

**QUARTERLY TECHNICAL PROGRESS REPORT
ON
AEC-SPONSORED ACTIVITIES**

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Approved



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ABSTRACT

This report is a summary of the technical progress made by Atomic Power Development Associates, Inc., in the period July through September 1969 under AEC Contract No. AT(11-1)-865. The individual projects are covered under the following headings:

Sodium-Water Reaction Test Program
Project Agreement No. 10

Sodium Technology Project
Project Agreement No. 11

Compilation of Fermi Experience
Project Agreement No. 15

Comparison of Methods for Heterogeneity Analysis
Project Agreement No. 19

SUMMARY OF CONTENTS

	<u>Page</u>
LIST OF ILLUSTRATIONS	vi
LIST OF TABLES.	vii
<u>Sodium-Water Reaction Test Program - Project Agreement No. 10 - E. C. Kovacic and H. V. Chamberlain</u>	<u>10.1</u>

The results of four wastage tests conducted in Rig 10 are summarized and comparisons of the results are made with those of previous APDA tests and with results reported by UKAEA in similar experiments. Inspection of the tube bundles after each test showed very little build-up of reaction products. Preliminary results are given for three tests conducted in Rig 43 and these results are compared with Rig-10 tests for corresponding results.

Also reported are acoustic leak detection, hot erosion studies, and hydrogen behavior in the cover gas.

<u>Sodium Technology Project - Project Agreement No. 11 - E. C. Kovacic and J. E. Meyers</u>	<u>11.1</u>
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The major components of the prototype Rhometer completed 10 months' operation during this quarter. The instrument's response to changes in impurity level are given for H₂, NaH, Na₂O, and for cold-trap clean-up of loop sodium. A permanent method for calibrating the Rhometer was installed and is described in detail.

The APDA hydrogen detector completed 2000 hours of continuous operation at 900 F, during which time it responded quickly to changes in hydrogen content. Other work reported here includes centrifuging, cover gas impurities, and sodium sampling reliability.

<u>Compilation of EFAPP Experience - Project Agreement No. 15 - E. C. Kovacic</u>	<u>15.1</u>
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The final reports for this contract were published.

SUMMARY OF CONTENTS (Continued)

Page

Comparison of Methods for Heterogeneity Analysis - Project Agreement No. 19 - J. B. Nims and E. M. Page	19.1
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In an effort to arrive at a consistent analysis of heterogeneity effects in fast critical assemblies and power reactors, an investigation is being made applying four analytical techniques using the same cross section data to selected critical experiments and power reactor designs.

Preliminary work is reported.

LIST OF ILLUSTRATIONS

<u>Fig. No.</u>		<u>Page</u>
10.1	Comparison of Material Wastage Results in Rig 10 Tests...	10.22
10.2	Comparison of Wastage Results at Very Low Leak Rates...	10.23
10.3	Tube Wastage Pattern from Rig-10 Test No. 50.....	10.24
10.4	Photographs of Target Tube from Rig 43 Test No. 1a.....	10.25
10.5	Target Area Showing Reaction Products in Rig 43 Test No. 2a.....	10.26
10.6	Steam-Cleaned Target Tube Showing Wasted Area in Rig 10 Test No. 3a.....	10.26
10.7	Sonic Output of Edo Pressure Transducers at Various Locations and Leak Rates.....	10.27
11.1	Response of Prototype Rhometer to Injections of Hydrogen Gas in Sodium.....	11.8
11.2	Response of Automatic Temperature-Compensated Proto- type Rhometer to Injections of Oxygen as Na ₂ O in Sodium...	11.9

LIST OF TABLES

<u>No.</u>		<u>Page</u>
10.1	Summary of Preliminary Data from Rog 10 Tests.....	10.4
10.2	Comparison of Preliminary Results of Rig 10 Tests..... No. 37 and 45.....	10.5
10.3	Preliminary Results of FY-70 Tests in Rig 43	10.13
11.1	Rhometer Response to Impurity Injections	11.2
19.1	Major Heterogeneity Experiments in ANL Fast Critical Assemblies	19.2
19.2	Comparison of Preliminary Assembly 48 Results with Those of APDA-216 using Method 1.....	19.6

SODIUM-WATER REACTION TEST PROGRAM

PROJECT AGREEMENT NO. 10

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I. PREFACE

A. Background Information

Achievement of the LMFBR program objectives is highly dependent on the development of reliable system components. With regard to the current status of development, the steam generator is recognized to be the weakest link in the heat transport system. The question of what occurs in a steam generator during a sodium-water reaction and how to accommodate such a reaction in the design has been a problem since the inception of sodium- and NaK-cooled reactors. The damage resulting from a reaction may be caused by water leaks of two general categories: large leaks and small leaks. Until recently designers have been concerned with large leaks such as those resulting from the complete circumferential rupture of a water tube. However, in late 1962 a steam generator in the Enrico Fermi Atomic Power Plant (EFAPP) experienced a sodium-water reaction due to a tube failure produced by vibration. Subsequent examination of the unit indicated that a general corrosion had occurred in the area of the sodium-water reaction, producing wastage and failure of some of the adjacent tubes. It is not known at what stage in the propagation of the leaks the wastage occurred; that is, did the wastage occur as a result of the initiating leak, or did it occur as a result of the subsequent leaks? The questions raised by this experience clearly indicate that a sodium-water reaction program should consider both small and large leaks. Subsequent to the EFAPP experience, the British conducted some tests in which they found that significant tube wastage rates can be incurred with small leaks.

B. Scope

As part of the AEC program of steam generator development, a project was initiated at APDA for the purpose of investigating both small and large leaks. An initial series of tests is being run to

- Establish a means of estimating the extent of tube wastage during a small leak of water into sodium in a sodium-heated steam generator.

- Determine the dominant parameters of tube wastage during a small water leak so that these parameters may be taken into account in the design of a unit.

C. Relationship to Other Projects

This program is applicable to the development of sodium-heated steam generators and to the technology of sodium-water reactions in the LMFBR program. Data generated in the program will be used to prepare design criteria and design analysis procedures for steam generators from the standpoint of sodium-water reactions. All of the activities of this program are within the scope of the Components Element (Vol. 3) of the LMFBR Program Plan (Wash 1103). However, some of the activities interface with the Instruments and Control Element (Vol. 4) of the Program Plan. With regard to sodium-water reactions in steam generators, the emphasis in Program Element 3 is on developing information related to mechanisms producing wastage and to the effect of various system parameters and jet characteristics on material wastage. In Program Element 4, the emphasis is on evaluating and on demonstrating leak detection systems which would minimize damage to the steam generator and secondary heat transport system.

Information on the test program and the results to date are available in the proceedings of the Sodium Components Development Program Information Meetings held on April 14, 1964, in Hollywood, California, and on June 17, 1965 in Chicago, Illinois; APDA quarterly technical progress reports on AEC-sponsored activities; in the following papers: "An Investigation of Tube Wastage Caused by Small Leaks of Water in Sodium-Heated Steam Generators," presented at the IAEA Symposium on Alkali Metals - Corrosion Studies and Systems Operating Experience, held at Vienna, Austria, November 28 to December 2, 1966; "Tube Wastage in Sodium-Water Reactions" and "Surface Temperature Measurements in Sodium-Water Reactions," presented at the American Nuclear Society Winter Meeting in Chicago, Illinois, in November, 1967; "Sodium-Heated Steam Generators," presented at the American Nuclear Society National Topical Meeting on Fast Reactor Systems, Materials, and Components, held in Cincinnati, Ohio, in April, 1968; and "Wastage of Steam Generator Materials by Sodium-Water Reactions," presented at International Conference on Sodium Technology and Large Fast Reactor Design, held at Argonne National Laboratory, Argonne, Illinois in November 1968; and a report, "Evaluation of Materials Wastage Due to Reactions of Water in Sodium," APDA-227, June, 1969.

II. TECHNICAL PROGRESS

A. Rig-10 Tube Wastage (Task 20)

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The objective of this task is to establish a means of estimating the extent of tube wastage during a small leak of water into sodium in a sodium-heated steam generator.

1. Test Planning (Job 02)

The scope of the FY-70 program is to conduct 12 material wastage tests by the end of June, 1970. The tests will be made using 2 1/4 Cr-1 Mo steel as the target material with nozzle-to-target spacings of 1/4, 1, and 2 inches. The water injection rate will range from approximately 0.005 to 1.5 lb/sec; the bulk sodium temperature will be approximately 600 F.

A test specification was completed and issued. The objectives of the tests are to (1) clearly confirm the phenomenon of a decreasing wastage rate observed at leak rates beyond approximately 0.01 lb/sec, (2) determine the effect of nozzle L/D on the wastage pattern, and (3) obtain preliminary wastage data for a 2-inch leak-to-target spacing.

2. Testing (Job 03)

a. Wastage Results

Four wastage tests (Tests No. 45, 48, 48a, and 50) were completed during this report period. A summary of the test data is given in Table 10.1 and the wastage results are shown in Figures 10.1 and 10.2.

The first test in the FY-70 Rig 10 Test Program (Test No. 45) was conducted with a leak-to-target spacing of 1/4 inch and a leak rate of approximately 0.009 lb/sec, to determine the effect of the nozzle L/D, i. e., the length-to-diameter ratio of the capillary, on the wastage pattern and rate. The nozzle for Test No. 45 had an L/D of 9.2 as opposed to an L/D of 37.0 for the nozzle used in Rig-10 Test No. 37, which was run at the same leak rate and spacing. A comparison of the results of Test No. 45 with the results of Test No. 37 in Table 10.2 shows that the wastage rate was reduced by a factor of approximately 3 in Test No. 45 and the wastage pattern was clearly of the toroidal type as opposed to pit-type wastage for Test No. 37. The leak rates for these tests coincided almost exactly, although the actual capillary diameters were somewhat different. Examination of all test data for Test No. 45 indicated that the test was not abnormal in any way. Based on the capillary diameter and length, however, the leak rates for the two tests should not have been equal. For this reason, it is hazardous to make an

TABLE 10.1 - SUMMARY OF PRELIMINARY DATA FROM RIG-10 TESTS

	Test No.			
	45	48	48a	50
SODIUM SYSTEM				
Flow rate, gpm	400	400	400	400
Velocity past target tube, ft/sec ~	2	2	2	2
Bulk temperature, F	602	606	600	605
Sodium level above injection point, ft, (nominal)	8.2	8.2	8.2	8.2
Plugging temperature, F				
Before injection	402	395	395	400
After injection	475	470	495	510
INJECTION WATER SYSTEM				
Water added, lb	0.30	0.24	0.24	1.0
Temperature, F	602	606	600	605
Pressure, psig	2650	2650	2650	2650
Orifice size, in.	0.0109	0.0089	0.0088	0.0188
Capillary L/D	9.2	3.19	3.21	15.2
Injection point-to-target spacing, in.	1/4	1/4	1/4	1
Injection duration, sec	32.6	726	11,040	42
Injection rate, lb/sec (actual)	0.009	3.3x10 ⁻⁴	2.17x10 ⁻⁵	0.024
Injection rate, lb/sec (predicted)	0.010	0.005	0.025	0.025
RECIRCULATING WATER SYSTEM (TARGET TUBE COOLANT)				
Pressure, psig	100	100	100	100
Coolant	N ₂	N ₂	N ₂	N ₂
WASTAGE				
Target material	← Croloy (2 1/4 Cr-1 Mo) →			
Target tube				
Wastage pattern	← pit-type →			Toroidal
Depth of penetration, mils	18	17	2	26
Wastage rate, mils/sec	0.545	2.3x10 ⁻²	1.81x10 ⁻⁴	0.62
Specific wastage, mils/lb H ₂ O	60	70.8	8.33	26
Other wastage	None	None	None	*
Maximum measured tube temperature, F	1553	983	639	1628
Time of maximum temperature, sec	17.7	0.6	0.05	35.6
COVER GAS				
Pressure, psig				
Before injection	5.9	5	5	5.2
During injection, peak	12.4	**	***	14.3
After injection	12.4	**	***	10.0
Hydrogen concentration, ppm				
Before injection	5,800	12,000	5,800	3600
Peak during test	36,400	32,000	8,600	138,800
Change in concentration	30,600	20,000	2,800	135,200
Rate of H ₂ change, ppm/sec	317	37	0.48	1160
Elapsed time between leak initiation and initial H ₂ change, sec	102	106	365	59
Elapsed time between leak initiation and peak H ₂ concentration, sec	213	909	1380	177

