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HALLAM NUCLEAR POWER FACILITY
VOLUME II

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CONTENTS

AI-P-1109	Nitrogen System
AI-P-1110	Radioactive Vent System
AI-P-1111	Radioactive Liquid Waste System
AI-P-1113	Auxiliary Steam System
AI-P-1116	Preheating System
AI-P-1117	Instrument Air System
AI-P-1118	Emergency Power System
AI-P-1119	Nuclear Instrumentation System
AI-P-1120	Plant Control System

HALLAM NUCLEAR POWER FACILITY
PREOPERATIONAL TEST COMPLETION REPORT
NITROGEN SYSTEM

AI-P-1109

Test and Analysis

by

E. J. FIRSICK

H. C. KEMPT

Evaluation

by

L. L. JOHNSON

A T O M I C S I N T E R N A T I O N A L
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CONTENTS

	Page
I. Purpose of Test	1
II. Discussion of Test Performance	1
A. Nitrogen System	1
B. Primary Sodium Equipment Cells	5
III. Analysis and Presentation of Test Results	7
A. Nitrogen System and Components	7
B. Primary Sodium Equipment Cells Nitrogen System	10
IV. Compliance With Test Completion Criteria.	13
V. Evaluation	15
A. Controls and Instrumentation.	16
B. High Pressure Supply.	16
C. Purge of the Primary Sodium System Cells	17
D. Verification of System Adequacy	17
E. Steam Generator Cell Supplies	19

TABLES

I. Relief Valves Lifting and Reseating Pressures (psig) . .	11
II. Primary Sodium Equipment Cell Purge Data.	12
III. Nitrogen Purge Rate and Time (R/A Sodium Piping and Equipment Cell)	18

FIGURES

1109-1A. Original Nitrogen System Manifold	3
1109-1B. Nitrogen System Manifold After Modification.	4
1109-2. Manifold Header Pressure <u>vs</u> Flow	8

HALLAM NUCLEAR POWER FACILITY
PREOPERATIONAL TEST COMPLETION REPORT
NITROGEN SYSTEM, AI-P-1109

I. PURPOSE OF TEST

The primary purpose of preoperational test AI-P-1109 was to prepare the nitrogen system for operation and to determine that the system and related system components function per design specifications. Related sub-purposes of the test were: (1) to purge and fill the nitrogen system, except for the nitrogen filled cells; and (2) to purge and fill the primary sodium equipment cells with nitrogen.

II. DISCUSSION OF TEST PERFORMANCE

A. NITROGEN SYSTEM

Primarily, the nitrogen system functions to reduce fire hazard by maintaining an inert atmosphere in cells containing piping and equipment handling radioactive primary sodium. Under plant operating conditions, all primary sodium equipment cells will be maintained with an inert nitrogen atmosphere.

Secondary functions of the nitrogen system are to:

- a) Maintain an inert atmosphere in a sodium tank car during sodium unloading operations.
- b) Displace the volume of radioactive liquid waste water in the laundry tanks.
- c) Purge fuel wash cells, pump wash cell and pickup cells.
- d) Provide a nitrogen atmosphere around the sodium drums at the drum melt station.
- e) Blow out wash cell cooling water lines.
- f) Provide a backup for the plant instrument air system.

- g) Relieve excessive negative pressure in the wash cell radio-active vent system.
- h) Operate nitrogen cooling control dampers in the primary pipe tunnel.
- i) Provide a backup for the air supply to the main sodium block and throttle valve air motors.
- j) Fill the maintenance cell door inflatable seal.
- k) Operate maintenance cell jib manipulators and tool slide air motors.
- l) Act as instrument air for the moisture switches in the primary sodium equipment cells.
- m) Act as an emergency cover gas for the steam generator cells in case of fire and/or sodium-water reaction.
- n) Provide an inert atmosphere in the maintenance cell.

The pressure reducing stations for the low pressure (50 psig) and high pressure (100 psig) nitrogen were designed assuming that nitrogen would be supplied at 2200 psig from trailers. Instead, a liquid nitrogen system was installed to supply nitrogen at 125 psig. (The supply pressure was later reduced to 100 psig.) System diagrams are shown in Figures 1109-1A and -1B.

Liquid nitrogen is stored in a 250,000 scf spherical storage tank located outside the reactor building. Six vaporizers are provided to convert the liquid to gas. Each vaporizer is capable of the following: 1400 cfh @ 125 psig continuously; 3000 cfh @ 125 psig for 8 hours; 8000 cfh @ 125 psig for 1 hour. The gaseous nitrogen is piped into the building where it branches to supply high pressure and low pressure needs.

At the start of the test all manually operated valves in the nitrogen system were closed. Here, the word "system" refers to the nitrogen system other than that portion supplying or venting the primary sodium equipment cells. The supply valves to these cells, however, were also closed. Gradually, portions of the "system" were opened, purged and tested for performance. Individual nitrogen control stations were tested to ascertain whether specified pressure and flow conditions could be met. Control station relief valves were pressure-lifted to determine set pressures and also depressurized to determine reseating pressure and to assure that the

Figure 1109-1A. Original Nitrogen System Manifold

Figure 1109-1B. Nitrogen System Manifold After Modification

valves reseated tightly. Low pressure alarms were checked for operation by bleeding down the pressure in the system. A final check of each control station was made to assure that the pressure control valve did not allow excessive pressure buildup under "no flow" conditions.

B. PRIMARY SODIUM EQUIPMENT CELLS

Primary sodium equipment cell pressures are controlled by dual-pilot pressure indicator-controllers which maintain the nitrogen atmosphere in the cells between one and six inches of water-column pressure. Nitrogen is admitted when cell pressure drops below one inch water gage (in. Wg) and is exhausted from a cell when the pressure rises above six in. Wg pressure. Relief valves are provided to relieve into the R/A vent system if the cell pressure should exceed 2 psig. One twelve-point oxygen analyzer monitors each primary equipment cell in succession, on a timed cycle, to verify that an atmosphere of one percent or less oxygen content is maintained.

All primary enclosure relief valves were tested to verify opening pressure and reseating pressure. Test equipment consisting of a pressure regulator, pressure gage, flowmeter and necessary block valves was installed at a test tee located between the relief valve and a permanent, normally locked-open, globe valve in the various vent lines. The normally locked-open valve was closed, and instrument air slowly admitted through the test equipment until the relief valve opened. By observation of the test flowmeter and pressure gage, the point at which the relief valve opened and reseated was immediately apparent. After the reseating point was determined, a pressure decay test was performed to assure that the relief valve had attained a positive seal. Where two relief valves are piped in parallel (venting the same cell), it was necessary to determine which valve opened first and then to install a test "gag" on this valve to allow testing of the other valve.

The pressure control system for each cell was thoroughly checked to ensure that all components functioned correctly. The pressure controller-transmitters which sense the pressure in the primary cells were individually

calibrated, adjusted as necessary, and signal output determined. The sensing line from the cell was disconnected and test apparatus consisting of a water manometer, pressure regulator and instrument air supply was attached to the input line of the transmitter. The input air was varied from zero to ten in. Wg pressure to determine whether the pressure controller-transmitter and the associated pressure controller were both indicating the same pressure.

The pressure controllers were set to maintain the primary sodium equipment cells between one and six in. Wg pressure. Proper action of the pressure controllers was substantiated by changing the air input into the pressure transmitter and determining that the controller transmitted an air signal to the control valves. By observation of the traveling indicator on the control valve stems it was proven that the pressure controller output signal would open the nitrogen supply control valve when the cell pressure decreased to one in. Wg pressure, and would open the control valve in the cell vent lines when the pressure increased to six in. Wg pressure.

Oxygen analyzer O₂An-900 was calibrated by use of span gas and zero gas introduction, and placed in operation. The solenoid valves in the sample lines from the cells to the analyzer were individually checked for proper operation from the control switches located on the radiation monitoring panel in the main control room.

Purging of the primary cells was accomplished in accordance with the test procedure. The oxygen analyzer was taken out of sequential operation and adjusted to continuously receive and analyze gas from the cell being purged. High oxygen concentration alarm O₂AH-900 was disconnected for the duration of the test. The exhaust control valve bypass valve in the vent line of the cell being purged was opened. Nitrogen was admitted to the cell by opening the inlet control valve bypass valve. Purge pressure was limited to a maximum of nine in. Wg pressure. Flow was established at a rate whereby the nitrogen vent and supply would achieve a balance while maintaining the cell at about six in. Wg pressure. Purging continued until the cell atmosphere was reduced below one percent oxygen. At this time the nitrogen and vent bypass valves were closed and the instrument control system put into operation. Cell atmosphere was sampled for an additional

two hours to verify that the oxygen content remained below one percent. When purging of all the primary sodium equipment cells was completed, the oxygen analyzer was set in sequential operation, and all cell atmospheres were maintained by the control system.

III. ANALYSIS AND PRESENTATION OF TEST RESULTS

A. NITROGEN SYSTEM AND COMPONENTS

The original nitrogen manifold was designed to reduce 2200 psig supply nitrogen to 100 psig and 50 psig, to handle high and low pressure nitrogen needs, respectively. Operation of this manifold was found to be unsatisfactory at the 125 psig provided by the liquid nitrogen evaporator-vaporizer unit which had been installed.

In general, pressure control valves and relief valves did not operate satisfactorily and required extensive maintenance to ensure working order. The relief valve on the 50 psig header (RV-900) could not be depended upon to repeat the lifting and reseating pressure. The low pressure control valves (PCV-900 and PCV-901) were incapable of controlling pressure under varying flow conditions. The downstream pressure vs flow curve for the original supply manifold, using PCV-900 and PCV-901 (both were set for 50 psig under no-flow conditions), is shown in Figure 1109-2. It was impossible to attain a flow of 90 cfm with these pressure control valves. Under no-flow conditions, these valves allowed downstream pressure to increase to full supply pressure (125 psig).

In addition, the relief valve (RV-914) on the high pressure nitrogen supply (100 psig) would lift at 113 psig and reseal at 79 psig under static conditions. During normal operation with PCV-904 in service, the pressure will not drop to 70 psig. RV-914 would, therefore, not reseal.

Low pressure alarms PAL-900 and PAL-905 required a 25 to 35 psig pressure increase to reset the alarm. For instance, PAL-905 alarmed at 95 psig and reset at 123 psig. Because of the above, it was necessary that the nitrogen manifold be completely rebuilt.

Figure 1109-2. Manifold Header Pressure vs Flow

The 125 psig nitrogen supply was reduced to 100 psig to eliminate PCV-904. The two original pressure reducing stations, PCV-900 and PCV-901, were replaced by a single unit and a bypass line and valve. Low pressure alarm units that would reset within a few psig were installed in place of the unsatisfactory units originally installed.

The following items on the new manifold were adjusted and set:

- a) RV-900 on the 50 psig header was set to lift at 68 psig.
- b) RV-914 on the high pressure side was set to lift at 114 psig and reseal at 105 psig.
- c) PAL-900 (low supply pressure alarm to the 50 psig reducing station) was set to alarm at 95 psig and reset at 100 psig.
- d) PAL-905 (low supply pressure alarm to the 100 psig header) was set to alarm at 90 psig and reset at 103 psig.
- e) PAL-901 (low pressure alarm on the nitrogen low pressure tank) was set to alarm at 43 psig and reset at 48 psig.

Pressure vs flow curves for the original manifold and the modified manifold are presented in Figure 1109-2. Comparing these curves illustrates the superiority of the modified manifold. A flow of 152 scfm was obtained on FI-900 with a header pressure of 41 psig. This was only a 9 psig drop from no-flow conditions (50 psig).

Nitrogen was admitted to the sodium tank car and melt station, and the associated piping was purged. PCV-903 was set to control downstream pressure at 2.5 psig with a flow of 18.9 scfm; under no-flow conditions the pressure increased to 5 psig. This subsystem is apparently satisfactory; all of the sodium tank cars were unloaded without difficulty, using this apparatus.

The pressure reducing station (PCV-909) which supplies nitrogen as a "backup" to the instrument air header was set at 30 psig. The pressure of the instrument air header was bled down. PCV-909 opened to maintain the instrument air header pressure at 30 psig. Flow from the manifold was 95 scfm (on FI-900) at 47.5 psig.

Piping associated with pressure reducing station PCV-905, nitrogen to pump wash cell, fuel wash cells, pickup cells, and R/A vent condenser vacuum breaker, was purged and the pressure control valve set to control

pressure at 1.0 psig and 15 cfm. Under no-flow conditions, the pressure increased to 5 psig after 1 hour. It is expected that the blocking valves will be manually closed when this subsystem is not in use, thus preventing pressure buildup. Nitrogen was not admitted to the various cells as this is included in preoperational test, AI-P-1133, Wash Cells. The pressure control valve (PCV-907) associated with the R/A vent condenser vacuum breaker was not set as this subsystem will be tested during preoperational test AI-P-1110, R/A Vent System.

The pressure control valve (PCV-920) associated with nitrogen to the wash cells cooling water lines was set at 20 psig with a slight bleed flow. Associated relief valve RV-922 was set to lift at 23 psig and to reseal at 22 psig. PCV-906, associated with nitrogen to the laundry holdup and monitoring tanks, was set to control pressure at 3/4 psig and 3 cfm. The respective relief valve (RV-915) was set to lift at 1.75 psig and reseal at 1.2 psig. Nitrogen was also admitted to each of the steam generator rooms to prove that this could be done.

B. PRIMARY SODIUM EQUIPMENT CELLS NITROGEN SYSTEM

Primary sodium equipment cell relief valve tests disclosed that of 16 valves in the system, 14 did not open at the 2 psig design pressure nor properly reseal leak-tight at an expected 1.5 psig pressure. Raising or lowering the valve spring adjustment screw corrected the relief opening pressure. However, it was necessary to install new diaphragms and seating discs in five valves, to ensure leak-tightness in the reseal position. Examination of the removed parts failed to show any significant reason why the original parts would not function properly. The malfunction may have been caused by foreign matter between the disc and valve seat, or minute flaws in the neoprene diaphragm. All relief valves now lift within 0.1 psig of the 2 psig design pressure and reseal leak-tight, as shown in Table I.

During the checkout of PIC-900T (the pressure controller transmitter for the primary fill tank cell) it was discovered that no transmitted output signal was being received by PIC-900 located on local board (LB-) 30.

TABLE I
RELIEF VALVES LIFTING AND RESEATING PRESSURES (psig)

Relief Valve	Lift Pressure (psig)	Reseat Pressure (psig)
RV-902 A	1.90	1.35
RV-902 B	2.00	1.60
RV-903 A	2.00	1.60
RV-903 B	2.00	1.45
RV-909 A	2.10	1.75
RV-909 B	2.00	1.75
RV-910 A	2.09	1.75
RV-910 B	2.00	1.60
RV-911 A	2.00	1.75
RV-911 B	2.10	1.75
RV-904	2.10	1.30
RV-905	2.00	1.70
RV-906	2.00	1.60
RV-907	2.10	1.65
RV-908	2.00	1.50
RV-913	2.00	1.45
RV-919	1.95	1.75

A large slug of solder material was found obstructing the 1/4 inch copper tubing at a soldered coupling joining two sections of the signal transmitting line. Removal of this plug cleared the interference between the transmitter and the controller located on LB-30.

The control mechanisms of the pressure controllers for primary enclosure atmospheres were set on a 5 percent proportional band, and the nitrogen inlet controls were set at one in. Wg pressure. With these settings, as a cell pressure decreases, the pressure controller output signal will begin to open the nitrogen supply control valve at a pressure of 1.2 in. Wg and the valve will be full open at about 0.8 in. Wg. The cell nitrogen outlet

setpoints were placed at six in. Wg pressure. As a cell pressure increases, the pressure controller output signal will start to open the outlet valve at a pressure of 5.8 in. Wg, with the valve opening fully at 6.2 in. Wg.

Purging of primary sodium equipment cells was completed with no unusual incidents. Purge flow rates, the time required to lower cell oxygen content below one percent, and the quantity of nitrogen used are tabulated in Table II.

TABLE II
PRIMARY SODIUM EQUIPMENT CELL PURGE DATA

Cell	*Flow Rate (cfm)	Time (Hours)	Nitrogen Usage (Ft ³)
Primary Fill Tank	60	32.7	117,772
Primary Pipe Tunnel and Moderator Pump Cells	60	67.0	241,200
Primary Service Cells	60	23.0	82,800
IHX Cell No. 1	38	36.7	83,676
IHX Cell No. 2	38	30.8	70,224
IHX Cell No. 3	45	35.2	95,040

* The nitrogen flow rates were observed on FI-900, located in Nitrogen Gage Board No. 28. This flow meter is calibrated for 60 F and 50 psig nitrogen flow; however, the listed flow rates are not temperature compensated, as corrections would be insignificant.

Although the three IHX cell volumes are the same, there is a noticeable difference in the quantity of nitrogen required to lower oxygen content of the cells below one percent. IHX cell No. 2, which was the last one purged, required the least amount. IHX cells No. 1 and No. 2, purged at a rate of 38 cfm, required less than IHX cell No. 3 which was purged at 45 cfm. Purging of IHX cell No. 2 was begun at a flow rate of 45 cfm; however, after a period of slightly over 3 hours, the purge was discontinued due to a low nitrogen supply. Purging operations were resumed about 16 hours later and continued until the oxygen content was reduced below one percent.

Based upon the foregoing, it is recommended that when time allows during any future purging that may be required, the inflow rate of nitrogen be reduced, and that instead of continuous purge operation, the purge be performed on an intermittent basis. For example, purging for alternate two hour periods with the purge being discontinued for alternate two hour periods, thus allowing better mixing of the nitrogen gas with the cell atmosphere. This method may result in a significant reduction in the amount of nitrogen required to purge a cell to the required oxygen content.

Oxygen analyzer O₂An-900 performs satisfactorily in sampling the cells in sequence, analyzing the sample gas, and recording the results. The cell high oxygen alarm (O₂AH-900) was set and verified to actuate the annunciator light at the main control board when any cell atmosphere exceeds one percent oxygen content.

Sample gas flow through the oxygen analyzer depends on a pressure differential between the cells and the vent header which ties into the exhaust from the analyzer. The analyzer vent line was connected into line No. 946-3"-E, upstream of PCV-1016 which is set to open at one in. Wg pressure. As the cell atmosphere pressure range is from one to six in. Wg, there was insufficient pressure differential to obtain flow from this cell, if a particular cell pressure was near one in. Wg. To overcome this, the discharge line from the analyzer was relocated to a position immediately downstream of PCV-1016, where the vent line is maintained at a negative pressure between 21 and 35 in. Wg. A pressure regulator was installed in the analyzer vent line and set to maintain a constant pressure of minus one in. Wg, thus establishing a pressure differential sufficient to maintain flow through the analyzer.

IV. COMPLIANCE WITH TEST COMPLETION CRITERIA

Following are the test completion criteria associated with preoperational test AI-P-1109, Nitrogen System, as listed in NAA-SR-5700 (Supplement 4) Pages XI(a)-30 and XI(a)-32, with remarks regarding the test to explain compliance with the criteria.

- a) Criterion: The nitrogen distribution system has been purged and filled.
Remarks: The nitrogen distribution system has been purged and filled.
- b) Criterion: All pressure control valves control pressure properly under specified flow conditions.
Remarks: This criterion has been met after system modification (see II. B. of test).
- c) Criterion: All low pressure alarms (PAL) alarm and reset properly.
Remarks: Proper operation of all low pressure alarms was verified by bleeding down the pressure until the alarm was received.
- d) Criterion: All relief valves lift and reseal properly.
Remarks: All relief valves have been tested to ensure that they lift and reseal properly.
- e) Criterion: No detectable leaks are present based on short time decay tests.
Remarks: No system leak checking was done during this test except in determining if the relief valves seat tightly. The system is welded construction, and all leak-checking was done during construction. Observation of system pressures and flow rates during operation has indicated that no appreciable leaks exist in the system.
- f) Criterion: Pressure gages and flow meters function in accordance with their design parameters.
Remarks: All system components met design parameters following system modifications.
- g) Criterion: All primary sodium equipment cells have been purged with nitrogen and contain 1% or less of oxygen by volume as ascertained by test.
Remarks: All primary sodium equipment cells were purged and the cell atmosphere reduced and controlled below 1% oxygen.
- h) Criterion: All cell pressure relief valves lift and reseal properly at design setpoints.
Remarks: All cell pressure relief valves have been determined to lift and reseal properly at design setpoints.
- i) Criterion: Pressure control valves to each cell maintain the cell pressure between approximately 1 and 6 inches of water, exhausting nitrogen to the R/A vent system when

cell pressure increases above 6 inches H₂O and admitting nitrogen when cell pressure falls below 1²/₂ inch of water.

Remarks: Pressure control valves have been determined to operate in accordance with system criteria.

- j) Criterion: The oxygen analyzer properly samples the atmosphere of each cell in sequence and an alarm occurs if the oxygen content exceeds 1%.

Remarks: The oxygen analyzer properly samples the atmosphere of each cell in sequence and an alarm occurs if the oxygen content exceeds 1%.

V. EVALUATION

The nitrogen system was designed to provide a low humidity - low oxygen content atmosphere in sodium equipment and piping cells, and other locations, for the purpose of reducing the fire hazards and/or to minimize corrosion. The system also provides back-up for the service and instrument air systems.

Preoperational testing of the nitrogen system, components and systems serviced by the nitrogen, and the subsequent operation of these items has confirmed that these design criteria have been satisfied.

As specified in the "Final Summary Safeguards Report for the Hallam Nuclear Power Facility", NAA-SR-5700, the test purpose and test completion criteria were met, with the exception that leak-tightness of the system was not confirmed during the test. The entire system was subjected to a rigorous pressure decay test at the completion of the construction phase. This test was performed by the construction contractor, under the surveillance of Atomics International and Bechtel Corporation quality control representatives. Some modifications and system maintenance have been performed since the leak testing, and it is possible that small leaks do exist. It is obvious that, if the leaks do exist, they are sufficiently small as not to affect system operation.

A. CONTROLS AND INSTRUMENTATION

Adequate operation of all pressure controllers, relief valves, pressure alarms and other instruments was demonstrated during the test.

The set pressure of each pressure control valve and relief valve was checked and adjusted as required. In several cases, relief and control valves failed to reseal properly. This problem was corrected in all valves except RV-900 and PCV-905. RV-900 (supply manifold low pressure relief) is set to lift at 68 psig, however, it does not reseal until the pressure decays to 43 psig. The system pressure is normally controlled at approximately 50 psig and must be manually reduced below the normal operating pressure, to reseal the valve. This is not a serious condition, but does result in excessive nitrogen loss and operating inconvenience. It is suggested that this valve be reset to a cracking pressure of 75 - 85 psig, in an attempt to correct the condition. The system is designed for pressures up to 100 psig; hence, no adverse effects would result.

PCV-905 (wash cells supply) is set to control at 1.0 psig at 15 scfm. The valve does control satisfactorily in this range, but at essentially zero flow conditions, the pressure creeps to approximately 5.0 psig in one hour. No detrimental effects will result from this condition, since the operating pressure of the cells serviced by this controller is 10 psig.

B. HIGH PRESSURE SUPPLY

Original design provisions for the nitrogen system included two high-pressure supply sources with individual pressure reducing stations. The system has been modified and at the present time consists of a single liquid nitrogen supply tank, vaporizer assembly and pressure reducing station. This installation does not provide the same high degree of reliability as did the original design.

To date, the existing installation has provided dependable trouble-free service; however, a leak or failure of the tank, vaporizer, or one of the

associated components will necessitate interrupting the nitrogen supply. It would be desirable to incorporate a small standby supply of bottled nitrogen which can be placed in service until repairs are accomplished.

C. PURGE OF THE PRIMARY SODIUM SYSTEM CELLS

The radioactive sodium piping and equipment cells were successfully purged with nitrogen, and the oxygen concentration reduced to less than 1.0%. Ability of the system to maintain this low concentration was also demonstrated during the test and the ensuing operation.

As shown in Table III, in almost all cases the quantity of nitrogen and the time required to purge the cells was greater than anticipated. Time-wise, this is primarily due to an arbitrary cell differential pressure limit of 9 inches of water, which is exceeded at design flow rates.

This pressure limit was imposed to prevent possible damage to the cell rupture discs, which could suffer fatigue failure due to repeated flexing at excessive differential pressure. However, the nitrogen flow capacity is available to purge the cells at the design flows, if deemed necessary.

The quantity of nitrogen used to purge the cells over and above the expected quantity was approximately 123,712 scf. This quantity is based on having complete mixing of the incoming nitrogen and the gas in the cell. Some channeling and stratification can be expected, which will increase the purge volumes required. Purge rates to IHX cells No. 1 and No. 2 were less than the rate to IHX cell No. 3. Apparently better mixing accounts for the considerably lower volumes required.

The major concern with the overage is the cost, which, based on the present price of nitrogen, is only \$870.00 for the volume of gas required in excess of the expected quantity. Because the cells are purged infrequently, the cost is minimal and of little concern.

D. VERIFICATION OF SYSTEM ADEQUACY

The individual nitrogen supplies were checked to ensure that design flow and pressure could be achieved. Except for the supplies to the sodium

TABLE III
NITROGEN PURGE RATE AND TIME
(R/A Sodium Piping and Equipment Cell)

Cell	Cell Volume (cu. ft.)	Purge Rate (scfm)		Purge Volume (scf)		Time (hours)	
		Design	Actual	Expected	Actual	Expected	Actual
Primary Fill Tank	23,000	100	60	69,000	117,772	11.5	32.7
Primary Pipe Tunnel & Mod Pump Cells	64,000	100	60	192,000	241,200	32.0	67.0
Primary Sodium Service Cells	21,000	30	60	63,000	82,800	35.0	23.0
IHX Cell No. 1	27,000	80	38	81,000	83,676	18.0	36.7
IHX Cell No. 2	27,000	80	38	81,000	70,224	18.0	30.8
IHX Cell No. 3	27,000	80	48	81,000	95,040	18.0	35.2

equipment cells, the test did not verify that the specified design conditions were adequate to perform the required function. However, during the testing and operation of these serviced systems and components, the adequacy of the nitrogen system supplies was verified as follows:

1. Sodium Melt Station Supply: Nitrogen was supplied at the required pressure and flow during the entire melting and loading of the initial charge of sodium for the heat transfer system.
2. Instrument Air System Back-Up Supply: Adequate supply was demonstrated during performance of the Instrument Air System preoperational test, AI-P-1117
3. Back-Up For Primary Throttle and Block Valve Operators: Required nitrogen supply was confirmed during the performance of the Instrument Air System preoperational test, AI-P-1117.
4. Nitrogen Cooler Control Dampers in the Primay Pipe Tunnel: Operation of the control dampers was demonstrated during the nitrogen purge of the pipe tunnel and subsequent plant operation.

5. Maintenance Cell Atmosphere Supply: The maintenance cell was satisfactorily purged on several occasions during performance of the Maintenance Cell preoperational test, AI-P-1139.
6. Maintenance Cell Inflatable Seal: During testing of the Maintenance cell, a leak-tight seal of the access hatch was effected, which is indicative of adequate nitrogen supply pressure.
7. Maintenance Cell Pneumatic Tools: Adequate nitrogen pressure and flow to the tools was demonstrated during the performance of the Maintenance Cell preoperational test, AI-P-1139.
8. Wash Cell Cooling Water Lines: The wash cells have been removed for maintenance on several occasions. Prior to each removal, the water was successfully purged from the cooling lines, with nitrogen.
9. Radioactive Laundry Tanks: The ability to displace water with nitrogen in the laundry hold-up tanks was demonstrated during the performance of the R/A Liquid Waste System preoperational test, AI-P-1111.
10. R/A Vent Condenser Vacuum Breaker: Required nitrogen flow and pressure were verified during the performance of the R/A Vent System preoperational test, AI-P-1110.
11. Wash Cell Supply: The wash cells were satisfactorily purged during the performance of the Wash Cell preoperational test, AI-P-1133.
12. Steam Generator Cell Emergency Purge: The ability to flow nitrogen to the steam generator cells was demonstrated during the performance of the nitrogen system test. However, the flow capacity was not checked, due to lack of instrumentation. See Section E. for further discussion.

E. STEAM GENERATOR CELL SUPPLIES

The time required to reduce the cell atmosphere oxygen concentration to a level which will extinguish a sodium fire was not determined during the test. An analysis of the system indicates that nitrogen flow to the cells will be limited by the liquid nitrogen vaporizer output, (300 scfm for a period of eight hours). At this rate, approximately six hours (minimum) will be required to reduce the oxygen concentration in the cell to a level which will not support combustion.

Excessive time would be required to extinguish a fire by this method, pointing up the necessity for initiating a nitrogen purge only when other fire fighting methods fail. It is suggested that a corrective action operating procedure be prepared, which will reflect the limitations of this method and specify a nitrogen purge as a last resort technique.

