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NaK LOOP TESTING OF THERMOELECTRIC CONVERTER MODULES

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FOREWORD

The work described here was done at the Atomics International Division of Rockwell International Corporation, under the direction of the Space Nuclear Systems Division, a joint AEC-NASA office. Project management was provided by NASA-Lewis Research Center and the AEC-SNAP Project Office.

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ABSTRACT

The history of testing of Westinghouse compact tubular modules in flowing NaK loops at Atomics International is summarized. Test procedures, data handling, and instrument calibration are discussed. Also included is descriptive information of the test facilities, operational problems encountered, and some recommendations for testing.

I. INTRODUCTION

Compact tubular thermoelectric power modules are being developed for use on the power conversion system of the space nuclear power system. The central hot leg of the modules, Figure 1, is heated by the NaK of the primary reactor coolant loop, while the peripheral cold leg is cooled by NaK from the secondary heat rejection loop. Some of the developmental modules were tested in facilities in which the temperature, flow rate, and temperature gradient of the NaK in each loop were closely controlled to simulate the operational system. The performance data from these tests were necessary to verify the analytical design of the modules and also to evaluate the results of other tests being conducted with electrically heated static NaK.

The flowing NaK test facilities had capabilities to provide controlled NaK flow rates of 0.14 to 0.28 lb/sec per module while maintaining the primary loop (hot leg) NaK temperature in the 1000 to 1250°F range and that of the secondary loop (cold leg) in the 450 to 600°F range. Cold trapping reduced and maintained the oxygen content of the NaK to less than 10 ppm. Instrumentation to measure the NaK flow rate and temperature in each loop, and the current and voltage output of each module was available.

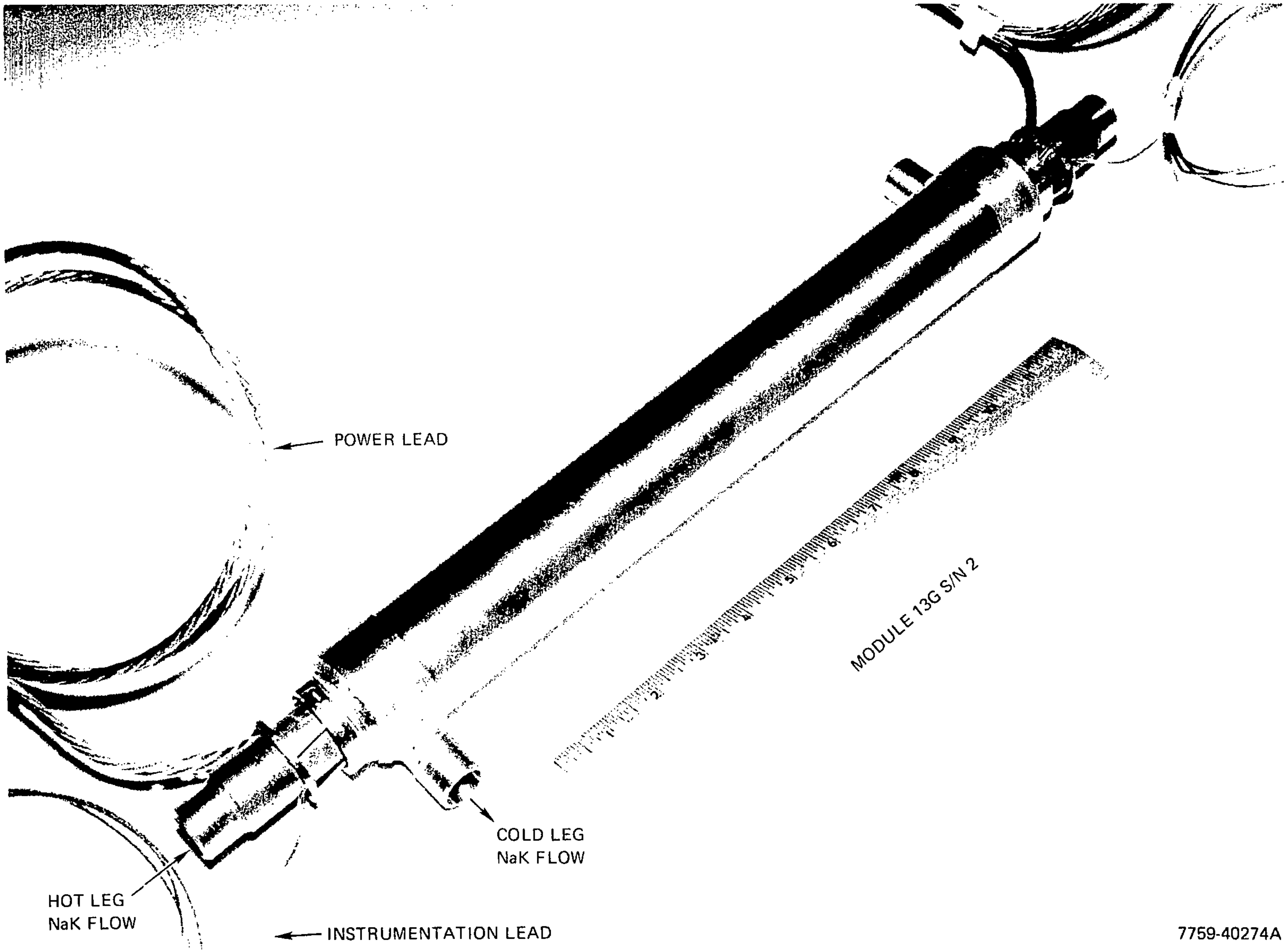

Figure 1. Tubular Thermoelectric Module

II. SUMMARY OF THERMOELECTRIC MODULES TESTED

A total of 13 compact tubular thermoelectric modules was tested in the NaK flow test facilities at Atomics International between July 1968 and February 1973. A description of these modules and the results of the performance tests are reported in References 1 and 2. The test hours, dates of tests, test temperatures, and number of thermal cycles for each of these modules are summarized in Table 1.

TABLE 1

THERMOELECTRIC MODULES TESTED IN FLOWING NaK TEST FACILITY

Module	Type	Serial Number	Test Facility*	Test Type†	Total Test Time (hr)	Test Start Date	Test Stop Date	Test Temperatures (°F)§				Number of Thermal Cycles**	
								Primary Inlet	Primary Outlet	Secondary Inlet	Secondary Outlet	Controlled	Rapid
TEM	9U	8	Steady State	SS	3,611	7-30-68	1-27-69	1192	1092	515	615	-	9
TEM	9U	10	Cyclic	C/SS	5,166	12-3-68	7-11-69	1192	1092	515	615	20	3
TEM	13F	3	Steady State	SS	1,173	6-30-69	8-28-69	1238	1038	465	665	-	1
TEM	13G	1	Steady State	SS	2,408	3-3-70	8-4-70	1239	1039	464	664	1	4
TEM	13G	2	Cyclic	SS	20,210	9-4-69	2-21-72	1138	938	432	632	5	4
TEM	13G	5	Steady State	SS	2,408	3-3-70	8-4-70	1339	1139	507	707	1	4
4-Pack Assembly													
TEM	13G	6	4-Pack	SS	7,040	1-8-70	11-15-70	1138	938	432	632	1	6
TEM	13G	7											
TEM	13G	8											
TEM	13G	9											
TEM	X	3D	4-Pack	C/SS	10,379	6-2-71	12-16-72	1150	1050	450	550	52	12
TEM	X	3F	4-Pack	SS	9,180	9-10-71	12-16-72	1204	1104	466	566	1	11
TEM	X	3K	Steady State	SS	1,122	12-4-72	2-22-73	1150	1050	450	550	-	1

*See Section III for description of NaK loop facilities.
†C = Thermal cycling tests; SS = steady-state tests.
§TEM X3D operated at 1200/1000°F (primary inlet and outlet) and 400/600°F (secondary inlet and outlet) for first 2200 hours of test; TEM X3F operated at 1200/1000°F (primary inlet and outlet) and 400/600°F (secondary inlet and outlet) for first 1000 hours of test.
**Temperature transients during rapid cycles ranged between 40 to 55°F/min depending on test loop and number of modules on test, and only occurred on cooldown. All heatups were controlled at specified rates.

III. NaK TEST FACILITY DESCRIPTION

Three test facilities, the Steady-State, Cyclic, and Converter Module (4-Pack) were designed and used for the performance testing of Thermoelectric modules. Each of the test facilities consisted of two separate NaK loops; the primary to provide heat input to the hot leg of the module, and the secondary to remove heat from the cold leg. A fourth facility consisting of a single NaK loop, was used to calibrate flowmeters used in these test facilities.

The flow capacity of the NaK pumps, and the thermal capacity of the heaters and the heat exchanger determine the overall capability of each facility. Thus the number of modules which can be tested simultaneously is dependent on the flow and thermal requirements of the test. When these test facilities were designed, the flow rate requirement of the TEM 9U thermoelectric modules was approximately 0.14 lb/sec of NaK. The latest TEM X-3 modules had a flow requirement of 0.28 lb/sec, reducing the number of modules which could be tested together. The performance characteristics of these facilities are shown on Table 2.

All of these facilities were designed and initially constructed in the GFY 1968 through 1970 period with some modifications being added subsequently. These facilities, which had been constructed and operated in Building T023 of the AEC Santa Susana Field Laboratory, have been dismantled and disposed.