* Wastage of some stainless steel thermocouple clips occurred

** Pressure recorder chart paper was not moving during test

*** Ink from chart pen was smudged over chart paper

TABLE 10.2 - COMPARISON OF PRELIMINARY RESULTS
OF RIG-10 TESTS NO. 37 AND 45

SODIUM SYSTEM	Test 37	Test 45
Flow rate, gpm	400	400
Velocity past target tube, ft/sec ~	2	2
Bulk temperature, F	600	602
Sodium level above injection point, ft	8.2	8.2
INJECTION WATER SYSTEM		
Water added, lb	0.197	0.300
Temperature, F	600	602
Pressure, psig	2650	2650
Orifice size, in.	0.0077	0.0109
Orifice length, in.	0.285	0.100
Orifice L/D	37.0	9.2
Injection point-to-target spacing, in.	1/4	1/4
Injection duration, sec	20.9	32.6
Injection rate, lb/sec	0.0094	0.0092
RECIRCULATING WATER SYSTEM		
Coolant	N ₂	N ₂
Pressure, psig	100	100
WASTAGE		
Target material	2 1/2 Cr-1 Mo	2 1/2 Cr-1 Mo
Target tube		
Wastage pattern	Pit with scallop shell pattern at top	Toroidal with ridges
Depth of penetration, mils	71	41
Wastage rate, mils/sec	3.4	1.26
Specific wastage, mils/lb H ₂ O	360	137

absolute comparison of the results of the two tests at this time. As a result of the anomaly, the data from Test No. 37 was re-examined to determine if the results for this test were in error. Based on the temperature charts, it appeared that there was slight evidence that a partial plug occurred 20.9 seconds after initiation of the test and that the test actually continued at a much lower leak rate for some undetermined time beyond 20.9 seconds. Re-examination of the acoustic recording of this test, however, gave strong evidence that the test actually terminated at 20.9 seconds. The fact that no water was seen when the injection system was vented after the test indicates that the full amount of water must have been injected.

Since the leak rate anomaly remains, positive evidence that nozzle L/D has an effect on wastage rate and pattern is not available. Since the results of Test No. 45 suggest that nozzle L/D may be important, the existing test program was reviewed and the following course of action outlined:

- a. The existing test program should be pursued unchanged for the present
- b. The exact length and length-to-diameter ratio of the nozzles used in all past tests should be determined and reported (this is now underway).
- c. The length of the nozzles to be used in the existing test program will be maintained at a value equal to that used for previous tests.

Test No. 48 was conducted with a leak-to-target spacing of 1/4 inch and a predicted leak rate of 0.005 lb/sec; however, the actual leak rate obtained was approximately 0.00033 lb/sec, indicating that the capillary was partially plugged. Immediately after triggering, there was a significant rise in target area temperature as noted on the optical oscillograph, and the maximum target temperature of 983 F was obtained less than 1 second after the test was initiated. The three thermocouples on the right-hand side and top of the target tube in the area of the reaction zone remained fairly constant throughout the injection period at temperatures in the range of 630 to 690 F. The three thermocouples on the left-hand side of the target area indicated higher temperatures in the range of 750 to 960 F and fluctuated with a frequency of approximately 8 cycles per second. These temperatures were considerably lower than expected for a nominal 8-mil-diameter capillary. The trigger mechanism was again actuated 18-1/2 seconds after initiation of the test; however, no change in recorded temperature readings was noted. The temperatures remained elevated for a period of 12 minutes and 42 seconds, indicating that a partial plug of the nozzle had probably occurred at the beginning of the test.

The first cold-flow test of the nozzle used in Test No. 48 confirmed that the nozzle had partially plugged. Subsequent cold-flow tests after clearing the nozzle of the obstruction gave cold flow rates in the range of those normally obtained with the nominal 8-mil-diameter capillary. The cause of the partial plug is not known.

Following removal of the tube bundle, examination of the target area showed a slight build-up of reaction products near the thermocouples in the target area and irregular deposits of reaction products in other areas; however, no large build-up typical of the higher leak rate tests was evident. Inspection of the target area after steam-cleaning revealed two small-diameter pits on the target tube. Both of these pits were located slightly to the left of the vertical center line of the intended target. One of the pits was approximately 3/32 inch from the tip of the thermocouple which indicated the highest temperature during the test. This pit was approximately 1/16 inch in diameter and 17 mils deep. The second pit, of a lesser depth, was located near the tip of thermocouple No. 6, which was approximately at the 11:00 o'clock position on the target area. Both pits were extremely mottled in appearance and were quite rough when compared to the wasted areas from many of the higher leak tests. The wastage rate obtained in Test No. 48 is somewhat high, although in fair agreement when compared to an extrapolation of the wastage rate-versus-leak rate information from previous tests.¹ Extrapolation of the previous test data to the measured leak rate gives an expected wastage rate of approximately 1×10^{-2} mils/sec, whereas the measured wastage rate for this test was 2.2×10^{-2} mils/sec. This comparison is shown in Figure 10.2. No wastage was observed on other tubes or tube supports.

Since a partial plug of the injection nozzle occurred during Test No. 48, a repeat run designated Test No. 48a was conducted with test conditions identical with those listed for Test No. 48 in the test program for Rig 10. After initiation of the test the thermocouples in the reaction zone indicated only a very small increase in the temperature; the nozzle was then retriggered several times to make sure that the capillary tube has been sheared. No additional change in temperature was seen after these operations. A maximum temperature of 639 F was recorded almost immediately after test initiation and most of the thermocouples hovered in the range of 600 to 630 F during the injection period. The duration of the test was considerably longer than the predicted 48 seconds--11,040 seconds, or a little more than 3 hours, indicating that again a partial plug of the nozzle had occurred.

Measurement of the target tube after it was removed from the tube bundle showed that approximately 2 mils of wastage had occurred. It should be pointed out that the depth measurement has an accuracy of ± 2 mils; therefore, the wastage measurement in this test could be in the range of 0 to 4 mils. Based on this measurement, a wastage rate of 1.81×10^{-4} mil/sec was observed for a leak rate of 2.17×10^{-5} lb/sec. Again, if previous

wastage data were extrapolated to the very low leak rate experienced in this test, the predicted wastage rate is somewhat lower than the actual wastage rate measured during the test. If, however, the extrapolation is made through the results of Test No. 48 (reported above) the measured wastage rate agrees well with the extrapolated wastage rate. No wastage was observed on other tubes or tube supports.

A comparison of the wastage rates obtained in Test No. 48 and 48a with those reported by Davies² is also shown in Figure 10.2. Davies' (UKAEA) experiments consisted of injecting steam through orifice diameters of 50 and 100 mils into stagnant sodium contained in a 5-inch-diameter, 15-inch-long pot. The very low injection rates ($\sim 3.7 \times 10^{-5}$ lb/sec) were obtained by using a small metering pump. As shown in Figure 10.2, the wastage rates reported by Davies are greater than those obtained in Rig 10 by factors of 10 to 100. The wastage patterns also greatly differ from those in Davies' experiments, being very rough and similar to patterns that would be obtained during corrosion of the material. More testing at these low leak rates is required to ascertain their effect on wastage rates.

A cold-flow test of the nozzle from Test No. 48a resulted in small drops coming out of the nozzle at a very low rate. Six drops of water was collected in the period of 47 minutes; therefore, no accurate measurement of the cold flow leak rate was possible. Efforts to mechanically dislodge the obstruction from the capillary were unsuccessful.

Since it was apparent that a plugging problem existed with the 8-mil-diameter orifices, a program was initiated to determine the cause of the plugs and to modify the procedures and/or material being used to prevent a recurrence of the problem. This program consists of running water flow checks on six pieces of nominal 8-mil-diameter capillary to establish that they are not plugged, making six nozzles using the pieces of capillaries tested, and then conducting six in-air injections to establish the reliability of the above steps to produce acceptable nozzles. In order not to delay the testing schedule to a point where the successful completion of the program would be in jeopardy, it was decided to proceed with Test No. 50, which utilized a 16-mil-diameter capillary, since plugging of this larger diameter capillary was not expected. Also, special precautions were taken in the preparation of the capillaries for this test to ensure that no plugging would take place.

Test No. 50 was conducted with a leak-to-target spacing of 1 inch and a leak rate of approximately 0.024 lb/sec to determine the effect of increased spacing on wastage at higher leak rates. This test ran for a duration of 42 seconds, which compared well with the predicted duration of 43 seconds. All measurements indicated that the test was successful and no plugging of the nozzle had occurred. The preliminary results of Test No. 50 are given in Table 10.1. Examination of the temperature chart showed that a notable rise in temperature had occurred when the test was triggered and

no thermocouples decreased below the initial temperature of 600 F. The maximum temperature of 1620 F was measured on thermocouple No. 5 after 35.6 seconds of the test run. The two thermocouples adjacent to thermocouple No. 5 were reading temperatures somewhat lower. Most of the thermocouples indicated a gradual increase in temperature throughout the test, amounting to approximately 120 to 200 F. The only thermocouple which showed a clear periodicity was a thermocouple installed on the row of tubes behind the target tube, and the temperature trace from this thermocouple showed a frequency of approximately 6 cps.

Inspection of the tube bundle after the test indicated a build-up of reaction products approximately the size of a quarter in the target area, and the remainder of the bundle contained only a light coating of reaction products. A small polished and wasted area in the region of the deposit was noted. Observations of the deposits showed that the water jet apparently sprayed toward thermocouple No. 5 (in the 7:00 o'clock position) and thermocouple No. 1 (in the 12:00 o'clock position) after impinging on the target tube. Thermocouple No. 5 indicated the highest temperature during the test. Also the stainless steel clip used to attach thermocouple No. 5 to the target tube was wasted and the tip of this thermocouple was observed to be thinned. After the reaction products were removed, it was apparent that the wastage area extended beyond the initial 1/4-inch-diameter polished area which was free of reaction products and extended out close to the tips of the thermocouples surrounding the target region. Damage was also noted on the stainless steel clip used to hold thermocouple No. 2 (in the 2:00 o'clock position), and after removal of thermocouples No. 2 and No. 5, impressions of the thermocouple and clip were left on the target tube due to the shielding from wastage of the tube by the thermocouple and clip (see Figure 10.3). The wastage pattern on the tube was a broad area approximately 7/8-inch square with a very slight indication of a toroidal pattern. The maximum depth of the wasted area, 26 mils, occurred slightly below the center of the tube.

When the nozzle from the test was cold-flow-checked, it plugged during the first run. Following removal of the plug by insertion of a small-diameter wire to the capillary, two additional cold-flow checks were made which resulted in an average flow rate of 0.042 lb/sec. The appearance of the jet during the last two tests was a straight, well-defined jet for a distance of at least 1 inch from the nozzle. The leak rate agreed well with a predicted cold-flow rate based on the hot-flow rate achieved during the test; however, both flow rates were slightly less than theoretical predictions based on the actual measurements of capillary diameter.

