioning) of contaminated boilers.

During the quarter, an investigation was made of the local liquid superheating characteristics of mercury pool boiling. It has been observed^{*} in pool boiling of sodium that the mode of heat transfer can alternate between non-boiling and nucleate boiling, with accompanying large periodic changes in wall temperature. This instability is most severe at low heat fluxes and disappears at a sufficiently high heat flux. It has been hypothesized that this phenomenon may be a cause of MRP boiler deconditioning.[†] To investigate this phenomenon in mercury pool boiling, a special 0.312-in. OD Haynes-25 clad heater was fabricated. Fast response chromel-alumel thermocouples were located in the Haynes-25 cladding 0.039 in. in from the mercury-heater interface. Provision was made to permit thermocouple readout on either a potentiometer or a multi-channel oscillograph. The results of runs made with this heater were as follows:

- 1) No surface temperature oscillation nor audible sound was detected in any of the runs. These runs covered the following range of parameters.

<u>Run No.</u>	<u>Saturation Temperature (°F)</u>	<u>Heat Flux (Btu/hr-ft²)</u>
102, 103	950 (130 psia)	50,000
104	950 (130 psia)	130,000
105	950 (130 psia)	155,000
106	950 (130 psia)	55,000
107	670 (14 psia)	155,000

*P. T. Marts and W. M. Rohsenow, "Nucleate Boiling Instability of Alkali Metals," ASME Paper 65-HT-22

†A. Koestal and T. T. Shimazaki, "The Mercury Rankine Program Boiler Deconditioning Problem and Planned Investigations," NAA-SR-10860, June 15, 1965 (Unc)

The degree of surface wetting in these runs ranged from partially wetted to completely wetted.

2) The wall superheat data differed from those obtained with the 0.45-in. diameter heaters, as shown in Figure 6 for Runs 102 and 105. A probable explanation for the erratic data of Run 102 is that the heater surface was not completely wetted. An explanation for the difference between the results of Run 105 and those obtained with the 0.45-in. diameter heaters has not been determined. The Run 105 data are in good agreement (allowing for the difference in system pressures) with those obtained by Lyon et al^{*} for mercury with 0.02% Mg and 0.001% Ti additives.

It is concluded from the results of this investigation that no boiling instability occurred in the range of mercury pool boiling conditions covered.

This project was terminated during the course of the investigation prior to completing the full range of investigations of the effects of various impurities on wetting characteristics.

*R. E. Lyon, A. S. Faust, and D. L. Katz, "Boiling Heat Transfer with Liquid Metals," Chemical Engineering Progress, Symposium Series 51, Paper No. 17 (1955)

Figure 6. Mercury Pool Boiling Heat Transfer at $\approx 950^{\circ}\text{F}$ Saturation Temperature From Haynes-25 Heater No. 6 Surface (Local liquid superheat)