A. STEADY-STATE THERMOELECTRIC MODULE TEST FACILITY

This facility was originally designed to test as many as four of the 7-in. TEM 9U modules under a constant temperature and flow condition. Only one of the TEM X-3 modules, with its higher flow rate requirement, could be tested at a time. The schematic of Figure 2 is applicable to this unit. The piping in both loops are 1-in.-diameter, Type 304 stainless-steel Schedule 10 pipe, except for the reduction to 1/2 in. diameter in the vicinity of the test module section. The primary loop NaK pump was the d-c conduction type, while that of the secondary loop was an a-c linear induction type. The heater assemblies consisted essentially of a housing into which a series of cartridge type immersion heaters was inserted. The containment seal between the heater and the heater housing was a

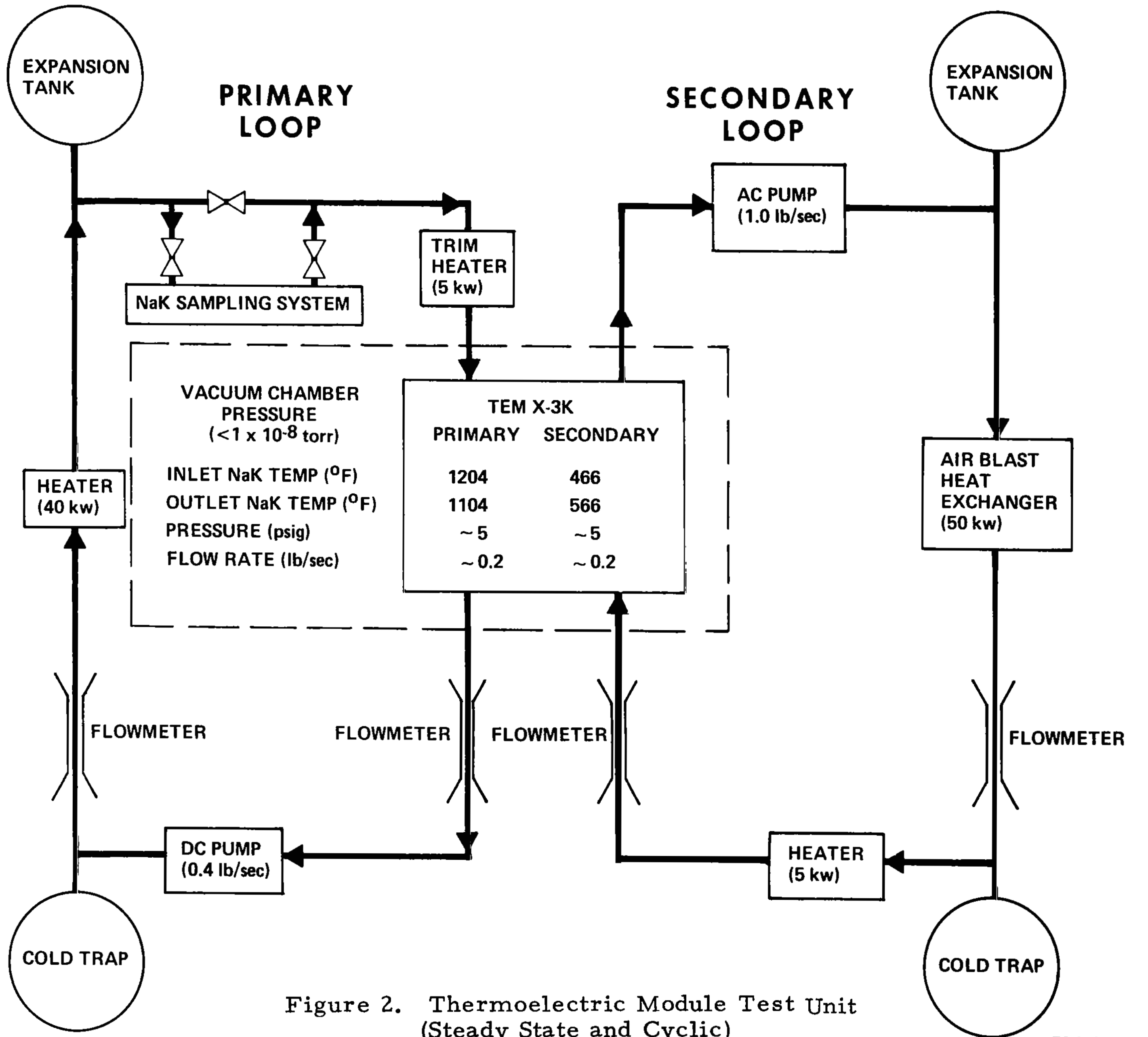

Figure 2. Thermoelectric Module Test Unit (Steady State and Cyclic)

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TABLE 2

THERMOELECTRIC MODULE NaK TEST FACILITY CHARACTERISTICS

	Converter Module, 4-Pack	Cyclic Tubular Module	Steady-State Tubular Module	Calibration
Maximum Operating Temperature (°F)	1300	1300	1300	1300
Maximum Flow Rate (lb/sec)	2.0	0.4/1.0	0.4/1.0	2.0
Maximum Operating Pressure (psig)	30	30	30	30
Maximum Heater Power (kw)	100	40	40	40
Nominal Operating Power (kw)	70	25	25	25
Heat Rejection at 550°F (kw)	75	40	40	None
Transient Capability (30°F/min)	Yes	Yes	No	No
Nominal Pipe Size (in.)	1-1/2	1	1	2
Date Constructed (GFY)	1969-70	1968	1968	1968

NOTE: All systems except calibration loop comprise two loops, and all loops are fabricated of Type 304 stainless steel.

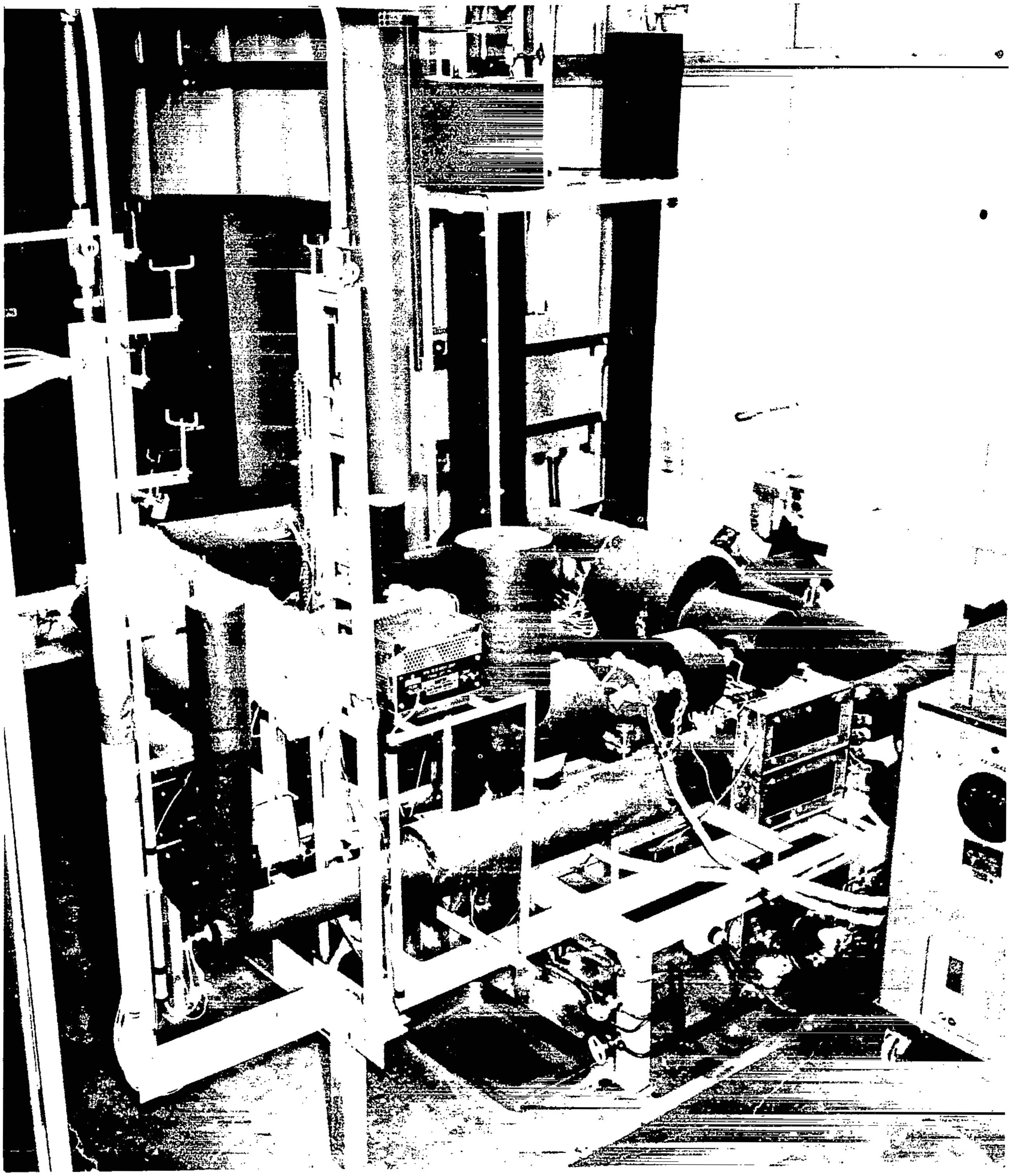

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Figure 3. TEM 13G Module Test in Steady-State Facility

mechanical Swagelock fitting. The total heater assembly capacity was determined by the number of immersion cartridges used. This typical heater design was used on all facilities. A view of the facility during the test of the TEM 13F-3 is shown on Figure 3. The operational history is shown in Table 3.