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A T O M I C S I N T E R N A T I O N A L
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CONTENTS

	Page
I. Purpose of Test	1
II. Discussion of Test Performance	1
A. Nitrogen System	1
B. Primary Sodium Equipment Cells	5
III. Analysis and Presentation of Test Results	7
A. Nitrogen System and Components	7
B. Primary Sodium Equipment Cells Nitrogen System	10
IV. Compliance With Test Completion Criteria.	13
V. Evaluation	15
A. Controls and Instrumentation.	16
B. High Pressure Supply.	16
C. Purge of the Primary Sodium System Cells	17
D. Verification of System Adequacy	17
E. Steam Generator Cell Supplies	19

TABLES

I. Relief Valves Lifting and Reseating Pressures (psig) . .	11
II. Primary Sodium Equipment Cell Purge Data.	12
III. Nitrogen Purge Rate and Time (R/A Sodium Piping and Equipment Cell)	18

FIGURES

1109-1A. Original Nitrogen System Manifold	3
1109-1B. Nitrogen System Manifold After Modification.	4
1109-2. Manifold Header Pressure <u>vs</u> Flow	8

HALLAM NUCLEAR POWER FACILITY
PREOPERATIONAL TEST COMPLETION REPORT
NITROGEN SYSTEM, AI-P-1109

I. PURPOSE OF TEST

The primary purpose of preoperational test AI-P-1109 was to prepare the nitrogen system for operation and to determine that the system and related system components function per design specifications. Related sub-purposes of the test were: (1) to purge and fill the nitrogen system, except for the nitrogen filled cells; and (2) to purge and fill the primary sodium equipment cells with nitrogen.

II. DISCUSSION OF TEST PERFORMANCE

A. NITROGEN SYSTEM

Primarily, the nitrogen system functions to reduce fire hazard by maintaining an inert atmosphere in cells containing piping and equipment handling radioactive primary sodium. Under plant operating conditions, all primary sodium equipment cells will be maintained with an inert nitrogen atmosphere.

Secondary functions of the nitrogen system are to:

- a) Maintain an inert atmosphere in a sodium tank car during sodium unloading operations.
- b) Displace the volume of radioactive liquid waste water in the laundry tanks.
- c) Purge fuel wash cells, pump wash cell and pickup cells.
- d) Provide a nitrogen atmosphere around the sodium drums at the drum melt station.
- e) Blow out wash cell cooling water lines.
- f) Provide a backup for the plant instrument air system.

- g) Relieve excessive negative pressure in the wash cell radioactive vent system.
- h) Operate nitrogen cooling control dampers in the primary pipe tunnel.
- i) Provide a backup for the air supply to the main sodium block and throttle valve air motors.
- j) Fill the maintenance cell door inflatable seal.
- k) Operate maintenance cell jib manipulators and tool slide air motors.
- l) Act as instrument air for the moisture switches in the primary sodium equipment cells.
- m) Act as an emergency cover gas for the steam generator cells in case of fire and/or sodium-water reaction.
- n) Provide an inert atmosphere in the maintenance cell.

The pressure reducing stations for the low pressure (50 psig) and high pressure (100 psig) nitrogen were designed assuming that nitrogen would be supplied at 2200 psig from trailers. Instead, a liquid nitrogen system was installed to supply nitrogen at 125 psig. (The supply pressure was later reduced to 100 psig.) System diagrams are shown in Figures 1109-1A and -1B.

Liquid nitrogen is stored in a 250,000 scf spherical storage tank located outside the reactor building. Six vaporizers are provided to convert the liquid to gas. Each vaporizer is capable of the following: 1400 cfh @ 125 psig continuously; 3000 cfh @ 125 psig for 8 hours; 8000 cfh @ 125 psig for 1 hour. The gaseous nitrogen is piped into the building where it branches to supply high pressure and low pressure needs.

At the start of the test all manually operated valves in the nitrogen system were closed. Here, the word "system" refers to the nitrogen system other than that portion supplying or venting the primary sodium equipment cells. The supply valves to these cells, however, were also closed. Gradually, portions of the "system" were opened, purged and tested for performance. Individual nitrogen control stations were tested to ascertain whether specified pressure and flow conditions could be met. Control station relief valves were pressure-lifted to determine set pressures and also depressurized to determine reseating pressure and to assure that the

Figure 1109-1A. Original Nitrogen System Manifold

Figure 1109-1B. Nitrogen System Manifold After Modification

valves reseated tightly. Low pressure alarms were checked for operation by bleeding down the pressure in the system. A final check of each control station was made to assure that the pressure control valve did not allow excessive pressure buildup under "no flow" conditions.

B. PRIMARY SODIUM EQUIPMENT CELLS

Primary sodium equipment cell pressures are controlled by dual-pilot pressure indicator-controllers which maintain the nitrogen atmosphere in the cells between one and six inches of water-column pressure. Nitrogen is admitted when cell pressure drops below one inch water gage (in. Wg) and is exhausted from a cell when the pressure rises above six in. Wg pressure. Relief valves are provided to relieve into the R/A vent system if the cell pressure should exceed 2 psig. One twelve-point oxygen analyzer monitors each primary equipment cell in succession, on a timed cycle, to verify that an atmosphere of one percent or less oxygen content is maintained.

All primary enclosure relief valves were tested to verify opening pressure and reseating pressure. Test equipment consisting of a pressure regulator, pressure gage, flowmeter and necessary block valves was installed at a test tee located between the relief valve and a permanent, normally locked-open, globe valve in the various vent lines. The normally locked-open valve was closed, and instrument air slowly admitted through the test equipment until the relief valve opened. By observation of the test flowmeter and pressure gage, the point at which the relief valve opened and reseated was immediately apparent. After the reseating point was determined, a pressure decay test was performed to assure that the relief valve had attained a positive seal. Where two relief valves are piped in parallel (venting the same cell), it was necessary to determine which valve opened first and then to install a test "gag" on this valve to allow testing of the other valve.

The pressure control system for each cell was thoroughly checked to ensure that all components functioned correctly. The pressure controller-transmitters which sense the pressure in the primary cells were individually

calibrated, adjusted as necessary, and signal output determined. The sensing line from the cell was disconnected and test apparatus consisting of a water manometer, pressure regulator and instrument air supply was attached to the input line of the transmitter. The input air was varied from zero to ten in. Wg pressure to determine whether the pressure controller-transmitter and the associated pressure controller were both indicating the same pressure.

The pressure controllers were set to maintain the primary sodium equipment cells between one and six in. Wg pressure. Proper action of the pressure controllers was substantiated by changing the air input into the pressure transmitter and determining that the controller transmitted an air signal to the control valves. By observation of the traveling indicator on the control valve stems it was proven that the pressure controller output signal would open the nitrogen supply control valve when the cell pressure decreased to one in. Wg pressure, and would open the control valve in the cell vent lines when the pressure increased to six in. Wg pressure.

Oxygen analyzer O₂An-900 was calibrated by use of span gas and zero gas introduction, and placed in operation. The solenoid valves in the sample lines from the cells to the analyzer were individually checked for proper operation from the control switches located on the radiation monitoring panel in the main control room.

Purging of the primary cells was accomplished in accordance with the test procedure. The oxygen analyzer was taken out of sequential operation and adjusted to continuously receive and analyze gas from the cell being purged. High oxygen concentration alarm O₂AH-900 was disconnected for the duration of the test. The exhaust control valve bypass valve in the vent line of the cell being purged was opened. Nitrogen was admitted to the cell by opening the inlet control valve bypass valve. Purge pressure was limited to a maximum of nine in. Wg pressure. Flow was established at a rate whereby the nitrogen vent and supply would achieve a balance while maintaining the cell at about six in. Wg pressure. Purging continued until the cell atmosphere was reduced below one percent oxygen. At this time the nitrogen and vent bypass valves were closed and the instrument control system put into operation. Cell atmosphere was sampled for an additional

two hours to verify that the oxygen content remained below one percent. When purging of all the primary sodium equipment cells was completed, the oxygen analyzer was set in sequential operation, and all cell atmospheres were maintained by the control system.

III. ANALYSIS AND PRESENTATION OF TEST RESULTS

A. NITROGEN SYSTEM AND COMPONENTS

The original nitrogen manifold was designed to reduce 2200 psig supply nitrogen to 100 psig and 50 psig, to handle high and low pressure nitrogen needs, respectively. Operation of this manifold was found to be unsatisfactory at the 125 psig provided by the liquid nitrogen evaporator-vaporizer unit which had been installed.

In general, pressure control valves and relief valves did not operate satisfactorily and required extensive maintenance to ensure working order. The relief valve on the 50 psig header (RV-900) could not be depended upon to repeat the lifting and reseating pressure. The low pressure control valves (PCV-900 and PCV-901) were incapable of controlling pressure under varying flow conditions. The downstream pressure vs flow curve for the original supply manifold, using PCV-900 and PCV-901 (both were set for 50 psig under no-flow conditions), is shown in Figure 1109-2. It was impossible to attain a flow of 90 cfm with these pressure control valves. Under no-flow conditions, these valves allowed downstream pressure to increase to full supply pressure (125 psig).

In addition, the relief valve (RV-914) on the high pressure nitrogen supply (100 psig) would lift at 113 psig and reseal at 79 psig under static conditions. During normal operation with PCV-904 in service, the pressure will not drop to 70 psig. RV-914 would, therefore, not reseal.

Low pressure alarms PAL-900 and PAL-905 required a 25 to 35 psig pressure increase to reset the alarm. For instance, PAL-905 alarmed at 95 psig and reset at 123 psig. Because of the above, it was necessary that the nitrogen manifold be completely rebuilt.

Figure 1109-2. Manifold Header Pressure vs Flow

The 125 psig nitrogen supply was reduced to 100 psig to eliminate PCV-904. The two original pressure reducing stations, PCV-900 and PCV-901, were replaced by a single unit and a bypass line and valve. Low pressure alarm units that would reset within a few psig were installed in place of the unsatisfactory units originally installed.

The following items on the new manifold were adjusted and set:

- a) RV-900 on the 50 psig header was set to lift at 68 psig.
- b) RV-914 on the high pressure side was set to lift at 114 psig and reseal at 105 psig.
- c) PAL-900 (low supply pressure alarm to the 50 psig reducing station) was set to alarm at 95 psig and reset at 100 psig.
- d) PAL-905 (low supply pressure alarm to the 100 psig header) was set to alarm at 90 psig and reset at 103 psig.
- e) PAL-901 (low pressure alarm on the nitrogen low pressure tank) was set to alarm at 43 psig and reset at 48 psig.

Pressure vs flow curves for the original manifold and the modified manifold are presented in Figure 1109-2. Comparing these curves illustrates the superiority of the modified manifold. A flow of 152 scfm was obtained on FI-900 with a header pressure of 41 psig. This was only a 9 psig drop from no-flow conditions (50 psig).

Nitrogen was admitted to the sodium tank car and melt station, and the associated piping was purged. PCV-903 was set to control downstream pressure at 2.5 psig with a flow of 18.9 scfm; under no-flow conditions the pressure increased to 5 psig. This subsystem is apparently satisfactory; all of the sodium tank cars were unloaded without difficulty, using this apparatus.

The pressure reducing station (PCV-909) which supplies nitrogen as a "backup" to the instrument air header was set at 30 psig. The pressure of the instrument air header was bled down. PCV-909 opened to maintain the instrument air header pressure at 30 psig. Flow from the manifold was 95 scfm (on FI-900) at 47.5 psig.

Piping associated with pressure reducing station PCV-905, nitrogen to pump wash cell, fuel wash cells, pickup cells, and R/A vent condenser vacuum breaker, was purged and the pressure control valve set to control

pressure at 1.0 psig and 15 cfm. Under no-flow conditions, the pressure increased to 5 psig after 1 hour. It is expected that the blocking valves will be manually closed when this subsystem is not in use, thus preventing pressure buildup. Nitrogen was not admitted to the various cells as this is included in preoperational test, AI-P-1133, Wash Cells. The pressure control valve (PCV-907) associated with the R/A vent condenser vacuum breaker was not set as this subsystem will be tested during preoperational test AI-P-1110, R/A Vent System.

The pressure control valve (PCV-920) associated with nitrogen to the wash cells cooling water lines was set at 20 psig with a slight bleed flow. Associated relief valve RV-922 was set to lift at 23 psig and to reseal at 22 psig. PCV-906, associated with nitrogen to the laundry holdup and monitoring tanks, was set to control pressure at 3/4 psig and 3 cfm. The respective relief valve (RV-915) was set to lift at 1.75 psig and reseal at 1.2 psig. Nitrogen was also admitted to each of the steam generator rooms to prove that this could be done.

B. PRIMARY SODIUM EQUIPMENT CELLS NITROGEN SYSTEM

Primary sodium equipment cell relief valve tests disclosed that of 16 valves in the system, 14 did not open at the 2 psig design pressure nor properly reseal leak-tight at an expected 1.5 psig pressure. Raising or lowering the valve spring adjustment screw corrected the relief opening pressure. However, it was necessary to install new diaphragms and seating discs in five valves, to ensure leak-tightness in the reseal position. Examination of the removed parts failed to show any significant reason why the original parts would not function properly. The malfunction may have been caused by foreign matter between the disc and valve seat, or minute flaws in the neoprene diaphragm. All relief valves now lift within 0.1 psig of the 2 psig design pressure and reseal leak-tight, as shown in Table I.

During the checkout of PIC-900T (the pressure controller transmitter for the primary fill tank cell) it was discovered that no transmitted output signal was being received by PIC-900 located on local board (LB-) 30.

TABLE I
RELIEF VALVES LIFTING AND RESEATING PRESSURES (psig)

Relief Valve	Lift Pressure (psig)	Reseat Pressure (psig)
RV-902 A	1.90	1.35
RV-902 B	2.00	1.60
RV-903 A	2.00	1.60
RV-903 B	2.00	1.45
RV-909 A	2.10	1.75
RV-909 B	2.00	1.75
RV-910 A	2.09	1.75
RV-910 B	2.00	1.60
RV-911 A	2.00	1.75
RV-911 B	2.10	1.75
RV-904	2.10	1.30
RV-905	2.00	1.70
RV-906	2.00	1.60
RV-907	2.10	1.65
RV-908	2.00	1.50
RV-913	2.00	1.45
RV-919	1.95	1.75

A large slug of solder material was found obstructing the 1/4 inch copper tubing at a soldered coupling joining two sections of the signal transmitting line. Removal of this plug cleared the interference between the transmitter and the controller located on LB-30.

The control mechanisms of the pressure controllers for primary enclosure atmospheres were set on a 5 percent proportional band, and the nitrogen inlet controls were set at one in. Wg pressure. With these settings, as a cell pressure decreases, the pressure controller output signal will begin to open the nitrogen supply control valve at a pressure of 1.2 in. Wg and the valve will be full open at about 0.8 in. Wg. The cell nitrogen outlet

setpoints were placed at six in. Wg pressure. As a cell pressure increases, the pressure controller output signal will start to open the outlet valve at a pressure of 5.8 in. Wg, with the valve opening fully at 6.2 in. Wg.

Purging of primary sodium equipment cells was completed with no unusual incidents. Purge flow rates, the time required to lower cell oxygen content below one percent, and the quantity of nitrogen used are tabulated in Table II.

TABLE II
PRIMARY SODIUM EQUIPMENT CELL PURGE DATA

Cell	*Flow Rate (cfm)	Time (Hours)	Nitrogen Usage (Ft ³)
Primary Fill Tank	60	32.7	117,772
Primary Pipe Tunnel and Moderator Pump Cells	60	67.0	241,200
Primary Service Cells	60	23.0	82,800
IHX Cell No. 1	38	36.7	83,676
IHX Cell No. 2	38	30.8	70,224
IHX Cell No. 3	45	35.2	95,040

* The nitrogen flow rates were observed on FI-900, located in Nitrogen Gage Board No. 28. This flow meter is calibrated for 60 F and 50 psig nitrogen flow; however, the listed flow rates are not temperature compensated, as corrections would be insignificant.

Although the three IHX cell volumes are the same, there is a noticeable difference in the quantity of nitrogen required to lower oxygen content of the cells below one percent. IHX cell No. 2, which was the last one purged, required the least amount. IHX cells No. 1 and No. 2, purged at a rate of 38 cfm, required less than IHX cell No. 3 which was purged at 45 cfm. Purging of IHX cell No. 2 was begun at a flow rate of 45 cfm; however, after a period of slightly over 3 hours, the purge was discontinued due to a low nitrogen supply. Purging operations were resumed about 16 hours later and continued until the oxygen content was reduced below one percent.

Based upon the foregoing, it is recommended that when time allows during any future purging that may be required, the inflow rate of nitrogen be reduced, and that instead of continuous purge operation, the purge be performed on an intermittent basis. For example, purging for alternate two hour periods with the purge being discontinued for alternate two hour periods, thus allowing better mixing of the nitrogen gas with the cell atmosphere. This method may result in a significant reduction in the amount of nitrogen required to purge a cell to the required oxygen content.

Oxygen analyzer O₂An-900 performs satisfactorily in sampling the cells in sequence, analyzing the sample gas, and recording the results. The cell high oxygen alarm (O₂AH-900) was set and verified to actuate the annunciator light at the main control board when any cell atmosphere exceeds one percent oxygen content.

Sample gas flow through the oxygen analyzer depends on a pressure differential between the cells and the vent header which ties into the exhaust from the analyzer. The analyzer vent line was connected into line No. 946-3"-E, upstream of PCV-1016 which is set to open at one in. Wg pressure. As the cell atmosphere pressure range is from one to six in. Wg, there was insufficient pressure differential to obtain flow from this cell, if a particular cell pressure was near one in. Wg. To overcome this, the discharge line from the analyzer was relocated to a position immediately downstream of PCV-1016, where the vent line is maintained at a negative pressure between 21 and 35 in. Wg. A pressure regulator was installed in the analyzer vent line and set to maintain a constant pressure of minus one in. Wg, thus establishing a pressure differential sufficient to maintain flow through the analyzer.

IV. COMPLIANCE WITH TEST COMPLETION CRITERIA

Following are the test completion criteria associated with preoperational test AI-P-1109, Nitrogen System, as listed in NAA-SR-5700 (Supplement 4) Pages XI(a)-30 and XI(a)-32, with remarks regarding the test to explain compliance with the criteria.

- a) Criterion: The nitrogen distribution system has been purged and filled.
Remarks: The nitrogen distribution system has been purged and filled.
- b) Criterion: All pressure control valves control pressure properly under specified flow conditions.
Remarks: This criterion has been met after system modification (see II. B. of test).
- c) Criterion: All low pressure alarms (PAL) alarm and reset properly.
Remarks: Proper operation of all low pressure alarms was verified by bleeding down the pressure until the alarm was received.
- d) Criterion: All relief valves lift and reseal properly.
Remarks: All relief valves have been tested to ensure that they lift and reseal properly.
- e) Criterion: No detectable leaks are present based on short time decay tests.
Remarks: No system leak checking was done during this test except in determining if the relief valves seat tightly. The system is welded construction, and all leak-checking was done during construction. Observation of system pressures and flow rates during operation has indicated that no appreciable leaks exist in the system.
- f) Criterion: Pressure gages and flow meters function in accordance with their design parameters.
Remarks: All system components met design parameters following system modifications.
- g) Criterion: All primary sodium equipment cells have been purged with nitrogen and contain 1% or less of oxygen by volume as ascertained by test.
Remarks: All primary sodium equipment cells were purged and the cell atmosphere reduced and controlled below 1% oxygen.
- h) Criterion: All cell pressure relief valves lift and reseal properly at design setpoints.
Remarks: All cell pressure relief valves have been determined to lift and reseal properly at design setpoints.
- i) Criterion: Pressure control valves to each cell maintain the cell pressure between approximately 1 and 6 inches of water, exhausting nitrogen to the R/A vent system when

cell pressure increases above 6 inches H₂O and admitting nitrogen when cell pressure falls below 1²/₁ inch of water.

Remarks: Pressure control valves have been determined to operate in accordance with system criteria.

- j) Criterion: The oxygen analyzer properly samples the atmosphere of each cell in sequence and an alarm occurs if the oxygen content exceeds 1%.

Remarks: The oxygen analyzer properly samples the atmosphere of each cell in sequence and an alarm occurs if the oxygen content exceeds 1%.

V. EVALUATION

The nitrogen system was designed to provide a low humidity - low oxygen content atmosphere in sodium equipment and piping cells, and other locations, for the purpose of reducing the fire hazards and/or to minimize corrosion. The system also provides back-up for the service and instrument air systems.

Preoperational testing of the nitrogen system, components and systems serviced by the nitrogen, and the subsequent operation of these items has confirmed that these design criteria have been satisfied.

As specified in the "Final Summary Safeguards Report for the Hallam Nuclear Power Facility", NAA-SR-5700, the test purpose and test completion criteria were met, with the exception that leak-tightness of the system was not confirmed during the test. The entire system was subjected to a rigorous pressure decay test at the completion of the construction phase. This test was performed by the construction contractor, under the surveillance of Atomics International and Bechtel Corporation quality control representatives. Some modifications and system maintenance have been performed since the leak testing, and it is possible that small leaks do exist. It is obvious that, if the leaks do exist, they are sufficiently small as not to affect system operation.

A. CONTROLS AND INSTRUMENTATION

Adequate operation of all pressure controllers, relief valves, pressure alarms and other instruments was demonstrated during the test.

The set pressure of each pressure control valve and relief valve was checked and adjusted as required. In several cases, relief and control valves failed to reseat properly. This problem was corrected in all valves except RV-900 and PCV-905. RV-900 (supply manifold low pressure relief) is set to lift at 68 psig, however, it does not reseat until the pressure decays to 43 psig. The system pressure is normally controlled at approximately 50 psig and must be manually reduced below the normal operating pressure, to reseat the valve. This is not a serious condition, but does result in excessive nitrogen loss and operating inconvenience. It is suggested that this valve be reset to a cracking pressure of 75 - 85 psig, in an attempt to correct the condition. The system is designed for pressures up to 100 psig; hence, no adverse effects would result.

PCV-905 (wash cells supply) is set to control at 1.0 psig at 15 scfm. The valve does control satisfactorily in this range, but at essentially zero flow conditions, the pressure creeps to approximately 5.0 psig in one hour. No detrimental effects will result from this condition, since the operating pressure of the cells serviced by this controller is 10 psig.

B. HIGH PRESSURE SUPPLY

Original design provisions for the nitrogen system included two high-pressure supply sources with individual pressure reducing stations. The system has been modified and at the present time consists of a single liquid nitrogen supply tank, vaporizer assembly and pressure reducing station. This installation does not provide the same high degree of reliability as did the original design.

To date, the existing installation has provided dependable trouble-free service; however, a leak or failure of the tank, vaporizer, or one of the

associated components will necessitate interrupting the nitrogen supply. It would be desirable to incorporate a small standby supply of bottled nitrogen which can be placed in service until repairs are accomplished.

C. PURGE OF THE PRIMARY SODIUM SYSTEM CELLS

The radioactive sodium piping and equipment cells were successfully purged with nitrogen, and the oxygen concentration reduced to less than 1.0%. Ability of the system to maintain this low concentration was also demonstrated during the test and the ensuing operation.

As shown in Table III, in almost all cases the quantity of nitrogen and the time required to purge the cells was greater than anticipated. Time-wise, this is primarily due to an arbitrary cell differential pressure limit of 9 inches of water, which is exceeded at design flow rates.

This pressure limit was imposed to prevent possible damage to the cell rupture discs, which could suffer fatigue failure due to repeated flexing at excessive differential pressure. However, the nitrogen flow capacity is available to purge the cells at the design flows, if deemed necessary.

The quantity of nitrogen used to purge the cells over and above the expected quantity was approximately 123,712 scf. This quantity is based on having complete mixing of the incoming nitrogen and the gas in the cell. Some channeling and stratification can be expected, which will increase the purge volumes required. Purge rates to IHX cells No. 1 and No. 2 were less than the rate to IHX cell No. 3. Apparently better mixing accounts for the considerably lower volumes required.

The major concern with the overage is the cost, which, based on the present price of nitrogen, is only \$870.00 for the volume of gas required in excess of the expected quantity. Because the cells are purged infrequently, the cost is minimal and of little concern.

D. VERIFICATION OF SYSTEM ADEQUACY

The individual nitrogen supplies were checked to ensure that design flow and pressure could be achieved. Except for the supplies to the sodium

TABLE III
NITROGEN PURGE RATE AND TIME
(R/A Sodium Piping and Equipment Cell)

Cell	Cell Volume (cu. ft.)	Purge Rate (scfm)		Purge Volume (scf)		Time (hours)	
		Design	Actual	Expected	Actual	Expected	Actual
Primary Fill Tank	23,000	100	60	69,000	117,772	11.5	32.7
Primary Pipe Tunnel & Mod Pump Cells	64,000	100	60	192,000	241,200	32.0	67.0
Primary Sodium Service Cells	21,000	30	60	63,000	82,800	35.0	23.0
IHX Cell No. 1	27,000	80	38	81,000	83,676	18.0	36.7
IHX Cell No. 2	27,000	80	38	81,000	70,224	18.0	30.8
IHX Cell No. 3	27,000	80	48	81,000	95,040	18.0	35.2

equipment cells, the test did not verify that the specified design conditions were adequate to perform the required function. However, during the testing and operation of these serviced systems and components, the adequacy of the nitrogen system supplies was verified as follows:

1. Sodium Melt Station Supply: Nitrogen was supplied at the required pressure and flow during the entire melting and loading of the initial charge of sodium for the heat transfer system.
2. Instrument Air System Back-Up Supply: Adequate supply was demonstrated during performance of the Instrument Air System preoperational test, AI-P-1117
3. Back-Up For Primary Throttle and Block Valve Operators: Required nitrogen supply was confirmed during the performance of the Instrument Air System preoperational test, AI-P-1117.
4. Nitrogen Cooler Control Dampers in the Primay Pipe Tunnel: Operation of the control dampers was demonstrated during the nitrogen purge of the pipe tunnel and subsequent plant operation.

5. Maintenance Cell Atmosphere Supply: The maintenance cell was satisfactorily purged on several occasions during performance of the Maintenance Cell preoperational test, AI-P-1139.
6. Maintenance Cell Inflatable Seal: During testing of the Maintenance cell, a leak-tight seal of the access hatch was effected, which is indicative of adequate nitrogen supply pressure.
7. Maintenance Cell Pneumatic Tools: Adequate nitrogen pressure and flow to the tools was demonstrated during the performance of the Maintenance Cell preoperational test, AI-P-1139.
8. Wash Cell Cooling Water Lines: The wash cells have been removed for maintenance on several occasions. Prior to each removal, the water was successfully purged from the cooling lines, with nitrogen.
9. Radioactive Laundry Tanks: The ability to displace water with nitrogen in the laundry hold-up tanks was demonstrated during the performance of the R/A Liquid Waste System preoperational test, AI-P-1111.
10. R/A Vent Condenser Vacuum Breaker: Required nitrogen flow and pressure were verified during the performance of the R/A Vent System preoperational test, AI-P-1110.
11. Wash Cell Supply: The wash cells were satisfactorily purged during the performance of the Wash Cell preoperational test, AI-P-1133.
12. Steam Generator Cell Emergency Purge: The ability to flow nitrogen to the steam generator cells was demonstrated during the performance of the nitrogen system test. However, the flow capacity was not checked, due to lack of instrumentation. See Section E. for further discussion.

E. STEAM GENERATOR CELL SUPPLIES

The time required to reduce the cell atmosphere oxygen concentration to a level which will extinguish a sodium fire was not determined during the test. An analysis of the system indicates that nitrogen flow to the cells will be limited by the liquid nitrogen vaporizer output, (300 scfm for a period of eight hours). At this rate, approximately six hours (minimum) will be required to reduce the oxygen concentration in the cell to a level which will not support combustion.

Excessive time would be required to extinguish a fire by this method, pointing up the necessity for initiating a nitrogen purge only when other fire fighting methods fail. It is suggested that a corrective action operating procedure be prepared, which will reflect the limitations of this method and specify a nitrogen purge as a last resort technique.

HALLAM NUCLEAR POWER FACILITY
PREOPERATIONAL TEST COMPLETION REPORT
RADIOACTIVE VENT SYSTEM

AI-P-1110

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CONTENTS

	Page
I. Purpose of Test	1
II. Discussion of Test Performance	1
A. R/A Vent System (Dry Gas Subsystem) . .	1
B. Wash Cell Vent System (Wet Gas Subsystem)	3
III. Analysis and Presentation of Test Results . . .	5
A. R/A Vent System	5
B. Wash Cell Vent System	16
IV. Compliance with Test Completion Criteria . . .	20
V. Evaluation	22
A. System Operation	22
B. Controls and Instrumentation	23
C. R/A Vent System	23
D. Wash Cell Vent System	24

TABLES

I. Compressor Operation Test Data	8
II. Sample Connection Test Data	8
III. Pressure Alarm Test Data	9
IV. System Relief Valve Data	11
V. Compressors Auto-Operation Setpoints	13
VI. Wash Cell Separator-Receiver Settings	17

FIGURE

1110-1.	Control Schematics for R/A Vent Compressors No. 3 and 4	7
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HALLAM NUCLEAR POWER FACILITY
PREOPERATIONAL TEST COMPLETION REPORT
RADIOACTIVE VENT SYSTEM, AI-P-1110

I. PURPOSE OF TEST

The purpose of the radioactive vent system test was to determine that the system and related system components operate properly, and that the system is prepared for normal operation.