Test No. 50 was run to verify the results of Test No. 31, which had a very short duration (2.5 sec), giving rise to some uncertainty as to whether the measured wastage was actually wastage or whether it was a machine mark on the tube surface. The results of Test No. 50 coincided almost exactly with those of Test No. 36, which was the same as Test No. 50 except that the spacing was 1-1/4 inch. The wastage rate from Test No. 50

(0.62 mil/sec) is considerably below that obtained in Test No. 31 (3.2 mils/sec). For this reason, the validity of Test No. 31 is highly questionable, since the results of Tests No. 50, 36, 40, 41, and 44 all tend to indicate a much lower wastage rate as the leak rate is increased in the range of 10^{-2} to 10^{-1} lb/sec at a 1-inch spacing.

Inspection of the tube bundles following each test showed that there generally was very little build-up of solid reaction products on the tube bundle. This was expected because the maximum quantity of water injected was only 1.0 lb. In Test No. 48a, which had a 11,040 sec duration, there was a relatively large build-up of reaction products between the nozzle and the target tube and the tube below the target tube; there was very little build-up of reaction products noted on the rest of the tube bundle.

b. Hydrogen Behavior in Cover Gas

A review of the hydrogen behavior in the cover gas as shown by the data in Table 10.1 shows that a period of approximately 59 to 365 seconds occurs before the detector begins to indicate a change in the hydrogen level and that another 177 to 1380 seconds elapses before the peak hydrogen concentration occurs. Inspection of the test data shows that there is a significant difference in the time from the first indication of a leak until the peak hydrogen concentration occurs between Tests No. 48 and 48a, where the leak rates were $<10^{-3}$ lb/sec, and Tests No. 45 and 50, where the leak rates were $>10^{-3}$ lb/sec; this is especially true in Test No. 48a.

Examination of the rate of hydrogen increase in the cover gas shows essentially a straight-line relationship with leak rate over the range of leak rate from 10^{-5} to 10^{-1} lb/sec. More data are needed to establish the relationship between rate of hydrogen increase and leak rate with leak rates greater than 10^{-1} lb/sec.

3. Test Analysis (Job 04)

The scope of this job is to perform additional detailed analyses of all Project-10 wastage data to (1) provide a better understanding of the material wastage phenomenon, (2) determine the most meaningful correlation of the data, and (3) provide guidance for the experimental program to be conducted in FY-70.

A review of a series of papers from a symposium dealing with the effects of liquid impact on loss of metal³ was initiated for the purpose of learning more about the erosive effects caused by liquid impacts and how liquid jet characteristics may contribute to material wastage. The symposium in general describes the effect of a liquid jet or liquid droplets moving at a very high velocity (600-1000 m/sec), and striking against a solid surface. At impact velocities in the region of 1000 m/sec, a small water drop of about the size of a raindrop will permanently deform or fracture almost any high-strength structural material. Even at more moderate velocities, in the region of 100 m/sec, the repeated impact of droplets will quickly erode the hardest surface.

Although the existing Rig-10 test conditions are considerably different from those considered in the symposium, it is still desirable to determine if the flashing of the water jet after it leaves the orifice and is blanketed by a gaseous envelope of steam and reaction products can produce a velocity of the resulting mixture in the central core region that is much greater than the sonic velocity existing at the exit of the orifice. Because of these conditions, the liquid jet could develop very high impact pressures as a result of the water hammer effect when it strikes the target tube. The water hammer pressure (impact pressure) P for such a liquid column striking the target tube is given by

$$P = \rho C V \quad (1)$$

where ρ = density of liquid

C = speed of compression wave in the liquid (at high impact pressures the compression wave propagates as a shock wave with speeds which are greater than the normal sonic speed)

V = Impact velocity of the liquid jet

Thus the impact pressure is a direct function of the velocity of the liquid jet. If the liquid mixture is greatly accelerated after the water-steam mixture leaves the nozzle, sufficient impact pressure could be developed to cause loss of metal in the impact zone. Review of related material is continuing.

B. Rig-43 Tube Wastage (Task 21)

J. A. Ford

The objective of this task is to perform scoping wastage tests to establish the significance of various system parameters on material wastage during small sodium-water reactions.

1. Test Planning (Job 02)

The scope of the FY-70 program is to conduct eleven material wastage tests by the end of June 1970. These tests will be made to determine the significance of lower water-side pressure, of water leaks in the gas space, and of steam leaks on material wastage.

The tests will be made using 2 1/4 Cr-1 Mo steel as the target material with a nozzle-to-target spacing of 1/4 inch. The water injection rates will range from 0.0026 to 0.008 lb/sec. The bulk sodium temperature (and the water or steam temperature) will be approximately 600 F for all tests except for the steam leaks, where it will be approximately 900 F. The pressure on the water injection system will be approximately 2650 psig in all tests except for the lower water-side pressure tests, where it will be approximately 1800 psig.

2. Testing (Job 03)

A test specification was written for the first series of tests. This initial series of tests was to (1) extend the range of leak rates for which correspondence checks are made between Rig 10 and Rig 43, and (2) determine the effect of injection water pressure on material wastage rates (this would be at conditions simulating those occurring during dumping of a steam generator). The target for this series of tests consisted of a sealed 3-inch length of 1-inch-OD, 0.120-inch wall tube as shown in Figure 10.4a. As in the Rig-10 tests, thermocouples are located on the target tube adjacent to impingement area.

Three tests were conducted in Rig 43 and the preliminary results of these are given in Table 10.3. The first test (Test No. 1a) was run to check the correspondence in wastage rate between Rig 10 and Rig 43 at a leak rate of approximately 0.005 lb/sec (previous Rig-43 tests established correspondence for leak rates of 0.0014 and 0.002 lb/sec). Also, this test was to provide base wastage rate information to be used in comparison with the next two tests, which were to use the same capillary size but at a lower pressure over the injection water.

The correspondence with Rig-10 wastage rate information in Test No. 1a was poor, since the wastage rate was only approximately 1/4 of that expected based on Rig-10 information. The wastage appeared to be made up of three pits adjacent to each other (see Figure 10.4b). Three possible reasons are proposed for the lower than predicted wastage rate obtained in Test No. 1a

- a. Reaction products causing interference with water jet
- b. The jet was unstable in direction and/or pattern
- c. Previous correspondence with Rig 10 was a fluke and the results of this test are correct.

At this time, it is suspected that reason (a) is the major cause of the noncorrespondence. This is because

- The reaction area was covered with reaction products, which is not typical of the reaction product distribution in Rig-10 tests (see Figure 10.4c).
- Reaction products filled the gap between the nozzle and target tube, which is good evidence of interference (see Figure 10.4d).
- The ratio of leak rate to sodium flow rate was higher for this test than any other test in Rig 43 in which sodium was flowing. This ratio is a direct index of reaction product concentration in the sodium.

TABLE 10.3 - PRELIMINARY RESULTS OF FY-70 TESTS IN RIG 43

	<u>TEST 1a^(a)</u>	<u>TEST 2a^(b)</u>	<u>TEST 3a^(c)</u>
Spacing, in.	1/4	1/4	1/4
Orifice diameter, mils	6.45-6.65	6.86-7.45	6.49-6.89
Water injected, lb	0.24	0.24	0.24
Leak rate, lb/sec	0.0033	0.00057	0.0024
Water pressure, psig	2650	1800	1800
Sodium and water temp, F	615-620	590	590
Duration of test, sec	72	420	100
Estimated wastage, mils	26	16	40
Wastage rate, mils/sec	0.36	0.038	0.40
Sodium flow, gpm	22.2	22.2	~22
Predicted leak rate, lb/sec			
Based on			
Cold flow check results	0.0028	0.00085/0.0015	0.0016
Orifice diameter	0.0033	0.0019	0.0016
Predicted wastage rate, mils/sec			
Based on			
Equiv leak rate & Rig 10 curve	1.5	0.01-0.028 (Extrap)	0.86
Equiv orifice size & Rig 10 Curve	1.5	0.57	0.40
Equiv orifice size & Rig 45 results	-	~0.36	~0.36

(a) Multiple pits (3), indicating jet movement

(b) Radical change in temperature and acoustic signal after injection had proceeded for 2.6 seconds, indicating that the nozzle partially plugged

(c) Wastage located 30 to 40 degrees above target area; since nozzle and target were properly aligned, jet must have been askew

- There was some evidence that sodium was bypassing the pipe containing the injection system, which would indicate that the sodium flow in the injection area could have been less than the flow measured during the test.

Reason (b) cannot be ruled out completely at this time, especially since the wastage pattern is typical of the pattern that would be expected if the direction of the jet were not constant. It is doubtful that such behavior could have been caused by a partial plug, since no indication such as abnormally long test duration or odd temperature behavior was noted. A cold flow check of the nozzle indicated that the jet was quite stable and was perpendicular to the axis of nozzle.

The second test (Test No. 2a), the first of two tests to determine the effect of water pressure on wastage, was conducted at a water pressure of 1800 psig and had an injection duration approximately 3-1/2 times longer than predicted. Examination of the temperature charts for this test indicated that approximately three seconds after initiation of the injection, the temperatures dropped from the 1100 F range to the 900 F range and remained there for the duration of the test. Also, a decrease in the amplitude of the acoustic signal occurred at the same time, confirming the change in injection rate. A first flow rate check of the nozzle from Test No. 2a was unsuccessful, since the orifice plugged almost immediately. After mechanically unplugging the nozzle, a cold-flow rate check indicated that it was still partially plugged; whereupon a third cold-flow rate check showed that the partial plug had been removed and the predicted cold flow rate was obtained. These results indicate that the nozzle had become partially plugged during the actual test.

The wastage rate in Test No. 2a was considerably less (a factor of 10) than that experienced in the first test; however, examination of Figure 10.2 shows that the observed wastage rate is slightly higher than would be predicted for that leak rate based on the extrapolation of the Rig-10 wastage data from the 1/4-inch leak-to-target spacing tests.

Two possible causes are advanced for this behavior

- Partial plug of nozzle by reaction products
- Partial plug of nozzle by dirt in nozzle.

The presence of considerable reaction products in the reaction zone tends to support the first reason (see Figure 10.5). Another factor which may be influencing the sodium flow through the reaction zone and product build-up is the considerably greater confinement of the reaction area in Rig 43 which may result in temporary sodium flow blockage due to the release of hydrogen. This could cause sodium to spill over the skirt and bypass the reaction zone. If the nozzle becomes partially plugged with dirt, the jet may have changed to a diffuse spray which then typically results in a considerable build-up of products. It is also possible, however, that at the lower pressure a spray-type pattern may have formed, since the water is much closer to saturation

conditions initially. The products produced by the spray may then have caused the partial plug. The diffuse spray theory is not supported by the wastage pattern on the tube, however, unless one assumes the wastage occurred in the first 3 seconds. The apparent agreement between the measured wastage and leak rates and the extrapolated Rig-10 wastage rate curve would tend to indicate that the jet did not become diffuse during the injection. If it is assumed that the wastage occurred only during the first 3 seconds of the injection, the tube would have been wasted at a rate greater than 5 mils/sec, which is considerably higher than anything measured in Rig 10 or Rig 43 to date. At this time, there is considerable uncertainty as to the meaning of the results of this test.

The third test (Test No. 3a) was a duplicate of Test No. 2a except that it ran for a duration of 100 seconds, which was close to that originally predicted. The wastage on the target tube consisted of a 40-mil-deep pit located 30-40 degrees above the target area (see Figure 10.6). Since it was confirmed that the nozzle and target were properly aligned and that a cold-flow rate test on the nozzle for this test resulted in a straight jet and no indication of a partial plug, it was concluded that the jet itself must have been skewed during the injection.