Prior to the test conducted on the Ta - 10 W tube sample, a NaK sampling system was added to the primary loop to permit periodic removal of NaK samples for chemical analysis.

TABLE 3

STEADY-STATE TEST FACILITY OPERATION

Module	Test Dates		Total Test Time (hr)	Average Temperature (°F)		Number of Thermal Cycles
	Start	Stop		Primary	Secondary	
TEM 9U-8	7-30-68	1-29-69	3611	1142	565	9
TEM 13F-3	6-30-69	8-28-69	1173	1138	565	1
TEM 13G-1	3-3-70	8-4-70	2408	1139	564	5
TEM 13G-5	3-3-70	8-4-70	2408	1239	607	5
Ta - 10 W Tube	11-24-70	3-23-71	2384	1200	-	2
TEM X-3K	12-4-72	2-22-73	1122	1100	500	1

B. CYCLIC THERMOELECTRIC MODULE TEST FACILITY

This facility is almost identical to the steady-state unit except that the heater in the secondary loop was increased in capacity to 40 kw. With this modification, it was possible to thermally cycle the hot leg of a module between 500 and 1200°F at the rate of 30°F/min while maintaining the required thermal gradient between the hot and cold legs. As shown on Table 4, a TEM 9U and a TEM 13G were tested in this facility.

During GFY 1973, the facility was modified, as shown on Figure 4, to conduct a series of tests to determine the effects of hydrogen in the NaK on the properties of the Ta - 10 W material. Provisions for NaK sampling, injection and measuring hydrogen concentration in the NaK, and testing both tubular samples and material specimens were added to the primary loop. The checkout of the modified facility was in progress at the time of program close-out.

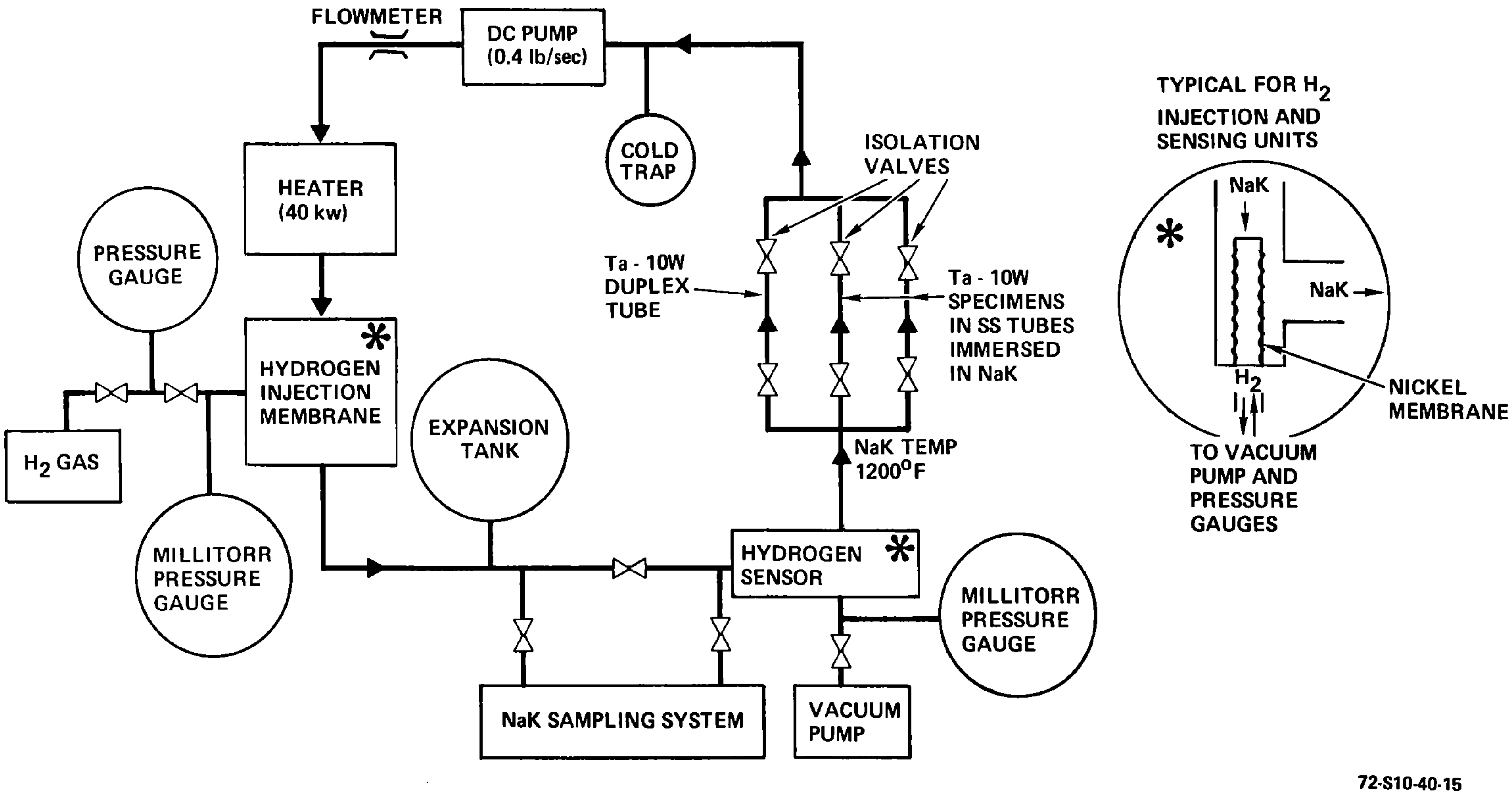

Figure 4. Cyclic Test Facility Modification for Hydrogen Effects Tests

TABLE 4

CYCLIC TEST FACILITY OPERATION

Module	Test Dates		Total Test Time (hr)	Average Temperature (°F)		Number of Thermal Cycles
	Start	Stop		Primary	Secondary	
TEM 9U-10	12-3-68	7-11-69	5,166	1142	565	23
TEM 13G-2	9-4-69	2-21-72	20,210	1038	532	9

C. CONVERTER MODULE (4-PACK) TEST FACILITY

This facility was designed in GFY 1969 to test up to four of the 4-module arrays (total of 16 TEM 13G type modules) simultaneously. Although actual hydraulic impedances were greater than expected, the facility could handle approximately six of the higher flow TEM X-3 type modules. As shown on Figure 5, an a-c linear induction pump was used in the primary as well as in the secondary loop. The basic piping system was of 1-1/2-in.-diameter Type 304 stainless-steel Schedule 10 pipe with reductions near the test modules to 1 and 1/2 in. diameters. The NaK sampling system and flow-through cold traps were added to the facility during the test sequence between the TEM 13G and TEM X-3 module tests listed in Table 5.

The construction stages of the facility are shown on Figures 6 and 7. Figure 8 shows the installation of the 4-module array prior to the addition of the thermal insulation. The various stages of the one and two TEM X-3 module installations are shown on Figure 9 and 10.

TABLE 5

CONVERTER MODULE (4-PACK) TEST FACILITY OPERATION

Module	Test Dates		Total Test Time (hr)	Average Temperature (°F)		Number of Thermal Cycles
	Start	Stop		Primary	Secondary	
TEM 13G-6 -7, -8, -9*	1-8-70	11-15-70	7,040	1038	532	7
TEM X-3D	6-2-71	12-16-72	10,379	1100	500	64
TEM X-3F	9-10-71	12-16-72	9,180	1154	516	12

*4-Pack (Converter Module S/N 001)