II. DISCUSSION OF TEST PERFORMANCE

A. R/A VENT SYSTEM (DRY GAS SUBSYSTEM)

1. Valves and Controls

The No. 1, 2, 3 and 4 R/A vent compressors motor leads were disconnected to initiate testing of the compressors. All controls, switches, timers, starters, and control valves related to the compressors were tested for proper functioning and verification of operability. It was necessary to rewire the control switches for compressors No. 3 and 4 to accomplish the desired operations.

Dummy pressure signals corresponding to various values of vacuum were fed into the compressor pressure switches to test the automatic starting and stopping of the compressors. The transfer switches for compressors No. 1, 2, 3 and 4 were tested to verify that these switches could designate which compressor "leads" or "sees" the pressure switch requiring the greatest vacuum in the system.

The level alarms on the No. 1 and 2 compressor disposable drip receiver were verified to be operating properly. The four radioactive gas decay tanks sample connection pressure control valves were tested to establish proper pressure settings. Some leaking pressure control valves were found; the required repairs were accomplished. Dummy pressure signals were used for testing the high pressure alarms associated with the four system gas decay tanks.

Gas decay tank discharge control valves CV-1008 and -1011, were determined to function properly and as directed by the associated pressure indicator-controller. The system control valves which are operable from the radiation detection and monitoring panel in the control room were tested and found to respond properly to manipulations from the panel.

Relief valves RV-1008, -1009, and -1010 were set at the associated setpoints and tested for lift and reseal pressures. Relief valves RV-1004 and -1005 were tested as a part of AI-P-1108, Helium System Preoperational Test.

2. Vent Compressors Operation

The level switch associated with the No. 4 vent compressor drip receiver was tested by increasing the water level in the receiver until the switch actuated. The resulting control and alarm action, with respect to the operating compressor, was observed and recorded. The No. 3 vent compressor drip-receiver level switch was similarly tested.

Automatic stopping and starting of the No. 3 and 4 compressors could not be tested as outlined in the test procedure. It was determined that neither of the compressors has the capacity to accept an air flow into the system while simultaneously maintaining the suction tank at the prescribed vacuum. Subsequently, it was found that various valves were not tightly closed, thus allowing air leakage into the system and the resultant condition described above. To test the compressors for automatic operation, a suction tank vacuum was maintained by compressor No. 1 or 2 (employing the recirculation line control valve), and a known flow was bled into the system. Compressors No. 3 and 4 were thus observed to stop and start at the prescribed pressures.

Compressor No. 1 was tested for automatic operation by bringing the compressor system up to atmospheric pressure through introduction of an air supply to the system and turning of the compressor control switch to AUTO with the other compressor control switches (compressors No. 2, 3 and 4) in the OFF position. The suction tank vacuum values at which compressor No. 1 automatically started and stopped were observed and recorded. Compressor No. 2 was similarly tested.

All four compressors were then placed on AUTO control and known flows of air were bled into the system. In this manner, all compressors were tested for automatic operation and the compressing capacity of each was determined. Temporary cooling water was provided to the compressors during the test, as the normal cooling water supply was not available. One gas decay tank was pressurized to normal maximum operating pressure.

The pressurized gas decay tank was vented through the gas decay tank discharge manifold. The control valves, pressure indicator-controller, and manual throttle valves were employed to establish specific gas decay tank discharge flows and, thus, to verify proper operation of the manifold. The various gas flows were routed through the radioactive vent fans, as per normal operation; the fans and associated controls and instruments were determined to function satisfactorily.

The vacuum pump associated with fuel handling cells was started and observed for proper operation. The pump suction header-pressure indicator was employed to determine whether the vacuum pump could establish and maintain a specific vacuum. Satisfactory results were obtained.

B. WASH CELL VENT SYSTEM (WET GAS SUBSYSTEM)

Circulating seal water was introduced to the separator-receiver and vent compressor (to the normal operating level) by means of the level control system. Cooling water flow was established through the seal water cooler, and the seal oil circulating unit was put into operation. The wash cell vent compressor suction piping was pressurized to 2 psig, by admitting service air into the system through a test fitting installed upstream of PCV-1009.

The wash cell vent gas compressor seal water-cooler temperature indicating controller element was placed in a constant temperature bath and the controller tested for proper operation.

Water was admitted to the wash cell separator-receiver level controller and the control points for the receiver fill valve and drain valve were established. Proper operation of the controller and the two control valves was verified.

The wash cell vent compressor seal oil circulating system was started from the local control station in the R/A waste facility, and observed for operation. Next, the wash cell vent compressor was started from the local control station in the waste facility. Immediately after starting the compressor the flow rate of air into the vent header was adjusted to 20 scfm and maintained at this rate.

During operation of the compressor, vacuum breaker PCV-907 was checked to verify proper operation, including the capability to feed nitrogen into the system to prevent the vent condenser vent line from going below a -6 in. Wg pressure. The wash cell vent compressor was operated until the pressure in the wash cell gas decay tank reached 75 psig; the compressor was then shut down.

By manipulation of valves, a direct flow path was established through the wash cell vent absolute filter, to the building exhaust stack. FI-1006 indicated no flow, confirming that the check valve between the separator-receiver and the wash cell gas decay tank, and the block valve at the outlet of the tank, were leak tight.

The ability to start and stop the wash cell vent compressor by means of the associated pushbutton on gage board 32 was demonstrated.

The volume of gas in the wash cell gas decay tank was vented to the atmosphere through the building exhaust stack with a flow rate of 20 scfm, as indicated on FI-1006.

III. ANALYSIS AND PRESENTATION OF TEST RESULTS

A. R/A VENT SYSTEM

1. Compressors No. 1 and 2 Control Tests

With motor leads disconnected, the control switch for compressor No. 1 was turned to START; the results were as follows:

- a) The compressor unloader valve and the seal leak-off valve opened immediately.
- b) In 5 seconds, the compressor starter pulled in, the cooling water solenoid valve opened, and the compressor inlet and outlet valves opened.
- c) In 30 seconds, the compressor unloader valve closed.

The No. 1 compressor control switch was turned to OFF; the results were as follows:

- a) The starter dropped out.
- b) The compressor inlet and outlet valves closed.
- c) The cooling water solenoid valve closed.
- d) In 2 minutes, the seal leak-off valve closed.

The No. 1 compressor seal leak-off valve was then operated from the push-button on the compressor control board and it was verified that the valve responded properly.

The control switch test described above was next performed on compressor No. 2. Results of the test on compressor No. 2 were the same as those listed above for No. 1 compressor.

2. Compressors No. 3 and 4 Control Tests

Prior to testing the circuits of compressors No. 3 and 4, it was necessary to install control switch wiring per Figure 1110-1, as opposed to that shown on the installation drawings used during construction. The compressors can be operated as intended with the changes having been accomplished. Normal operation now includes: Turning the control switch to START A position for either compressor results in the "A" starter for that compressor pulling in, the fan starter pulling in, and the associated cooling water solenoid valve opening. Moving the switch to START B drops out the "A" starter, picks up the "B" starter, holds in the fan starter, and keeps the cooling water solenoid valve open. Turning the control switch to STOP (from the START B position) results in the "B" starter and fan starter dropping out and the cooling water solenoid valve closing.

3. Automatic Compressor Start and Stop

Dummy pressure signals were fed into the system suction tank pressure indicator-controller (PIC-1000), to test "auto-start" and "trip-out" of the four vent compressors at specified suction tank vacuum. The data obtained during the test are tabulated in Table I.

4. Sample Connection Pressure Control Valve Tests

Air was supplied to gas decay tank sample connection pressure control valves (PCV's) through the Y-strainer associated with each of those valves. The pressure on the discharge side of the PCV was monitored by observing a test gage installed at the sample connection outlet with air flowing through the connection. Flow was then stopped by closing a valve downstream of the test gage to determine if the pressure control valve maintains proper pressures. Data collected during this test are tabulated in Table II.

P14

Ref: Bechtel Dwg. D-7949001, Rev. 1
Schemes 1021, 1022, 1023, 1024

Ref: Bechtel Dwg. D-7949001, Rev. 1
Schemes 1026, 1027

Figure 1110-1. Control Schematics for No. 3 and 4 R/A Vent Compressors

TABLE I
COMPRESSOR OPERATION TEST DATA

Compressor	Instrument	Auto-Start		Auto-Stop	
		Signal Press	Vacuum	Signal Press	Vacuum
4 and 2 leading	Test No. 1				
4	PS-1004	7.8 psig	-2.65 psig	6.8 psig	-3.2 psig
3	PS-1003	8.4 psig	-2.3 psig	7.7 psig	-2.7 psig
2	PS-1001	11.0 psig	-1.0 psig	9.3 psig	-2.0 psig
1	PS-1000	13.0 psig	0 psig	11.0 psig	-1.0 psig
3 and 1 leading	Test No. 2				
3	PS-1004	7.9 psig	-2.55 psig	6.8 psig	-3.2 psig
4	PS-1003	8.4 psig	-2.3 psig	7.7 psig	-2.7 psig
1	PS-1001	11.1 psig	-0.95 psig	9.2 psig	-1.9 psig
2	PS-1000	13.5 psig	-0.25 psig	11.1 psig	-0.95 psig
Final Pressure Switch Settings					
3 or 4	PS-1004		-2.8 psig		-3.2 psig
3 or 4	PS-1003		-2.3 psig		-2.7 psig
1 or 2	PS-1001		-1.0 psig		-2.0 psig
1 or 2	PS-1000		0 psig		-1.0 psig

TABLE II
SAMPLE CONNECTION TEST DATA

PCV No.	Air Supply Press	PCV Disch Press (with flow)	PCV Disch Press (without flow)
PCV-1005	100 psig	5 psig (after adj.)	7 psig (in 5 min)
PCV-1004	100 psig	5 psig (after adj.)	15 psig (+)
PCV-1003	100 psig	1/4 psig	15 psig (+)
PCV-1002	100 psig	1/4 psig	15 psig (+)

Subsequent to this test, PCV-1003 and PCV-1002 were adjusted to provide 5 psig with flow through the valve. All four sample connection pressure control valves leak through under no-flow conditions, as shown by the data in Table II.

5. Pressure Alarm Tests

Dummy pressure signals were fed from the transmitters associated with the four gas decay tanks high pressure alarms and the suction tank high pressure alarm to the alarm switches, to test the respective alarm and reset setpoints. A tabulation of the results obtained from the tests is given in Table III.

TABLE III
PRESSURE ALARM TEST DATA

Alarm (service)	Instrument	Alarm Point		Reset Point
		Signal Press	Actual Press	
Suction tank press (high)	PAH-1001	13.0 psig	0 psig	-0.7 psig
Gas Decay tank No. 1	PAH-1006	9.8 psig	176 psig	125 psig
Gas Decay tank No. 2	PAH-1007	9.75 psig	176 psig	105 psig
Gas Decay tank No. 3	PAH-1008	10.0 psig	176 psig	125 psig
Wash cell gas decay tank	PAH-1005	10.8 psig	100 psig	58 psig

The Radioactive Waste Facility annunciators and the main board annunciator associated with excessive pressure in the vent system gas tanks were verified to actuate properly during the tests.

Following completion of the high pressure alarm test, the alarm setpoints were reduced to 140 psig and 85 psig for the three gas decay tanks and the wash cell gas decay tank, respectively, in accordance with a safeguards report revision.

6. Liquid Level Alarm Tests

The high level alarms, LAH-1002 and -1003 (compressors No. 1 and 2, respectively), associated with the compressor disposable drip receivers were tested by venting the float chamber and then filling the chamber until the alarm actuated. The Radioactive Waste Facility annunciators and the main board annunciators related to the alarms functioned properly as the alarm condition was simulated. The No. 1 compressor drip receiver high alarm actuated at a level of 10 inches and the No. 2 compressor drip receiver alarm at a level of 11 inches.

7. Control Valve Tests

The following control valves were operated from the radiation detection and monitoring panel in the control room to test for proper operation as a function of the control station:

- CV-1008, Gas decay tank discharge control valve
- CV-1011, Gas decay tank discharge control valve
- CV-1012, Wash cell gas decay tank discharge control valve
- CV-1006, Non-radioactive gas to suction tank control valve
- CV-1007, Non-radioactive gas to stack control valve

All the valves responded correctly to the associated control switch. A dummy pressure signal was fed to PIC-1002 to verify the controller properly positioned gas decay tank discharge control valves CV-1008 and CV-1011.

8. Relief Valve Tests

System relief valves were tested to determine the lifting and re-seating pressures; results of the test are tabulated in Table IV. Relief valves

RV-1004 and -1005 were tested and set as a part of preoperational test AI-P-1108, Helium System.

TABLE IV
SYSTEM RELIEF VALVE DATA

Relief Valve	Service	Lift Pressures		Reseat Pressures
		Expected	Actual	
RV-1006	Non-radioactive gas header relief	2 psig	2.75 psig	2 psig
RV-1009	Wash cell vent header relief	15 psig	15.0 psig	14.5 psig
RV-1010	Disconnect cell vent relief	5 psig	5.4 psig	4.7 psig

9. Drip Receiver No. 3 and 4 Level Switches

The level switch in each of the two drip receivers actuates at three inches water level in the drip receiver pots. Upon actuation, the associated compressor shuts down and the level alarm in the waste facility annunciator panel annunciates. The compressor cooling fan and the cooling water solenoid valve are not affected by the high level in the drip receiver. The fan and valve respond only to the compressor control switch and the associated pressure switch when in the AUTO position. Clearing of the level switch alarm condition results in automatic restart of the compressors.

10. Compressor Capacity Determination and Auto-operation Test

Compressor No. 4 has a capacity of approximately five scfm. This capacity determination was accomplished by balancing the compressor No. 1 measured in-flow with the discharge, starting compressor No. 4, and rebalancing the in-flow and discharge. The increase in total flow was five scfm, and was attributed to compressor No. 4. Compressor capacity could

not be tested as outlined in the test procedure, because the compressor could not maintain the system suction tank at -3.2 psig and still accept flow. Compressor capacity was sufficient to maintain the suction tank at -2.8 psig without any in-flow, but the compressor ran continually to maintain this vacuum. Adding flow to the tank, as required by the procedure, resulted in the loss of tank vacuum and took the compressor from the normal operating range of vacuum. The results of the test as written were thus inconclusive.

Following completion of the test, it was determined that various system valves were not tightly closed during the test. This resulted in sufficient in-leakage to create the off-normal condition listed above. Re-testing of the compressor, after the valves were closed tightly, established that the compressor could maintain the suction tank at the prescribed -3.2 psig while handling five scfm flow.

Compressor No. 3 was determined to have a capacity of approximately four scfm. The method used in the determination was the same balanced in-flow and discharge technique described above. It was necessary to terminate testing of compressor No. 3 for a sufficient length of time to allow repair of a cooling coil rupture which developed within the compressor housing.

Compressor No. 2 capacity was determined to be sufficient to maintain the suction tank at -0.5 psig, with a measured system in-flow of approximately 90 cfm at 30 psig. The in-flow of 90 cfm at 30 psig was the maximum flow available to the system (from the plant service air system) and establishes a minimum value of compressor capacity during operation. However, this minimum value is more than adequate for proper vent system operation. The in-flow was applied at the Y-strainer in the compressor suction header.

Compressor No. 1 capacity was found sufficient to maintain the suction tank at -1.0 psig with a measured system in-flow of approximately 90 cfm at 30 psig. Again, this is the minimum operational capacity of the compressor. The in-flow was applied at the Y-strainer in the compressor suction header.

Automatic stopping and starting of the four compressors at the prescribed suction tank vacuum (as described in III 3. of this report) were re-verified. Air in-flow to the system was established with the suction tank at -3.2 psig. As suction tank pressure increased, the compressors started at the points indicated in Table V.

TABLE V
COMPRESSORS AUTO-OPERATION SETPOINTS

Compressor	Auto-Start (psig)	Auto-Stop (psig)
No. 4	-2.8	-3.2
No. 3	-2.3	-2.7
No. 2	-1.0	-2.0
No. 1	0	-1.0

Compressor No. 1 did not start in this test because compressor No. 2 had sufficient capacity to handle the in-flow and hold the tank at a maximum pressure of -0.5 psig, which is below the auto-start setpoint of compressor No. 1. With compressors No. 2, 3 and 4 operating, the suction tank was returned to the -3.2 psig condition, with the compressors stopping automatically at the points listed in Table V. It was necessary to turn compressor No. 2 control switch to OFF to verify the setpoints associated with compressor No. 1.

The above listed compressor capacity data clearly indicate that more than adequate capacity is provided for normal radioactive vent system operation.

11. Timer Settings

It was necessary to make adjustments to the time delay relays associated with the operation of compressors No. 1 and 2. Compressor No. 1 now operates for a minimum of 2 min 50 sec and compressor No. 2 for a minimum of 2 min 56 sec.

During system capacity testing, it was necessary to adjust the time delay relays associated with unloading valves CV-1021 and CV-1022. This adjustment was required to prevent compressor cycling. With all compressors operating on AUTO and the suction tank at -2.0 psig (no compressors running), the 50 scfm in-flow to the suction tank resulted in tank pressure increasing to atmospheric before the unloader valves on compressors No. 1 and 2 closed, allowing the compressors to function normally as compressors after 30 sec (the time delay relay setting). The time delay relays associated with the minimum compressor operating time would then continue compressors No. 1 and 2 in service for three min, which would reduce suction tank pressure to the -3.5 psig maximum vacuum allowed by the associated recirculation valve. At the end of the three min, both compressors No. 1 and No. 2 would stop and the 50 scfm in-flow would again increase suction tank pressure to atmospheric, re-initiating the cycle.

The above situation was corrected by adjusting unloader control valves CV-1021 and CV-1022 time delay relays to 5 sec, from the design setting of 30 sec. With the five sec time delay relay setting, the compressors come to speed immediately and operate unloaded for four sec. It has been determined that this is a satisfactory compressor operating parameter and relieves the cycling problem described above.

The discharge pressure controller (CV-1024) associated with compressors No. 1 and 2, has been set at 90 psig and functions properly.

12. R/A Vent Fans and Instrumentation

The low differential pressure alarm associated with the R/A vent fans was verified to operate properly. The main board R/A vent fans low-flow alarm annunciated when both fans were not operating.

A pressure switch is also provided (on the suction header for the fans) which actuates at -10 in. water gage (in. Wg) pressure (increasing). A decrease in R/A vent fans inlet pressure from the normal -35 in. Wg to -10 in. Wg, or greater, results in the following R/A vent system automatic operations:

- 1) closing of CV-1008, gas decay tanks discharge control valve
- 2) closing of CV-1011, gas decay tanks discharge control valve
- 3) opening of CV-1006, suction tank inlet control valve
- 4) closing of CV-1007, R/A vent fans inlet control valve

Each fan was verified to have a capacity of 100 scfm as evidenced by the flow meter provided on the associated suction header. At a flow of 100 scfm, the fan suction header was maintained at a -25 in. Wg pressure. Normal system operations can be accomplished without difficulty under these conditions.

13. Gas Decay Tanks Discharge Manifold

It was determined that a maximum of 10 scfm could be passed through the high flow gas decay tanks discharge header as well as through the low flow discharge header at design conditions. It was necessary to adjust the pressure control valve on the outlet header (maintains a minimum pressure on the header) from the initial setting of 2 in. Wg to 1 in. Wg, and to increase the header supply controller to 10 in. Wg from 5 in. Wg, to obtain 50 scfm through the high flow side. The increased supply pressure and the decreased discharge pressure are required to overcome the pressure drops experienced in the high flow discharge header at 50 scfm.

The adjustment of the supply pressure controller from 5 in. Wg to 10 in. Wg must be accomplished only during use of the high flow side of the discharge manifold. The change from 2 in. Wg to 1 in. Wg setpoint on the discharge controller is permanent.

Flow rates established through the discharge manifold were 1 scfm, 5 scfm, 10 scfm, 30 scfm and 50 scfm. In each instance, considerable manual throttle valve manipulation was required to establish the exact flows. However, once established, the specific flows were maintained constant. A gas decay tank was vented from approximately 140 psig to 60 psig through the discharge manifold during performance testing of the manifold. Differential pressure across the gas decay tanks discharge filter differed from that of normal operation during the test. The variance was because a temporary system clean-up filter was installed at the time of the test, as opposed to a normal operating absolute filter.

14. Fuel Handling Cells Vacuum Pump

The fuel handling cells vacuum pump is capable of establishing and maintaining a 26 in. Hg vacuum, which is adequate for the operations to be performed by the pump. To date, the fuel handling cells vacuum pump has been utilized in evacuating fuel storage cells as a part of the helium purge operation performed on the storage cells. When evacuating the storage cells, the vacuum pump discharged into the R/A vent system and ultimately into the R/A vent fans suction. The pump performed adequately, as expected, during these operations.

B. WASH CELL VENT SYSTEM

1. Controller Tests

The thermal bulb associated with the seal water-cooler temperature controller (TIC-1002, for the wash cell vent compressor) was placed in a 40 - 50 F bath, and CV-612 was verified to be full closed and controller output to be 15 psig. At a bath temperature of 150 F, CV-612 was verified to be full open and controller output 3 psig.

Testing of the wash cell separator-receiver level controller was accomplished by venting and filling (with water) the float chamber associated with the separator-receiver and then varying the level therein. A separator-receiver water level of 15 inches, corresponding to a setpoint of 5 on the controller float setting dial, was established as the control point for LC-1000. The proportional band setting for the controller was established at 15 inches $\pm$ 3.5 inches with CV-611 (water fill) and CV-1014 (water drain) movement as shown in Table VI.

Proper control of the water level in the separator-receiver by LC-1000 was verified. The setpoint on the proportional band was placed at 50% and, as the range of the float is 14 inches, when the water level exceeded the normal operating level by about 3-1/2 inches, CV-1014 was properly actuated and dumped excess water into the R/A liquid waste system. Conversely, make-up water was added to the system by LC-1000 causing CV-611 to admit water via the injection lance into the system.

TABLE VI
WASH CELL SEPARATOR-RECEIVER SETTINGS

Signal Pressure (psig)	Water Level (inches)	Valve	
		No.	Position
3	-3.5	CV-611	Open
9	0	CV-611	Close
10	0	CV-1014	Close
15	+3.5	CV-1014	Open

2. Wash Cell Vent Compressor

During operation of the compressor it was observed that the flow of cooling water to the compressor seal water cooler was controlled by the action of CV-612, which receives its signal from TIC-1002. After the seal oil circulating unit had been operating for a short time, it was observed there was no cooling water flow through the unit. Investigation disclosed that SV-615 was not opening, due to faulty wiring inside gage board 906. This was repaired and flow established. The seal oil circulating unit discharge pressure (to the wash cell vent compressor) was verified at 125 psig.

The wash cell vent compressor recirculating line control valve (CV-1023) regulated by PC-1023, was tested to ascertain that it would not allow the compressor suction line pressure to go below -6 in. Hg. With no make-up air being added to the system, a test gage installed on the suction piping verified the pressure. Visual observation of the action of CV-1023 during this phase of the test, and the actual compression test, indicated the CV maintained suction line pressure nearly constant at the negative 6 in. Hg.

After the compressor had operated for about 4-1/2 hours, wash cell gas decay tank pressure had increased to 75 psig. Discharge from the compressor was then diverted from the wash cell gas decay tank and routed through the wash cell vent absolute filter to the building exhaust stack. After confirming that the compressor could discharge either to the decay tank or exhaust stack, the compressor was shut down. Gas in the decay tank was then released via the discharge manifold to the atmosphere at a flow rate of 20 scfm, as indicated on the flow meter installed in the vent line immediately upstream of the wash cell absolute filters.

As part of the first phase of the preoperational test of this system, the compressor was operated for a short time to aid in the adjustment of PCV-1009 which was reinstalled in line No. 1246-2"-F. Before starting the unit, make-up water was added to the separator-receiver and the wash cell compressor, by means of LC-1000. After the adjustment of PCV-1009 was completed, and the compressor shut down, the water level in the separator-

receiver was noticed to have dropped and LC-1000 was "calling" for water. Consequently, make-up water was being admitted to the system through CV-611. Investigation of the condition revealed that when the compressor was shutdown, there was a pressure of about 20 psig in the separator-receiver (as indicated on PI-1011) and in the wash cell gas decay tank (as indicated on PI-1005). As there is no check valve upstream of the wash cell vent compressor, the 20 psig pressure in the separator-receiver forced the seal water through line No. 2532-1"-G, through valve V-10115 (which was open), through line No. 1348-1"-G, then through the injection lance into line No. 1246-2"-F. The pressure in the system upstream of the check valve (V-10108) in the inlet to the wash cell gas decay tank then reached an equilibrium of about 8 psig as indicated on PI-1011 and PI-1012 (located on line No. 1246 near the wash cell vent filter). To prevent the future introduction of water into line No. 1246, solenoid valves were installed in lines No. 1248-1"-G and No. 1349-1"-G controlled by the compressor operating switch. These valves have since been checked with 75 psig pressure in the separator-receiver and perform satisfactorily.

IV. COMPLIANCE WITH TEST COMPLETION CRITERIA

Following are the test completion criteria associated with preoperational test AI-P-1110, Radioactive Vent System, as listed in NAA-SR-5700 (Supplement 4) pages XI (a)-33 through XI (a)-38, with remarks regarding the test to explain compliance with the criteria.

- a) Criterion: The radioactive vent compressors can be started and stopped manually and automatically as verified by imposing synthetic signals on all automatic control devices.
Remarks: Proper functioning of the compressor manual and automatic stop and start features was verified as described within this report.
- b) Criterion: R/A vent system alarms actuate at the proper setpoint.
Remarks: Proper alarm setpoints were verified as described within this report.
- c) Criterion: R/A vent system pressure control valves maintain the required pressures in their respective headers.
Remarks: Pressure control valves were verified to control properly from appropriate signals as described within this report.
- d) Criterion: R/A vent system relief valves lift at the correct pressures and reseal tightly.
Remarks: Proper relief valve lift and reseal pressures were verified as described within this report.
- e) Criterion: The level switches associated with R/A vent compressors Nos. 3 and 4 actuate at the proper setpoint.
Remarks: Level switching actuation at the proper setpoint was verified as described within this report.
- f) Criterion: R/A vent compressors Nos. 1, 2, 3 and 4 start and stop automatically at the prescribed pressures.
Remarks: Proper stopping and starting of the vent compressors at the prescribed pressures were verified as described within this report.

- g) Criterion: R/A vent compressors will compress gas at their design pressure, temperature, and flow conditions without distress or malfunction.
- Remarks: Compressor capacities were verified to be as required at design pressure, temperature, and flow conditions as described within this report. Neither distress nor malfunctioning of the compressors was detectable.
- h) Criterion: R/A vent fans each control back pressure within design limits at flows up to 100 scfm.
- Remarks: Adequate and proper back pressure is maintained by each fan, at flows up to 100 scfm, as described within this report.
- i) Criterion: The fuel handling cells vacuum pump operates properly at design pressure/temperature conditions in conjunction with the R/A vent fans.
- Remarks: The fuel handling cells vacuum pump functions properly as described within this report.
- j) Criterion: No detectable leaks exist in the system.
- Remarks: The system piping was pressure decay tested during construction. No further leak testing was done as part of this test.
- k) Criterion: Cooling water to the separator-receiver and to the wash cell vent compressor set-seal is automatically maintained at the proper level and temperature.
- Remarks: The above criterion has been met as described in this report. However, no data are presented regarding the temperature criterion, due to the very low gas temperature.
- l) Criterion: The wash cell vent compressor is capable of pressurizing the wash cell gas decay tank to 85 psig at its design flow rate.
- Remarks: The limiting factor on the system pressure is the separator-receiver which has a design pressure of 100 psig maximum. As it is not desirable to exceed 75% of design pressure the system was tested at, and will be limited to, a maximum operating pressure of 75 psig. The wash cell vent compressor adequately demonstrated the capability of providing ~20 cfm at this pressure.

- m) Criterion: The wash cell vent compressor suction line vacuum breaker relieves at approximately -3 psig.
Remarks: The original design of this system included PCV-1007 as the suction line vacuum breaker. Subsequent design changes replaced this instrument with PC-1023 and CV-1023. This control system was designed to prevent exceeding a -6 in. Hg (-3 psig) in the vent header and this was verified.
- n) Criterion: The wash cell vent compressor is capable of discharging to the stack as well as to the gas decay tank.
Remarks: This was verified as described in the report.
- o) Criterion: The wash cell vent compressor mechanical seal lubrication system functions satisfactorily in accordance with design parameters.
Remarks: This was verified.

V. EVALUATION

A. SYSTEM OPERATION

The radioactive vent system was designed to collect, monitor and control the disposal of the gaseous effluent from all potentially radioactive equipment and systems. Preoperational testing and subsequent operation of the system demonstrated conformance to these design criteria. Likewise, the test purpose was accomplished and the test completion criteria, as specified in the Final Summary Safeguards Report for the Hallam Nuclear Power Facility (NAA-SR-5700), were met, with the exception that leak-tightness of the system was not verified during the test. Pressure decay testing of the entire system was conducted during the construction phase, under the surveillance of Atomics International and Bechtel Corporation quality control personnel. However, there are indications of air in-leakage to the system. Gas sampled from the decay tanks, after a period of relatively normal operation where only nitrogen or helium containing spaces were vented to the compressors, indicated an oxygen content of approximately 19.0%.