A considerable build-up of reaction products throughout the entire injection area was noted for all three tests; however, a small area at the top of the target tube after Test No. 3a was found to be clear of reaction products. It appeared that reaction products entirely filled the space between the target tube and injection nozzle in the reaction area after all the tests. Typically, the target area in Rig-10 tests is void of reaction products at least in a circular area centered on the target tube. Also, reaction products were noted on the outside of the Rig-43 skirt assembly in which the injection target assemblies are located. This could be an indication that sodium flow is spilling over this skirt and bypassing the pipe in which the injection nozzle is located; however, it is not definitive, since the skirt communicates with the outlet sodium plenum and could pick up impurities from there. If the build-up of reaction products in the reaction zone is the cause of the poor results for Tests No. 1a and 3a, it may signal a basic limitation of the rig, i. e., it is limited to leak rates something less than 0.005 lb/sec with the present geometry in the reaction zone. The cross-sectional area of the reaction zone for Rig 43 is considerably smaller than that for Rig 10 and the distribution of reaction products is, therefore, considerably more confined. Efforts will be made to ensure that no sodium flow bypasses the injection area during future tests so that this is eliminated as a variable. Also, an attempt will be made to determine whether the reaction product build-up and hydrogen generation in the injection area actually caused flow bypassing during Tests No. 1a, 2a, and 3a.

Since the three tests that have been run have not resulted in data good enough to determine the effect of pressure on wastage, the remainder of the Rig 43 program for FY-70 was re-examined to determine a course of action. It was decided that the existing test program will be kept intact for the present.

3. Procurement, Fabrication, and Installation of Steam Injection System (Job 06)

Work was re-initiated during this report period to provide a steam injection system for Rig 43. A vendor was selected to fabricate the steam reservoir and its associated piping (the design of this system⁴ was completed in FY-69). Fabrication of the steam injection system is approximately 90% complete.

4. Water Injection into Gas Space Design (Job 11)

Conducting tests of leaks of water into the gas space above the sodium surface in Rig 43 requires modifications to the rig. Work was initiated on preparing (1) the functional requirements for the modifications required to Rig 43 for conducting the gas space leaks, (2) conceptual sketches of these modifications, (3) a preliminary cost estimate to make the modifications, and (4) a cost estimate for preparing the test specification, conducting the tests, and analyzing the test data.

C. Leak Detection (Task 22)

The scope of the acoustic leak detection program is to establish the feasibility of this technique for detecting small leaks of water or steam into sodium. Preliminary acoustic data obtained in Rig-10 tube wastage tests conducted during FY-68 and FY-69 showed that a detectable noise level above the background noise existed during the injection of the water into sodium. For the most part, the spectra generated during this injection were found to be in the sonic region, mostly below 10 kHz. However, much higher frequencies (up to approximately 80 kHz) were detected in a bench-scale test, suggesting that frequencies at least that high are generated during the reaction between sodium and water. The scope of the FY-70 program is (1) to prepare a revised test program to confirm that high frequencies are generated during the reaction of sodium and water and to establish the proper mounting techniques for the transducers to detect these high frequencies, and (2) to complete the analysis of the acoustic data obtained during Tests No. 40 through 44 conducted in FY-69.

1. Planning - Acoustic (Job 12)

C. C. Scott
S. Barkhoudarian

A work plan was prepared to obtain fundamental data on acoustics. The program consisted of three phases: The first phase would consist of introducing chips of sodium in a tank of water with acoustic transducers immersed in the water and attached to the outside of the tank to determine the characteristic acoustic spectra. The second phase, to be done in parallel with the sodium-water reaction experiments, would consist of generating sound spectra of known frequencies by magnetostrictive devices in a tank of water with acoustic transducers mounted in the water and on the walls of

the tank to determine the proper mounting techniques for the transducers. It is expected that the results would provide information pertinent to the ability to detect acoustic spectra on tank walls and would also serve as calibration signals for the acoustic detection system. The third phase of the program, assuming that phases 1 and 2 were successful, would consist of installing transducers both internal and external to either Rig 10 or Rig 43 to demonstrate the techniques required to detect the high frequencies generated during the injection of water into sodium.

Because of limited funding, no work on this revised program is planned for FY-70.

2. Test Analysis (Job 14)

Additional acoustic analyses were performed for Tests No. 40 through No. 44 conducted in FY-69. A description of the instrumentation and of the transducer locations, for these tests as well as some preliminary analysis of the acoustic data, are presented in Reference 1.

In particular, the sonic spectra obtained from the three Edo pressure transducers mounted at various locations on Rig 10 were analyzed to determine the attenuation of the signal primarily as a function of the distance away from the reaction zone (see Figure 10.7). It should be noted in Fig 10.7 that the side valve position refers to the transducer location on a valve in the outlet piping approximately 13 feet downstream of the reaction vessel and that the bottom valve position refers to the transducer location on a valve in the outlet piping approximately 1 foot from the reaction vessel.

Examination of the spectrograms from Tests No. 40-44 showed that the spectra varied greatly between locations, due to the possible non-reproducibility of mounting conditions, nonuniformity of the transducer shells, valve shaft positions, etc. However, based on the analysis of the spectrograms, the following general statements can be made:

- The net amplitude, i. e. the signal obtained during the injection minus the signal of the background noise, of acoustic spectra from the waveguide (11 feet in total length) mounted on the top of the Rig 10 reaction vessel and extending into the sodium pool was larger over the frequency range of 0-5 kHz than was the amplitude of the spectra from the transducers located at other positions.
- The net spectra from the waveguide mounted through the top of the Rig 10 reaction vessel and the spectra from the transducer mounted on the side valve exhibited larger amplitudes beyond the 2 kHz band than did the spectra from the transducers mounted on the side of the reaction vessel.

- The amplitude of the spectra from the transducer mounted on the side valve indicated a slope of approximately one-half for the 2 kHz band peak when plotted versus leak rate on log-log paper (Figure 10.7).
- The amplitude of the spectra from the waveguide mounted in the top of Rig 10 reaction vessel and the spectra from the transducers mounted on the side of the vessel exhibited a smaller slope than did the amplitude of the spectra from the transducer mounted on the side valve. The significance of this difference in slope is not known.

It is concluded that the location and the configuration of the mounting fixture for externally mounted transducers affect both the amplitude of the spectra in the 2 kHz range and the overall spectra. This is probably due to the excitation of various local acoustic modes. It is recommended that acoustic transducers be mounted at positions where system components will not contribute to acoustic attenuation.

At this stage of development it is considered to be imperative that pressure transducers rather than accelerometers be immersed in the sodium inside the vessel so that characteristic sodium-water leak spectra can be obtained. Mounting the pressure transducer in the liquid sodium will serve to isolate extraneous spectra that may be present as a result of exciting vessel walls, etc. It is also expected that ultrasonic spectra, which have not been observed with the external mounts, will be detected. As more data become available through continued experimentation such as that described above, external mounting of the pressure transducers to detect spectra from sodium-water reactions may be used.

No further analysis of acoustic data will be done in FY-70, although taking of the acoustic data will continue primarily for the purpose of having an independent measure of the leak duration.

3. Leak Detection Criteria (Job 20)

J. H. Coleman
 J. A. Ford
 P. S. Lindsey

The scope of this job is to establish a basis for evaluating methods of detecting sodium-water reactions in sodium-heated steam generators. The need is for early detection of leaks to prevent damage to the unit. Included in this effort are (1) definition of leak detection criteria for the LMFBR program, (2) description of a reference LMFBR secondary sodium coolant system, (3) determination of the behavior of the reaction products throughout the coolant system, (4) assessment of candidate detection systems, and (5) recommendations for a leak detection system for an LMFBR plant.

Work was initiated in FY-68 on establishing the criteria, describing

a reference secondary system, and a preliminary evaluation of the candidate leak detection systems. In FY-69, the first draft of the report was written and after review was revised to incorporate more up-to-date information. In FY-70, the scope is to incorporate additional comments in the revised report and then to issue the report.

Incorporating additional comments into the report is in progress.

D. Hot Erosion Studies (Task 60)

G. H. Reicks

The scope of this task was to establish the relative contribution of erosion and corrosion to the wastage process by injecting water, sodium, and sodium hydroxide against targets made of the materials of interest to the LMFBR program. Construction of test equipment and initial operation was completed in FY-68. Several operating problems, including failure of the injection tube, were encountered during the initial operation period.

In FY-69 the scope of the work was (1) to make an evaluation of the design and performance of the hot erosion test equipment including analysis of the failed injection tube and (2) to make recommendations for corrective action. The design evaluation report was essentially completed and ready for internal review by the end of FY-69. In FY-70 the final report is to be issued.

1. Design Evaluation of Hot Erosion Test Equipment (Job 12)

A draft of the design evaluation was issued internally for comments, and incorporation of the comments is underway.

E. Leak Detection Topical Report (Task 71)

The objective of this task is to prepare a report covering the leak detection studies conducted by APDA. Included will be the leak detection criteria, preliminary evaluation of leak detection systems, acoustic detection studies, plugging meter experience, and cover gas hydrogen behavior.

1. Research and Planning (Job 01)

C. C. Scott
S. Barkhoudarian

The outline of that portion of the report covering the acoustic detection work was prepared and issued for internal review.

III. NEXT REPORT PERIOD ACTIVITIES

A. Rig-10 Tube Wastage (Task 20)

Four Rig-10 tests (Job 03) will be completed and preliminary test results published. Detailed analysis of existing wastage data (Job 04) will continue.

B. Rig 43 Tube Wastage (Task 21)

Installation of the steam injection system for Rig 43 (Job 06) will be completed by the manufacturer.

Preparation of the functional specifications, conceptual design, and preliminary cost estimate for the modifications to Rig 43 (Job 11) needed to conduct gas space leaks will be completed and detailed design of the modifications initiated.

C. Leak Detection (Task 22)

The completed APDA technical memorandum covering leak detection criteria and a preliminary evaluation of leak detection methods (Job 20) will be completed and issued.

D. Hot Erosion Studies (Task 60)

The report summarizing the design evaluation of the hot erosion test equipment (Job 12) will be issued.