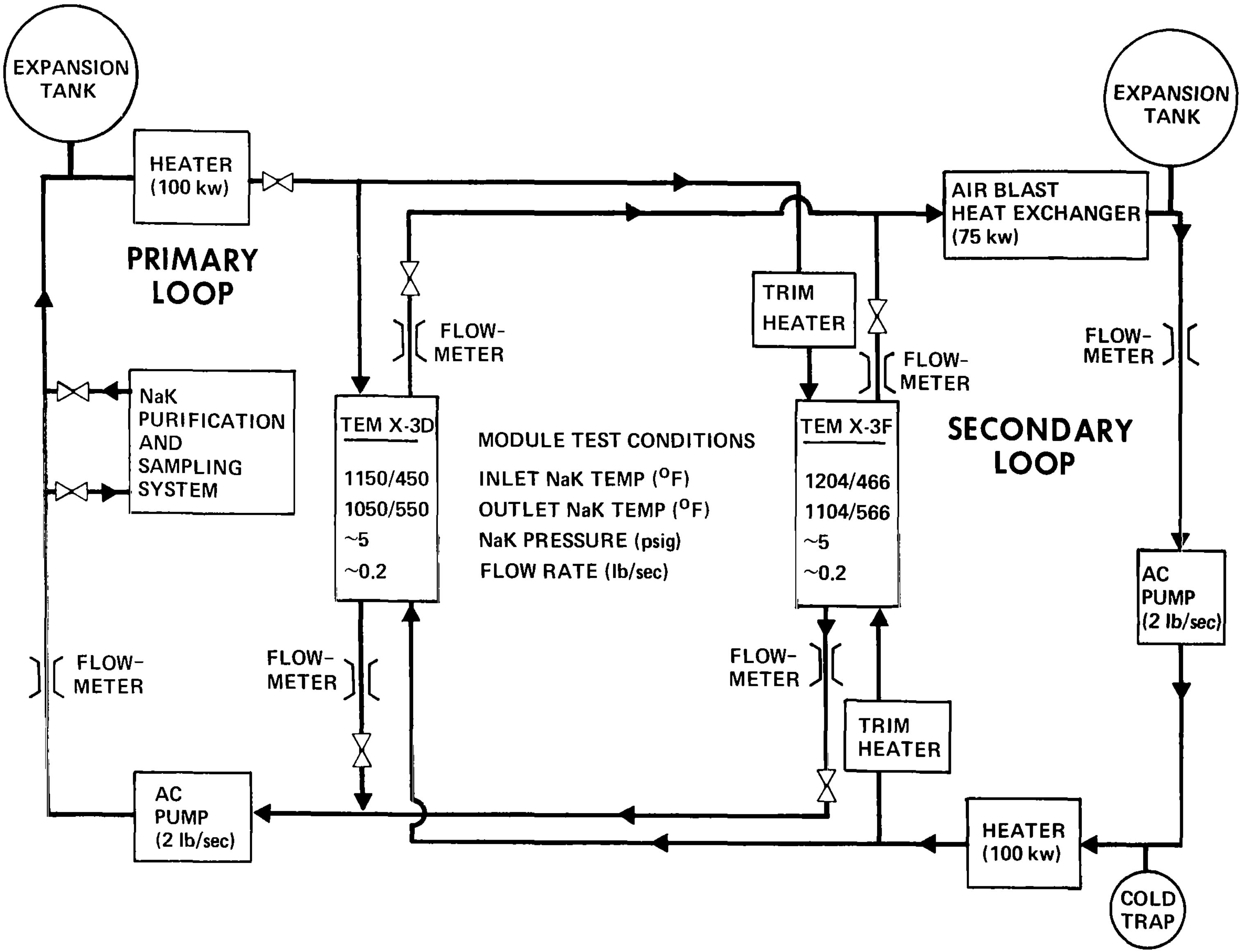

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Figure 5. Converter Modules Test Facility (4-Pack)

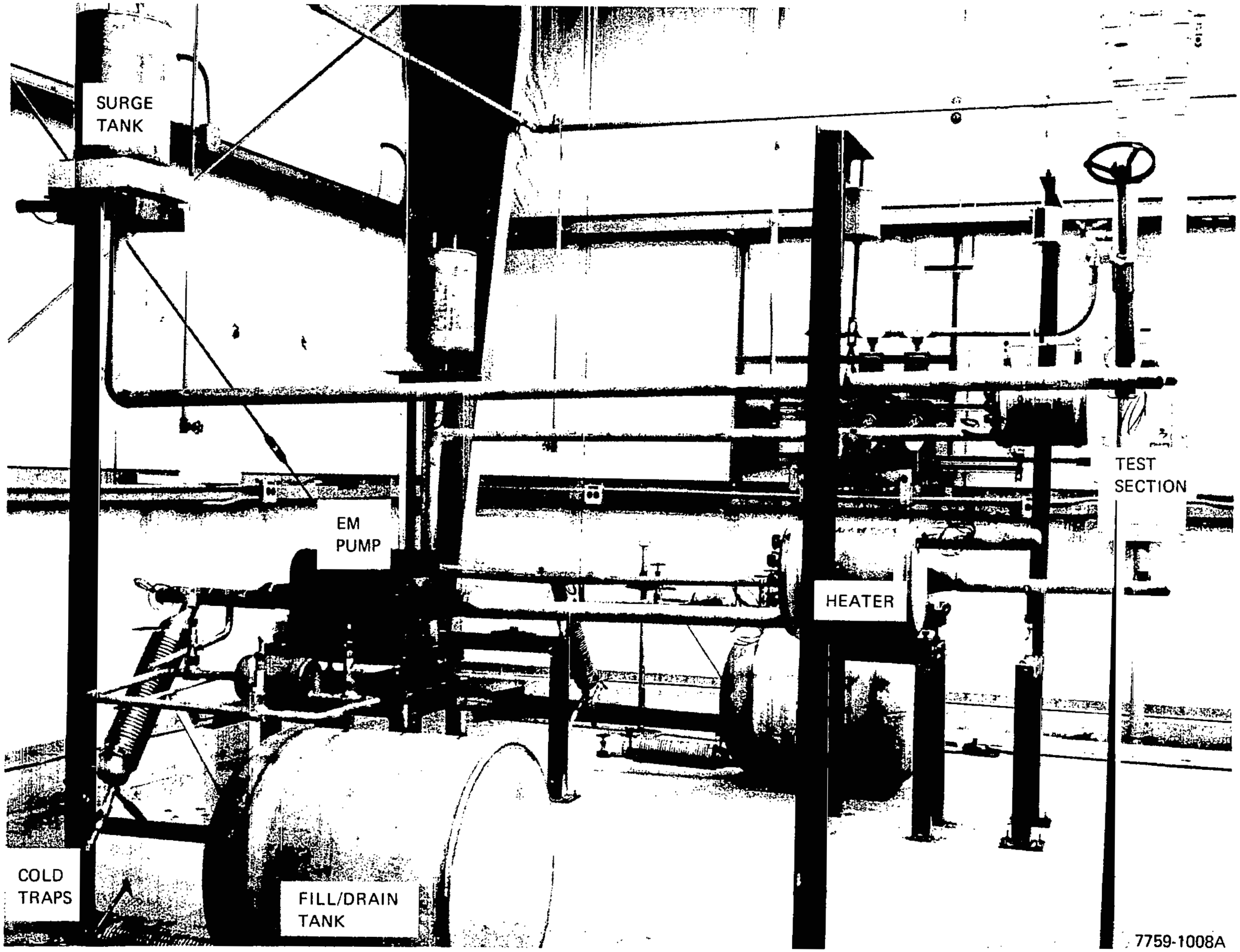

Figure 6. Construction Phase of 4-Pack Facility

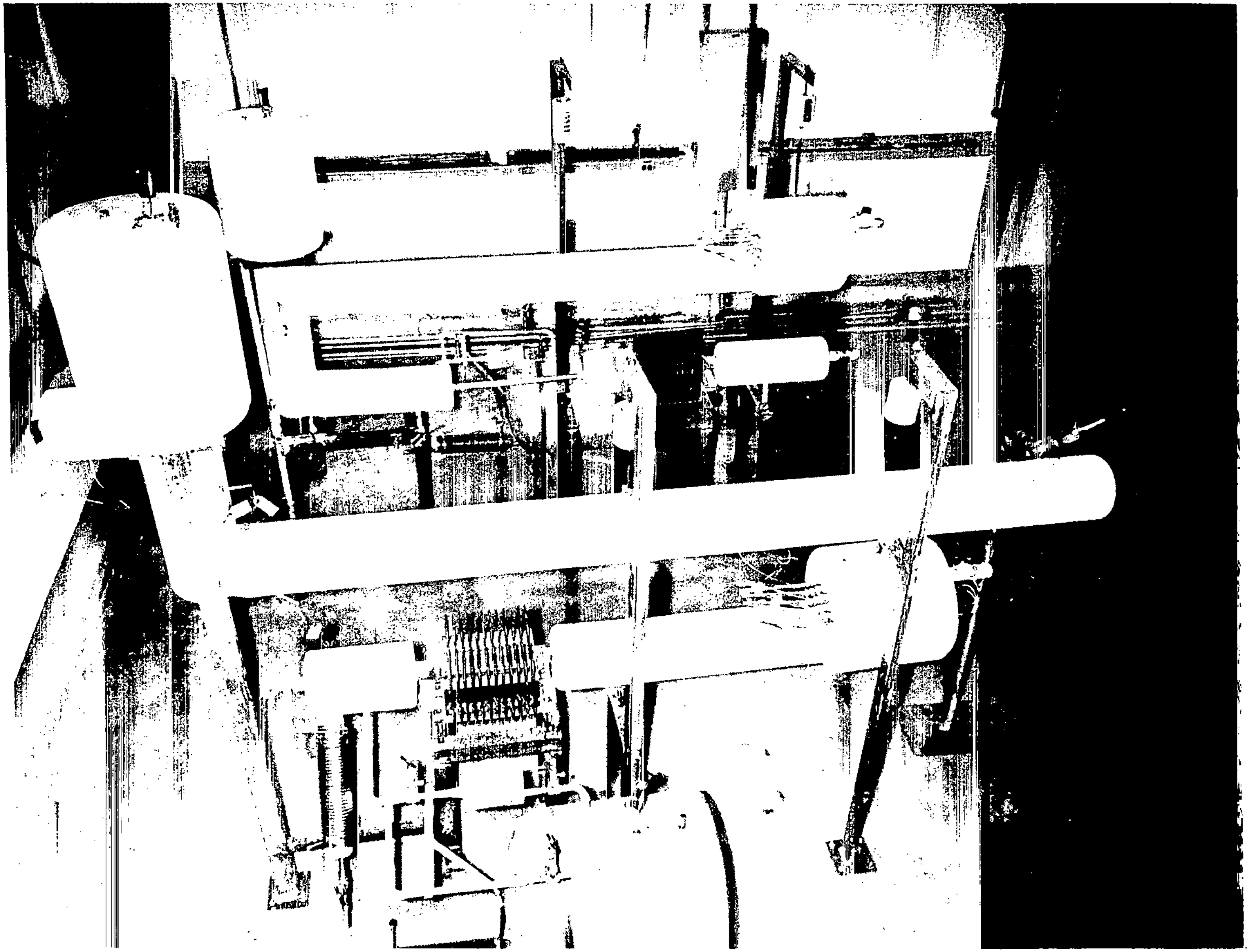

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Figure 7. Construction Phase of 4-Pack Facility (Insulation Partially Added)