Since the system operates at a negative pressure, it is doubtful that any personnel hazard would result from the leaks. Air in-leakage does, however, reduce the storage capacity for radioactive gas. It is recommended that a leak test of the system be performed.

Operating experience to date indicates that the system is well designed and will provide satisfactory and dependable service during power operation of the plant. Some problems were encountered during initial operation of the system, but these were corrected by minor system modifications.

B. CONTROLS AND INSTRUMENTATION

All controls and instrumentation were checked, calibrated and determined to function satisfactorily. During the initial portion of the test, the operation of all automatic controls was individually verified by imposing synthetic signals. Later in the test, proper performance of the controls was confirmed during actual system operation. The various level and pressure instruments, pressure regulators and relief valves were functionally tested and in every case operated as required to insure proper system performance.

Testing of the valves which are controlled by the radiation detectors was limited to a functional check of the valve and manual controls. However, during preoperational testing of the Radiation Detection and Monitoring System (AI-P-1122), the flow-through radiation detectors and associated valve controls were tested. Each detector was exposed to an external radioactive source and the appropriate valves observed for proper operation. All valves and controls performed as required to direct the gas for the desired (to compressors or stack) disposal.

C. R/A VENT SYSTEM

Normal operation was simulated by introducing measured quantities of gas to the system. The compressors and vent fans functioned properly and demonstrated the ability to handle gas at the required flow and pressure conditions. This portion of the system has been operated for several

months at near normal conditions. During this period the system and associated equipment performed satisfactorily, with a minimum of maintenance.

During the initial phase of operation, water was discovered in a large portion of the dry gas sub-system. A detailed investigation of this anomaly was conducted and the cause was determined to be overfilling of the maintenance cell hold-up tanks. The water backed up in the tank vent line and entered the dry gas header. To prevent reoccurrence of this undesirable condition, system modifications were made. All water-containing equipment was isolated from the dry gas headers and vented directly to the compressor suction tank. A moisture alarm was installed in the vent compressor suction tank, which will inform the operators of excessive moisture before detrimental effects result. In addition, moisture traps were installed at strategic locations in the system to provide absolute stoppage of water.

In the opinion of the evaluator, the above described modifications have eliminated the possibility of a further occurrence of this problem.

D. WASH CELL VENT SYSTEM

A measured quantity of air was introduced to the wash cell vent header at the maximum expected wash cell vent rate. Under these conditions the required negative pressure was maintained in the header and the ability of the compressor to pressurize the decay tank to design pressure was verified.

During performance of the test, an operative problem was discovered which resulted from not following the proper operating sequence of the compressor controls and associated seal water valves. It was found that if the compressor water valves were not closed before the compressor was de-energized, the water in the separator-receiver would drain to a low point in the compressor suction line. Due to the elevation difference (approximately 60 ft) between the compressor and the low point, the compressor is not capable of lifting the water and returning it to the separator-receiver. During

the operation of the wash cells, water in this line will create a back-pressure and prevent the wash cells from venting freely.

To prevent this condition from occurring, solenoid valves, which close when the compressor is de-energized, were installed in the seal water lines. This modification should correct the condition if the valves function properly. However, there is a possibility that condensate will form in this line or that the solenoid valves will leak. The low point in this line has no provisions for the detection or removal of moisture, short of actually cutting the line.

A simple solution to this problem would be to install a small drain pot with a float-actuated level alarm at the line low point. The drain pot could then be connected to the radioactive transfer tank, which would permit the line to be drained if and when moisture collects.

HALLAM NUCLEAR POWER FACILITY
PREOPERATIONAL TEST COMPLETION REPORT
RADIOACTIVE LIQUID WASTE SYSTEM

AI-P-1111

Test and Analysis
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A T O M I C S I N T E R N A T I O N A L
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CONTENTS

	Page
I. Purpose of Test	1
II. Discussion of Test Performance	1
A. System Description	1
B. System Deficiencies	5
III. Analysis and Presentation of Results	7
A. Tank Level Instrumentation	7
B. Steam Jet Ejectors	7
C. Decay Tanks Drains Pot	10
D. Pump and Tank Interlocks	10
E. Pump and Evaporator Capacities	11
F. Portable Sample Unit	13
IV. Compliance with Test Completion Criteria	13
V. Evaluation	14

TABLES

I. Instrumentation Alarms and Setpoints	8
II. Steam Jet Ejector Capacity	9

FIGURES

1111-1. Radioactive Liquid Waste System	2
1111-2. Liquid Waste Transfer Pump	12

HALLAM NUCLEAR POWER FACILITY
PREOPERATIONAL TEST COMPLETION REPORT
RADIOACTIVE LIQUID WASTE SYSTEM, AI-P-1111

I. PURPOSE OF TEST

The purpose of preoperational test AI-P-1111, Radioactive Liquid Waste System, was to verify that:

- a) The system instrumentation was checked and/or calibrated.
- b) The drains to all tanks functioned properly.
- c) The maintenance cell tank room sump pump operated satisfactorily.
- d) The steam jet ejectors associated with the reactor building tanks functioned properly.
- e) The transfer piping from the reactor building to the waste facility was intact and capable of transferring liquids.
- f) The disposal system from the R/A waste facility to the leach field was operable.
- g) The liquid waste evaporator system performed satisfactorily.

II. DISCUSSION OF TEST PERFORMANCE

A. SYSTEM DESCRIPTION

The radioactive liquid waste system shown in Figure 1111-1 is designed to collect, segregate, monitor and store all liquid waste that could be radioactive, and to dispose of low-level liquid waste. Facilities are provided for the collection, monitoring and storage of high activity liquid waste. In the event high-level liquid waste is generated, it will be stored while disposal facilities are constructed. Major sources of radioactive liquid waste are as follows:

- a) Fuel and equipment wash cells
- b) Maintenance cell
- c) Decontamination room

Figure 1111-1. RADIOACTIVE LIQUID WASTE SYSTEM

Shielded facilities are provided in the main reactor building, for safe steam cleaning of fuel elements and other components, and for collecting the liquid waste in a 1250 gallon transfer tank. Other liquid wastes in the plant are segregated and monitored in three sets of monitoring tanks. The laundry waste water effluent will be of a level that can be disposed of directly to the leach field after monitoring. A cross connection is provided to allow laundry waste to be pumped to the radioactive waste storage tanks should it become contaminated above permissible levels due to an emergency or other unforeseen condition. Clothing will not be laundered if the activity of the wash water would be above that disposable to the leaching field. All other wastes will be pumped to storage tanks in the waste disposal facility after sampling. All waste transfer to the waste disposal facility is by use of steam jet ejectors to minimize the possibility of leakage, and to minimize maintenance requirements.

The liquid waste disposal facility contains the following major equipment, together with all interconnecting piping, valving, and controls to permit storage of all aqueous liquid waste, and to permit ultimate disposal of low level liquid waste:

- a) One 1000-gallon stainless-steel high-level liquid waste tank
- b) Two 5000-gallon low and intermediate-level liquid waste tanks
- c) One 25-gpm transfer pump
- d) One low-capacity positive displacement pump for metered flow to leach fields and evaporator
- e) One 5-gph evaporator for low-level waste
- f) A pipeline monitor and automatic valve for shutting off flow should excessive activity level product be pumped inadvertently.

The tanks, pumps and piping are installed in sealed, below-grade, shielded vaults. These vaults serve as personnel protection, and as secondary containment in the remote event of an inadvertent spill or leak, thus minimizing the possibility of ground contamination.

Three liquid waste storage tanks are provided. It is anticipated that liquid waste will be segregated in these three tanks based on activity levels. Tankage is expected to be adequate for approximately two years storage. Disposal will be to one of several different disposal facilities. The basic dis-

posal facility will be to the leaching field to be diluted with sanitary sewage. Under normal conditions, all liquid waste produced in the plant will be of such low activity that it can be disposed of in this manner. For liquids which are of slightly higher activity, a small evaporator has been provided. This will permit evaporation and concentration of the higher activity material with subsequent dilution of the distillate into the leaching field. A manual packaging area has been provided whereby the concentrate from the evaporator can be packaged, provided the activity is low enough to permit unshielded packaging.

In addition to the above facilities, a truck loading line is provided so that low-level liquid waste may be shipped by tank truck. All liquid waste will be measured as to volume and will be monitored and sampled prior to disposal by any means. Thus, a permanent and accurate record of waste disposal will be kept. Disposal to the leaching field will be under carefully metered conditions to insure that at no time will the activity of the waste being discharged exceed maximum permissible levels. As a final safeguard, a radiation recorder and a control valve are provided in the effluent line to the leaching field and to the coolant blowdown effluent. Should high-level activity inadvertently be discharged, flow will be stopped automatically. Resumption of this flow will be possible only after activity is lowered to permissible levels.

Prior to testing any of the components of the liquid waste system, the instrumentation associated with that component was calibrated and checked by using the test procedure as guide or under the direction of a Test Engineer.

All drains to the liquid waste tanks, with exception of the drains from the maintenance cell and wash cells, were checked by admitting water to the drain and listening to the water enter the tank and/or by noting a level increase in the tank. The drains from the wash cells were checked during the preoperational testing of the wash cells, and the maintenance cell drains were checked during the preoperational testing of maintenance cell equipment.

The maintenance cell tank room sump pump was checked by admitting water to the sump and noting that the pump operated automatically as designed.

The steam jet ejectors associated with the liquid waste tanks in the reactor building were tested by admitting steam to the ejector and circulating liquid within the tank and by transferring liquid either to the leach field or to

the storage tanks in the radioactive waste facility. Flow from the steam jet ejector was indicated by the thermocouple on the discharge side of the steam ejector. When flow had not been established, the indicated temperature approached the steam temperature. As flow was established, the steam ejector outlet temperature would drop and level out at approximately 115 F. This temperature is dependent on the tank bulk temperature.

Transfer piping from the reactor building holdup and monitoring tanks to the radioactive waste facility and leach field was checked by transferring water through the piping and observing whether any leaks were present. Operational checking of the disposal system from the radioactive waste facility was accomplished by transferring liquid from the storage tanks (with the 25 gpm transfer pump) to the leach field and truck loading station.

The liquid waste evaporator and positive displacement metering pump were tested as an integral unit. The positive displacement pump was placed on automatic control and allowed to control the level in the evaporator while the evaporator was operating.

Check-out of the gas decay tanks drains pot collection system was performed by admitting water to the system and noting that the low level alarm cleared and that the high level alarm came on as the drains pot filled. The method of emptying the drains pot was checked by admitting nitrogen and observing that the high level alarm cleared and that the low level alarm actuated when the tank was near empty.

The portable sample unit was tested by drawing a sample from a waste storage tank.

Tests were performed to determine the capacity of the positive displacement pump, the normal operating volume of the waste evaporator and the reliability of the integral unit.

B. SYSTEM DEFICIENCIES

During testing of the radioactive liquid waste system, some maintenance and modifications were required in order to make the system operate satisfactorily. These changes and the more important maintenance performed are listed below, along with the reasons for the listed work.

1. System Modifications and Changes

a. Steam Supply Check Valve

The check valve in the steam supply line to the decontamination room holdup and monitoring tank No. 1 steam jet ejector was found to be reversed. This valve was subsequently cut out, reoriented and welded back into the line.

b. Drain Trap Equalizing Piping

Modification of the equalizing piping of drain trap 1103 in line 2557 from the liquid waste evaporator condenser was effected, to ensure proper operation of the drain trap. The equalizing line entering the top of the Stets drain trap was from the steam side of the evaporator condenser. Consequently; once opened, the drain trap would not close, since steam passed through the top of the trap through the area between the valve stem guide bushing and the valve stem, and through the opened valve port to the leach field. This resulted in loss of pressure on the evaporator, since the valve did not close.

c. Valve Operator Extension Shafts

Valve operator extension shafts contained universal joints made of pot metal which broke easily. All of the pot metal universal joints have been replaced with heavy steel universal joints.

d. Tank Level Indicator Scales

It was found that the tank level indicator dial faces were of the wrong type. Dial faces with proper scales were purchased and installed.

2. Maintenance

a. Floor Drains

A number of the floor drains in the reactor building were plugged with silt and construction material and had to be cleaned before the drain would work properly. Some of the back-water valves in the floor drains were stuck shut. These valves were opened by pushing an electricians tape

through the drain to force the valves open; once opened, the valves operated properly.

b. RD-1100

Liquid waste radiation detector RD-1100 in line No. 2561 to the leach field was found to be quite temperature sensitive. Some maintenance has been performed on this detector, but to date it does not work satisfactorily.

III. ANALYSIS AND PRESENTATION OF RESULTS

In addition to the problems requiring system modification and unscheduled maintenance as discussed above, certain other system discrepancies were noted. These discrepancies were not considered to be serious in nature. The equipment concerned is deemed adequate for the intended use.

A. TANK LEVEL INSTRUMENTATION

Instrumentation for monitoring level in the tanks (alarms and indications) perform satisfactorily and are maintenance free. Table I is a tabulation of instrumentation alarms and setpoints.

B. STEAM JET EJECTORS

Steam jet ejector capacities are listed in Table II. The capacities vary somewhat from the design values listed by the manufacturer. Jet ejectors for the laundry and decontamination from holdup and monitoring tanks were determined to operate within design capacity. Design value for these ejectors is 25 gpm, requiring 376 lb/hr of steam at 150 psig, handling water with a suction lift of 8 feet and a discharge head of 34 feet. The steam consumption for these ejectors is less than design, since the discharge head is approximately one-sixth of the design value.

Jet ejectors for the maintenance cell holdup tanks are adequate for the purpose. If the design pressure and steam requirements to the ejectors had

TABLE I
INSTRUMENTATION ALARMS AND SETPOINTS

Unit Served	Component	Expected Setpoint Value	Actual Setpoint Value	Reset Value
Laundry Holdup and Monitoring Tk No. 1	LAH 1113	3'9"	3'9"	---
Laundry Holdup and Monitoring Tk No. 2	LAH 1114	3'9"	3'9"	---
Decon Rm Holdup and Monitoring Tk No. 1	LAH 1106	3'0"	3'0"	---
Decon Rm Holdup and Monitoring Tk No. 2	LAH 1107	3'0"	3'0"	---
Maintenance Cell Holdup and Monitoring Tk No. 1	LAH 1108	3'0"	3'0"	2'4"
Maintenance Cell Holdup and Monitoring Tk No. 2	LAH 1109	3'0"	3'0"	2'5"
R/A Transfer Tank	LAH 1110	3'4"	3'6"	---
	LAL 1100	8"	1'3"	---
Liquid Waste Holdup Tk, Normal Level	LAH 1124	6'6"	6'1"	5'11"
	LSL 1124	6"	6"	1' 9"
Liquid Waste Holdup Tk, Intermediate Level	LAH 1125	6'6"	6'6"	5'10"
	LSL 1125	6"	6"	1'10"
Liquid Waste Holdup Tk, High Level	LAH 1126	3'0"	3'1/8"	2'9"
	LSL 1126	6"	6-1/8"	1'8"
Liquid Waste Evap	LS 1135	minus 1-1/2"*	minus 1-1/8"	---
	Pump Start			
	LS 1135	plus 1-1/2"*	plus 2"	---
	Pump Start			
	LAL 1102	minus 7-1'2"*	minus 6-3/4"	minus 5-1/2"
	LAH 1130	plus 7-1/2"*	plus 8"	plus 6-5/8"
Gas Decay Tks Drains Pot	LAH 1121	15-1/2"x	15-1/2"	13"
	LAL 1103	7-1/2"x	5-1/4"	7"

* Reference point is 1/2 the distance between the evaporator level connections.

x Reference point is the center line of the lower level sensing line to the level switch.

TABLE II
STEAM JET EJECTOR CAPACITY

Ejector	Capacity	Steam Consumption	Steam Pressure
Laundry Holdup and Monitoring Tk No. 1	28.2 gpm	138 lb/hr	Approx 95 psig
Laundry Holdup and Monitoring Tk No. 2	25.9 gpm	----	Approx 95 psig
Decon Rm Holdup and Monitoring Tk No. 1	20.5 gpm	----	Approx 95 psig
Decon Rm Holdup and Monitoring Tk No. 2	23.75 gpm	----	Approx 95 psig
Maintenance Cell Holdup and Monitoring Tk No. 1	14.5 gpm	314 lb/hr	Approx 130 psig
Maintenance Cell Holdup and Monitoring Tk No. 2	16.5 gpm	----	Approx 130 psig
Radioactive Waste Transfer Tank	14.5 gpm	330 lb/hr	Approx 95 psig

been met, the ejectors would have performed closer to design. Design value for these ejectors is 25 gpm, requiring 412 lb/hr of steam at 150 psig, handling water with a suction lift of 10 feet and with a discharge head of 55 feet. The ejectors are working against the full design head of 55 feet. The difference in elevation from the ejector to the high point in the system is approximately 52 feet. This elevation difference, plus the head loss due to friction, will sum up to 55 feet of discharge head or greater. The amount of steam consumption for handling 14.5 gpm was calculated by heat balance to be 314 lb/hr. With a higher steam supply pressure and the full steam design flow of 412 lb/hr to the ejector it is estimated that the ejector would handle 19 gpm or more with the existing head conditions.

R/A waste transfer tank ejector capacity as tabulated in Table II is below the design value of 25 gpm. After correction for design steam consumption and pressure, capacity of the ejector would be approximately 23 gpm. The 14.5 gpm test value was obtained while using 95 psig steam supply and a steam flow rate of 330 lb/hr (calculated). Design value for this ejector is 25 gpm, requiring 518 lb/hr of steam at 159 psig, handling water with a suction lift of 10 feet and a discharge head of 55 feet. The tank is located near the maintenance cell holdup tanks and has the same discharge head.

C. DECAY TANKS DRAINS POT

The gas decay tanks drains pot collection and discharge system operates satisfactorily. Associated alarms are set as listed in Table I. In keeping with safety requirements, the motive force to empty the drains pot was changed from service air to nitrogen.

D. PUMP AND TANK INTERLOCKS

The liquid waste transfer pump interlocks were checked along with the tank level and tank discharge valve interlocks; all were found to perform per design. The pumps are interlocked to prevent operation in the event the tank discharge valves are closed, or if a discharge valve is open and the tank level

is below six inches in that particular tank. This prevents the possibility of pumping a tank dry.

Testing of the liquid waste centrifugal transfer pump was accomplished at three discharge heads, in order to determine the head capacity curve for the pump and to determine whether the pump meets guarantee conditions of 30 gpm at a 70 ft discharge head. The pump does meet the guarantee value as listed above, but the head capacity curve as tested does not compare with the design curve (Figure 1111-2).

E. PUMP AND EVAPORATOR CAPACITIES

The capacity of positive displacement pump P-1102 was checked and found to be 13.5 gph. The capacity check was made by measuring the time required to pump a known volume of liquid.

Originally, the liquid waste evaporator was intended to operate between 9 psig and 12 psig. However, because of the construction of the Stets drain trap, the evaporator will now operate at essentially zero pressure. It was found that the trap functioned to maintain a constant level in the trap piping and evaporator condenser. Since the drain trap valve remains open during operation, the pressure in the evaporator is the pressure required to overcome the elevation head of the discharge piping from the drain trap. There seems to be no good reason why the evaporator should operate at approximately 10 psi. On the other hand, the reasons for operating it at very low pressure are as follows:

- 1) Less heat is required to evaporate water at a low pressure
- 2) Should the vessel develop a leak, there will be less chance of spraying contaminated liquid over the surrounding area.

The volume in the evaporator between the pump start-level and the pump stop-level was measured, so that if the evaporator were to be operated on a strict on-off basis the operator would know how much liquid had been pumped into the evaporator. The measured volume was 3.5 gallons. Evaporation rate was determined to be 6.3 gph, by removing a plug in the drain trap and catching the condensate in a container. Design evaporation rate is 5 gph.

Figure 1111-2. Liquid Waste Transfer Pump
(P-1101)

F. PORTABLE SAMPLE UNIT

The portable sample unit consists of a vacuum pump and sample receiver for use in taking samples from the liquid holdup and storage tanks. Performance of the unit was satisfactory. Shortening of the sample lines from the liquid waste storage tanks in the waste facility was required (above the floor), in order for the liquid in the portable sample receiver to return by gravity to the storage tank. The portable sample unit used for sampling the maintenance cell holdup tanks must be elevated in order to drain the sample receiver back to the tanks. The sample lines enter the operating area through the wall at a point approximately 3.5 feet above the floor.

IV. COMPLIANCE WITH TEST COMPLETION CRITERIA

Following are the test completion criteria associated with preoperational test AI-P-1111, Radioactive Liquid Waste System, as listed in NAA-SR-5700 (Supplement 4) page XI (a)-40, with remarks regarding the test to explain compliance with the criteria.

- a) Criterion: All reactor building drains that flow to radioactive liquid waste tanks are free of obstructions and connect to the proper tanks.

Remarks: Reactor building drains were checked by the admission of water to the drains and by noting a level change in the tank and/or by listening to the water flow into the tank. All drains are open and connect to the correct tank.

- b) Criterion: System instrumentation functions properly; indicating correctly with alarms actuating at proper setpoints.

Remarks: Correct operation of all instrumentation was verified.

- c) Criterion: Liquid in the system hold-up tanks and storage tanks can be recirculated to accomplish mixing.

Remarks: The liquid in all tanks except the radioactive waste transfer tank may be recirculated to accomplish satisfactory mixing. The radioactive waste transfer tank was not designed to include a recirculation line for mixing.

- d) Criterion: The steam transfer jets establish adequate flow and are capable of performing the required liquid transfers.

Remarks: The steam transfer jets perform adequately. As pointed out in part III of this report, the steam transfer jets for the maintenance cell holdup and monitoring tanks and for the radioactive waste transfer tank do not transfer liquid at the 25 gpm rate. The steam jets have a capacity somewhat lower than design (25 gpm); however, as the tank volumes are small, this does not present a problem. Operation of the steam jets is considered satisfactory.

- e) Criterion: The liquid waste evaporator and associated feed pump function properly at the designed capacity.

Remarks: The evaporator and evaporator feed pump were checked separately and as an integral unit. Both perform satisfactorily. Evaporator operating pressure was changed, due to the function of drain trap 1103. This drain trap remains open allowing the evaporator to operate at essentially zero pressure.

- f) Criterion: Liquid can be discharged to the leaching field or the truck loading line as required by liquid activity levels.

Remarks: Liquid may be discharged to the leach field or the truck loading line as required.

V. EVALUATION

Based upon predicted HNPF liquid waste disposal requirements, the disposal system is deemed adequate. As a result of work performed during the test, all components are in proper operating condition. Test completion criteria as listed in NAA-SR-5700, Supplement 4, have been satisfied. The fact that some of the steam jet pumps did not produce design flow is not a violation of criterion d), since "adequate flow" is not defined as 25 gpm. The flow rates established during the test are, in fact, adequate. With the flow rates indicated, any tank in the system can be emptied in less than two hours; pumping rates in all instances could, nevertheless, be increased by supplying steam at design conditions to the ejectors.

The main sources of radioactive waste at HNPF are from fuel and equipment wash cells, maintenance cell, decontamination room and laundry room.

Under normal conditions, all liquid waste will be of such low activity that it can be eliminated with little or no on-site storage. Approximately 500 gallons of higher activity liquid may be generated per year. An evaporator has been installed to concentrate this to 86 gallons of high activity liquid to be stored in the high level liquid waste storage tank.

A final protection to prevent high activity liquid release is provided by RD-1100, which actuates a control valve to stop flow to the leach field when the activity exceeds $2 - 4 \times 10^{-6} \mu\text{C/cc}$. The detector has been found to be temperature sensitive. An additional problem which may occur is the deposition of radionuclides on the sensing elements of the detector, and consequent interference with proper discharge of liquid waste. Consideration should be given to the elimination of this detector.

HALLAM NUCLEAR POWER FACILITY
PREOPERATIONAL TEST COMPLETION REPORT
AUXILIARY STEAM SYSTEM

AI-P-1113

Test and Analysis

by

I. O. SUNDERMAN

Evaluation

by

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CONTENTS

	Page
I. Purpose of Test	1
II. Discussion of Test Performance	1
A. Auxiliary Steam System, Reactor Building.	2
B. Steam and Condensate Lines	2
C. Condensate Return Pumps.	3
III. Analysis and Presentation of Results.	3
A. Auxiliary Heating System, Reactor Building.	3
B. Steam and Condensate Lines	4
C. Condensate Return Pumps	4
IV. Compliance With Test Completion Criteria.	4
V. Evaluation	6

HALLAM NUCLEAR POWER FACILITY
PREOPERATIONAL TEST COMPLETION REPORT
AUXILIARY STEAM SYSTEM, AI-P-1113

I. PURPOSE OF TEST

The purpose of preoperational test AI-P-1113, Auxiliary Steam System, was to verify the operability of the auxiliary steam system in those areas served by the system, and to determine that related system components operate satisfactorily.

Whereas the test was conducted in three sections, all three sections were combined to provide a composite report covering the entire system.

II. DISCUSSION OF TEST PERFORMANCE

The auxiliary steam system consists of service steam lines in the reactor building. System service includes the main heating and cooling units, booster units, steam wash service units, evacuating lines, and steam service stubs.

The test covered operation of the auxiliary steam system in the following areas:

- 1) Steam generator cell heating and ventilating units No. 1, 2, and 3.
- 2) Reactor building heating and ventilating units No. 1, 2, 3, and 4.
- 3) Reactor building personnel rooms.

Performance of the test was during the time the plant was in the final phase of construction. This factor, plus the narrow scope of the test, imposed limitations which prevented obtaining specific data covering steam flow, pressures, and temperatures.

A. AUXILIARY STEAM SYSTEM, REACTOR BUILDING

The auxiliary steam system in the reactor building was operated and tested to verify satisfactory operation of the system as a whole. Steam sources utilized for this portion of the test included steam from the desuperheating station, service boilers, and extraction steam from the turbine. Operation of steam inlet to heater coil control valves was verified by cycling the pneumatic input signals (from minimum to maximum) via the thermostats.

Strainers in this portion of the auxiliary steam system were removed and cleaned. Temperature of the steam traps was checked to ascertain that the traps were operating properly, and the direction of check valve installation was noted.

The wall type thermostats were tested by individually setting each thermostat at the maximum and minimum setting and noting operation of the related control valve. During the initial test, it was observed that some of the control valves failed to respond to a change in the setting of the controlling thermostat. Investigation of the problem disclosed that the thermostats were at fault, not the control valves. The faulty thermostats were repaired, and the test repeated, verifying that the control valves responded to a signal from the thermostat.

B. STEAM AND CONDENSATE LINES

Steam and condensate lines were visually traced to verify correct connections. Identification numbers of valves, steam traps, strainers, controls, indicators, and related auxiliary steam system devices were verified. Unnumbered items were assigned component numbers, and tags ordered. The Bechtel process P & I drawing D-070509, Miscellaneous Service, was corrected to an "as built" condition.

The self-contained pressure control valves were tested for pressure control under steam flow requirement conditions. Initial testing revealed that the control valves did not hold at a constant pressure. New control

valves were installed and the test repeated to verify satisfactory operation of the replacement valves.

C. CONDENSATE RETURN PUMPS

The condensate return pumps were tested for timed effluent flow; flow rates were found to be too low for satisfactory operation of the condensate return system. Additional flow tests disclosed that the ball type check valves in the pump outlet lines were restricting the flow. These valves were replaced with a flapper type check valve, and the pumps again tested.

III. ANALYSIS AND PRESENTATION OF RESULTS

A. AUXILIARY HEATING SYSTEM, REACTOR BUILDING

The auxiliary steam system performs satisfactorily from the design standpoint of heating the reactor building and in providing the steam required for various functions in the reactor area.

Severe cold weather conditions provided a positive basis for determining the ability of the auxiliary steam system to satisfy reactor building heating requirements. Daily temperatures ranged from zero to minus 24°F during the testing period. Steam flow to the heating and ventilating units and to the booster coil units proved adequate to meet the heating needs. This was verified by noting the ability of the system to follow the steam demand, and thus satisfy the heat requirements established by the wall thermostats installed in the reactor building.

Failure of the control valves to respond to signals from the wall thermostats was traced to leakage in the air lines of these components. Correction of leakage resulted in satisfactory operation of the control system.

The present reactor building temperature control thermostats have a range of 75°F to 115°F. Thus, building area temperatures tend to be higher than average for a work area of this type. It is recommended that the temperature control thermostats be replaced with a type having a range of 55°F

to 90°F to reduce the temperature to an acceptable limit in areas frequented by personnel.

B. STEAM AND CONDENSATE LINES

The action of the self-contained pressure control valves serving the wash cells (PCV-1300), H & V units No. 3 and No. 4 (PCV-1304) and the laundry equipment area (PCV-1305) was found to be sluggish. A wide-band low pressure range was noted. The low pressure side did not hold a constant pressure, varying from 5 to 30 psig. Slight variations in control settings provided erratic operation and non-reproducible on-off low pressure cycling limits. No reason was found for the erratic operation; it could only be concluded that the operation was characteristic of these valves.

All three control valves of this type were replaced. Further tests demonstrated that the new control valves maintained a narrow-band low-pressure range under load conditions.