E. Material Wastage Topical Report (Task 70)

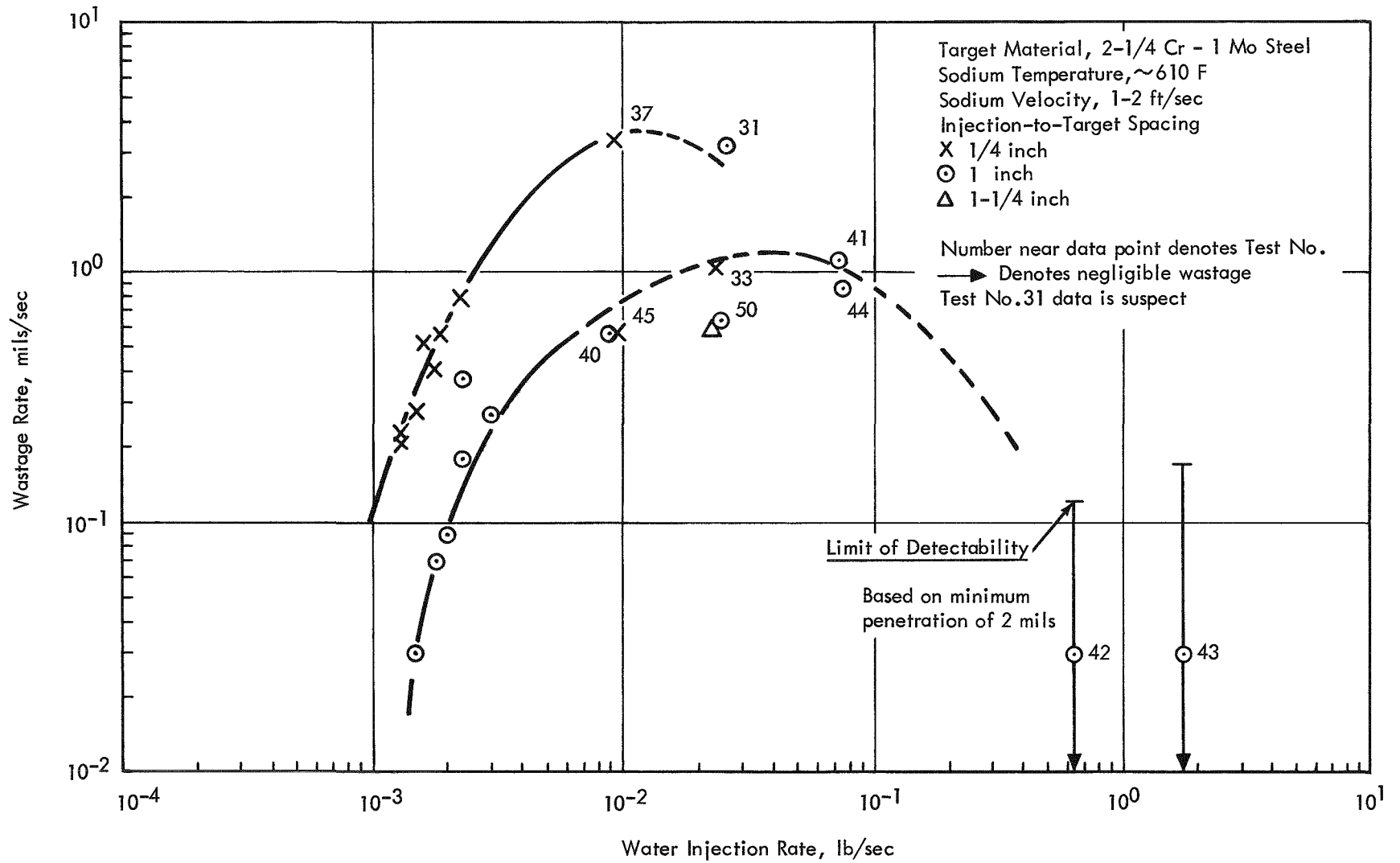
Work will be initiated on planning for the material wastage topical report (Job 01).

F. Leak Detection Topical Report (Task 71)

The detailed outline for the remainder of the leak detection topical report (Job 01) will be completed. A draft of the section of the report covering the acoustic studies (Job 02) will be issued for internal review.

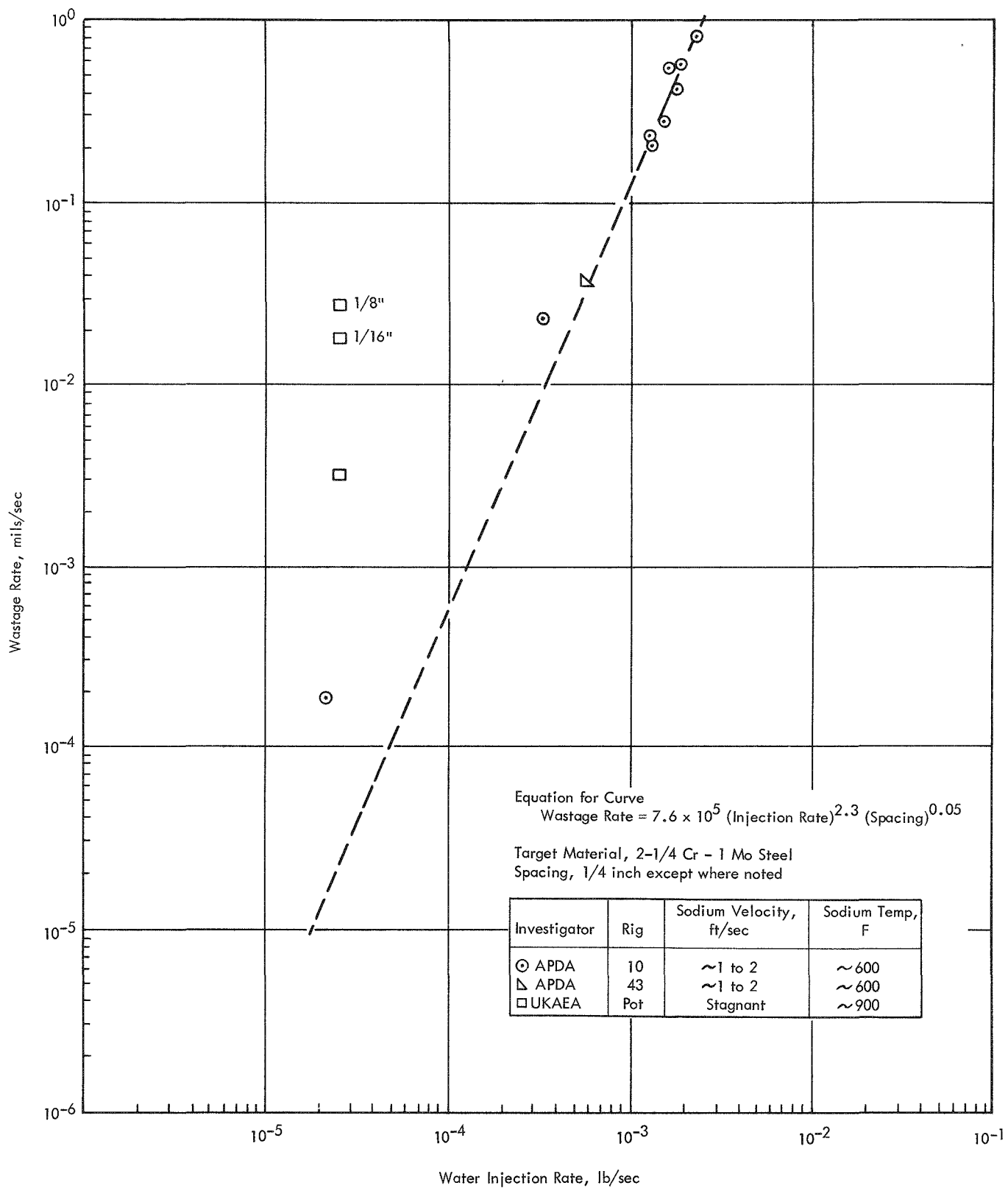
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2. Davies, R. A., Bray, J. A., and Lyon, J. M., "Corrosion of Steels in the Vicinity of a Sodium-Water Reaction." SM-85/15, Symposium on Alkali Metal Coolants-Corrosion Studies and System Operating Experience, Vienna, Austria, November 28 - December 2, 1966.
3. Bowden, F. R. S., "A discussion of Deformation of Solids by the Impact of Liquids, and its Relation to Rain Damage in Aircraft Missiles, To Blade Erosion in Steam Turbines, and Cavitation Erosion," Philosophical Transactions of the Royal Society, Volume 260, No.1110, pp 73-315, July 28, 1966.
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045470