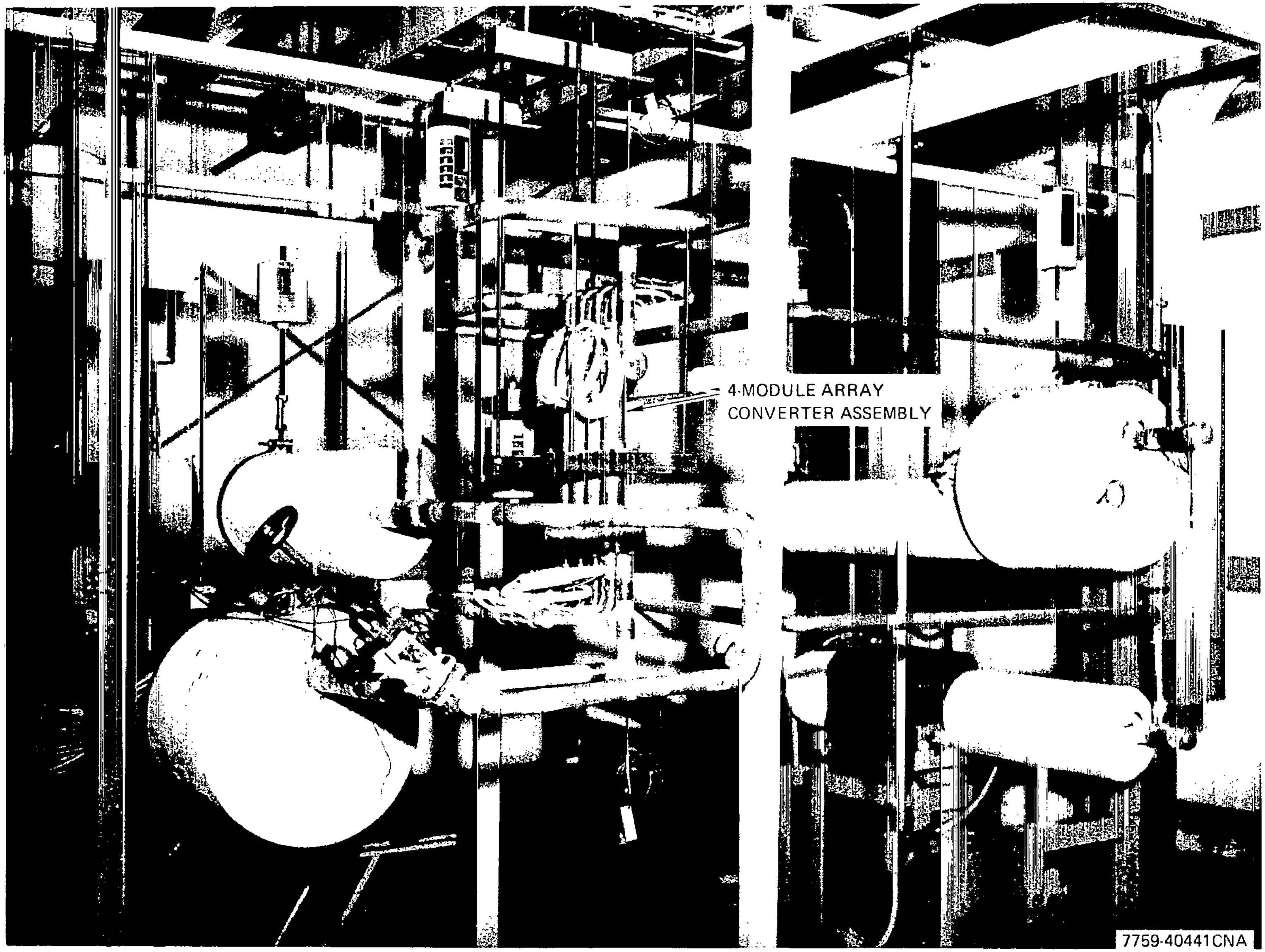

Figure 8. 4-Module Array Converter Assembly in 4-Pack Facility

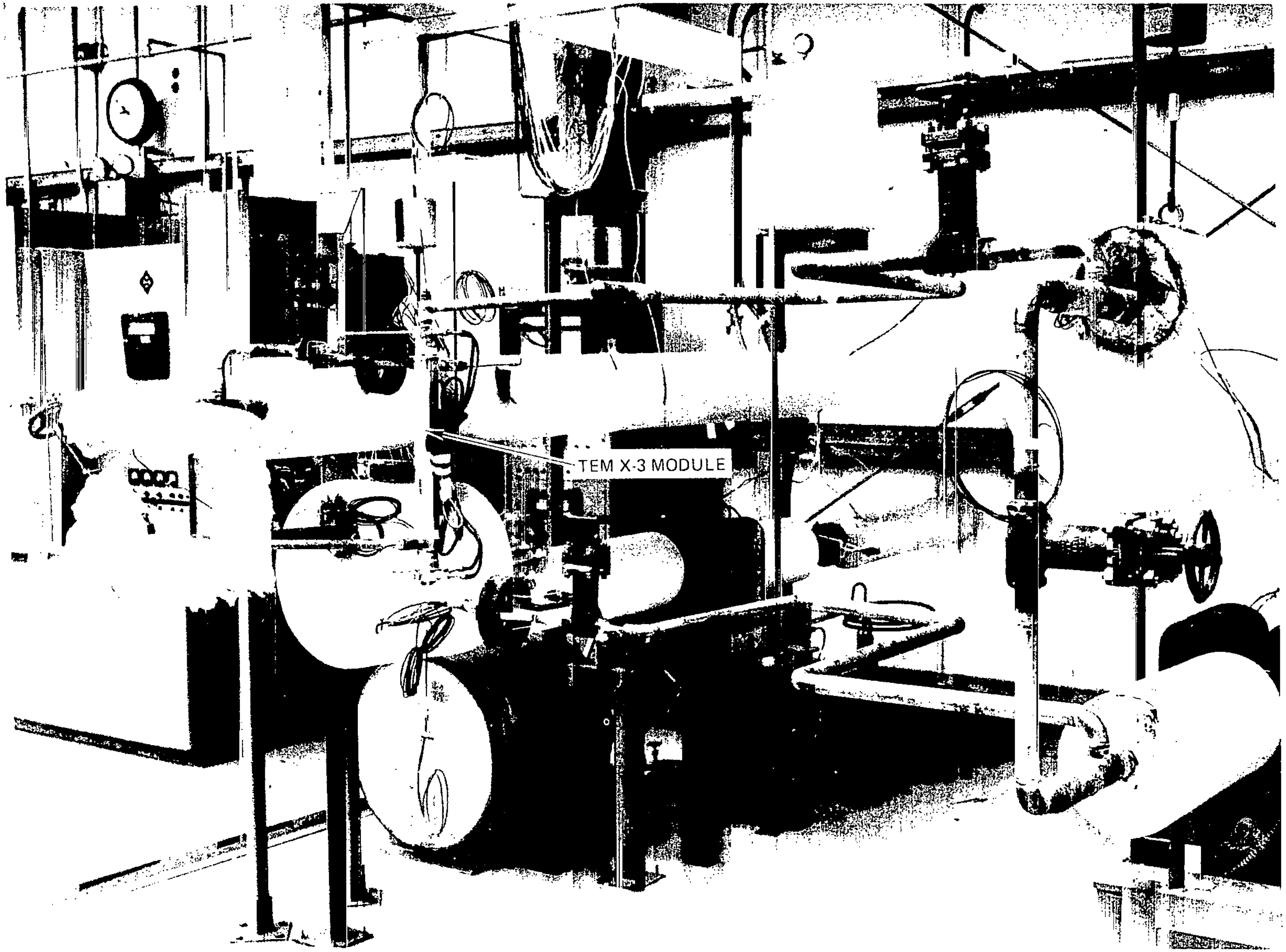

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Figure 9. Single TEM X-3 Module in 4-Pack Facility