C. CONDENSATE RETURN PUMPS

Test performance of the condensate return pumps indicated that the condensate return flow rate of 5 to 6 gpm was too low. The ball check valves in the output lines of the four condensate return pumps (P-1301, P-1302, P-1303 and P-1304) were replaced with flapper-type check valves. This modification increased the return flow to a value of ~17 gpm, which was deemed satisfactory for the condensate return system.

IV. COMPLIANCE WITH TEST COMPLETION CRITERIA

Following are the test completion criteria associated with preoperational test AI-P-1113, Auxiliary Steam System, as listed in NAA-SR-5700 (Supplement 4) Page XI(a)-41, with remarks regarding the test to explain compliance with the criteria.

- a) Criterion: The facility heating system was activated and the necessary adjustments were made to acquire the required steam flows through heating unit coils. The control valves and temperature controls of the units operate properly.
- Remarks: The facility heating system was activated and steam flows through the heating coils were noted to be satisfactory. The system demonstrated the ability to provide adequate flow and heat for all parts of the building in coldest weather. Control valves and temperature controls operate properly.
- b) Criterion: The system condensate return pumps operate properly. Level switches and floats in the condensate tanks and steam traps throughout the system operate properly.
- Remarks: The system condensate return pumps operated properly. The level switches and floats in the condensate tanks operated the pumps in proper cascade fashion. Steam traps throughout the system operate properly.
- c) Criterion: Steam can be introduced to the cerrobend melt-out coils around the loading face shield.
- Remarks: As there is no such thing as a cerrobend melt-out coil, this criterion apparently is in reference to the sodium melt-out coils which are dual purpose coils used for not only sodium melt-out, but likewise for loading face shield cavity cooling during reactor operation. Circulation of cooling water through the coils has verified that the coils are open. Four special steam hoses are maintained in a storage location to provide steam from steam service stubs to the melt-out coils. These hoses were connected to the outlet stubs to verify readiness for use; all connections proved satisfactory.
- d) Criterion: Service steam can be introduced to the wash cells, decontamination room, laundry, maintenance cell, R/A waste facility and all the various hold up and transfer tanks.
- Remarks: Service steam is available at the related service stubs and can be introduced to the wash cells, decontamination room, laundry, maintenance cell, and all the various hold up and waste transfer tanks. Construction design changes deleted the steam line from the reactor building to the R/A waste facility.

V. EVALUATION

The auxiliary steam system provides steam and condensate return for building heating as well as steam for miscellaneous decontamination and general utility services.

Basically, the auxiliary steam system preoperational test required activation of the auxiliary steam system in the reactor building and radiation waste facility. In this manner, proper operation of the system and related components was determined, as was the adequacy of the system in meeting test completion criteria. Specifically, the test was intended to demonstrate that steam flow could be maintained through the heating coils, and that service steam could be introduced to the wash cells, decontamination room, laundry, maintenance cell, and the various holdup and transfer tanks. To fulfill these requirements, it was necessary to determine the proper operation of related control valves, temperature control valves, condensate return pumps, level switches and floats in the condensate tanks, and steam traps throughout the system.

As steam service to the R/A waste facility has been discontinued, meeting of the related criterion from NAA-SR-5700, Final Summary Safeguards Report for the Hallam Nuclear Power Facility, was not included in the test.

The standards used to verify heating requirements were based on the adequacy of heating in various areas during the winter of 1961-62. The high and auxiliary bay areas were satisfactorily heated during this time. The primary and secondary sodium pumps were not running during the coldest part of the winter; hence, did not contribute any heat to these areas. As the pumps will contribute considerable heat to the high bay when the plant is in operation, it may be necessary to lower the incoming air temperature to the area in order to compensate for the added heat. Pump operation should not affect the temperature of the auxiliary bay.

Several times during the winter, when personnel were working in the steam generator rooms, the steam flow to these areas had to be secured for the comfort of the personnel. This indicates that the steam flow to these areas is more than adequate.

All reactor building personnel areas were kept warm during the cold months, thus demonstrating the adequacy of the system in meeting heating requirements. Those areas serviced by heating and ventilating units No. 3 and No. 4 were heated satisfactorily and are receiving an adequate quantity of steam.

During the time the system was in use, the condensate pumps could not handle the condensate flow. Large quantities of water were wasted due to the condensate tanks filling up and over-flowing. An investigation revealed oversized globe-type-lift check valves. These valves were designed for systems with a much higher discharge pressure than that developed by the condensate pumps. As a result, the check valves were not opening fully, thus causing an excessive pressure drop across the valve. When these valves were replaced with flapper-type checks, the system functioned properly. The level switches in the system were tested and found to operate properly.

Steam coils are used to melt out any condensed sodium that may be frozen in the gap between the cavity liner and the loading face shield. The steam supply to the melt-out coils is at approximately 135 psig and 355 F. This temperature and pressure should be adequate to melt sodium in the region of the coils.

The wash cells, decontamination room, laundry, maintenance cell and hold-up tanks can be supplied with steam of adequate pressure and flow. The only problem encountered in these areas is where the steam must pass through small nozzles, as in the wash cells and decontamination room. There is considerable scale and rust in the piping which feeds the nozzles, causing rapid plugging of the small diameter nozzles. Installation of 100-mesh strainers ahead of the nozzles has alleviated the condition.

In the laundry room, a system of valves is used to mix steam and water in order to obtain hot water for the washing machine. With present conditions, when the system is turned on, the washer fills with steam instead of water. The normal steam supply pressure to the laundry rooms is ~90 psig, whereas the valving arrangement for the washing machine was designed for about 40 psig steam pressure; a pressure that can be obtained by throttling the inlet

steam valve. With this adjustment, proper operation can be attained. A permanent modification which would drop the steam pressure is being studied.

Steam flow to the wash cells was proven to be adequate when put to actual use in washing primary sodium pump No. 1. On the other hand, the 135 psig steam to the various hold-up and transfer tanks is below the specified 150 psig delivery pressure. This difference will lower the pumping capacity of the various jet ejectors, but not to a point where the flows will be unsatisfactory.

Design steam pressure, if required, can be obtained by adjusting the set points on the control valves feeding the auxiliary steam system, or by using a different extraction point on the turbine.

HALLAM NUCLEAR POWER FACILITY
PREOPERATIONAL TEST COMPLETION REPORT
PREHEATING SYSTEM

AI-P-1116

Test and Analysis
by
W. H. SPALDING

Evaluation
by
S. L. PFAHLER

A T O M I C S I N T E R N A T I O N A L
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CONTENTS

	Page
I. Purpose of Test	1
II. Discussion of Test Performance	1
A. Sodium Service System	1
B. Main Heat Transfer System	2
III. Analysis and Presentation of Test Results	3
IV. Compliance with Test Completion Criteria	17
V. Evaluation	18

APPENDICES

A. Preheat of Steam Generator No. 1	21
B. Review and Comments on Analysis of Thermal Transient Effects on Hallam Steam Generator- Superheater Analysis	59

TABLES

I. Comparison of Oven Temperatures With Component Shell Temperatures At a Nominal 350 F Preheat Temperature	4
II. IHX No. 3B Oven Temperature Excursion	14

FIGURES

	Page
1116-1 Temporary Installed Steam Generator Thermocouples	10
1116-2 Steam Generator No. 2 Evaporator Preheat Curves	12
1116-3 Steam Generator No. 3 Evaporator Preheat Curves	13
1116-4 Preheat Thermocouple Locations on An IHX	16

HALLAM NUCLEAR POWER FACILITY
PREOPERATIONAL TEST COMPLETION REPORT
PREHEATING SYSTEM, AI-P-1116

I. PURPOSE OF TEST

The purpose of this test was to determine that the sodium pipe and equipment preheating system operates satisfactorily. The ultimate objective of the test was to preheat all sodium systems so they could be filled with sodium. This procedure excludes the reactor vessel preheating system which was tested in the reactor heaters preoperational test, AI-P-1164.

II. DISCUSSION OF TEST PERFORMANCE

A. SODIUM SERVICE SYSTEM

All sodium service system heaters, thermocouples, and control circuits were individually tested to make certain that for each control circuit the associated thermocouple and heater operated correctly. With the setpoint temperature at 100 F all heater control switches were energized and the preheat temperature was allowed to rise to 100 F. The setpoints were then advanced in 50 degree increments until 250 F was reached. During this time, malfunctioning preheat circuits were corrected.

At this point in the test, deviation from the step by step procedure was necessary in order that the delivered sodium could be "dumped" from the tank cars into the plant's fill tanks. All fill tanks and components to the primary fill tanks were preheated to 350 F while all heaters on the remaining part of the service system were shut off so that cell leak tests could be performed. After the primary fill tanks were filled, all piping and components necessary for unloading sodium into the secondary fill tanks were preheated to 350 F. Upon completion of this operation the remaining secondary sodium piping and components were preheated to 350 F. Cold trapping was then performed and plugging meter runs were made. Finally, the remainder of the primary service system piping

and components were preheated to 350 F. This was followed by further cold trapping and plugging meter runs.

B. MAIN HEAT TRANSFER SYSTEM

All sodium main heat transfer system heaters, thermocouples, and control circuits were individually tested to make certain that for each control circuit the associated thermocouple and heater operated correctly. The large components were then preheated to approximately 225 F.

In preheating steam generator No. 1, preheat rates and temperature differences called out in the procedure were exceeded when 45 psig warmup steam was admitted in the water and steam side. In order to prevent exceeding limits on steam generators No. 2 and No. 3, preheat procedure was revised to incorporate a temporary steam jet ejector to permit vacuum heating of the steam generators.

In lieu of admitting 45 psig steam, a vacuum of about 24 in. Hg absolute was first pulled on the steam and water side of the steam generators. The warmup steam was then slowly admitted through the throttling valves to the continuously maintained vacuum. The saturated temperature of steam at this pressure is about 135 F thus insuring that no temperature in the steam heated sections can exceed this value. After equilibrium temperatures were reached, the vacuum was gradually reduced allowing the temperatures to increase. Simultaneous to the heating of the steam heated sections, sodium sections were heated electrically. Successful preheating of steam generators No. 2 and No. 3 resulted.

While preheating intermediate heat exchanger (IHX) No. 3B, a thermocouple lead wire accidentally grounded. Preheating temperature rates as indicated by oven thermocouples* were exceeded. Upon correcting the grounded thermocouple, temperatures were brought within limits.

During preheating of the main heat transfer system it became evident that the heater oven thermocouples did not accurately measure component

* An oven type thermocouple is one that has its sensing element in the gas space between the component shell wall and the metal jacket.

and piping temperatures. For this reason, many temporary thermocouples were discharge-welded to the shells of the steam generators, main pumps and valves, and to the intermediate heat exchangers. Locations of these temporarily installed thermocouples are called out in Table I and are shown in Figure 1116-1. The majority of these temporary thermocouples were installed in the locality of oven thermocouples so that comparison of temperatures could be made. The temporary thermocouples were read out periodically to be certain that component temperatures were being controlled.

At the same time the last components of the main heat transfer system were preheated to 225 F, the reactor was preheated per preoperational test AI-P-1165. Next, the main heat transfer system, along with the reactor, was preheated to 325 F. The system was then filled with sodium.

III. ANALYSIS AND PRESENTATION OF TEST RESULTS

Many preheat problems were encountered during the performance of this test. Various types of problems along with their solutions are described in the following paragraphs:

- a) Several of the heater control relays would not latch or unlatch. Adjustment of the relay contact leafs remedied the problem.
- b) Stepping switches occasionally caused the system scanning mechanism to become out of synchronization. In addition, the stepping switches would often have high resistance thermocouple contacts. Cleaning and adjusting these switches corrected the difficulty.
- c) Many open or high resistance thermocouples were found and corrected. Loose terminals and oxidized iron lead wires caused most of these troubles. A few faulty lead wire connections were found in the seal connectors which penetrated the primary cells and pipeway.

TABLE I

COMPARISON OF OVEN TEMPERATURES WITH COMPONENT SHELL
TEMPERATURES AT A NOMINAL 350 F PREHEAT TEMPERATURE

Component and Thermocouple	Oven Temperature	Shell Temperature	Temperature Difference
IHX No. 1A	-1E	320	350
	-2E	300	350
	-3E	290	321
	-4E	268	304
	-5E	208	308
	-6E	232	286
IHX No. 1B	-1E	312	334
	-2E	304	343
	-3E	294	318
	-4E	274	306
	-5E	250	298
	-6E	182	276
IHX No. 2A	-1E	308	325
	-2E	298	325
	-3E	292	305
	-4E	266	295
	-5E	248	305
	-6E	200	385
IHX No. 2B	-1E	310	336
	-2E	288	336
	-3E	274	310
	-4E	248	290
	-5E	206	326
	-6E	270	340
IHX No. 3A	-1E	303	331
	-2E	297	327

TABLE I continued

Component and Thermocouple	Oven Temperature	Shell Temperature	Temperature Difference
-4E	275	322	45
-5E	326	374	48
-6E	291	372	81
IHX No. 3B -1E	223	346	123
-2E	291	357	66
-3E	297	333	36
-4E	263	311	48
-5E	293	336	43
-6E	242	317	75
Stm Gen No. 1			
Evaporator -5E	264	334	70
Superheater -5E	265	323	58
Stm Gen No. 2			
Evaporator -5E	263	321	58
Superheater -5E	250	319	69
Stm Gen No. 3			
Evaporator -5E	228	302	74
Superheater -5E	248	290	42
Sec. Pump No. 1 -1E	312	328	16
-2E	290	300	10
-3E	298	312	14
-4E	295	313	18
Sec. Pump No. 2 -1E	318	332	14
-2E	300	333	33
-3E	304	326	22
-4E	307	330	23
Sec. Pump No. 3 -1E	308	328	20
-2E	306	324	18
-3E	304	326	22
-4E	310	326	16

TABLE I continued

Component and Thermocouple		Oven Temperature	Shell Temperature	Temperature Difference
Sec. Throttle				
Valve No. 1	-1E	306	310	4
	-2E	362	390	28
	-3E	368	389	21
	-4E	350	384	34
Sec. Throttle				
Valve No. 2	-1E	386	370	-16
	-2E	320	375	55
	-3E	312	378	66
	-4E	304	370	66
Sec. Throttle				
Valve No. 3	-1E	290	271	- 19
	-2E	324	360	36
	-3E	302	324	22
	-4E	274	306	32
Pri. Block				
Valve No. 1*	-1E	263	282	19
	-2E	268	310	42
	-3E	224	294	70
Pri. Block				
Valve No. 2*	-1E	236	286	50
	-2E	250	312	62
	-3E	222	284	62

* Temperatures taken after loops were filled with sodium and after sodium had been circulated for several days.

TABLE I continued

Component and Thermocouple		Oven Temperature	Shell Temperature	Temperature Difference
Pri. Block				
Valve No. 3*	-1E	254	301	47
	-2E	268	308	40
	-3E	240	292	52
Pri. Throttle				
Valve No. 1*	-1E	278	316	38
	-2E	302	328	26
	-3E	274	320	46
	-4E	214	271	57
Pri. Throttle				
Valve No. 2*	-1E	296	318	22
	-2E	306	325	19
	-3E	248	312	64
	-4E	142	250	108
Pri. Throttle				
Valve No. 3*	-1E	260	308	48
	-2E	264	315	51
	-3E	232	290	58
	-4E	274	320	46
Pri. Check				
Valve No. 1*	-1E	308	338	30
	-2E	304	338	34
	-3E	308	338	30

* Temperatures taken after loops were filled with sodium and after sodium had been circulated for several days.

TABLE I continued

Component and Thermocouple	Oven Temperature	Shell Temperature	Temperature Difference
Pri. Check			
Valve No.2* -1E	300	340	40
-2E	290	338	48
-3E	298	339	40
Pri. Check			
Valve No.3* -1E	285	338	53
-2E	292	338	46
-3E	285	338	53
Moderator Block			
Valve * -1E	-	286	-
-2E	258	306	48
-3E	186	278	92
Moderator Throttle			
Valve * -1E	157	248	91
-2E	302	320	18
-3E	275	333	58
-4E	248	300	52
Pri. Pump No.1* -1E	300	306	6
-2E	294	305	11
-3E	298	314	16
-4E	298	315	17
-5E	254	315	61
Pri. Pump No.2* -1E	306	306	0
-2E	292	301	9
-3E	292	314	22

* Temperatures taken after loops were filled with sodium and after sodium had been circulated for several days.

TABLE I continued

Component and Thermocouple	Oven Temperature	Shell Temperature	Temperature Difference
-4E	288	314	26
-5E	270	314	44
Pri. Pump No. 3* -1E	285	213	-72
-2E	293	213	-80
-3E	293	308	15
-4E	298	308	10
-5E	273	308	35

* Temperatures taken after loops were filled with sodium and after sodium had been circulated for several days. Primary Pump No. 3 had been shut down a few hours prior to the temperature measurements and was without preheat power.

- d) The preheat thermocouples, (each of which consists of a 3/8 -in. diameter sheathed probe) penetrate into the heater ovens to within 1/2 - 1/4 in. of the component or piping. The temperatures sensed by these thermocouples were generally found to run below the component and piping temperature. In some cases, the oven temperatures read as much as 50 F to 100 F below the actual component and piping temperature as shown in Table I. The causes of these discrepancies were such things as insufficient insulation around the thermocouple probe insertion, heat shorts from support structures and seals, and irregularly located heaters. Many thermocouples were relocated closer to the component shell. Insulation was added around the probes of other thermocouples to reduce heat loss through the sheath.
- e) The secondary cold trap heaters had been wired without a neutral connection and the cold trap's clam shell had been wired with insufficient heater power to allow raising its temperature above 180 F. The heaters were recircuited to obtain additional heat.

<u>Evaporator TCs</u>	<u>Superheater TCs</u>
-----------------------	------------------------

21E	28E
22E	30E
23E	31E
24E	32E
25E	33E
26E	34E
27E	
35E

Thermocouples installed on Steam Generator No. 2 and No. 3 were the same as on No. 1 except for -35E which was only installed on Steam Generator No. 1.

Figure 1116-1. Temporary Installed Steam Generator Thermocouples

- f) Replacement of one balancing motor and one reference voltage box in the controllers of the preheat panel was found necessary due to failure.
- g) Many of the heaters shorted to ground at their junction box. Terminals which were wrapped with glass type insulation and which lay up against the junction box would arc over if any moisture was present. By moving the connector away from the box the problem was solved.
- h) The 20 in. pipe on the steam generators had insufficient heating. These heaters were rewired from 227 V power to 480 V power. Auxiliary relays were rewired from 227 V power to 480 V power. Auxiliary relays were required to make this change.

Since the temperature difference limit in the preheat test procedure (50 F between two points) was exceeded on steam generator No. 1, an investigation concerning the subject was made. The investigation showed that the steam generator was not damaged. The summary of the incident and subsequent analysis is reported in a letter from Mr. F. C. Gronemeyer of Atomics International to Mr. Claude Pursel of the AEC. That letter comprises Appendix A of this report.

Successful preheating of steam generators No. 2 and No. 3 is shown by the steam generator temperature vs time curves in Figures 1116-2 and 1116-3.

The incident where the preheat rate of IHX No. 3B exceeded allowable preheat limits as called out in the test procedure was reviewed. At the time, only oven thermocouples were available for obtaining IHX temperature information. Since oven thermocouples respond much more rapidly to heater temperatures than does the IHX itself, the possibility of damage to IHX No. 3B was deemed unlikely. Table II gives all available temperature information taken during the excursion. Figure 1116-4 identifies the location of the IHX thermocouples.

Figure 1116-2. Steam Generator No. 2 Evaporator Preheat Curves

Figure 1116-3. Steam Generator No. 3 Evaporator Preheat Curves

TABLE II

IHX NO. 3 B OVEN TEMPERATURE EXCURSION

Date	Time	Thermocouples					
		E6-1E	E6-2E	E6-3E	E6-4E	E6-5E	E6-6E
2-18-62	0700	212F	214	197	183	214	218
	0800	-	-	208	193	216	-
	0900	-	-	-	-	-	-
	1000	-	-	-	-	-	-
	1100	240	220	215	197	223	218
	1200	280	256	-	-	-	217
	1300	305	205	-	-	-	222
	1400	-	-	-	280	276	-
	1500	-	-	-	281	269	-
	1600	-	-	-	271	263	-
	1700	330	240	-	288	269	226
	1800	340	322	-	268	258	226
	1900	320	292	270	237	242	230
	2000	306	278	268	234	243	233
	2100	300	126	263	230	245	234
	2200	-	-	289	253	262	-
	2300	-	-	335	289	278	-
	2400	-	-	-	-	-	-

NOTE: Thermocouple E6-2E acquired a partial short to ground on 2-18-62 at about 0700. Partial short was corrected on 2-19-62 at about 1000.

TABLE II continued

Date	Time	Thermocouples					
		E6-1E	E6-2E	E6-3E	E6-4E	E6-5E	E6-6E
2-19-62	0100	354	232	340	290	200	242
	0200	351	224	342	291	275	241
	0300	359	241	341	291	275	233
	0400	355	236	340	291	275	236
	0500	348	222	339	291	275	235
	0600	348	237	337	291	274	240
	0700	347	200	341	289	276	240
	0800	346	-	315	268	269	230
	0900	338	160	280	240	245	233
	1000	-	-	284	247	248	-
	1100	322	267	264	231	240	239

NOTE: Thermocouple E6-2E acquired a partial short to ground on 2-18-62 at about 0700. Partial short was corrected on 2-19-62 at about 1000.

Figure 1116-4. Preheat Thermocouple Locations On An IHX

The comparison of oven temperatures with component shell temperatures as shown in Table I reveals the inconsistencies of the oven thermocouple readings. To overcome these inconsistencies the use of contact thermocouples is recommended. Time cycling of heater controls could be used to allow for soaking time and to prevent uneven component temperatures which a contact control thermocouple might cause.

The primary throttle, block, and moderator valves are enclosed in containment piping. Heaters and component shell thermocouples are located around the outside of the containment piping. In preheating these valves, large temperature differences between the preheat thermocouples were measured. Even after the valves were filled with circulating sodium and temperatures had a chance to stabilize these large temperature differences existed. Data in Table I show these temperature differences.

IV. COMPLIANCE WITH TEST COMPLETION CRITERIA

Following are the Test Completion Criteria Associated with pre-operational test AI-P-1116, Preheating System as listed in NAA-SR-5700, Supplement 4, Page XI (a) - 43 with remarks regarding the test to explain compliance with the criteria.

- a) Criterion: The operability of heaters has been demonstrated on the sodium service system, the sodium main heat transfer system and associated equipment.

Remarks: Each heater and control circuit was individually tested for correct operation.

- b) Criterion: Heater control circuits operate and maintain set-point temperatures of associated piping and equipment.

Remarks: All heater control circuits were energized at one time or another and were found to operate correctly. Temperatures sensed by the oven thermocouples were automatically controlled at the set point of their controller. This was not, true in a few cases where the heat loss, through such things as supports

and seals, prevented the temperature sensed by the oven thermocouple from attaining the setpoint temperature. Investigation of these cases always revealed the actual piping or component temperature to be above the oven thermocouple temperature and well above the melting point of sodium.

- c) Criterion: Sodium service system has been preheated to 350 F.

Remarks: The system was preheated to approximately 350 F.

- d) Criterion: The sodium main heat transfer system has been preheated to 350 F.

Remarks: The sodium main heat transfer system was adequately preheated so that it could be filled with sodium without danger of plugging. The system was preheated to approximately 325 F.

V. EVALUATION

The purpose of the preoperational test, AI-P-1116, was to determine that the pipe and equipment preheating system would operate satisfactorily. Malfunctioning of heater control relays, stepping switches, individual heaters, and thermocouples during the test was not unexpected considering the complexity of the equipment involved. Most malfunctions, however, were not of serious consequence, and were detected and repaired as soon as they occurred. The preheating system is adequate, and the test completion criteria have been met.

As discussed in Part III d) of the test completion report, oven type thermocouples proved inadequate for correct component temperature indications. Shell type thermocouples appear more reasonable and consideration should be given to the permanent installation of shell type thermocouples on the various, large, sodium components. The allowable heating rates and allowable point to point ΔT s; that were maintained during the latter part of the system preheating are:

IHX

100 F Δ T point to point
2.6 F/hr up to 350 F

Steam Generator

50 F Δ T point to point
20 F/hr up to 200 F
4 F/hr from 220 to 350 F

Evaluation of heating rates must include consideration of component wall thickness, tube sheet to shell joint configuration, tube sheet thickness, and tube bundle arrangement. It can be concluded from data recorded during the preheating operation that steam generators No. 2 and No. 3, and IHX No. 1A, 1B, 2A, 2B, 3A, and 3B were brought to temperature within allowed limits.

The IHX No. 3B temperature excursion has been evaluated. A fatigue life reduction of only 0.001 (total allowable 0.8) according to Miner's hypothesis is indicated, using conservative assumptions to calculate stresses for the tube sheet to shell joint (the critical point). Also, on reviewing Table II, it must be remembered that individual temperature indications are meaningless as absolute quantities since shells, plates, and tubes expand or contract proportional to their average temperature.

The incident associated with the preheating of steam generator No. 1 has been analyzed by Mssrs. Walters, Laupa, et al (appendix B). The assumptions made for the analyses, in general, are conservative. A more rigorous analysis includes the flexibilities of the tube sheet and that of the six inch transition cylinder from the tube sheet to the shell, and local flexibility of the half space at the tube sheet to cylinder junction. The effect of these refinements is a reduction of calculated stress. A stress concentration factor of 2 must be applied to the axial stresses calculated for the critical point to investigate the fatigue effect of the incident. Assuming one complete cycle of zero to maximum computed stress to zero, a more severe condition than actually existed, gives the fatigue life reduction of 0.0002 - a negligible amount. Stresses due to the 45 psig pressure in the vessel during the temperature excursion were negligible.

The radial deflection of a cylinder due to internal pressure is expressed by $\frac{PR^2}{EH} (1 - \nu/2)$. Dr. Laupa's comparison of the hydro-

static test pressure to an equivalent ΔT then becomes 100 F rather than 118 F as shown in Appendix B. This is still larger than the ΔT thought to have actually existed.

A primary sodium fill tank was successfully maintained at 650 F, as indicated by oven thermocouples. The sodium temperature in the one third full tank was lower. It will be possible to maintain a full tank of sodium at the desired temperature.

In conclusion, the preoperational test revealed some minor problems with the heating system; these were corrected. During the preheating operation heating rates exceeded recommended values on IHX No. 3B and steam generator No. 1. Stress analyses of the transients indicate that no damage to the vessels had resulted. No data was obtained concerning heater duty cycles. However, much valuable experience was gained for future reference regarding preheating of large scale sodium piping systems and heat exchangers. The primary and secondary loops were prepared for sodium filling.

APPENDIX A

Preheat of Steam Generator No. 1

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

March 15, 1962

*In reply refer -
62AT1824*

Mr. Claude Pursel, Director
Reactor Engineering Division
U. S. Atomic Energy Commission
Chicago Operations Office
9800 South Cass Avenue
Argonne, Illinois

Subject: Hallam Nuclear Power Facility - Preheat
of Steam Generator #1

Dear Mr. Pursel:

During initial preheat of steam generator #1, the temperature difference limit in the preheat test procedure AI-P-1116 of 50°F between two points on the steam generator shell was exceeded. AI personnel have investigated this heating above the limit and have concluded the steam generator has not been damaged. The other two steam generators have been heated within the limits previously established. This letter summarizes the incident and subsequent analysis.

I. Background

In order to insure that secondary sodium will not freeze when admitted to the sodium side of the HNPF steam generators, it is necessary to preheat the liquid metal containing areas to 300-350°F. To accomplish this preheat, an oven has been constructed around the sodium inlet end of the steam generator, which contains electrical resistance heaters. The steam generator shell, normally containing feedwater and steam in the evaporator, and saturated and superheated steam in the superheater, is not heated electrically. The shell sections were designed to be heated by steam admitted from an auxiliary source when the sodium end was being heated by the electric oven.

The superheater shell and steam tube sheet are fabricated of 2½ Cr, 1 Mo steel, with 5 Cr, ½ Mo heat transfer tubes, sodium tube sheet and sodium chambers. The evaporator shell

P.O. Box 309, Canoga Park, California

Cable Address: ATOMICS

is fabricated of carbon steel with 2 1/4 Cr, 1 Mo tube sheets and sodium inlet and outlet chambers. The 2 1/4 Cr, 1 Mo steel is air hardening, and requires a post-welding heat treatment of 1400°F, furnace cooled to 1100°F, and air cooled from 1100°F to ambient. This heat treatment is necessary to relieve stresses set up during welding and to prevent metallurgical changes which would embrittle the steel were it not heat-treated. The superheater steam side shell is 2 7/8 inches thick; the sodium inlet and outlet chamber walls are 1 inch and 7/8 inch thick respectively; the tube sheets are 7 inches thick. The evaporator steam side shell is 2 5/8 inches with a transition section 2 7/8 inches thick; the sodium inlet and outlet chamber walls are 1 inch and 7/8 inch thick respectively; the tube sheets are 8 inches thick.