FIG. 10.1 COMPARISON OF MATERIAL WASTAGE RESULTS IN RIG 10 TESTS



045570

FIG. 10.2 COMPARISON OF WASTAGE RESULTS AT VERY LOW LEAK RATES

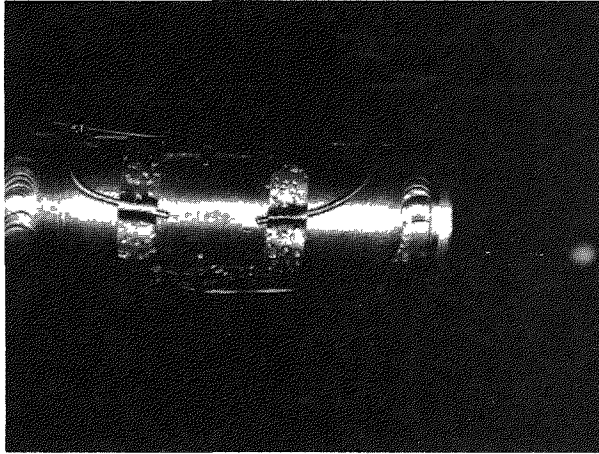
Imprint of Thermocouple and Clip



2X

045670

FIG. 10.3 TUBE WASTAGE PATTERN FROM RIG 10 TEST NO. 50

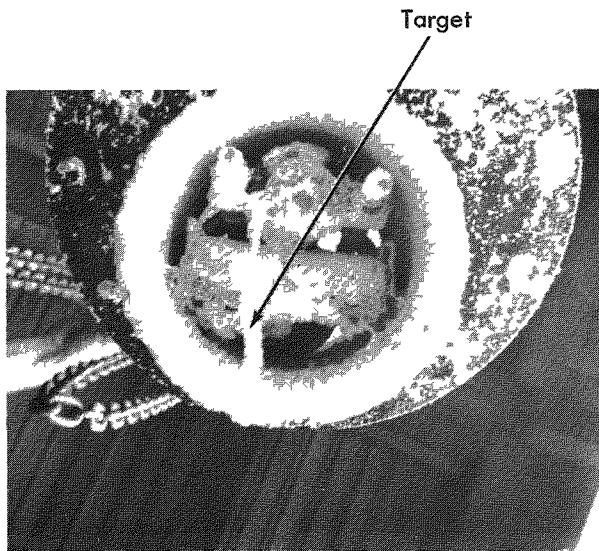


(a) Pretest Target Tube

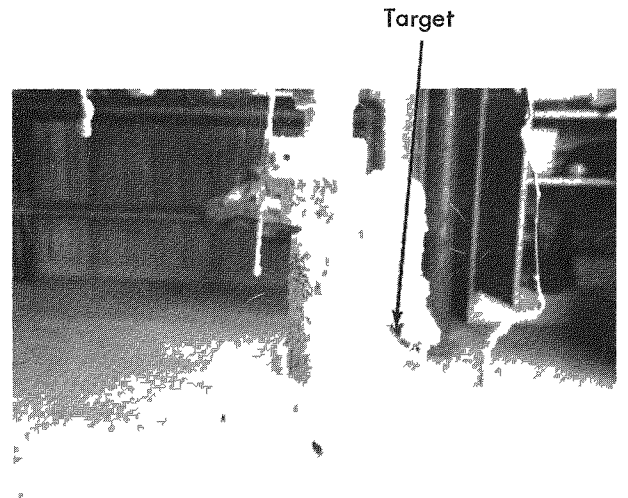


(b) Steam-cleaned Target Tube
Showing Wasted Area

X4



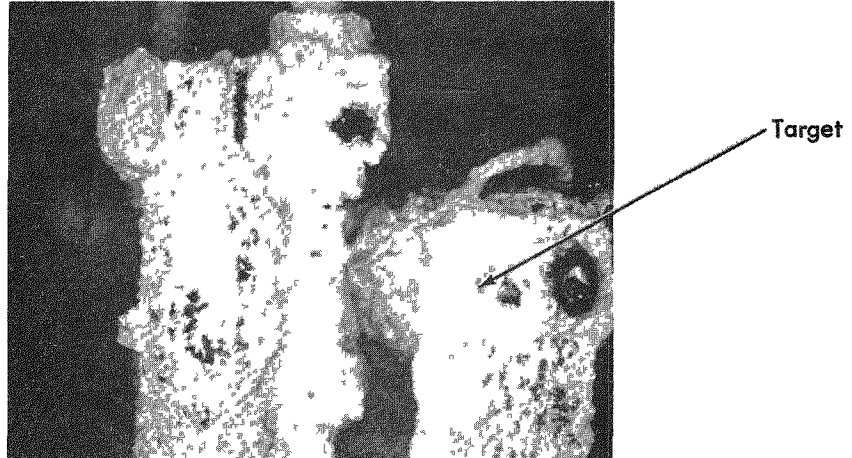
(c) Looking Up Into Reaction Pipe



(d) Target and Injection Nozzle
Covered with Reaction Products

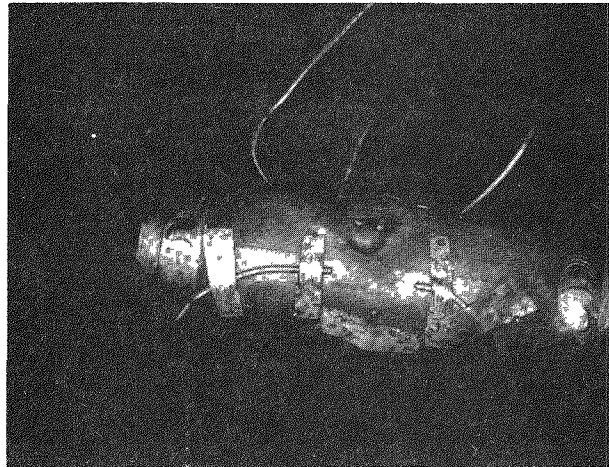
045770

FIG. 10.4 PHOTOS OF TARGET TUBE FROM RIG 43 TEST NO. 1A



045870

FIG. 10.5 TARGET AREA SHOWING REACTION PRODUCTS IN RIG 43 TEST NO. 2A



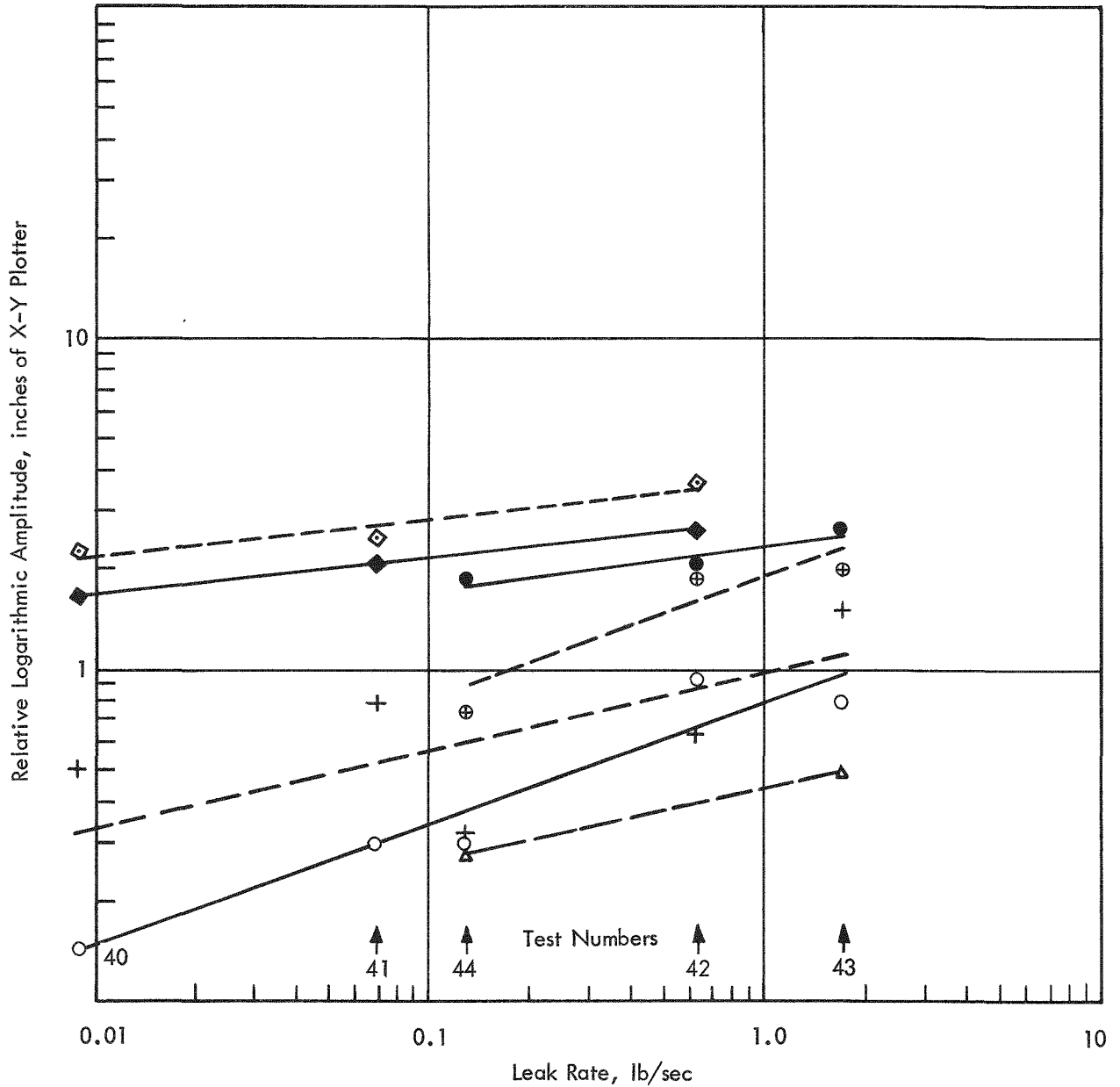
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FIG. 10.6 STEAM-CLEANED TARGET TUBE SHOWING WASTED AREA IN RIG 43 TEST NO. 3A

- Side 2-kHz Band
- ⊕ Side Lower Frequencies
- Side Valve 2-kHz Band
- + Side Valve Lower Frequencies
- △ Bottom Valve Lower Frequencies
- ◆ Top Waveguide 2-kHz Band
- ◇ Top Waveguide Lower Frequencies

16-Trace Logarithmic Averages
 1024 Normalization Factor
 ±4 v Attenuation
 500 μsec Time-Constant Smoothing
 +40 db Amplifier Gain
 0-5 kHz Analysis Range

———— 2-kHz-Band Peaks
 - - - - Lower-Frequency Peaks



046070

FIG. 10.7 SONIC OUTPUT OF EDO PRESSURE TRANSDUCERS AT VARIOUS LOCATIONS AND LEAK RATES

SODIUM TECHNOLOGY PROJECT

PROJECT AGREEMENT NO. 11

SENIOR PROJECT ENGINEER: E. C. KOVACIC

PROJECT ENGINEER: J. E. MEYERS

I. PREFACE

A. Scope

The present scope of the sodium technology project encompasses the following elements:

1. Impurity monitoring devices, including the development and evaluation of the Rhometer, oxygen meter, hydrogen meter, and plugging meter.
2. Sodium purification processes, including the evaluation and/or development of cold trapping, hot trapping, centrifuging, movable bed gettering, and thermal decomposition.
3. Sodium sampling and analysis, including the reliability of through-flow samplers, oxygen analysis, and hydrogen analysis.
4. Physical and chemical behavior of sodium and impurities, including the investigation of the solubility of hydrogen and sodium carbonate in sodium, the equilibrium distribution of hydrogen between sodium and the cover gas, and interaction of hydrogen and oxygen in sodium.

B. Relationship to Other Projects

This project is oriented entirely to the Commission's research and development program on the LMFBR.

II. TECHNICAL PROGRESS

A. Impurity Monitoring Instruments

1. Rhometer (Task 20)

W. D. Huston
C. C. Scott

The objective of this program is to develop and test an automatic temperature compensator and resistivity meter system capable of operating in the range of 400 F to 1000 F with sufficient sensitivity and stability to detect a change in sodium resistivity equivalent to 1 ppm of oxygen.

a. Loop Evaluation, Prototypes (Job 06)

Response to Impurity Injections. The prototype of the Rhometer automatic temperature compensator was operated on line in the sodium technology loop during the present reporting period to obtain data on the response of the prototype to changes in impurities in the loop sodium. The major components of the prototype completed 10 months of continuous operation. The resistance temperature detector (RTD) which had been tested to 730 F completed four months of satisfactory operation at temperatures from 600 F to 700 F.

The response of the prototype Rhometer to changes in the impurity level in sodium was obtained for the injection of hydrogen as gas and hydrogen as NaH, for oxygen as Na₂O, for water, and for cold trap clean-up of the sodium. The response data for those injections during which the Rhometer was operating are given in Table 11.1. A malfunction in the

TABLE 11.1 RHOMETER RESPONSE TO IMPURITY INJECTIONS

Date 1969	Material	Form	Amount Injected, ppm	Rhometer Output		Indicated Change, ppm*
				mv	% R	
7-23	Hydrogen	NaH	1.0	9.5	0.074	1.33
9-11	Water	Argon and Vapori- zed H ₂ O	6.4	5.5	0.043	4.6
9-26	Hydrogen	Gas	1.0	6.5	0.051	0.92
9-29	Oxygen	Na ₂ O	10.0	3.5	0.027	6.3
9-30	Hydrogen	Gas	1.0	9.5	0.074	1.33
10-1	Oxygen	Na ₂ O	10.0	2.5	0.019	4.4
10-2	Hydrogen	Gas	0.8	9.5	0.074	1.33

* Based on response data obtained at APDA and reported in Reference 1 and the assumption that water is completely converted to Na₂O and NaH

toroid ambient temperature controller and the oven containing the electronic components did not permit response to be obtained for all of the injections. Only an estimate based on calculated material balance of the quantity of material injected is available at this time. The Rhometer response is given in millivolts, the units used on the prototype being evaluated. The conversion from millivolts to per cent change in resistivity is 1.29 millivolts = 0.01 %R. In the sequence of injections from September 29 to October 2, the impurity content of the sodium was additive, starting with cold-trapped sodium on September 29.

A typical response curve for the prototype Rhometer to an injection of hydrogen gas in sodium followed by a cold trap clean-up is shown in Figure 11.1. Response curves for two injections of oxygen as Na_2O are shown in Figure 11.2. From the curves, it can be seen that the Rhometer output follows the injection of impurities and the cold trap clean-up closely. There is no indication of instrument lag or delayed response.

On-Line Calibrating Device. For routine checkout of Rhometer performance, APDA has devised a means of simulating a step change in the resistivity of the sodium-filled toroid. The on-line calibrating device consists of a single turn of a solid conductor wound adjacent to and concentric with the sodium toroid, and in the central flux field of the toroid transformer. When shorted out, the single turn generates a known step change in the resistivity as seen at the toroid. The resistance value of the single turn is selected to produce a known deflection at the output for adjusting the measuring circuits. In the tests previously reported,² the single turn at the toroid was brazed to form a shorted turn and the turn was cut to produce a positive, instantaneous change in resistance. The procedure has been referred to as the cut-wire calibration.

In this quarter, a permanent method for carrying out the calibration was installed. A single shorted turn was permanently mounted on the toroid transformer. The ends of the single turn are normally open, and are connected to a mercury contact relay with low resistance contacts. The relay is operated to short the single turn from a remote switch at the instrument panel to generate a step change in resistance for calibration. The value of the step change selected is a span of 0.05%. This is the equivalent of 4.0 millivolts on the output scale and approximately 10 ppm equivalent of oxygen and 0.7 ppm of hydrogen in the sodium. This device is being operated on a daily basis to ensure that the Rhometer is operating properly.

b. Topical Report (Job 07)

The objective of this job is the preparation of a topical report for the development and testing of the Rhometer resistivity meter with automatic temperature compensation at APDA through FY-1970.

The work plan for the report has been approved. The initial draft of the report was begun during the current reporting period.

2. Oxygen Meter (Task 27)

J. E. Meyers
M. K. Deora

a. Topical Report (Job 06)

The objective of this job is the publication of a topical report on the oxygen meter evaluation program performed at APDA incorporating all of the results obtained through FY-70.

The final draft is in the final stages of preparation and will be submitted to the AEC for review early in the next quarter.

3. Hydrogen Detector (Task 21)

J. H. Coleman
J. A. Ford

a. Data Evaluation (Job 09)

The scope of this job is to prepare computer programs for the IBM 1130 which will (1) model the hydrogen detector installation on the sodium technology loop and (2) reduce the raw data from the test to aid in data evaluation. Complete data evaluation will be performed and reported under this job.