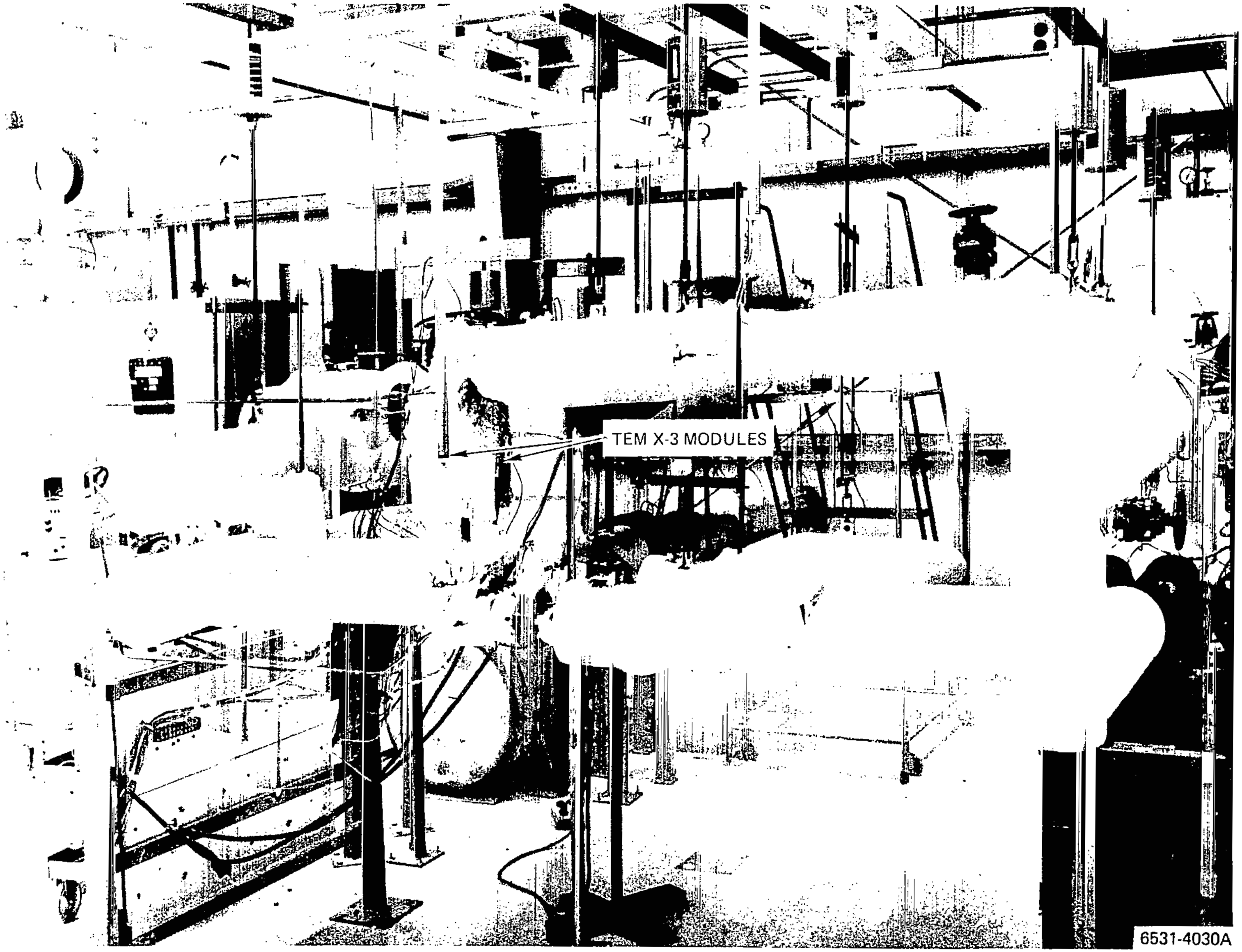

Figure 10. 2 TEM X-3 Modules in 4-Pack Facility

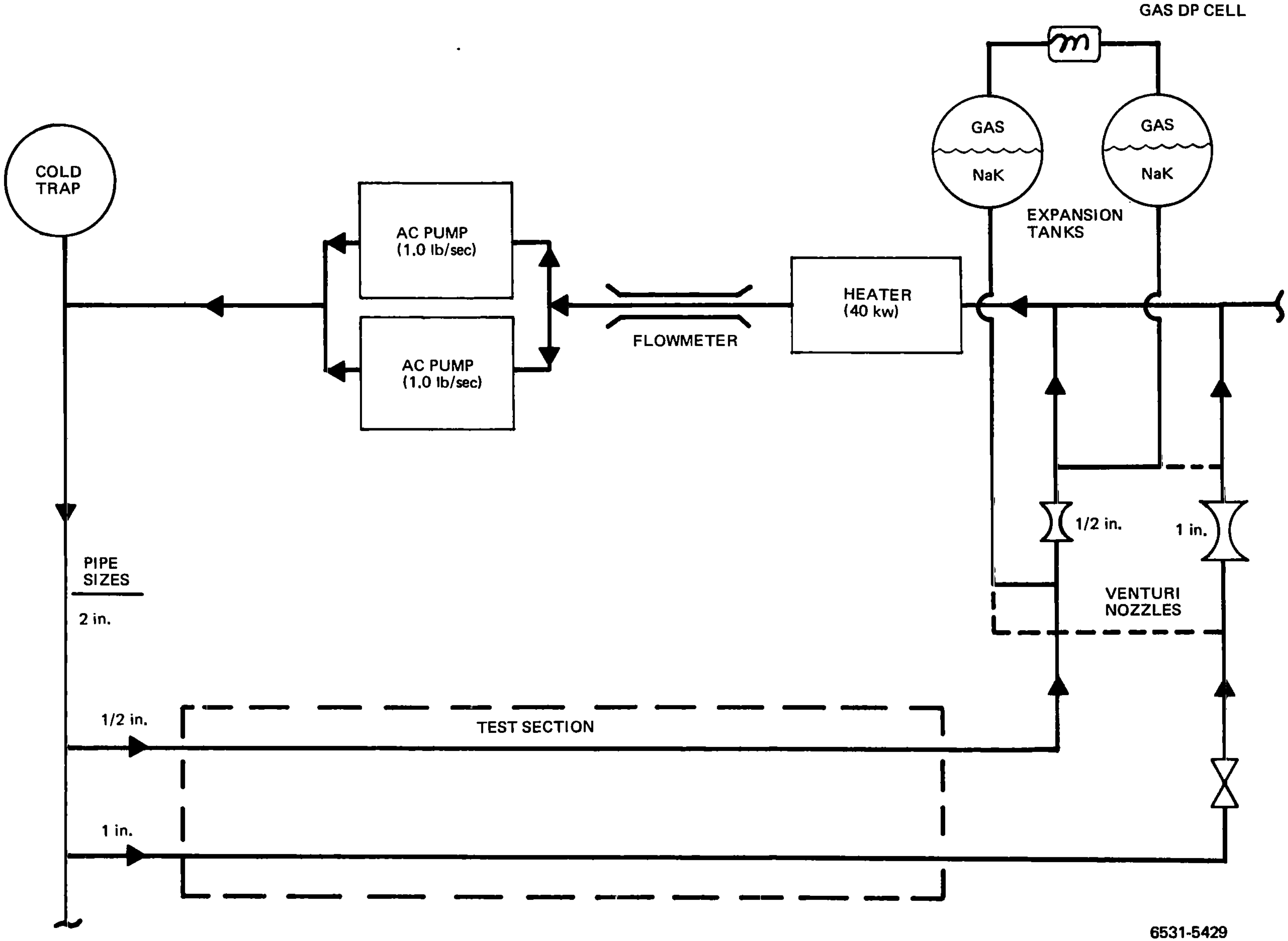

Figure 11. Flowmeter Calibration Loop

D. CALIBRATION FACILITY

This single loop facility was designed and constructed in GFY 1968 and used to calibrate flowmeters of other test facilities during GFY 1969 and 1970. As discussed in Section VI-B, later calibration of the flowmeters was conducted without the use of this facility. Subsequent to the flowmeter calibration activities, this loop was used to conduct tests on fuel-element-simulating heater assemblies for the core heat transfer studies.

The overall schematic of the loop is shown on Figure 11. The main piping was 2-in. Type 304 stainless-steel Schedule 10 pipe with appropriate reduction to 1 or 1/2 in. for the flowmeter being calibrated.

IV. TEST OPERATIONS

Testing of thermoelectric modules in flowing NaK facilities was generally successful, although not without incident. Transfer and handling of the liquid metal was performed without incident throughout the program. The principal hazard with these facilities was exposed hot surfaces such as valve stems and flowmeters that might cause burns. Operating personnel were trained and knowledgable in safe procedures for handling liquid metal, and although several minor NaK leaks occurred during test operations, no personnel injuries from NaK were incurred. The principal incidents affecting module NaK testing were the unscheduled shutdowns with rapid uncontrolled cooldown rates. These shutdowns shortened the scheduled tests of some modules and probably contributed to their performance degradations. Because the cooldown rates experienced during the shutdown were approximately those expected from reactor shutdown, information useful in assessing the module capabilities was gained.