During fabrication, it was found impractical by the manufacturer, the Griscom-Russell Company, to furnace heat treat the circumferential weld joining the steam containing shell to the tube sheet, as this would have involved heat treating the entire assembled unit. This would have relaxed the mechanical bond between the duplex heat transfer tubes obtained by roller expanding the inner into the outer tube. The bayonet tube assembly had been heat treated during fabrication prior to the roller expanding step. The circumferential weld was locally heat treated by applying electric heat to the vicinity of the weld. In the case of the superheaters, the circumferential weld was made between 2 1/4 Cr, 1 Mo and 5 Cr, 1/2 Mo materials.

Following local heat treating of the steam shell-to-tubesheet circumferential welds in the superheaters, cracks were observed both visually and by X-ray examination in two of the three superheaters. This indicated that the welds were undesirably brittle despite the heat treating applied. The welds were repaired, and re-heat treated, again locally, resulting in apparently sound welds which were accepted by all inspection agencies; the vessels have received the ASME code stamp. There is, however, some concern that these welds may be somewhat less ductile than fully heat treated material, although with the heat treatment applied the weld was placed in the most ductile condition possible.

The preheating test procedure, AI-P-1116 was designed to preheat the steam generators at a rate not to exceed 25°F/hr, and to limit temperature difference between any two points on the steam generator shell to 50°F. These limits were set up to insure that the maximum thermal stress which could be applied to these steam generators was no more than 36,000 psi, a figure well within the yield strength of the material, which had been demonstrated by

test bars of all material employed in the steam generator to be greater than 42,000 psi. The lowest published yield stress for this material is 40,000 psi. Temperatures were monitored by thermocouples placed as noted in Figure I. These thermocouples were not all attached to the steam generators according to the engineering design, but some were mechanically pressed against the shell on the steam end, and located $\frac{1}{4}$ inch from the shell, in the oven space, on the sodium end.

II. Steam Generator Preheat

Preheat of steam generator Number One was commenced on February 15, 1962, at 0800. Electrical preheating of the sodium side of the evaporator and superheater, proceeded normally until 1100, at which time temperatures rose to approximately 95°F. Steam side valves had been set up according to steps VII-B-6 through 11 of preheat test procedure AI-P-1116, except for free blow valves V-2523 and V-2530, which were closed to keep steam condensate from draining on the floor of the steam generator room. It was considered that the steam traps located adjacent to the free blow valves would accommodate condensate drainage, for which purpose they were installed. In order to heat the steam side of the steam generator, steam was admitted through valve CV-77. The steam used was bleed steam from the CPPD turbine at approximately 45 psig. This is the lowest pressure extraction point on the CPPD turbine. Valve CV-77 was cracked slightly at approximately 1100 on February 15, 1962, admitting steam at approximately 5 psig. This valve position was held for approximately 15 minutes. No increase in temperature on the steam side of the steam generator was observed on the thermocouples. Free blow valves V-2523 and V-2530 were opened to insure that condensate was not accumulating in either the evaporator or superheater. A small amount of water was drained; the volume was observed to correspond with that which had accumulated in the piping during a flushing operation with demineralized water which had taken place three days before.

In the absence of any large amount of condensate, valve CV-77 was opened to the $\frac{1}{2}$ open position, and maintained in this position for approximately 15 minutes. A slight rise on the steam side thermocouples was noted, as indicated in enclosure II. CV-77 was then open full and held for approximately 15 minutes, in order to improve what was indicated by the thermocouples readings to be an inordinately slow rate of temperature rise. At 1200 on February 25, temperatures were noted to have risen 25° on some thermocouples, but a rise of 55° was noted on one thermocouple, TI-155-5. CV-77 was immediately closed and steam

flow stopped for approximately 30 minutes. At about 1230, it was observed that steam side temperatures were dropping slowly, and CV-77 was cracked to again admit steam and continue the preheating process.

At 1400 it was noted that the temperature difference between top and bottom of the superheater shell was approaching the 50° limit; it was considered that steam was condensing in the top portion of the superheater, and that heat therefore could not reach the bottom of the shell. At about 1430 CV-77 was operated one-half open in an attempt to get steam throughout the steam generator as indicated by a flow of steam from the free blow valves at the bottom of the evaporator. CV-77 was left in one-half open position for about 30 minutes without obtaining steam out of the free blow valves, but steam shell temperatures started to rise. Because of thermal inertia between the interior of the shell, where steam heating was taking place, and the thermocouples, the temperature limit of 50°F between points on the steam generator was exceeded, although valve CV-77 was closed at about 1500. The 1500 hours temperature readings recorded in enclosure II indicate a rise of as much as 88°F at one point, although steam had been shut off earlier when it was apparent that the rate of heating exceeded limits. At 1700, with temperatures still outside of limits, it was decided to operate CV-77 full open, in order to obtain steam from the free blows and reduce temperature differences, recognizing that the rate of heatup would probably be exceeded in those areas of the steam generator which were not being satisfactorily heated. It was considered at that time that shutting off CV-77 and allowing the steam generator to cool could subject the steam generator to additional damage as there would be no control over the cool-down rate, and the entire heated portion of the steam generator would certainly be subjected to at least one thermal cycle regardless of the rate at which natural (and uncontrolled) cooling occurred. At this time, the sodium side heaters were switched on to automatic control with control set at 225°F, and the superheater steam trap was placed in service. Operating CV-77 full open permitted steam to exit from the evaporator free blow valves 2523 and 2530; they were then closed and the evaporator steam trap placed in service. Just prior to 1700, it was noted that the temperature spread between top and bottom of the evaporator still remained far apart, despite the observation that steam flow throughout the evaporator had been evidenced by passage of steam through free blow valves. It was apparent that the steam traps were not operating. The free blow valves were opened; condensate was present and was drained. Recognizing that the rate of rise of cold portions of the steam generator

was beyond limits, but still desiring to avoid additional thermal cycling of the steam generating apparatus, valve CV-77 was operated so as to provide sufficient steam to flow through the free blow valves through the remainder of the evening, in order to soak the entire steam generator at approximately 200°. This condition was achieved by approximately 1800. One thermocouple, TI-155-6, continued to read cold as noted on enclosure II; this thermocouple is not located on the steam generator shell but is on piping down stream of the attemperator. No significance should be attached to its reading with regard to steam generator temperatures.

III. Discussion of Stresses

Reviewing the operating history and temperature data gathered from the rather meager amount of installed thermocouples, it is apparent that from about 1500 to 1700, condensate built up in the bottom of the evaporator and superheater. This condensate was drained at approximately 1700, when it was apparent, from observation of the temperatures at top and bottom of these units, that the steam traps were not functioning. The condensate acted as a heat sink in addition to that provided by the massive tube sheet, and the somewhat less massive shell. The zone of immediate concern in the superheater is the circumferential weld joining the shell to the steam tube sheet. This is the weld which had previously been repaired in two of the three superheaters, and is considered the most sensitive portion of the steam generator. Stress analyses were performed, first at Hallam on a "first order" basis and later, on a refined basis, at Canoga Park. The analysts were the men who had been concerned with reviewing the manufacturer's original design calculations. The "first order" stress analysis was performed, using a simplified model of the shell and tube sheet which assumed complete restraint of all sections, and a discontinuity in temperature distribution circumferentially around the superheater. The shell was assumed to have been heated uniformly at the most unfavorable temperature condition, 90° above the level at which condensate was expected to accumulate, the condensate was assumed to have been present all the time during which temperature variations were observed, and a step temperature change at the condensate surface was assumed. These calculations, made the day following the preheating of Number One steam generator, indicated that the maximum possible stress to which the circumferential weld could have been subjected was 40,000 psi. In view of the extreme conservatism of the assumptions, and the knowledge that this area had been subjected to 36,000 psi stress during the

required hydrostatic test ($1\frac{1}{2}$ x normal working pressure) performed subsequent to installation, no immediate action was taken to cool the boiler down for inspection. Furthermore, the first order analysis, later verified by more detailed computation, indicated that the point of maximum stress was on the inside of the weld joining the tube sheet welding lip to the shell. Therefore, visual and magniflux inspection would not reveal a crack in this area should one have occurred. The presence of a crack all the way through the material would have been revealed by steam leakage which was not evident, although searched for. Therefore, the steam generator was permitted to "soak" at about 225°F.

A more refined stress analysis, using two methods, has been performed. The first method of analysis refined the "first order" computations made at Hallam, taking into account structural variations from the simplified model, while retaining an infinitely rigid tube sheet with a step change of temperature in the shell. The second method of analysis assumed a sinusoidal temperature variation in the shell with an infinitely rigid tube sheet at 70°F. The assumptions of an infinitely rigid tube sheet, and temperature step changes are conservative. It should be noted that radial temperature gradients in the shell wall, and axial temperature gradient in the tube sheet have been neglected, as these effects are small relative to computed stresses under the most pessimistic assumed conditions; confirmation of these assumptions is not possible on the steam generators. The only method by which radial and axial gradients could be experimentally approximated is by manufacturing a full scale model, and investigating gradients either by analog or by physically inserting temperature measuring devices at the required distance into the shell and tube sheet. Neither of these methods promise substantial improvement in accuracy and both are extremely time consuming. The two methods of computation are summarized in enclosure III; one yields a stress level of 34,000 psi and the other a stress level of 36,000 psi. The lowest published yield stress of 2½ Cr, 1 Mo at these temperatures is 40,000 psi. The lowest yield strength obtained from test coupons of HNPF steam generator materials is 42,000 psi. Although the conservatively calculated stresses reached about 85% of the yield stress of the material, they did not exceed the stresses previously imposed on the evaporator superheater combination during hydrostatic testing, and therefore are considered to have imposed no damage on the critical portion of the steam generator.

The analyses performed by AI personnel directly concerned with

the steam generators over the period of their design and fabrication have been checked by other trained and qualified AI personnel skilled in stress analyses, but not previously connected with the problem. These checks have indicated the methods used were both correct and conservative to the best knowledge of these personnel. Additional review is being made by a stress expert not previously connected with AI. It is considered that this independent check by a third, disinterested party should provide confidence in the stresses obtained by analysis.

Should this third, disinterested party not concur with the analysis performed to date, a plan of action has been prepared to non-destructively examine the weld area by ultrasonic shear wave techniques. This non-destructive examination is being held in reserve, as it involves cool-down of the steam generators, thus possibly subjecting them to additional thermal cycling. Removal of a substantial amount of equipment and insulation in order to perform adequate inspection is also required.

IV. Discussion of Operational Lessons

Steam generator number one was the first unit to be so heated; the experience acquired during this period has been applied to the heatup of subsequent units. This experience has been applied as follows:

1. Careful account has been taken of the thermal inertia demonstrated in the number one unit; thermal inertia is, of course, to be expected but its magnitude in a complex structure such as the HNPF steam generator can only be poorly estimated at best. With operational experience, proper account may be now taken of the time constants associated with this equipment.
2. The method of preheating has been altered. In lieu of admitting bleed steam at 45 psig, a vacuum of 24 inches Hg absolute is first pulled on the steam generator. Steam from an auxiliary source is admitted through throttling valves to the vacuum, which is continuously maintained. The saturation temperature of steam at this pressure is 135 F, thus insuring that no temperature in the steam heated section can exceed this value. The vacuum is, of course, reduced when equilibrium temperatures at 135 F have been obtained.
3. The thermocouple installation on steam generator number one was found to be inadequate both in number, placement, and method of application. Additional thermocouples have been applied to all three steam generators at critical locations adjacent to the

Mr. C. A. Pursol
USAEC - COO

-8-

March 15, 1962
62AT1824

tube sheet, on the periphery of the tube sheet, and circumferentially so as to reduce uncertainty of temperature distribution over the surface of the unit. These thermocouples were applied by the capacitor discharge welding technique, which was first checked out at Canoga Park to insure that the minute weld nugget formed at the thermocouple junction would not be deleterious to the 2% Cr, 1 Mo superheater shell, or to the carbon steel evaporator shell.

4. Steam traps are not relied upon to discharge condensate. Drain valves are opened at any time condensate can be expected, in order to avoid creation of thermal sinks in the unit.

5. Additional formal and informal liaison has been established by the plant operations and designers, in order to insure to the maximum extent possible that critical areas of systems and components are completely understood by all personnel concerned with their design, erection and operation.

Preheating of numbers 2 and 3 units, carried out in accordance with the above modifications, has proceeded without incident, and within the specified temperature limits.

If you require further information on this matter, please advise us immediately.

Very truly yours,

F. C. Gronemeyer
Project Manager
Atoms International Division

Addressee (5) w/encl. (5)
cc: J. V. Levy (1) w/encl. (1)

Enclosure 1 - Diagram of Steam Generator
Enclosure 2 - Number 1 Steam Generator Preheat Temperature Data
Enclosure 3 - Summary of Number 1 Steam Generator Preheat
Stress Calculations

PREPARED BY:	ATOMICS INTERNATIONAL A DIVISION OF NORTH-AMERICAN AVIATION, INC.	PAGE NO. OF
CHECKED BY:		REPORT NO.
DATE:		MODEL NO.

DIAGRAM OF STEAM GENERATOR

ENCLOSURE I

TO LETTER No. 62 AT 1824

Enclosure II To Letter 62AT1824

No. 1 Steam Generator Preheat Temperature Data

Preheat Rate Must Be Limited to 25°F/hr.

Temperature Difference Between Any Point on Steam Generator Should Be Limited to 50°F.

Steam Generator (Steam End)

<u>Time</u>	<u>TI-155-1</u>	<u>TI-155-2</u>	<u>TI-155-3</u>	<u>TI-155-4</u>	<u>TI-155-5</u>	<u>TI-155-6</u>	<u>TI-155-7</u>	<u>TI-155-8</u>
0730	102	100	100	100	100	105	103	102
0830	102	102	102	103	103			
0900	80	80	80	80	80	80	80	80
1000	85	85	85	85	85	85	85	85
1100	85	85	85	85	87	88	88	88
1200	110	110	109	138	142	89	88	85
1300	110	110	110	130	130	82	80	80
1400	110	110	112	130	120	82	70	82
1500	190	195	200	200	125	80	70	90
1600	199	200	200	199	198	75	73	90
1700	195	195	195	195	190	80	180	168
1800	198	198	196	195	200	97	195	195
1900	199	200	197	196	200	100	197	197
2000	200	200	200	199	200	102	200	200
2100	210	205	205	204	205	108	205	205
2200	213	214	214	213	216	112	213	213
2300	212	213	210	209	210	115	210	210
2400	212	212	210	208	205	122	205	205

Enclosure II Cont'd

No. 1 Steam Generator Preheat Temperature Data

Preheat Rate Must Be Limited to 25°F/Hr.

Temperature Difference Between Any Point on Steam Generator Should Be Limited to 50°F. (Especially Across Tube Sheets).

Superheater (Sodium End)

<u>Time</u>	<u>TRC-P8-7-9E</u>	<u>TRC-P9-11-4E</u>	<u>TI-P-F1-2-3E</u>	<u>-4E</u>	<u>-5E</u>	<u>-6E</u>	<u>-7E</u>
0730	96		79	76	75	76	77
0900	96	86	78	79	80	79	80
1000			96	90	90	83	87
1100	98	98	88	88	88	84	87
1200	95	92	98	887	87	85	87
1300	96	99	108	93	89	86	90
1500	112	104	100	98	92	90	93
1600	126	126	165	127	100	111	120
1700	142	144	182	135	104	120	130
1800	154	160	159	153	112	134	142 **
1900	158	164	155	156	113	136	143
2000	167	175	150	168	117	144	147
2100	179	183	156	169	119	149	154
2200	179	184	193	177	123	157	160
2300	183	192	171	183	126	162	166*
2400	188	198	162	184	130	164	172

* Note: Heaters were turned on for a period of 20 min. to heat up superheater no. 1. Leaving heaters on longer will result in overheating. Used switch No. 126 on "System B".

** These readings at 1820.

Enclosure II Cont'd

No. 1 Steam Generator Preheat Temperature Data

Preheat Rate Must Be Limited to 25°F/Hr.
Temperature Difference Between Any Point on Steam Generator Should Be
Limited to 50°F. (Especially Across Tube Sheets)

Evaporator (Sodium End)

<u>Time</u>	<u>TRC-P8-7-11E</u>	<u>TRC-P9-11-5E</u>	<u>TI-P-F1-1-3E</u>	<u>-4E</u>	<u>-5E</u>	<u>-6E</u>	<u>-7E</u>
0730			82	77	75	77	75
0900	94	88	81	80	80	80	80
1000			92	90	87	90	90
1100	98	89	88	88	87	87	88
1200	96	100	88	91	87	89	89
1300	94	111	100	100	88	97	95
1500	108	110	103	106	88	92	92
1600	126	174	137	134	97	123	122
1700	146	205	153	143	101	131	128
1800	157	178	174	160	110	143	141 Those read
1900	159	173	176	161	112	146	144 ing at 184
2000	174	169	186	170	117	151	149
2100	183	215	192	176	122	155	151
2200	183	209	198	183	125	158	157
2300	188	191	204	188	130	162	161*
2400	194	190	208	196	137	166	165

* Elect. Htrs were turned on for a period of 20 min to heat up
#1 superheater. Leaving heaters on longer will result in
overheating. Used switch No. 126 on "System B".

superheater Analysis

*Analysis of Thermal Transient Effects
on Hallow Steam Generator*

ATOMIC INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.		REWARD ST. <i>El Walters</i> 9-17-62 CHECKED BY <i>R. G. [Signature]</i>
PAGE NO. <i>1</i> OF <i>1</i>	REPORT NO.	DATE
MODEL NO.		

PREPARED BY:	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. <u>1</u> OF <u>02</u>
CHECKED BY:		REPORT NO.
DATE:		MODEL NO.

DIAGRAM OF STEAM GENERATOR

No. 1 Steam Generator Preheat Temperature Data

Preheat Rate Must Be Limited to 25°F/hr.

Temperature Difference Between Any Point on Steam Generator Should Be Limited to 50°F.

Steam Generator (Steam End)

<u>Time</u>	<u>TI-155-1</u>	<u>TI-155-2</u>	<u>TI-155-3</u>	<u>TI-155-4</u>	<u>TI-155-5</u>	<u>TI-155-6</u>	<u>TI-155-7</u>	<u>TI-155-8</u>
0730	102	100	100	100	100	105	103	102
0830	102	102	102	103	103			
0900	80	80	80	80	80	80	80	80
1000	85	85	85	85	85	85	85	85
1100	85	85	85	85	87	88	88	88
1200	110	110	109	138	142	89	88	85
1300	110	110	110	130	130	82	80	80
1400	110	110	112	130	120	82	70	82
1500	190	195	200	200	125	80	70	90
1600	199	200	200	199	198	75	73	90
1700	195	195	195	195	190	80	180	168
1800	198	198	196	195	200	97	199	195
1900	199	200	197	196	200	100	197	197
2000	200	200	200	199	200	102	200	200
2100	210	205	205	204	205	108	205	205
2200	213	214	214	213	216	112	213	213
2300	212	213	210	209	210	115	210	210
2400	212	212	210	208	205	122	205	205

No. 1 Steam Generator Preheat Temperature Data

Preheat Rate Must Be Limited to 25°F/Hr.

Temperature Difference Between Any Point on Steam Generator Should Be Limited to 50°F. (Especially Across Tube Sheets).

Superheater (Sodium End)

<u>Time</u>	<u>TRC-P8-7-9E</u>	<u>TRC-P9-11-4E</u>	<u>TI-P-F1-2-3-E</u>	<u>-4E</u>	<u>-5E</u>	<u>-6E</u>	<u>-7E</u>
0730	96		79	76	75	76	77
0900	96	86	78	79	80	79	80
1000			96	90	90	83	87
1100	98	98	88	88	88	84	87
1200	95	92	98	887	87	85	87
1300	96	99	108	93	89	86	90
1500	112	104	100	98	92	90	93
1600	126	126	165	127	100	111	120
1700	142	144	182	135	104	120	130
1800	154	160	159	153	112	134	142**
1900	158	164	155	156	113	136	143
2000	167	175	150	168	117	144	147
2100	179	183	156	169	119	149	154
2200	179	184	193	177	123	157	160
2300	183	192	171	183	126	162	166*
2400	188	198	162	184	130	164	172

* Note: Heaters were turned on for a period of 20 min. to heat up superheater no. 1. Leaving heaters on longer will result in overheating. Used switch no. 126 on "System B".

** These readings at 1820.

No. 1 Steam Generator Preheat Temperature Data

Preheat Rate Must Be Limited to 25°F/Hr.

Temperature Difference Between Any Point on Steam Generator Should Be Limited to 50°F. (Especially Across Tube Sheets)

Evaporator (Sodium End)

<u>Time</u>	<u>TRC-P8-7-11E</u>	<u>TRC-P9-11-5E</u>	<u>TI-P-F1-1-3E</u>	<u>-4E</u>	<u>-5E</u>	<u>-6E</u>	<u>-7E</u>	
0730			82	77	75	77	75	
0900	94	88	81	80	80	80	80	
1000			92	90	87	90	90	
1100	98	89	88	88	87	87	88	
1200	96	100	88	91	87	89	89	
1300	94	111	100	100	88	97	95	
1500	108	110	103	106	88	92	92	
1600	126	174	137	134	97	123	122	
1700	146	205	153	143	101	131	128	
1800	157	178	174	160	110	143	141	Those read
1900	159	173	176	161	112	146	144	ings at
2000	174	169	186	170	117	151	149	1840
2100	183	215	192	176	122	155	151	
2200	183	209	198	183	125	158	157	
2300	188	191	204	188	130	162	161*	
2400	194	190	208	196	137	166	165	

* Elect. Htrs. were turned on for a period of 20 min. to heat up no. 1 superheater. Leaving heaters on longer will result in overheating. Used switch No. 126 on "System B".

Since the superheater was the critical item, the analysis is made on that unit. Two analytical methods will be used.

Method No. 1

Assume:

- 1) Infinitely rigid tubesheet
- 2) Step change in shell temperature of 130°F
(70°F to 200°F)
- 3) No axial gradient in tubesheet
- 4) No radial gradient in shell wall
- 5) Tubesheet radial gradient in form of
- 6) All stresses additive at tubesheet to shell junction.

Justification of Assumptions:

- 1) An infinitely rigid tubesheet will give the highest shell stress condition and therefore is a conservative assumption.
- 2) A step change in the shell temperature will give higher stresses than "spreading" that gradient out.
- 3) Any axial gradient in the tubesheet will cause rotation and relieve stresses at the top.

- 4) Because of the insulation, the radial gradients in the shell wall would be small. The assumption of a step temperature in the shell compensates for neglecting these gradients.
- 5) The 1300F temperature difference was not an instantaneous change, therefore this a reasonable assumption.
- 6) The stresses calculated away from the ends do not fully develop at the boundaries. Therefore, adding these stresses at the boundary is conservative.

DESIGNED BY: <i>F.J. Waters</i> CHECKED BY: <i>Method R. G. L. T.</i>	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. <i>7</i> OF <i>02</i>
DATE:		REPORT NO.
		MODEL NO.

Superheater Thermocouple Locations

DESIGNED BY: <i>FW</i> CHECKED BY: <i>[Signature]</i> DATE:	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. 8 OF REPORT NO. MODEL NO.
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As first cut

1) Assume in shell away from ends

$\phi_T = 73.8^\circ$; T based on time 1900 hrs on 2/15/62

Since symmetry is involved above, we can use the configuration shown

In ①

$$M = M_0 - H_0 R (\sin \phi - \sin \alpha) - X_0 R (\cos \alpha - \cos \phi); \phi \text{ from } \alpha \text{ to } \pi$$

In ②

$$M = M_0 + X_0 R (\cos \phi - \cos \alpha) + H_0 R (\sin \alpha - \sin \phi); \phi \text{ goes from } 0 \text{ to } \alpha$$

Where $\alpha = 36.9^\circ$

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ATOMICS INTERNATIONAL
 A DIVISION OF NORTH AMERICAN AVIATION, INC.

PAGE NO. 9 OF 9
 REPORT NO. _____
 MODEL NO. _____

DATE: _____

$$U = \int \frac{M^2 ds}{2EI}$$

For cylinder $EI = D = \frac{Eh^3}{12(1-\nu^2)}$

In ①

$$U_1 = \frac{1}{2D} \int_{-\alpha}^{\pi} [M_0 - H_0 R (\sin \phi - \sin \alpha) - X_0 R (\cos \alpha - \cos \phi)]^2 R d\phi$$

$$\frac{\partial U}{\partial M_0} = 0_1 = \frac{1}{D} \int_{-\alpha}^{\pi} [M_0 - H_0 R (\sin \phi - \sin \alpha) - X_0 R (\cos \alpha - \cos \phi)] R d\phi$$

In ②

$$U_2 = \frac{1}{2D} \int_0^{\alpha} [M_0 + X_0 R (\cos \phi - \cos \alpha) + H_0 R (\sin \alpha - \sin \phi)]^2 R d\phi$$

$$\frac{\partial U_2}{\partial M_0} = 0_2 = \frac{1}{D} \int_0^{\alpha} [M_0 + X_0 R (\cos \phi - \cos \alpha) + H_0 R (\sin \alpha - \sin \phi)] R d\phi$$

@ junction; $0_1 = -0_2$

$$\delta_{x1} - \delta_T \sin \alpha - \delta_{x2} = 0$$

$$\delta_{H1} - \delta_T \cos \alpha - \delta_{H2} = 0$$

where; $\delta_T = R(\frac{T_1}{H_1} + \frac{T_2}{H_2})(1+\nu)$

$$\frac{\partial U_1}{\partial X_0} = \delta_{x1} = \frac{1}{D} \int_{-\alpha}^{\pi} [M_0 - H_0 R (\sin \phi - \sin \alpha) - X_0 R (\cos \alpha - \cos \phi)] R^2 (\cos \alpha - \cos \phi) d\phi$$

$$\frac{\partial U_2}{\partial X_0} = \delta_{x2} = \frac{1}{D} \int_0^{\alpha} [M_0 + X_0 R (\cos \phi - \cos \alpha) + H_0 R (\sin \alpha - \sin \phi)] R^2 (\cos \phi - \cos \alpha) d\phi$$

DESIGNED BY FJW	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. 10 OF
APPROVED BY R.H.		REPORT NO.
DATE		MODEL NO.

$$\frac{\partial U}{\partial H_0} = S_{H_1} = -\frac{1}{D} \int_{-\pi}^{\pi} [M_0 - H_0 R (\sin \phi - \sin \alpha) - X_0 R (\cos \alpha - \cos \phi)] R^2 (\sin \phi - \sin \alpha) d\phi$$

$$\frac{\partial U}{\partial H_0} = S_{H_2} = \frac{1}{D} \int_0^{\alpha} [M_0 + X_0 R (\cos \phi - \cos \alpha) + H_0 R (\sin \alpha - \sin \phi)] R^2 (\sin \alpha - \sin \phi) d\phi$$

$$\Theta_1 = \frac{1}{D} \left[M_0 \phi + H_0 R (\cos \phi + \phi \sin \alpha) - X_0 R (\phi \cos \alpha - \sin \phi) \right]_{-\pi}^{\pi}$$

$$= \frac{1}{D} \left[M_0 (\pi - \alpha) + H_0 R (-1 + \cos \alpha + \{\pi - \alpha\} \sin \alpha) - X_0 R (\{\cos \alpha\} \{\pi - \alpha\} - 0 + \sin \alpha) \right]$$

$$\Theta_2 = \frac{1}{D} \left[M_0 \phi + X_0 R (\sin \phi - \phi \cos \alpha) + H_0 R (\phi \sin \alpha + \cos \phi) \right]_0^{\alpha}$$

$$= \frac{1}{D} \left[M_0 (\alpha) + X_0 R (\sin \alpha - \alpha \cos \alpha) + H_0 R (\alpha \sin \alpha + \cos \alpha - 1) \right]$$

Since $\Theta_1 = -\Theta_2$

$$M_0 (\pi - \alpha) + H_0 R (-1 - \cos \alpha + \{\pi - \alpha\} \sin \alpha) - X_0 R (\{\pi - \alpha\} \cos \alpha + \sin \alpha) \\ = - \left[M_0 \alpha + X_0 R (\sin \alpha - \alpha \cos \alpha) + H_0 R (\alpha \sin \alpha + \cos \alpha - 1) \right]$$

$$M_0 (\pi - \alpha + \alpha) + H_0 R (-1 - \cos \alpha + \{\pi - \alpha + \alpha\} \sin \alpha + \cos \alpha - 1) \\ - X_0 R (\{\pi - \alpha + \alpha\} \cos \alpha + \sin \alpha - \sin \alpha) = 0$$

$$M_0 \pi + H_0 R (\pi \sin \alpha - 2) - X_0 R (\pi \cos \alpha) = 0$$

FORMER NO. FJW	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. 11 OF 12
DESIGNED BY Chetwood R. J.		REPORT NO.
DATE		MODEL NO.