The APDA hydrogen detector, in operation since the first part of this report period, has accumulated approximately 2000 hours of continuous operation at 900 F. During this time, there have been 17 impurity injections: one NaH, two H₂O, two Na₂O, and twelve H₂. The injections ranged from 0.35 to 1.35 ppm H₂ (except the Na₂O, which was 10 ppm O₂). The 12 hydrogen injections were performed by diffusing the gas through a nickel membrane located just upstream of the detector.

In every case where the hydrogen content of the sodium was varied, by injection or by cold-trapping, the hydrogen detector responded quickly and appeared to closely reflect the changing H₂ level. The two Na₂O injections produced no apparent effects on the performance of the H₂ detector, nor did the H₂ detector respond to these injections. Of the 17 injections, 13 were performed during the last three weeks of the quarter and data analysis is not complete. A detailed summary and the complete results of the analysis will be reported in the topical report to be issued in the final quarter of this fiscal year.

b. Topical Report (Job 10)

The objective of this job is publication of a topical report covering the installation of the APDA hydrogen detector and its operation through FY-70.

B. Sodium Purification Processes

1. Centrifuging (Task 12)

J. Matte

The final draft of the topical report on the design, construction, and initial testing of the sodium centrifuge was sent to AEC-RDT for review and comment.

b. Examination of Bowl Surface for Impurities (Job 16)

W. E. McHugh
A. A. Shoudy

This work has been completed and is reported in the topical report mentioned in II. B. 1. a.

C. Physical and Chemical Behavior of Sodium Impurities

1. Hydrogen Solubility (Task 31)

A. A. Gordus*
E. F. Hill
S. A. Meacham

a. Data Analysis (Job 5)

This job was completed. The effort consisted primarily of thermodynamic and kinetic calculations which will be included in the topical report (Job 06) and which also form the basis of the ACS paper presented at the national meeting in New York on September 11, to be published in the Journal of Chemistry Thermodynamics, Academic Press.

b. Topical Report (Job 06)

Work has been initiated on the draft of the topical report. Much of the art work is complete and the data are essentially tabulated.

2. Cover Gas Impurities (Task 33)**

J. H. Coleman
J. A. Ford

a. Hydrogen Gettering in Gas Sample Lines (Job 02)

The objectives of the job are to determine the quantity and composition of the deposits collected in the technology loop cover gas analysis.

* University of Michigan

** Because of recent budgetary limitations imposed on the project agreement under which this work is being funded, all jobs under this task are being terminated.

Effort during this quarter was restricted to eliminating leakage in the sample lines. The leaks have now been eliminated and heat was restored to the sample lines.

b. Compilation of Chromatograph Experience (Job 03)

The objectives of this job are to compile the data obtained from the chromatograph and evaluate it in terms of loop operation and loop chemistry.

The amount of hydrogen indicated in the surge tank following heat-up of the sample lines agrees well with the concentration expected when calculated from the hydrogen detector data. Because of the limited amount of data obtained so far, it is not possible to be sure the system has yet approached steady state following the initial heat-up.

c. Topical Report (Job 04)

The objective of this job is the publication of a topical report covering the experience and experimental work conducted on the cover gas chromatograph installation on the sodium technology loop.

Only the report outline has been completed.

D. Sodium Sampling and Analysis

M. K. Deora
A. J. Friedland

1. Sampling Reliability (Task 70)

a. Topical Report - Oxygen (Job 03)

The internal review for this report has been completed and is in the final stages of editing prior to submittal to the AEC for review.

2. ASTM Round Robin on Oxygen
in Sodium (Task 73)

E. F. Hill
S. A. Meacham

a. Reduction of Data and Report (Job 05)

During this period, the final comments from committee members and AEC-RDT were received and incorporated into the report. The report was put into shape for publication and the revised copy was submitted for printing and distribution. The revised copy was also sent to the committee members for review and discussions at the final committee meeting in Gatlinburg, October 1, 1969.

III. NEXT REPORT PERIOD ACTIVITIES

Effort will continue on performance evaluation of the APDA hydrogen detector and the automatically temperature compensated Rhometer in the Sodium Technology Loop.

Draft reports on the UNC oxygen meter and on sampling and analysis for oxygen in sodium will be submitted to the AEC for review and comment.

Effort will continue on the preparation of the Rhometer, hydrogen detector, hydrogen solubility, and project summary reports.

The ASTM Round Robin on Oxygen in Sodium topical report will be published in final form.

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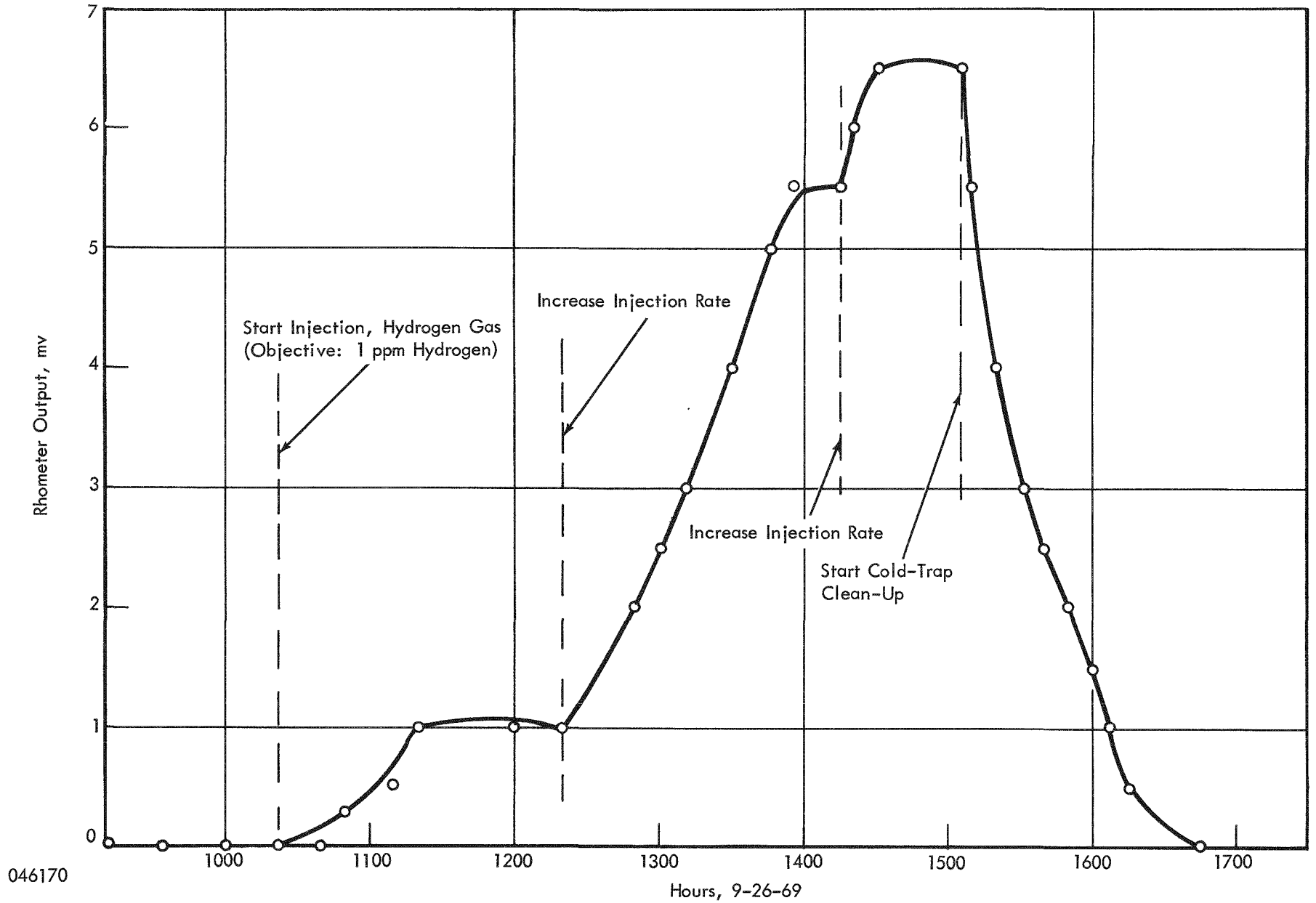
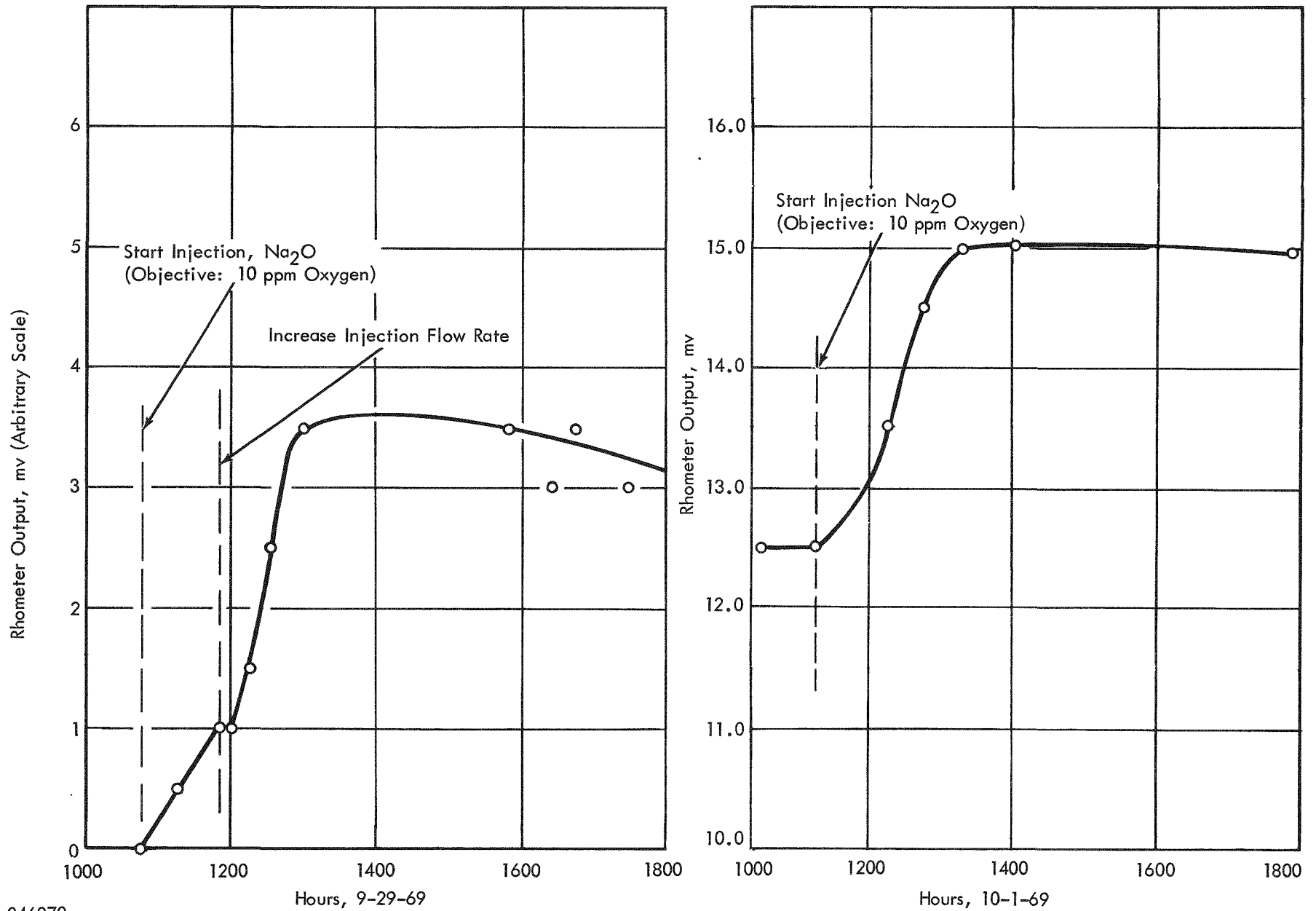


FIG. 11.1 RESPONSE OF AUTOMATIC TEMPERATURE-COMPENSATED PROTOTYPE RHOMETER TO INJECTIONS OF HYDROGEN GAS IN SODIUM



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FIG. 11.2 RESPONSE OF AUTOMATIC TEMPERATURE-COMPENSATED PROTOTYPE RHOMETER TO INJECTIONS OF OXYGEN AS Na₂O IN SODIUM

COMPILATION OF FERMI EXPERIENCE

PROJECT AGREEMENT NO. 15

PROJECT ENGINEER: E. C. Kovacic

I. PREFACE

A. Scope

The purpose of the project is to make available to the fast reactor development program the experience that has been gained from the Enrico Fermi Atomic Power Plant project. The scope of effort covers the compilation of noteworthy experience into reports suitable for general use, starting with the evolution of the design and progressing through fabrication, construction, testing, and operation of the Fermi plant. Important components and systems will be treated in individual reports which will include sufficient descriptive and background material to make each a reporting entity.