A. STEADY-STATE NaK FACILITY

As could be expected, the first test of a module (TEM 9U S/N 008) in a NaK facility resulted in the most unscheduled shutdowns. During the first three months of operation in the steady-state loop, eight such shutdowns occurred. Four of these were caused by facility electrical power failures, three by high temperature trips, and one by shorting out of a temperature controller during its repair (operator error). The power failures were all of short duration (1 to 10 sec). The temperature trips were caused by poor temperature control. Powerstats were being used to control the heaters with no voltage or power regulation. This resulted in temperature swings of 20 to 30°F because of the cyclic nature of the power supplied to the test facility. To remedy these problems, the powerstats were replaced with silicon-controlled rectifiers (SCR), and a 10-sec time delay was incorporated into the automatic shutdown electrical circuits. During the remaining 3 months of testing on TEM 9U S/N 008, only one unscheduled shutdown occurred and temperature oscillations were reduced to about 5°F. The SCR power supplies and the time delay were incorporated into the cyclic test and the converter module test facilities prior to testing any modules.

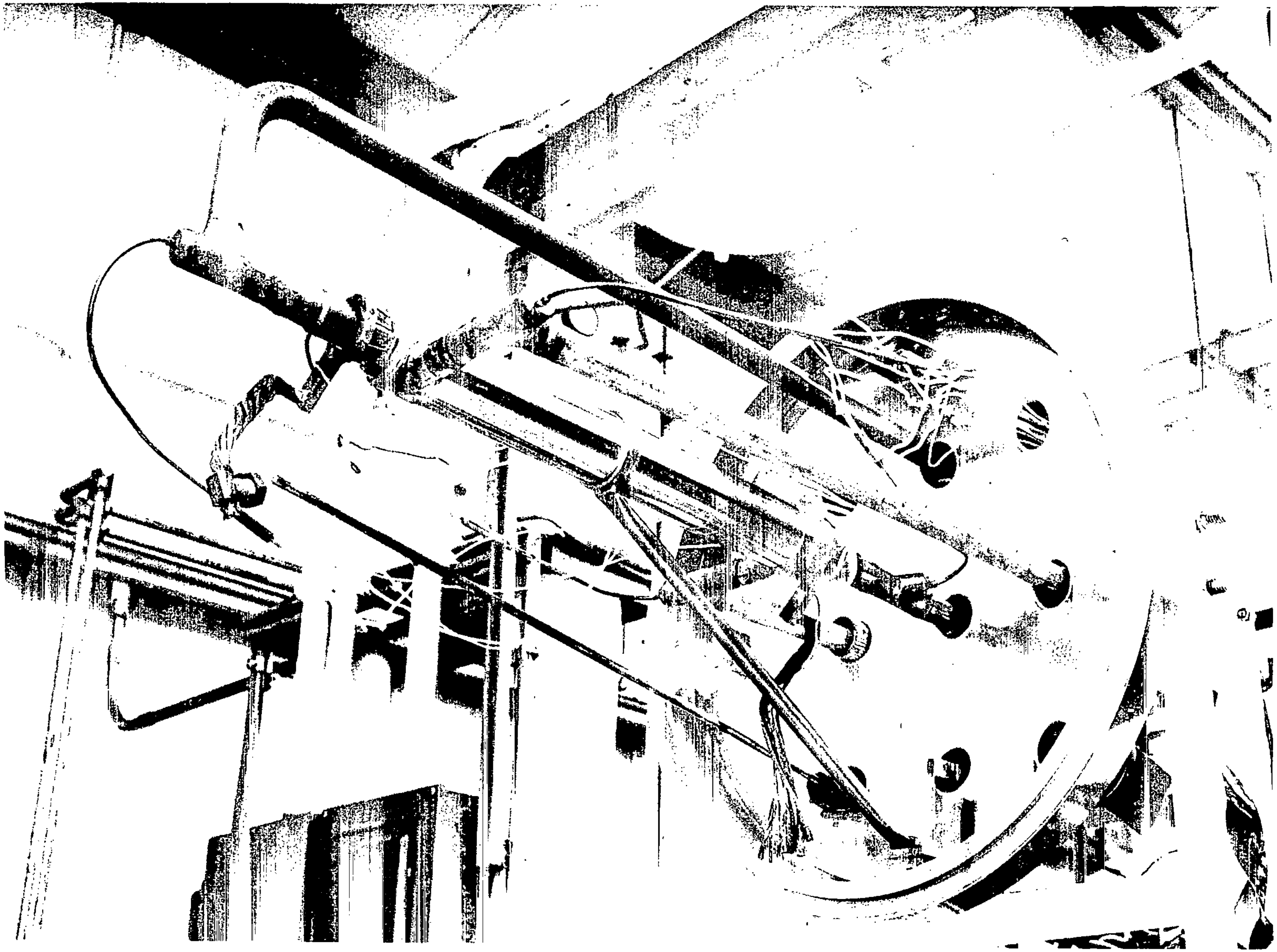

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Figure 12. Installation of TEM X-3K for Vacuum Environment Testing

The second test conducted in this facility was on TEM 13F S/N 003, the first such test on a 15-in. module. One unscheduled shutdown occurred, caused by a malfunctioning controller which was replaced. The principal anomaly encountered during this test was caused by NaK plugging in both loops at the start of the test. A small bore valve (1/4 in.) was removed from each loop, and the NaK replaced with clean NaK. This operation eliminated the plug in the secondary loop but partial plugging persisted in the primary loop until loop temperatures attained ~750°F, at which time flow in the primary returned to normal. More stringent procedures were imposed to preclude oxidation within the loops during subsequent component removal and replacement in all NaK test facilities, and no more small bore valves were used. This appeared to eliminate the problem on subsequent module tests.

Two modules, TEM 13G S/N 001 and S/N 005, were tested concurrently during the third test sequence. Five unscheduled shutdowns occurred during the first 1000 hours of this test. Three of these were due to a NaK leak at the immersion heaters which were being operated at high power range to provide 1400°F NaK temperature. After the third incident, the heater assembly was modified so that the mechanical Swagelock seal between the cartridge immersion heaters was relocated from the outlet to the cooler inlet end of the heater assembly. No heater problems were experienced after this modification. The other two shutdowns were attributed to faulty instrumentation, the exact cause not being specifically identified. The last 1400 hours of the test were completed without any incidents.

The 2,000-hour test on the Ta - 10 W tube sample, placed in lieu of a module, was completed without any shutdowns or problems. The purpose of this test was to assess the compatibility of Ta - 10 W, the material for the central tube of TEM X-3 module design, with flowing NaK.

The fifth and last test was on the TEM X-3K module with the module operating in a vacuum environment. This installation is indicated on Figure 2 and the assembly of the TEM X-3K module on the cover plate of the vacuum test chamber is shown in Figure 12. To accommodate the larger primary loop pressure losses associated for the vacuum environment installation, a larger d-c power supply was installed to increase the output of the d-c conduction pump.

The failure of this power supply contributed the only shutdown during the test of this module. At the beginning of the test, eliminating all the leaks in the vacuum system required considerable effort. Partial plugging of the primary NaK loop was also indicated at the test startup, but this was cleared when the operating NaK temperature was reached.

After approximately 200 hours of testing, a large decrease in the insulation resistance between the element and the cladding became apparent. This was attributed to the formation of electrically conducting surface film on the insulation from the breakdown of the diffusion pump oil backstreaming into the test environment. The oxidizing heat cleaning of this film and the replacement of the oil diffusion pump with an ion pump eliminated this problem.

B. CYCLIC NaK FACILITY

The first module tested was TEM 9U, S/N 010, subjected to a combination of 20 scheduled thermal cycles followed by steady-state testing for over 5,000 hours. During the steady-state part of this test, 3 additional unscheduled thermal cycles were experienced due to shutdown caused by facility power failures exceeding 10 sec.

Attempts were made during this test to measure the NaK flow rate using a simple thermal type flowmeter consisting of an immersion heater located in the line and between two thermocouples. The flow rate could then be calculated from power input to the heater and temperature rise of the NaK, after accounting for thermal losses. This method of flow measurement proved to be unreliable, generally indicating lower than actual flow rate with large errors at higher flow rates. Contributing factors are small temperature differential of the two thermocouples, inability of the thermocouples to measure the actual bulk average temperatures, and the possibility of inadequate mixing of the heated NaK.

The second and final test was on TEM 13G, S/N 002, which was also the longest duration test conducted on any tubular module in a flowing NaK facility during this program. During the 20,210 hours of steady-state testing, nine shutdowns were experienced, eight caused by facility power loss (either unplanned or planned for maintenance) and one by the malfunction of the temperature controller. The controller was replaced.

C. CONVERTER MODULE (4-PACK) FACILITY

The initial test was on Converter Module S/N 001, which consisted of 4 TEM-13G modules closely coupled hydraulically. During the first 1400 hours of testing five unscheduled shutdowns occurred, four of which were caused by loss of cooling water to the SCR power supplies of the main loop heaters. The other was caused by a momentary outage of electrical power to the air blast heat exchanger on the secondary loop. This outage automatically shut off the power to the secondary loop heater. To preclude this type of shutdown, the control circuitry was modified to include the heat exchanger power in the time delay. The remaining shutdowns occurred due to an area power failure (at ~6000 hours) and malfunction of the heater controller at the end of the test. This controller was repaired prior to the next test sequence.