$$S_{x1} = -\frac{B^2}{D} \left[M_0 (\phi \cos \alpha - \sin \phi) - H_0 R (-\cos \alpha \cos \phi - \phi \sin \alpha \cos \alpha - \frac{\sin^2 \phi}{2} + \sin \alpha \sin \phi) - X_0 R (\phi \cos^2 \alpha - \cos \alpha \sin \phi - \cos \alpha \sin \phi + \frac{1}{2} \phi + \frac{1}{4} \sin 2\phi) \right]_{\alpha}^{\pi}$$

$$S_{x2} = -\frac{B^2}{D} \left[M_0 (\phi \cos \alpha - \sin \phi) - H_0 R (-\cos \alpha \cos \phi - \phi \sin \alpha \cos \alpha - \frac{\sin^2 \phi}{2} + \sin \alpha \sin \phi) - X_0 R (\phi \cos^2 \alpha - \cos \alpha \sin \phi - \cos \alpha \sin \phi + \frac{1}{2} \phi + \frac{1}{4} \sin 2\phi) \right]_0^{\alpha}$$

$$S_{x1} = -\frac{B^2}{D} \left[M_0 (\{\pi - \alpha\} \cos \alpha + \sin \alpha) - H_0 R (\{\pi - \alpha\} \cos \alpha \{1 + \cos \alpha\} - \{\pi - \alpha\} \sin \alpha \cos \alpha + \frac{\sin^2 \alpha}{2} - \sin^2 \alpha) - X_0 R (\{\pi - \alpha\} \cos^2 \alpha + 2 \cos \alpha \sin \alpha + \frac{1}{2} \{\pi - \alpha\} + \frac{1}{4} \sin 2\alpha) \right]$$

$$S_{x2} = -\frac{B^2}{D} \left[M_0 (\alpha \cos \alpha - \sin \alpha) - H_0 R (\{\pi - \alpha\} \cos \alpha \{\cos \alpha - 1\} - \alpha \sin \alpha \cos \alpha - \frac{\sin^2 \alpha}{2} + \sin^2 \alpha) - X_0 R (\alpha \cos^2 \alpha - 2 \cos \alpha \sin \alpha + \frac{1}{2} \alpha + \frac{1}{4} \sin 2\alpha) \right]$$

Deflection equation in x

$$-\frac{B^2}{D} \left[M_0 \{(\pi - \alpha - \alpha) \cos \alpha + \sin \alpha + \sin \alpha\} - H_0 R \{(\cos \alpha) (1 + \cos \alpha + \cos \alpha - 1) - (\pi - \alpha - \alpha) \sin \alpha \cos \alpha - \sin^2 \alpha\} - X_0 R (\{\pi - \alpha - \alpha\} \cos^2 \alpha + 4 \cos \alpha \sin \alpha + \frac{1}{2} \{\pi - \alpha - \alpha\} - \frac{1}{2} \sin 2\alpha) \right] - [R \alpha \bar{T}_1 - R \alpha \bar{T}_2] (1 + \nu) \sin \alpha$$

$$\begin{aligned}
 & - \frac{R^2}{D} \left[M_0 \left[(\pi - 2\alpha) \cos \alpha + 2 \sin \alpha \right] - H_0 R \left[2 \cos^2 \alpha - (\pi - 2\alpha) \sin \alpha \cos \alpha \right. \right. \\
 & \quad \left. \left. - \sin^3 \alpha \right] - X_0 R \left[(\pi - 2\alpha) \cos^2 \alpha + 4 \cos \alpha \sin \alpha \right. \right. \\
 & \quad \left. \left. + \frac{1}{2} (\pi - 2\alpha) - \frac{1}{2} \sin 2\alpha \right] \right] R \left[\alpha, \pi \bar{T}_1 - R \alpha, \pi \bar{T}_2 \right] \left[\frac{1}{2} \sin 2\alpha \right]
 \end{aligned}$$

Deflection equations in H

$$\begin{aligned}
 S_{H1} = & - \frac{R^2}{D} \left[M_0 (-\cos \phi - \phi \sin \alpha) - H_0 R \left(\frac{1}{2} \phi - \frac{1}{4} \sin 2\phi + 2 \sin \alpha \cos \phi + \phi \sin^2 \alpha \right) \right. \\
 & \left. - X_0 R \left(-\cos \alpha \cos \phi - \frac{\sin^2 \phi}{2} + \phi \sin \alpha \cos \alpha + \sin \phi \sin \alpha \right) \right]
 \end{aligned}$$

$$\begin{aligned}
 S_{H2} = & - \frac{R^2}{D} \left[M_0 (-\cos \phi - \phi \sin \alpha) - H_0 R \left(\frac{1}{2} \phi - \frac{1}{4} \sin 2\phi + 2 \sin \alpha \cos \phi \right. \right. \\
 & \left. \left. + \phi \sin^2 \alpha \right) - X_0 R \left(-\cos \alpha \cos \phi - \frac{\sin^2 \phi}{2} - \phi \sin \alpha \cos \alpha \right. \right. \\
 & \left. \left. + \sin \phi \sin \alpha \right) \right]
 \end{aligned}$$

$$\begin{aligned}
 S_{H1} = & - \frac{R^2}{D} \left[M_0 \left\{ 1 - \pi \sin \alpha + \cos \alpha + \alpha \sin \alpha \right\} - H_0 R \left\{ \frac{\pi}{2} - 2 \sin \alpha + \pi \sin^2 \alpha \right. \right. \\
 & \left. \left. - \frac{\alpha}{2} + \frac{1}{4} \sin 2\alpha - 2 \sin \alpha \cos \alpha - \alpha \sin^2 \alpha \right\} - X_0 R \left\{ \cos \alpha \right. \right. \\
 & \left. \left. - \pi \sin \alpha \cos \alpha + \cos^2 \alpha + \frac{\sin^2 \alpha}{2} + \alpha \sin \alpha \cos \alpha + \sin^2 \alpha \right\} \right]
 \end{aligned}$$

$$\begin{aligned}
 = & - \frac{R^2}{D} \left[M_0 (1 + \cos \alpha + \{\alpha - \pi\} \sin \alpha) - H_0 R \left(\frac{\pi - \alpha}{2} + \{\pi - \alpha\} \sin^2 \alpha \right. \right. \\
 & \left. \left. - \{2 \sin \alpha\} \{1 + \cos \alpha\} + \frac{1}{4} \sin 2\alpha \right) - X_0 R \left(\cos \alpha \right. \right. \\
 & \left. \left. + \{\sin \alpha \cos \alpha\} \{\alpha - \pi\} + \cos^2 \alpha - \frac{\sin^2 \alpha}{2} \right) \right]
 \end{aligned}$$

PREPARED BY: <u>ELW</u>	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. <u>13</u> OF
CHECKED BY: <u>Method R.D.</u>		REPORT NO.
DATE:		MODEL NO.

$$\begin{aligned} \delta_{H2} = -\frac{B^2}{D} \left[M_0(-\cos\alpha - \alpha \sin\alpha + 1) - H_0 R \left(\frac{\alpha}{2} - \frac{1}{4} \sin 2\alpha + 2 \sin\alpha \cos\alpha \right. \right. \\ \left. \left. + \alpha \sin^2\alpha - 2 \sin\alpha \right) - X_0 R \left(-\cos^2\alpha - \frac{\sin^2\alpha}{2} - \alpha \sin\alpha \cos\alpha \right. \right. \\ \left. \left. + \sin^2\alpha + \cos\alpha \right) \right] \end{aligned}$$

Deflection equation;

$$\begin{aligned} -\frac{R^2}{D} \left[M_0(\pi - \pi \sin\alpha + \cos\alpha + \alpha \sin\alpha + \cos\alpha + \alpha \sin\alpha - \pi) \right. \\ \left. - H_0 R \left(\frac{\pi}{2} - 2 \sin\alpha + \pi \sin^2\alpha - \frac{\alpha}{2} + \frac{1}{4} \sin 2\alpha - 2 \sin\alpha \cos\alpha - \alpha \sin^2\alpha \right. \right. \\ \left. \left. - \frac{\alpha}{2} + \frac{1}{4} \sin 2\alpha - 2 \sin\alpha \cos\alpha - \alpha \sin^2\alpha + 2 \sin\alpha \right) \right. \\ \left. - X_0 R \left(\cos\alpha - \pi \sin\alpha \cos\alpha + \cos^2\alpha + \frac{\sin^2\alpha}{2} + \alpha \sin\alpha \cos\alpha \right. \right. \\ \left. \left. - \sin^2\alpha + \cos^2\alpha + \frac{\sin^2\alpha}{2} + \alpha \sin\alpha \cos\alpha - \sin^2\alpha - \cos\alpha \right) \right] \end{aligned}$$

$$= (1+D)R [\alpha_{1T} \bar{T}_1 - \alpha_{2T} \bar{T}_2] \cos\alpha \neq 0$$

$$\begin{aligned} -\frac{R^2}{D} \left[M_0(\{2\alpha - \pi\} \sin\alpha + 2 \cos\alpha) - H_0 R \left(\frac{\pi - \alpha}{2} + \{\pi - \alpha\} \sin^2\alpha \right. \right. \\ \left. \left. + \frac{1}{2} \sin 2\alpha - 4 \sin\alpha \cos\alpha \right) - X_0 R (\{2\alpha - \pi\} \sin\alpha \cos\alpha + 2 \cos^2\alpha \right. \\ \left. - \sin^2\alpha) \right] - R [\alpha_{1T} \bar{T}_1 - \alpha_{2T} \bar{T}_2] [\cos\alpha] [1+D] = 0 \end{aligned}$$

✓

PREPARED BY: <u>FJW</u>	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. <u>11</u> OF
DESIGNED BY: <u>R.D.</u>		REPORT NO.
DATE:		MODEL NO.

$$\sin \alpha = 0.6 ; R = 29.06 \text{ in}$$

$$\cos \alpha = 0.8 \quad h = 2.875 \text{ in}$$

$$D = \frac{5h^3}{12(1-\nu^2)} = \frac{29 \times 2.875^3 \times 10^6}{12(0.91)} = 63 \times 10^6$$

$$E = 29 \times 10^6 \text{ psi}$$

$$\alpha = 6 \times 10^{-6} \text{ in/in}^\circ\text{F}$$

$$\nu = 0.3$$

$$M_0 \pi + H_0 [R] [\pi \times 0.6 - 2] - X_0 R (\pi \times 0.8) = 0$$

$$M_0 + H_0 [-1065] - 23.25 X_0 = 0$$

$$M_0 - 1.065 H_0 - 23.25 X_0 = 0 \quad (1)$$

$$- \frac{R}{63 \times 10^6} \left\{ M_0 \left[\frac{\pi - 1.288}{1.852} 0.8 + 2 \times 0.6 \right] - H_0 R \left[2 \times 0.64 - (1.852) 0.8 \right] \right. \\ \left. - 0.36 \right\} - X_0 R \left[1.852 \times 0.64 + 4 \times 0.18 + \frac{1.852}{2} - 0.18 \right] \\ - R (1.8) [6 \times 10^{-6}] [130] [0.6] = 0$$

$$+ \frac{R}{13} \left\{ M_0 [2.68] - H_0 R [-0.03] - X_0 R [3.552] \right\}$$

$$+ \frac{63 \times 10^6}{R} = 0$$

$$2.68 M_0 - 0.8718 H_0 - 1032 X_0 = -1319 \quad (2)$$

PREPARED BY: <u>FJW</u>	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. <u>15</u> of
DESIGNED BY: <u>R. J. R.</u>		REPORT NO.
DATE:		MODEL NO.

$$\begin{aligned}
 & - \frac{R}{D} \left[M_0 \left(\{-1.852\} 0.6 + 1.6 \right) - H_0 R \left(0.926 + \frac{0.666}{1.852 \times 0.36} \right) \right. \\
 & \quad \left. + 0.48 - 1.92 \right) - X_0 R \left(-1.852 \times 0.48 + 1.28 - 0.36 \right) \right] \\
 & - R \left(6 \times 10^{-6} \right) (1.3) [130] 0.8 = 0
 \end{aligned}$$

$$\begin{aligned}
 & + \frac{29.06}{63} \left[0.4888 M_0 - H_0 R (0.152) - X_0 R (0.03) \right] \\
 & + 6 \times 1.3 \times 130 \times 0.8 = 0
 \end{aligned}$$

$$0.4888 M_0 - 4.42 H_0 - 0.8718 X_0 = -1759 \quad (3)$$

Solving Equations 1, 2 & 3 yields:

$$\begin{aligned}
 M_0 &= 2198 \text{ in-lb} \\
 X_0 &= 62.3 \text{ lb} \\
 H_0 &= 619 \text{ lb}
 \end{aligned}$$

$$\begin{aligned}
 \sigma_\phi &= \pm \frac{6 M_0}{h^2} - \frac{(H_0 \sin \alpha - X_0 \cos \alpha)}{h} \\
 &= \pm \frac{6}{2.875^2} \times 2198 - \frac{(619 \times 0 - 62.3 \times 0.8)}{2.875} \\
 &= \pm 1535 - 112
 \end{aligned}$$

$$\sigma_\phi \begin{cases} = -1697 \text{ psi outside} \\ = 1423 \text{ psi inside} \end{cases}$$

PREPARED BY: FJW	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. 16 OF
CHECKED BY: Reith R.G.		REPORT NO.
DATE:		MODEL NO.

Axial Effects

Consider unit unrestrained in expansion or bowing
then the axial stress is given by

$$\sigma_x = -E\alpha [T - \bar{T} - \Delta T \sqrt{h}]$$

$$\text{where } \bar{T} = \frac{1}{A} \int T dA$$

$$\Delta T = \frac{2\alpha}{I} \int T y dA$$

since $R/h > 10$ use annular formulas,

$$\bar{T} = \frac{1}{2\pi rh} \left[T_1 2\pi rh \left(\frac{73.8}{360} \right) + T_2 2\pi rh \left(\frac{286.2}{360} \right) \right]$$

$$= 70 (.205) + 200 (.795)$$

$$\bar{T} = 14.35 + 159 = 173.4 \text{ F}$$

$$\begin{aligned} \Delta T &= \frac{2\alpha}{\pi r^3 h} \left[T_1 2\pi rh \left(-r \frac{\sin 36.9}{\frac{36.9\pi}{180}} - r \cos 36.9 + r \cos 36.9 \right) + (200) T_2 2\pi rh \left(r \frac{\sin 143.1}{\frac{143.1\pi}{180}} - r \cos 143.1 - r \sin 53.1 \right) \right] \\ &= \frac{2r}{\pi r^3 h} \left[(70) 2\pi rh \left(-r \frac{.6 \times 180}{36.9\pi} \right) + (159) 2\pi rh \left(\frac{.6 r \times 180}{143\pi} \right) \right] \end{aligned}$$

PREPARED BY: <u>FJW</u>	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. <u>17</u> of
CHECKED BY: <u>Richard R. G.</u>		REPORT NO.
DATE: <u>2/23/62</u>		MODEL NO.

$$\Delta T = \frac{Z_1}{\pi + \pi K} \left[- (205 \times \pi \times 24) \pi_1 (0.932) + T_2 \times \pi \times 24 (0.2405 \times 795) \right]$$

$$= 4 \left[- 0.932 (70 \times 205) + (715 \times 200 \times 2405) \right]$$

$$= 4 \left[- 1835 + 38,2 \right]$$

$$\Delta T = 99 \text{ F}$$

$$\sigma_K = - 174 \left[200 - 173.1 - \frac{99}{2} \right] = 3980 \text{ psi @ Top}$$

$$\sigma_K = - 174 \left[70 - 173.1 + \frac{99}{2} \right] = 9390 \text{ psi @ Bottom}$$

STRESS DISTRIBUTION

$$@ y = .87$$

$$\sigma_K = - 174 \left[200 - 173.1 + 99 \right]$$

$$= - 11,510 \text{ psi}$$

$$\sigma_K = - 174 \left[70 - 173.1 + 39.6 \right]$$

$$= 11,100 \text{ psi}$$

PREPARED BY: <u>FW</u>	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC	PAGE NO. <u>18</u> OF
CHECKED BY: <u>R. J.</u>		REPORT NO.
DATE:		MODEL NO.

AT Tubesheet ; Assume

- 1) Shell expands @ $T_{AVE} = 200 F$
- 2) Tubesheet radial gradient of

$$T = T_0 + T_1 \frac{r^2}{b^2}$$

where $T_1 = 130 F$
 $T_0 = 70$

The average temp. is;

$$\bar{T} = \frac{\int_0^b T r dr}{\int_0^b r dr} = \frac{2}{b^2} \left[\int_0^b T_0 r dr + \int_0^b T_1 \frac{r^3}{b^2} dr \right]$$

$$= \frac{2}{b^2} \left[T_0 \frac{b^2}{2} + T_1 \frac{b^2}{4} \right]$$

$$\bar{T} = T_0 + \frac{T_1}{2} = 135 F$$

The stress at the junction assuming built-in conditions is;

$$\sigma_r = \pm 1.82 E \alpha (T_{shell} - T_{Tubesheet})$$

$$\sigma_r = \pm 20,600 \text{ psi}$$

Compression outside
Tension inside

$$\frac{M}{EI} - \frac{Q}{2EI} = 0$$

$$\frac{Q}{2EI} - \frac{M}{2EI} = R \Delta T$$

$$M = 2\beta^3 D R \Delta T$$

$$Q = 4\beta^3 D R \Delta T;$$

$$Q = 2\beta M$$

$$\sigma_{\phi} = - \frac{2QR}{h} \cdot 4\beta^3 D R \Delta T$$

$$= - \frac{8}{h} R^2 \frac{2\beta^3 D R \Delta T}{\beta^3 h^2} \frac{E h^3}{12(1-\nu)} \Delta T$$

$$= - 2E \alpha \Delta T$$

$$= - 22,400 \text{ psi}$$

PREPARED BY: FJW	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. 19 OF
CHECKED BY: R.G.		REPORT NO.
DATE:		MODEL NO.

$$\sigma_{\phi M} = E \alpha \Delta T = \pm 11,300 \text{ psi throughout}$$

$$\sigma'_M = 0.3 \times 20,600 = 6,180 \text{ comp. outside}$$

ten. inside

Axial Stress

Circumferential Stress

1) 3890 psi (top of shell)	1) -1650 psi (outside)
9390 psi (bottom of shell)	1420 psi (inside)
-11,310 psi (@ step for 200 portion)	-11,300 psi (through out)
11,100 psi (@ step for 70F portion)	-6180 psi (outside)
-20,600 psi (@ lip outside)	6,180 psi (inside)
20,600 psi (@ lip inside)	

Using equivalent uniaxial stress

$$\sigma_i = \sqrt{\sigma_{x \max}^2 + \sigma_{\phi \max}^2 - \sigma_x \sigma_{\phi}}$$

$$= \sqrt{(31,700)^2 + (-3700)^2 + .37 \times 31,710^2}$$

$$\sigma_i = 33,700 \text{ psi}$$

[@ step inside lip
bottom of unit]

PREPARED BY: <u>Waters</u>	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. <u>20</u> OF
CHECKED BY: <u>Method</u>		REPORT NO.
DATE:		MODEL NO.

To establish a stress range, the second method will assume;

- 1) An infinitely rigid tubesheet
- 2) A shell temperature distribution of the form

$$T = T_0 + T_1 \sin \phi$$
- 3) A tubesheet temperature of 70°F (constant).
- 4) No axial gradient in tubesheet
- 5) No radial gradient in shell wall
- 6) All stresses additive at the tubesheet to shell junction.

Justification.

Assumptions (1), (4), (5) and (6) are justified in method number 1.

2) This is a conservative assumption because for this form, the temperature difference from top to bottom of the unit becomes 186°F which is larger than the measured difference.

3) This is a very conservative assumption because it implies that the shell reacts instantly to the temperature field while the tubesheets show no response at all.

PREPARED BY: <u>FJW</u>	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. <u>21</u> OF
CHECKED BY: <u>R. J. J.</u>		REPORT NO.
DATE:		MODEL NO.

Method Two. Assume

$$T = T_0 + T_1 \sin \phi \quad (\text{This is less accurate than steps for overall section distortion})$$

$$@ \phi = 86.9 \quad T = 200 F$$

$$\phi = -53.1 \quad T = 70 F$$

$$200 = T_0 + T_1 (.6)$$

$$70 = T_0 - T_1 (.8)$$

$$130 = 1.4 T_1$$

$$T_1 = 92.9 F$$

$$T_0 = 74.4 + 70 = 144.4 F$$

$$@ \text{Top } T = 144.4 + 92.9 = 237.3$$

$$@ \text{Bottom: } T = 51.5 F$$

From Goodier's method for $\Delta T = 0$ & $T = \bar{T}$

$$\frac{M \phi}{I} = -E \left[\alpha \frac{92.9}{r} \sin \phi \right]$$

$$\sigma_{\phi \max} = -E \alpha \frac{92.9}{r} \left(\pm \frac{h}{2} \right) \left[\begin{array}{l} \text{Compression inside} \\ \text{Tension outside} \end{array} \right]$$

$$= -174 \times \frac{92.9}{29.06} \left(\pm \frac{2.875}{2} \right) = \pm 800 \text{ psi}$$

$$\text{now } w = -r \alpha \bar{T}_0 \text{ where } \bar{T}_0 = 144.4 F$$

PREPARED BY: <u>FJW</u>	ATOMICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	PAGE NO. <u>22</u> OF
CHECKED BY: <u>R.M.</u>		REPORT NO.
DATE:		MODEL NO.

for overall distortion of section

$$\begin{aligned}\bar{T} &= \frac{1}{A} \int T dA \\ &= \frac{1}{\pi r^2} \int_{-\pi/2}^{\pi/2} [T_0 + T_1 \sin \phi] r^2 d\phi \\ &= \frac{1}{\pi} \left[T_0 \phi + T_1 (-\cos \phi) \right]_{-\pi/2}^{\pi/2}\end{aligned}$$

$$\bar{T} = T_0$$

$$\Delta T = \frac{2r}{\pi r^2} \int_{-\pi/2}^{\pi/2} [T_0 + T_1 \sin \phi] r^2 \sin \phi d\phi$$

$$= 2 \times \frac{2}{\pi} \left\{ \left[T_0 (-\cos \phi) \right]_{-\pi/2}^{\pi/2} + T_1 \frac{1}{2} (\pi/2 + \pi/2) \right\}$$

$$\Delta T = 2T_1$$

Considering unit as unrestrained in expansion but only half-restrained in bending (support will allow half of bowing, this is conservative since if full bowing allowed $\sigma_x = 0$)

$$\text{then } \sigma_x = -E\alpha [T - T_0 - T_1, 3/2r]$$

$$\sigma_x = -174 \left[237.3 - 141.1 - \frac{92.9}{2} \right] = -8090 \text{ psi Top}$$

$$\sigma_x = -174 \left[51.5 - 141.1 + \frac{92.9}{2} \right] = +8090 \text{ psi Bottom}$$

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CHECKED BY: <u>RG</u>		REPORT NO.
DATE:		MODEL NO.

If tubeshoot expands @ $T_{AVG} = 135^{\circ}F$
 then @ lip

$$\textcircled{1} \quad \sigma_x = \pm 1.82 \times 174 [144.4 - 135] = 2980 \text{ psi}$$

[Compression outside
Tension inside]

If Tubosheet @ $T_{AVG} = 70$

$$\textcircled{2} \quad \sigma_x = \pm 1.82 \times 174 [144.4 - 70] = 23,600 \text{ psi}$$

[outside Compression
inside Tension]

$$\sigma_{\phi 1} = -1,640 \text{ psi (Throughout)}$$

$$\sigma_{\phi 2} = -12,950 \text{ psi (Throughout)}$$

$$\sigma_{\phi' 1} = 895 \text{ psi (compression outside; Tension inside)}$$

$$\sigma_{\phi' 2} = 7,090 \text{ psi (compression outside; Tension inside)}$$

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CHECKED BY: <i>Method 29</i>		REPORT NO.
DATE:		MODEL NO.

For 70F tubeshort

σ_x

-8090 psi (Top)

8090 psi (Bottom)

-23,600 psi (outside)

23,600 psi (inside)

σ_ϕ

-800 psi (inside)

+800 psi (outside)

-12,950 psi (throughout)

-7090 psi (outside)

7090 psi (inside)

$$\sigma_L = 10^3 \sqrt{3.17^2 + 0.666^2 + 0.666 \times 3.17}$$

$$\sigma_L = 35,600 \text{ psi} \quad (\text{Bottom-inside lip})$$

For $T \frac{r^2}{b^2}$ in tubeshort

σ_L negligible since σ_a discontinuity ≈ 3000 psi

From previous work the maximum stress is believed to lie between

$$\sigma_L = 33,700 \text{ and } 35,600 \text{ psi}$$

The maximum stress is equivalent to an elastic strain of:

$$\epsilon = \frac{35.6 \times 10^3}{29 \times 10^4} = 1.228 \times 10^{-3}$$

DESIGN NO. <i>FDW</i> ORDER NO. <i>25</i> DATE	ATONICS INTERNATIONAL A DIVISION OF NORTH AMERICAN AVIATION, INC.	DRAWING NO. <i>25</i> REVISION NO. MODEL NO.
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During hydrostatic test the vessel withstood a pressure of 2040 psi which is equivalent to a strain of;

$$\epsilon = \left(\frac{1.82 \times 2040 \times 30}{2.875} \right) / 29 \times 10^6 + \frac{2040 \times 30}{2 \times 2.875} / 29 \times 10^6$$

$$\epsilon = 1.34 \times 10^{-3} + 0.367 \times 10^{-3} = 1.707 \times 10^{-3}$$

Therefore the hydrostatic test strain was larger than that occurring during the shock and cracking should not have occurred.

APPENDIX B

Review and Comments

on

Analysis of Thermal Transient Effects
on Hallam Steam Generator - Superheater
Analysis

APPENDIX B

Review and Comments

on

"ANALYSIS OF THERMAL TRANSIENT EFFECTS ON HALLAM STEAM GENERATOR - SUPERHEATER ANALYSIS", (A Set of Calculations by Atomics International)

The assumptions and results of Methods I and II of the subject calculations are summarized in the attached Tables I and II.

A review of the assumptions made in the calculations Table I indicates that Assumptions A and E have a direct effect on the calculated stresses while Assumptions B, C, and D do not enter the calculations directly. Furthermore it can be shown that the latter three assumptions are conservative:

Assumption B neglects a possible thermal gradient through the shell thickness. Since the unit was externally insulated and heated from the inside, such gradient should be rather small. Furthermore, the heat flow is from the inside to the outside. This gradient would produce compressive stresses on the inner surface and tensile stresses on the outer surface of the shell wall. It is seen in Table II that these stresses are of an opposite sign to the predominant stresses set up by the shell and tubesheet discontinuity effects.

Assumptions C and D have essentially the same effect in restraining the radial expansion and rotation of the tubesheet so as to make the discontinuity stresses more pronounced. The assumptions are again conservative.

Essentially the calculated stresses are determined on the basis of Assumptions A and E. These assumptions interpret the fragmentary thermocouple data in order to establish the pertinent temperature gradients for stress calculations. The Methods I and II assign different temperature distributions to both the shell and the tubesheet and calculate the resultant stresses.

TABLE B-I
SUMMARY OF ASSUMPTION

Item		Method I	Method II
Shell	A	Step change in shell temperature from 70 to 200 F, giving $T_{avg} = 173.4 \text{ F}$	Shell temperature taken as $T = T_0 + T_1 \sin \phi$, giving $T = 144.4 + 92.9 \sin \phi$ and $T_{avg} = 144.4 \text{ F}$
	B	No radial gradient.	No radial gradient.
Tubesheet	C	Infinitely rigid.	Infinitely rigid.
	D	No axial gradient.	No axial gradient.
	E	Radial gradient taken as $T = 70 + 130 r^2 / b^2$, giving $T_{avg} = 135 \text{ F}$	Constant temperature of 70F

TABLE B-II

SUMMARY OF CALCULATED STRESS

Item	Method I	Method II
Free Shell		
Circumferential, σ_{ϕ} bending	-1650* out	800 + out
	*1420 in	- in
Axial, σ_x membrane	-11,500	8-90 - Top
	+11,100	+Bottom
Shell & Tubesheet discontinuity		
ΔT	200-135 = 65F	144.4-70 = 74.7F
Axial, σ_x bending	20,600 - out	23,600 - out
	+ in	+ in
Circumferential, σ_{ϕ} membrane	11,300	12,950
σ_{ϕ} bending	6180 - out	7-90- out
	+ in	+ in
Combined Stresses by Distortion energy method	33,700	35,600

* These stresses are in error, should be even smaller.

The stress calculations show that the "free shell" stresses are rather small and not very sensitive to differences in the assumed variation of the shell temperature. The predominant stresses are caused by the discontinuity effects between the tubesheet and the shell. These stresses are directly proportional to the difference between the average temperatures of the two elements. In both calculation methods, this difference is about the same 65 F and 74.7 F, respectively. This results in a combined stress of some 35,000 psi.

In line with the recorded temperatures, the assumed temperature variations are not unreasonable. A somewhat more conservative but less realistic assumption would consider that the tubesheet remained at a constant temperature of 70 F (E from Method II) while the average shell temperature increased to 173 F (A from Method I). The temperature difference is then about 103 F.

$$\sigma_{\chi} = \pm 32,600 \qquad \sigma_{\phi} = 18,000 \pm 9,800$$

The combined stress increases then to about 47,500 psi.