B. Relationship to Other Projects

This project is related generally to the Commission's program of the development of fast reactor technology.

II. TECHNICAL PROGRESS

A. Compilation of Current EFAPP
Experience (Task 19)

R. A. Costello

Reports for the months of April, May, and June were published, bringing this project to a close.

COMPARISON OF METHODS FOR HETEROGENEITY ANALYSIS

PROJECT AGREEMENT NO. 19

SENIOR PROJECT ENGINEER: J. B. Nims

PROJECT ENGINEER: E. M. Page

I. PREFACE

A. Scope

The objective of this program is to provide a consistent comparison and evaluation among various methods of computing heterogeneity effect in fast reactor critical assemblies and power reactors, particularly with regard to its effect on sodium void analysis. In the case of plate-type criticals, specific voiding and heterogeneity experiments will be analyzed by various methods. In the case of the power reactor, a conceptual design will be chosen for analysis.

Four methods are to be applied in the heterogeneity analysis, as follows:

1. One-dimensional transport theory calculations by DTF-IV of the flux distribution for the plate or pin arrangement forming a symmetric cell followed by flux weighting the cross sections in each region of the cell to define cell homogenized cross sections. The homogenized cross sections are then used in diffusion theory calculations to incorporate the heterogeneity effects directly in the calculations.¹
2. The same as Method 1 above, but using the cell-homogenized cross sections in perturbation theory to calculate heterogeneity corrections to a homogeneous calculation.²
3. The same as Methods 1 and 2 above, but using bilinear averaging to define the homogenized cross sections.³
4. Use of collision probability-perturbation methods to obtain correction terms to homogeneous diffusion theory calculations.⁴

In addition, attempts will be made to furnish Oak Ridge National Laboratory with consistent data to allow Monte Carlo calculations of selected cases, thus furnishing a more nearly exact approach that can serve as a reference calculation.

B. Relationship to Other Projects

A consistent analysis of heterogeneity effects in fast critical assemblies and power reactors is of general interest to the LMFBR industry and complements the current ANL efforts in this area.

II. TECHNICAL PROGRESS

A. Program Plan

The effects of heterogeneity in fast reactors have recently received considerable attention. Experiments have been performed in the more recent ANL critical assemblies for the purpose of determining the sensitivity of important parameters to the degree and nature of assembly heterogeneity (see Table I).

TABLE 1 - MAJOR HETEROGENEITY EXPERIMENTS IN ANL
FAST CRITICAL ASSEMBLIES

ZPR-III Assembly 48 (400-liter Pu-C Diluent)	Effect of plate arrangements on reactivity and sodium void coefficients at central and axial edge positions ⁵
ZPR-VI Assembly 3 (950-liter UC Pancake)	Effect of various plate arrangements and intradrawer voiding patterns on sodium void coefficients ⁶
ZPR-VI Assembly 5 (2600-liter UC)	Effect of various plate arrangements on reactivity and the effect of various plate arrangements and intradrawer voiding patterns on the sodium void coefficient. Also, the worths of equivalent pellet, plate, and homogeneous core samples in two plate loading environments ⁷
ZPR-VI Assembly 6 (4000-liter UC)	Effect of various plate arrangements on reactivity and on sodium void coefficients. Also, the measurement of sodium void coefficients in pellet, plate and homogeneous core samples in plate and rodDED environments. ^{8,9}

A number of analytical techniques have been developed to predict heterogeneity effects in fast reactors and critical assemblies. These have been applied by several investigators as corrections to a number of standard critical experiments as well as to special heterogeneity experiments such as listed above. Intercomparison among the applications of different investigators is sometimes difficult to achieve, since the techniques are applied with

different basic data, varying interpretations of reported assembly parameters, and at varying stages of development of the given techniques. Moreover, varying definitions of the "heterogeneity effect" exist, increasing intercomparison difficulties. (More recently, ANL has initiated the GEDANKEN approach¹⁰ where various methods are applied to a fictitious and simplified model amenable to an "exact" calculation).

It is the intent of the present investigation to apply four analytical techniques of current interest (refer to Sec 1. A. 1 through 4) using the same cross section data to selected critical experiments and to a power reactor design. The cases chosen are as follows:

ZPR-III Assembly 48

- a. Corrections of assembly reactivity and central region sodium void reactivities due to the heterogeneity of the standard configuration
- b. Prediction of the effects of central region bunching experiments on system reactivity and sodium void coefficients

ZPR-VI Assembly 6

- a. Corrections of assembly reactivity and central region sodium void reactivities due to the heterogeneity of the standard configuration
- b. Prediction of the effects of central region bunching experiments on system reactivity sodium void coefficients

ZPR-III Assembly 51 (Minimum of One Method)

Corrections of assembly reactivity and central sodium void coefficient due to the heterogeneity of the standard configuration

Two-Zoned 860-Mw Power Reactor Design (Minimum of One Method)

Correction of critical mass, sodium void coefficient, and Doppler coefficient due to the heterogeneity of the subassemblies

The results of these analyses will be evaluated and intercompared to achieve the following:

- A measure of the quantitative difference obtained for a given parameter among the various methods
- A measure of the importance of the effect, particularly with regard to the power reactor calculation

- A measure of the difference in manpower and computer time required among the various methods
- A measure of the accuracy of the methods for cases where a comparison with experimental results is meaningful. A comparison with results obtained by Monte Carlo techniques at Oak Ridge is also planned for selected cases.

Where possible, auxiliary studies will be performed including variation of assumptions within a given technique, calculation of sample worth-type experiments as performed in ZPR-VI Assemblies 5 and 6, inclusion of voiding experiments requiring two-dimensional global calculations, and sensitivity to recent changes in the measured U-238 inelastic scattering cross section.

While it is not the intent of this program to perform a cross section sensitivity study, it is important that care be exercised in the selection of the base cross section set. The following criteria were observed:

- The basic data should be reasonably accurate, since in most cases calculations are to be made of real experiments as opposed to the GEDANKEN approach currently followed at ANL.
- The cross section format should be compatible or easily made compatible with the pertinent computer codes to be used in the study.
- The multigroup structure should allow a reasonable definition of the neutron spectrum over the energy ranges of importance in the chosen assemblies and reactor design.

A 25-group cross section set based largely on the evaluation reported in APDA-216¹¹ has been chosen as the basic set for this study. Modifications to that reported in APDA-216 include the following:

1. U-238 capture below 40 keV frequently lower than MENDF/B due to use of $\Gamma\gamma = 22$ mv rather than 24.6 mv due to influence of Petrel (bomb) data.¹²
2. U-238 fission a few per cent lower due to reduction in U-235 fission above 2 Mev since based on U-238/U-235 fission ratios. Further reduction below 2 Mev through more consistent use of the Stein normalization as in Davey's evaluation.¹³
3. Pu-239 fission generally 1 to 3% lower due to reduction in U-235 fission above 2 Mev as above and as result of trial and error to force better agreement on Assembly 48.

4. Pu-239 alpha contains small energy-dependent changes due to use of recent RPI data.¹⁴ Values actually taken from informal presentation at 1968 Toronto ANS meeting.
5. Pu-240 extensively revised due to the recent measurements at Geel - generally higher capture.¹⁵⁻¹⁸
6. U-238 inelastic slightly higher in 0.5 to 2.0 Mev range due to re-interpretation of same data which places the cross sections above MENDF/B but below Schmidt's evaluation (ENDF/B).
7. Na capture higher for 53.5 kev resonance due to increase of $\Gamma\gamma$ from 0.4 ev to 1.58 ev based on Hockenbury measurement.¹⁹
8. Na inelastic slightly higher particularly near 1.5 Mev due mainly to different interpretation of same data. (ENDF/B picks lower limit of uncertainty range.) Values for the 2.98 Mev level are almost doubled because earlier evaluation did not account for the fact that the measured 2.98 Mev γ decay to ground state accounts for only 50% of the possible transitions.²⁰
9. U-235 fission slightly lower above 2 Mev due to use of Smith, Henkel, and Nobles data²¹ as scatter corrected by Hansen and McGuire,²² bringing the current evaluation more into line with that of Davey.¹³ (See also Figure 1 of Volume 1, Reference 11.) Also slightly lower near 100 kev to give better agreement in critical assembly analyses.
10. U-235 alpha slightly higher above 50 kev to give better agreement in critical assembly analyses.
11. Pu-239 fission spectrum is similar to that in MENDF/B but based on "simple fission spectrum" with effective temperature of 1.40 Mev to be compatible with the format of the MC² system.²³
12. Pu-239 ν increased according to Euratom progress report and reported formally in Reference 24.
13. In addition to the re-evaluations given above, there was an increase in the U-238 self-scatter for two groups in the low kev region to adjust for apparent deficiencies in the MC² averaging processes.

The multigroup energy structure is the same as that of the 24-group set shown in Table 9 of APDA-216 except that an additional group is added to extend the energy coverage to 0.683 ev.

B. Present Progress

1. Literature Survey

A literature search has been undertaken to more precisely define the techniques for calculating the heterogeneity effect and to establish the current status of such analytical development. A selected bibliography concerning the four methods to be investigated is attached to this report. The selection includes some of the more definitive papers, a sampling of different investigators, and those indicating the current status of development.

2. Base Calculation for Assembly 48

A preliminary base calculation using Method 1 in Sec. I. A. 1 has been performed for Assembly 48 to determine the effect of heterogeneity on reactivity and a simple first-order perturbation calculation of sodium voiding in the standard drawers of Assembly 48. Table 2 is a comparison of the results with those given in References 1 and 11.

TABLE II - COMPARISON OF PRELIMINARY ASSEMBLY 48 RESULTS
WITH THOSE OF APDA-216 USING METHOD 1

	Present Calculations (PUCR library)	APDA-216 Calculations (MENDF/B library)
Diffusion theory, k_{eff}	0.975	0.984
Heterogeneity correction, ΔK	0.0138	0.0139
Region-A+B sodium voiding, ih/kg		
Volume-weighted cross sections	2.55	3.76
Flux-weighted cross sections	1.73	1.85

While there are minor differences in the calculational techniques employed, the difference between the present results and APDA-216 results is mainly due to the differences in the cross sections used.

III. NEXT REPORT PERIOD ACTIVITIES

During the second quarter of FY-1970, calculations of the heterogeneity experiments of ZPR-III Assembly 48 with Methods 1 and 2 (refer to Sec I. A. 1 and 2) should be essentially completed and those in ZPR-VI Assembly 6 will have been initiated. Techniques for implementing Methods 3 and 4 will be investigated.

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