The last operations conducted in this loop consisted of concurrent testing of TEM X-3D and TEM X-3F. TEM X-3D was tested for about 1200 hours prior to insertion of TEM X-3F into the loop. During this interval, two thermal cycles occurred, one due to malfunction of a temperature controller and the other due to a scheduled area power shutdown. During the final test with the two TEM X-3 modules, a total of 12 unscheduled shutdowns occurred. Three of the shutdowns were caused by the loss of cooling water to the SCR controller on the heater temperature controller, one was caused by the malfunction of the temperature controller, and the other eight due to malfunction of the SCR on the temperature controller of the primary or the secondary loop heaters. Several corrections were attempted on these SCR's without any permanent success. After the last test shutdown, a decision had been made to replace these SCR's with those from another manufacturer and also the temperature controllers, when the program was closed out.

D. TEST SYNOPSIS AND RECOMMENDATIONS

The test program was started without NaK sampling devices on any test facilities, but they were added to the primary loop of each test facility. Both diffusion and flow-through types of oxygen cold traps performed well, although somewhat slowly. NaK specimens removed after various periods of time showed that oxygen levels below 10 ppm could be attained in ~200 hours, even with comparatively dirty (100 ppm oxygen) NaK. A used loop is much more susceptible to contamination, and special care must be taken to prevent air from being admitted into these loops when shut down for repairs or replacement of the test article.

There were several NaK leaks during the course of these tests, occurring in heater cartridges, immersion thermocouples, or valve stems, none of which created potential danger to operating personnel. All of these leaks were detected during module startup except those in the heater bundle on the steady-state facility discussed previously. The leaks in immersion thermocouples were in the sheaths behind blind welds and the valves that leaked contained nonwelded bellows seals. Subsequent ones were welded. There were no NaK leaks in any of the AI-built components including the pumps, flowmeters, cold traps, or heaters (except at Swagelock fittings), or in the NaK piping system. All welds on the components and the loops had been inspected visually, helium leak tested, and dye penetrant checked.

The loop piping and the test modules were supported in a manner to minimize the reaction on both the test modules and the loop components.

Automatic safety control was provided on all test facilities to shut down the system (reduce heater power but continue the NaK flow) whenever any specified emergency conditions occurred and required manual restart. Initially, no time delay was incorporated into the electrical circuit of the safety system, resulting in many shutdowns from momentary "emergency" conditions. Subsequently, appropriate short time delays were included in selected circuits to permit the test system to ride out these fluctuations.

Although the power input to the facility was often erratic (voltage swings of ±1%), temperatures at the modules could be maintained within about a ±3°F band by using the solid-state rectifier (SCR) controllers and sensing temperature at the heater outlet. With loss of NaK flow, the heater power was then automatically reduced, preventing damage to loop equipment.

Some of the more obvious conclusions that can be drawn from reviewing the history of this program are:

1) Controllers and power supplies from the same manufacturer should be utilized to reduce compatibility problems.

2) Maximum time delays, consistent with the test requirements, should be provided in the electrical safety circuits to minimize shutdowns from momentary power losses or "emergency" conditions.

3) Air-cooled electrical components are less susceptible to shutdowns, justifying their slightly higher cost and larger envelope. Where water cooling is required, a separate closed system should be used.

4) A new reliable temperature controller which can be procured as an off-the-shelf item for approximately $150.00 should be installed. The temperature controllers used on these facilities were 10 to 15 years old, but were used primarily because they were on hand when the facilities were designed and built.

5) If thermal cycling cannot be tolerated, or should be minimized, some type of emergency standby electrical power should be provided.

6) If time response is not important (as was the case during these tests), thermal wells should be used for installing thermocouples so that all NaK containment welds can be easily inspected.

7) Only welded bellows should be used in valves and, if possible, only Y-pattern full-flow valves should be used to minimize hydraulic pressure losses and areas for potential plugging.

8) Equipment such as heaters containing mechanical seals should be installed in such a manner as to keep these joints at the lowest possible temperature during operations. Except for the one set of incidents on the steady-state loop discussed above, there were no problems with these mechanical seals on any other heaters in any loop. About 70 heater cartridges were employed in this manner on these test loops during this program with an additional 45 heaters successfully employed in an adjacent test loop, without incident.

V. TEST PROCEDURE

A. MODULE PREPARATION AND INSTALLATION

Upon receipt of the modules from Westinghouse, the modules were inspected for physical damage, and the internal resistance and the resistance to cladding were measured. Immersion-type thermocouples were welded into fittings at all four NaK entry orifices, and additional surface thermocouples were mounted on the module in accordance with the applicable Westinghouse shrouded module assembly drawing. All welding and weld inspection was performed in accordance with approved AI procedures. An adjustable external resistive load was connected to the module, and the module thermally insulated.

B. MODULE TESTING

Module test startup, steady-state testing, thermal cycling, and test shutdown were conducted in accordance with Westinghouse- and AI-approved procedures. The general test sequence was as follows:

1) Fill NaK loops and establish specified flow rates.

2) Increase temperature of both loops at specified rate (per a temperature envelope), acquiring performance data at ~100°F intervals on primary loop.

3) Acquire performance data 1 hour after achieving specified operating temperatures, and then once daily for 2 weeks and bi-weekly thereafter for the duration of the test. The external resistance should be maintained at approximately match load.

4) During controlled shutdowns, acquire data at 100°F intervals as measured on the primary loop while lowering temperature at specified rates.

5) Determine the cause of unscheduled shutdowns, and take corrective action if necessary prior to restart of the test.

C. MODULE REMOVAL AND RETURN

At the conclusion of the test the loops were drained and the modules were carefully cut out of the loops. On all modules except the TEM X-type containing refractory metal, the residual NaK was reacted with butyl alcohol, followed with a distilled water rinse. They were then flushed with dry nitrogen or air-dried and repackaged in their original shipping containers.

The secondary sides of the TEM X type modules were cleaned in this same manner, but the primary sides were cleaned with mercury after removing the flow swirler. The flow swirler was also cleaned with butyl alcohol and replaced in the module. All modules, except for the TEM X-3 types, were returned to Westinghouse for their examination and evaluation. The TEM X-3 modules are being stored at AI.

D. DATA HANDLING

The data acquired during the module testing included the module load and open circuit voltage, module output current, module-to-cladding resistance, primary and secondary loop NaK flow rates, and surface and immersion temperature at the four NaK orifices of the module. Where required by the test procedure, additional temperatures were also taken.

All test data were recorded as voltage signals by the digital data logger, except for the module-to-cladding resistance which was taken manually with a megohmmeter. The punched paper tape output of the data logger and the megohmmeter data were then inputted into a timeshare computer for reduction into engineering units using a previously prepared program. These engineering unit test data along with other information were prepared in the form of printed and punched paper tape output by the computer. Both forms of the computer output were transmitted to Westinghouse.

E. INSTRUMENTATION AND CALIBRATION

The module resistance to cladding was measured with a megohmmeter. A current shunt was utilized to determine the module output current. This and other voltage signals from remainder of the instrumentation were monitored and recorded by the Hewlett Packard Model 2410B data logging system.

All instruments were periodically calibrated in accordance with AI Standards Laboratory procedures, and all measurements are referenced to Company primary standards, whose calibrations are traceable to the National Bureau of Standards. The overall (sensor and readout) accuracy of the data is given in Table 6.

TABLE 6

INSTRUMENT CALIBRATION DATA

Parameter	Accuracy (% of Reading)	Range
Flow (lb/hr)	±4.0	400 to 2000
Temperature, Immersion (°F)	±3/8	500 to 1200
Temperature, Surface (°F)	±3/4	500 to 1200
Module Voltage (v)	±0.01	5 to 30
Module Current (amp)	±0.05	1 to 100
Resistance to Cladding (ohms)	±2.0	10^4 to 10^7

The immersion thermocouples on the module hot side and the module cold side were calibrated and matched (selected, based on a difference in voltage generated in their respective operating range being a minimum so that when module axial ΔT is determined by subtracting the measured immersion temperatures, an accuracy of ±2°F in ΔT results). The results of the pre- and post-test calibration of the thermocouples used on the test of converter Module S/N 001 (~7000 hours) showed shifts of less than 2°F, and the thermocouples used on the test of TEM 13G S/N 002 (~20,000 hours) showed shifts of less than 4°F. These temperature shifts were in the same direction, so that overall hot side to cold side temperature differentials remained practically constant throughout these tests.

Prior to initial tests of the modules including converter Module S/N 001, the electromagnetic flowmeters were calibrated in a NaK calibration loop in the temperature range of 300 to 1300°F against a standard Venturi nozzle. The discharge coefficient of this Venturi nozzle was certified by the manufacturer to have an error no greater than ±1/2%. A consideration of all errors involved in the calibration operation indicated an overall flowmeter accuracy of better than

±3% in the range of 400 to 2000 lb/hr. These experimentally determined flow rates were compared to the calculated flow rates taking into consideration the actual physical configuration of the flowmeter, the measured temperature conditions, and the measured flux density. These calculated flow rates were found to agree with the experimentally determined rates (flow/output signal) within the experimental accuracy. Subsequently, flowmeters were no longer experimentally calibrated in the Calibration Loop as noted earlier. Instead the flowmeters were mechanically and magnetically stabilized, the flux density remeasured, and the flow rates determined analytically. Provisions for rechecking the magnetic flux without removing the flowmeters from the test loop were incorporated.

REFERENCES

1. "Compact Thermoelectric Converter Program Final Report," WANL-PR (EEE)-055
2. SNAP Reactor Programs Progress Reports (1968 through 1972)

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