It is of interest to compare the discontinuity stresses during preheating with those of the hydrostatic test. In both cases, the shell would like to expand away from the tubesheet and must be restrained by discontinuity moments and shears. Assuming as before that the tubesheet is infinitely rigid the discontinuity stresses are proportional to the following expansions.

$$\text{Hydrostatic test} \qquad w = pR^2 / Eh$$

$$\text{Thermal expansion} \qquad w = R\alpha \Delta T$$

Equating the two expressions and substituting:

$$\Delta T = \frac{R}{h\alpha E} p = 2040 \times 29 / 2.875 \times 174 = 118 \text{ F}$$

This calculation implies that the hydrostatic pressure of 2040 psi produced stresses that correspond to a temperature difference of 118 F between the shell and the tubesheet. This difference is somewhat larger than the previous assumptions.

In conclusion, the writer's review of the subject stress calculations indicates that the calculations on the whole adequately describe the stress conditions at the junction between the shell (steam end) and the tubesheet

during preheating of the steam generator unit. The writer has not examined the possible state of stress at other locations of the unit.

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HALLAM NUCLEAR POWER FACILITY
PREOPERATIONAL TEST COMPLETION REPORT
INSTRUMENT AIR SYSTEM

AI-P-1117

Test and Analysis

by

D. J. SOBO

Evaluation

by

W. P. CORCORAN

A T O M I C S I N T E R N A T I O N A L
A DIVISION OF NORTH AMERICAN AVIATION, INC.
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CONTRACT: AI(11-1)-GEN-8

April 17, 1962

CONTENTS

I. Purpose of Test.	1
II. Discussion of Test Performance	1
III. Analysis and Presentation of Test Results. . .	3
IV. Compliance with Test Completion Criteria . . .	7
V. Evaluation	8

TABLES

I. Performance of Instrument Air System During Back-Up Test.	5
II. Calibration of Accumulator Pressure Gages. . .	5
III. Performance of Accumulator Relief Valves . . .	6
IV. Accumulator Pressure Alarm Settings.	6

FIGURES

1117-1 Daily Range, in Pressure, for Instrument and Service Air	10
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HALLAM NUCLEAR POWER FACILITY

PREOPERATIONAL TEST COMPLETION REPORT

INSTRUMENT AIR SYSTEM, AI-P-1117

I. PURPOSE OF TEST

The purposes of AI-P-1117, "Instrument Air System", were as follows:

- a) To verify that the CPPD instrument air supply to HNPf has sufficient capacity and was free of oil, water, dirt, and scale.
- b) To verify that the nitrogen system would adequately back up the instrument air system should that system ever fail.
- c) To verify proper operation of the relief valves, pressure gages, and alarms associated with the 14 inch sodium throttle valve service air accumulators.
- d) To verify that the instrument air and nitrogen systems serve as two separate and independent back up sources to the service air supply to the throttle valve accumulators.
- e) To verify proper operation of the reactor unit main control board low instrument air pressure alarm.

II. DISCUSSION OF TEST PERFORMANCE

Each and every instrument air filter or combination filter-regulator was blown-down and observed for foreign matter. No foreign matter was observed.

With all HNPf pneumatic instrument air supplies turned on, except the maintenance cell consoles, the HNPf

instrument air supply from CPPD was shut down. It was observed that the nitrogen supply cut into the instrument air supply through line 979-1 1/2"-E when the instrument air pressure fell to 30 psig. Instrument air gage PI-1600 was observed to then hold the system at 30 psig.

All five throttle valve service air accumulators were put in service and pressurized to 125 psig using the service air system. The annunciator drop "Low Pressure Throttle Valve Accumulators" was cleared. Then, one at a time, each accumulator was valved out of the system, and a nitrogen bottle and regulator were attached to the accumulator through the drain valve. The valved-out accumulator was then pressurized to 140 psig and proper operation of the accumulator relief valve and pressure gage was verified. After removal of the nitrogen bottle, the accumulator was vented down to 120 psig, and proper operation of the annunciator drop was verified. The accumulator was repressurized to 125 psig with the service air system and returned to service. While at 140 psig, proper operation (no leakage) was verified for the accumulator inlet check valve. This was repeated for the other four accumulators.

All five sodium throttle valve accumulators were put in normal service and pressurized to 125 psig. The service air to HNPF was then shut off at CPPD's block valves, and the service air system was vented. At 100 psig, it was observed that the instrument air system cut into the service air supply to the accumulators through check valve V-1651. This held the accumulators at 100 psig, and no back-pressuring of the service air system through check valve V-1649 was observed on PI-1601, the service air pressure gage.

The system was returned to normal service by opening the service air supply valves. System pressure was returned

to 125 psig. The instrument air back-up block valve, V-1650, and the service air supply valve, V-1648 were closed. The nitrogen back-up supply valve, V-943, had been previously closed. By using the drain valve on one of the accumulators, the accumulators were all bled down to 75 psig. Then, the nitrogen back-up was allowed to flow by opening V-943. It was observed that the accumulators were repressurized to 90 psig by the nitrogen back-up.

The service air system was returned to normal operation by opening all block valves that had been closed for test purposes.

The HNPF main board instrument air supply valves (four valves in the main board) were shut. The annunciator drop "HNPF Low Instrument Air Pressure" actuated at 18 psig. The supply valves were re-opened, and the alarm reset at 19.5 psig.

III. ANALYSIS AND PRESENTATION OF TEST RESULTS

Blowdown of the instrument air filters showed that the air supply was clean, and free of moisture and foreign particles.

The capacity of the instrument air system during normal operation was sufficient. The system maintained supply pressure at 94 psig vs an expected supply pressure of 100 psig.

During performance of the nitrogen backup test, all instrument air users, except the maintenance cell consoles, were in service. (The maintenance cell consoles were not complete at the time of this test.) As can be seen in Table I, system pressure dropped to a minimum of 25 psig and then recovered to 31 psig. Since the maintenance cell consoles would only use a

few scfm of supply air (or nitrogen), the nitrogen system has sufficient capacity to back up the instrument air system.

The results of the tests of relief valves, pressure gages, and alarms associated with the sodium throttle valve accumulators are presented in Tables II through IV.

When an individual accumulator was at 140 psig, and the other accumulators were at 125 psig, it was observed that no leakage occurred through check valves V-1667, V-1671, V-1675, V-1661, and V-16131.

When the service air supply pressure dropped below the instrument air supply pressure, instrument air cut into the accumulator supply line through check valve V-1651. No back-leakage to the service air system through check valve V-1649 was observed.

When the supply pressure to the accumulators dropped below 90 psig, the nitrogen system backup, from PCV-913 through line 978-1"-E kept the accumulators pressurized to 90 psig.

The main board low air pressure alarm was set to alarm at 18 psig and reset at 19.5 psig.

TABLE I
PERFORMANCE OF INSTRUMENT AIR SYSTEM DURING BACK-UP TEST

Time	Instrument Air Supply	Instrument Air System Pressure (psig)
0440	On	94
0445	Start Shut Off	94
0448	Finish Shut Off	94
0458	Off	25
0503	Off	30
0523	Off	31
0530	Off	31

TABLE II
CALIBRATION OF ACCUMULATOR PRESSURE GAGES

Accumulator	Correct Pressure (psig)	Pressure Gage	Observed Pressure (psig)
T 1601	125	PI-1603	128
T 1602	125	PI-1604	126
T 1603	125	PI-1605	126
T 1605	125	PI-1606	124
T 1604	125	PI-1607	124

TABLE III

PERFORMANCE OF ACCUMULATOR RELIEF VALVES

Accumulator	Relief Valve	Expected Lift Pressure (psig)	Lift Pressure (psig)	Expected Reseat Pressure (psig)	Reseat Pressure (psig)
T 1601	RV-1603	140	142	130	129
T 1602	RV-1604	140	140	130	136
T 1603	RV-1605	140	141	130	131
T 1605	RV-1606	140	140	130	133
T 1604	RV-1607	140	140	130	131

TABLE IV

ACCUMULATOR PRESSURE ALARM SETTINGS

Accumulator	Expected Alarm (psig)	Alarm Pressure (psig)	Alarm Reset Pressure (psig)
T 1601	120	119	122
T 1602	120	119	123
T 1603	120	119	122
T 1605	120	118	122
T 1604	120	119	123

IV. COMPLIANCE WITH TEST COMPLETION CRITERIA

The following is a list of the Test Completion Criteria taken from pages XI(a)-7 and XI(a)-8, NAA-SR-5700, Supplement 2, with remarks about the test to show compliance with the criteria.

- a) Criterion: The instrument air system is free of visible dirt, scale, oil and water at each air filter by blowdown into cheesecloth or white paper.

Remarks: Cleanness of system verified.

- b) Criterion: The instrument air system maintains pressure at about 100 psig with all components operating.

Remarks: The system maintains 94 psig with the conventional and nuclear plant pneumatic instruments operating. This is considered satisfactory.

- c) Criterion: The nitrogen system maintains pressure at > 30 psig in the event of instrument air system failure. If the instrumentation system cannot hold pressure under these conditions, subsystems will be deleted until pressure is held and an operating procedure will be prepared for this circumstance. (The maintenance cell consoles' supply will be the first subsystem valved out.)

Remarks: After a 15 min stabilization period, the nitrogen system maintains the instrument air system at 31 psig. During stabilization, following an air system shutdown, the minimum system pressure was 25 psig. Since all HNPF

instruments will operate with supply pressures as low as 18 psig, the nitrogen back-up to the instrument air system is considered adequate. (The maintenance cell consoles were not connected during this test, as construction was not yet complete. Since air consumption by the consoles is less than 5 scfm, there will be no problem.)

- d) Criterion: The service air accumulators normally operate at about 125 psig. The relief valve on each accumulator opens at 140 psig, the alarm operates at 120 psig, the instrument air system backs up service air to the accumulators at 100 psig, and the nitrogen system backs up service air to the accumulators at 90 psig.

Remarks: The service air accumulators operate at 124-128 psig. The relief valves operate at 140-142 psig. The accumulator low pressure alarms actuate at 118 to 119 psig. The instrument air and nitrogen system back-ups to the service air to the accumulators operate as designed at 100 psig and 90 psig, respectively.

V. EVALUATION

Although the instrument air system and certain sections of the service air system have been satisfactorily tested and operated at design conditions, these systems cannot be favorably evaluated until we can be assured that "normal" operating conditions will conform to design conditions.

FIG. 1117-1 DAILY RANGE IN PRESSURE FOR INSTRUMENT & SERVICE AIR

HALLAM NUCLEAR POWER FACILITY
PREOPERATIONAL TEST COMPLETION REPORT
EMERGENCY POWER SYSTEM

AI-P-1118

Test and Analysis
by
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Evaluation
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A T O M I C S I N T E R N A T I O N A L
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CONTENTS

	Page
I. Purpose of Test	1
II. Discussion of Test Performance	1
A. Diesel Generator (Section 1)	1
1. Preliminary Relay and Protective Device Tests	1
2. Engine Accessory Equipment Checkout	5
3. Diesel Engine Operation	7
4. Generator Operation	9
5. Switchgear and Load Tests	10
B. Automatic Operation of Diesel Generator (Section 2)	13
C. Noise-Sensitive Power System (Section 3)	15
1. Battery Charging System Tests	15
2. Noise-Sensitive and Critical Power System No-Load Tests	19
3. Noise-Sensitive Power System Response Tests	22
III. Analysis and Presentation of Test Results	28
A. Diesel Generator (Section 1)	28
1. Relay and Protective Device Tests	28
2. Diesel Engine Accessory Equipment	28
3. Diesel Engine Operation	28
4. Diesel Generator Operation	30
5. Diesel Generator Switchgear and Load Tests	30
B. Automatic Operation of Diesel Generator (Section 2)	32
C. Noise-Sensitive Power System (Section 3)	32
1. Battery Charging System Tests	32
2. Noise-Sensitive and Critical Power System No-Load Tests	33
3. Noise-Sensitive Power System Response Tests	34
4. Twenty-Four Hour Integrated Frequency	34
IV. Compliance With Test Completion Criteria	35

CONTENTS

	Page
V. Evaluation	39
A. AC-DC Motor-Generator	40
B. The 250V DC Batteries	40
C. Critical Bus Transfer to Noise-Sensitive Power .	41
D. Automatic Start of Diesel Generator	42

APPENDICES

Appendix A	43
Noise-Sensitive Neutrals	43
Appendix B	46
Discharge Rate of 250V DC Batteries	46

TABLES

	Page
I. Setting of Diesel Generator Auxiliary Equipment . .	29
II. Diesel Engine Operating Parameters	30
III. Diesel Generator Operating Parameters	31
IV. Battery Charger Operating Data	33
V. Battery Charger Transient Data	33
VI. M-G Set Input Load-Change Transient Response	34
VII. M-G Set Output Load-Change Transient Response	34
VIII. M-G Set Integrated Frequency Test	34
IX. Discharge Test Data	47

FIGURES

	Page
1. Diesel Generator Protective and Starting Circuit . .	3
2. Simplified Diesel Generator Breaker Trip and Close Circuit	11
3. Single-Line Diagram of 250V DC System	16
4. Single-Line Diagram of M-G Set Output	21
5. Oscillograph Trace of M-G Set No. 1, Hot Side-to-Neutral	23
6. Oscillograph Trace of M-G Set No. 1, Neutral-to-Ground	24

HALLAM NUCLEAR POWER FACILITY
PREOPERATIONAL TEST COMPLETION REPORT
EMERGENCY POWER SYSTEM, AI-P-1118

I. PURPOSE OF TEST

This test consisted of three sections. The purpose of Section 1 was to determine that the Diesel Generator portion of the Emergency Power System would operate satisfactorily.

The purpose of Section 2 was to verify proper automatic startup of the Emergency Power System in the event of loss of electrical power, and to verify that the system could accommodate the plant emergency electrical load.

The purpose of Section 3 was to determine that the Critical and Noise-Sensitive Instrument Power Supply portion of the Emergency Power System would operate satisfactorily.

II. DISCUSSION OF TEST PERFORMANCE

A. DIESEL GENERATOR - (Section 1)

1. Preliminary Relay and Protective Device Tests

In order to make a preliminary check of the diesel engine protective devices, all auxiliary power to the engine control panel was shut off, the diesel generator circuit breaker was racked-out, and the diesel engine compressed air cranking pipe was disconnected. The main d-c feeder breaker 72-61, which feeds d-c control power

to the engine control panel, was then turned on. Refer to Figure 1118-1 for a schematic of the diesel generator starting and protective devices.

Since the compressed air start tanks (T-1305 and T-1306) were at atmospheric pressure, relay R-86 should have picked up and annunciated "Low Starting Air Pressure". However, it did not. Investigation revealed that PS-715, which operates R-86, was an SPST pressure switch, having a normally open contact. This should have been a normally closed contact. Since PS-715 could not be reversed, an auxiliary relay was added in order to obtain the correct control action. After installation of the auxiliary relay, proper annunciation at the diesel engine control panel was obtained. Simultaneously with this local annunciation, it was observed that the main board annunciator, "Diesel System" also responded properly. Then the hot side of relay R-86 was disconnected and it was possible to reset the main and local board annunciators.

Next, relay R-46, the low lubricating oil pressure alarm relay, was actuated manually. The local annunciator "Low Lube Oil Pressure" and the main board annunciator, "Diesel System", responded correctly. After allowing relay R-46 to drop out, it was possible to reset the local and main board annunciators. The same procedure was repeated with relay R-66, "High Water Temperature"; relay R-76, "Engine Overspeed"; and relay R-96, "Day Tank Low Level". In all cases, proper operation of the main board annunciator "Diesel System" was observed, as well as proper response of the individual local board annunciators.

Relay R-56, "Diesel Start Failure" was manually actuated. It was observed that the local board and main board annunciator "Diesel Start Failure" responded correctly.

Figure 1118-1. Diesel Generator Protective and Starting Circuit

Proper operation of both the engine fuel solenoid valve and the engine cranking cycle relays was then verified by manually operating engine starting relays AR and RR.

With the main control board engine starting switch in the AUTO position, the local board "Engine Start" pushbutton was actuated, and it was observed that the starting air solenoid valve, SV-700, went through its proper cyclic operation. At the end of the cranking cycle, relay CL dropped out, releasing relays S1, AR, CR, and RR and the engine start failure annunciators responded properly. The alarms were reset, the start cycle was actuated again, and, by means of a stopwatch, the time duration of relay CR (the cranking cycle relay) was obtained. Relay CR allows the engine to crank for six sec, and rest between cranks for 15 sec. The alarms were reset, the start cycle was re-actuated, and, by means of a stopwatch, the time delay for relay CL (the cranking limit relay) was obtained. At the end of two min, relay CL dropped out, preventing further engine cranking, and initiated the start failure annunciator. Next, the "Engine Start" pushbutton was operated, and then the "Engine Stop" pushbutton was actuated before the cranking limit was reached. Proper drop out of cranking cycle relays S1, CR, CL, RR, and AR was observed. The same procedure was repeated, using relays R-46, R-66, and R-76, respectively, to interrupt the cranking cycle. In each case, proper drop out of relays S1, CR, CL, RR, and AR was observed.

Next, the starting cycle was initiated from the main control board by turning the main control board engine switch to TEST, to start the cranking cycle, and then to STOP, to drop out the cranking relays. Finally, the main board control switch was put into the lockout

position, and it was observed that operation of the local "Engine Start" pushbutton would not start the cranking cycle.

2. Engine Accessory Equipment Checkout

The engine overspeed-trip-switch was actuated and proper operation of relay R-76 and associated alarms was observed.

The engine governor speed control was operated from the main control board, and proper governor response to "raise" and "lower" speed signals was observed.

The high water temperature switch was removed from the engine and immersed in a water container along with a mercury thermometer. Heat was applied to the water container. Proper operation of the temperature switch and associated alarms and relays was observed to occur at 203 F. Upon cooling, the temperature switch reset at 201 F.

Circuit breaker 52-A308A was closed, thus supplying 480V a-c auxiliary power to the diesel accessories. As soon as power was applied, the engine water jacket heaters became energized.

The fuel oil day tank drain valve was open and the fuel drained. The day tank low level alarm actuated when the tank level dropped to 1/8 full.* The drain

* After completion of this test, the control circuit for the day tank was modified so that the transfer pump now starts automatically when the low level alarm point is reached. The transfer pump still shuts off automatically when the high level point is reached.

valve was then closed, and the main fuel storage tank valves to the day tank were opened. The day tank transfer pump, which pumps fuel from the storage tank to the day tank, was started. It was noted that the pump was running backwards. Investigation revealed that two of the three-phase electrical leads to the pump motor were reversed. The wiring was corrected, and the pump restarted. Although the pump was then running correctly, the motor continuously tripped out on overload. Investigation revealed that the pump motor thermal overload devices were grossly undersized. Correct overload devices were installed and the pump and motor then functioned satisfactorily.

As the day tank level was pumped up, it was noted that the low level alarm could be reset. Level was increased until the day tank was 13/16 full; at this point the day tank pump was automatically stopped by the high level switch. The high level switch was then temporarily jumpered out and the day tank pump restarted. When the day tank level reached 7/8 full, the day tank started overflowing back to the main storage tank through line 702-1½"-C. With the pump still operating, the pump discharge valve was closed, and it was observed that the relief valve from pump discharge to suction popped at 45 psig.

Next, both compressed air starting tanks were valved open to the atmosphere through their drain valves. The gasoline engine driven air compressor was started and no-load engine speed was observed to be 3360 RPM. Tank T-1305 was then valved into the gasoline engine driven compressor and pumped up until its relief valve popped at 210 psig. At full load, engine speed was observed to be 3050 RPM.

Tank T-1306 was then valved into the electrically driven air compressor and the compressor was put in manual operation to pressurize the tank. Tank T-1306 relief

valve popped at 205 psig. Tank T-1306 pressure was then vented to atmospheric, and the electrically driven air compressor was put in automatic operation. The electrically driven air compressor pressurized tank T-1306 to 185 psig, at which point it automatically stopped. Tank T-1306 pressure was then slowly vented, and, at a pressure of 179 psig, the electrically driven air compressor started automatically. The vent valve was reclosed and the compressor automatically shut off again at 185 psig.

The hot side of relay R-36, which had been previously disconnected, was reconnected, and tank T-1306 was valved into the diesel engine starting system. Since starting air pressure was up, no low starting air pressure alarm occurred. However, severe air leaks were noted at SV-700, and at a piping union just upstream of SV-700. The leaks were repaired by tightening loose connections. The electrically driven air compressor was shut off, and tank T-1306 pressure was slowly bled-off. At 98 psig, the starting air low pressure alarm actuated.

The bleed valve was shut and both tanks T-1305 and T-1306 were valved together into the diesel engine starting system. The starting air pipe was left disconnected. The electrically driven air compressor was placed in automatic operation and both tanks were pressurized to the compressor shutoff pressure. The "Engine Start" pushbutton was actuated at the local control board, and proper relay actuation of the cranking circuit, along with cyclic blasts of air from the engine starting pipe, was observed.

3. Diesel Engine Operation

Using a mercury thermometer, it was observed that engine cooling water was at 133 F due to proper operation of the jacket water heaters.

The engine fuel solenoid valve was disconnected, the engine speed governor turned to its lowest setting, and the fuel linkage tripped, to insure that the engine could not run above "idle" speed.

The engine starting air pipe was reconnected, and the local board "Engine Start" pushbutton was actuated. The engine started cranking at a speed of 120 RPM. After six attempted starts, the start failure alarms actuated.

The alarms were reset, and the fuel solenoid valve was reconnected. The "Engine Start" pushbutton was actuated, cranking commenced, and the diesel engine started and ran at an "idle" speed of 550 RPM. Proper operation of all starting cycle relays was observed. The "Engine Stop" pushbutton was actuated, and the diesel engine stopped.

The engine was restarted and was operated at idling speed for warm-up. The engine jacket water heaters de-energized automatically when water temperature reached 145 F.

By manual adjustment of the governor, engine speed was raised to 900 RPM. No abnormal temperatures, pressures, or vibrations were observed. The governor setting at 900 RPM (measured with a G.R. Strobelight) was 952. Engine speed was then increased to 1050 RPM, at which point the overspeed trip actuated, shut down the engine, and brought in the overspeed alarms.

The governor was manually set at 952 for an engine speed of 900 RPM. The engine was started twice, once from the local control board and once from the main board, and in both cases the engine went directly on governor control at 900 RPM without tripping the overspeed device.

4. Generator Operation

With the diesel generator voltage regulator in "Manual", and with the exciter field rheostat in the full LOWER position, the diesel engine was started and run at 600 RPM. The exciter field rheostat was operated until exciter voltage appeared. Correct polarity of exciter voltage was observed.

Engine speed was then increased to 900 RPM and the exciter rheostat operated until 480V generator voltage was developed. The exciter rheostat was not at the end of its range. The generator voltmeters and frequency meters at the local and main control boards were observed to be functioning correctly.

The governor control at the main control board was operated to raise and lower engine speed; the frequency meter responded properly.

At this point, the undervoltage and underfrequency relays which block generator breaker closure until proper voltage and frequency are developed were to be checked. It was noted that incorrect (overvoltage and overfrequency) relays had been furnished. A new undervoltage relay was used to replace the overvoltage relay; the action of the overfrequency relay was reversed to make it an underfrequency relay. The undervoltage and underfrequency relays were set to operate at 432V and 57.9 cps, respectively, and settings were verified in operation.

The diesel generator was then shut down and the voltage regulator was switched to automatic control. The local and main board automatic voltage regulator potentiometers were set at mid-range. The diesel generator was restarted, and at rated engine speed of 900 RPM, it was observed that ample control range was present in each potentiometer.

Generator voltage was set at 480V a-c, using the automatic voltage regulator. Engine speed was varied suddenly, and in small increments, from the main board engine governor control, and it was observed that the automatic voltage regulator rapidly returned generator voltage to 480V a-c, following speed changes.

By the use of a phase sequence indicator, correct phasing between the 480V A bus and the diesel generator feeder bus was verified.

5. Switchgear and Load Tests

The diesel generator circuit breaker, 52-A2, was racked into the TEST position. The diesel generator system was set up for complete automatic operation. Since 480V switchgear breakers A and B were closed, the diesel did not attempt to start. Figure 1118-2 shows the diesel generator breaker closing and tripping circuit.

480V main circuit breakers, 52-A1 and 52-B1, for main buses A and B were then tripped in sequence. The diesel engine started automatically and the diesel breaker closed automatically after sufficient voltage and frequency were developed. It was also noted that all A and B control centers, except A-3, had tripped on undervoltage, as they should have. Also, control centers 52-A2 and 52-B2 (preheat) were locked out.

Attempts were then made to re-close 480V main breaker 52-A1, without using the synchronizing bus. (With the diesel breaker in TEST, a cell switch permits the synchronizing bus to be bypassed.) However, it was not possible to close 52-A1. Investigation revealed that a cell switch in the diesel breaker was not wired into 52-A1's closing circuit. This wiring omission was corrected, and it was then possible to re-close 52-A1. As soon as 52-A1 was closed, diesel generator circuit breaker 52-A2 tripped automatically.

Figure 1118-2. Simplified Diesel Generator Breaker Trip and Close Circuit

The diesel engine was stopped and 480V main breaker 52-B1 was racked-out to the TEST position. Main breaker 52-A1 was then tripped and proper automatic startup of the engine and automatic diesel breaker closure was observed. When 52-B1 was reclosed, proper automatic tripping of the diesel generator breaker was observed. This test was then repeated, but with 52-A1 in the TEST position and 52-B1 used to initiate automatic action.

The main A and B 480V circuit breakers were returned to normal operating condition and the diesel generator system was shut down and set up for automatic starting. A Sanborn high speed recorder was connected to record diesel generator voltage, current, and frequency. Diesel generator circuit breaker 52-A2 was racked into the operating position. All A and B bus control center feeders were tripped. The main A and B 480V circuit breakers were tripped. The elapsed time from main breaker trip to diesel generator breaker closure was seven seconds. Generator no-load frequency and voltage were observed to be 60 cps and 480V.

About 150 KVA load was applied by manually closing-in control centers fed from the A bus. The No. 1 cooling water pump was started and after this transient had stabilized, the No. 1 building exhaust fan was started. The maximum transient observed was a voltage and frequency dip to 384V and 58.6 cps. Maximum voltage transient duration was 0.35 sec.

The electrical load was increased to 400 kw and this load was sustained for two hours. The diesel engine operated satisfactorily at this load.

Using the main board controls, the diesel generator output was synchronized into the 480V A bus feed. When synchronism was indicated, main breaker 52-A1 was closed and the diesel breaker tripped with no "bump"

occurring. When the diesel breaker tripped, the diesel engine was subjected to a transient from full-load to no-load; however, governor control kept engine speed at 900 RPM.

The engine was stopped and the plant electrical system returned to normal operation. Main 480V circuit breakers 52-A1 and 52-B1 were manually tripped. Then, the diesel system automatically started, and the diesel generator automatically and satisfactorily picked up its normal initial load.

B. AUTOMATIC OPERATION OF DIESEL GENERATOR (Section 2)

The plant electrical system was set up as follows:

- 1) Power feed to the HNPF was through the reserve station transformer.
- 2) 4160V A, B, and C feeder breakers closed.
- 3) 480V A, B, and C main breakers closed.
- 4) All 480V control centers closed.
- 5) 480V A-to-B tie breaker set up for automatic closing upon loss of A or B bus.
- 6) Cooling tower pump No. 1 running; cooling tower pump No. 2 on standby.
- 7) Nitrogen cooler No. 6 operating.
- 8) CPPD battery chargers, and two CPPD instrument air compressors were operating; power source from HNPF.

The plant set-up above was verified, and the reserve station transformer circuit breaker was tripped.

As soon as the reserve breaker was tripped, it was observed that 480V main breakers A and B tripped, all 480V control centers except A-3 tripped, cooling tower pump No. 1 and nitrogen cooler No. 6 tripped, and the 480V tie breaker closed.

Meanwhile, the diesel generator system, sensing the loss of 480V main breakers A and B, started automatically and the diesel breaker closed automatically. As soon as the diesel breaker had closed, cooling tower pump No. 2, which had been on standby, started automatically. Also, equipment on control center A-3, including the two CPPD battery chargers, resumed normal operation. The two CPPD instrument air compressors which were being fed from breaker 52-A7, which had stopped operating, resumed normal operation when the diesel breaker closed. (Breaker 52-A7 does not have an undervoltage trip.) Critical transformer voltage was observed to be normal.

At this time, priority loads were placed on the diesel system. Nitrogen cooler No. 6 was restarted. (NOTE: When cooler No. 6 tripped, No. 5 should have started automatically upon power resumption. However, cooler No. 5 had a bad bearing and was tagged out of service. The automatic start feature had been previously checked.) Loading face shield compressor No. 1, fuel wash cell storage pit pump No. 1, and the tank room sump pump were started. A grapple on the fuel handling machine was operated. Since vent compressors No. 3 and No. 4, as well as the dry scrubber, were not available for operation, load was simulated by operating a building exhaust fan.

At this point, the diesel generator was putting out 420 kw. The diesel system was operating satisfactorily, and this load was sustained for four hrs. It was observed that fuel consumption during this four hr period of full load operation was 100 gal.

The reserve station breaker was re-closed, and the diesel generator was synchronized with the 480V A bus. When synchronized, 480V main breaker A was closed, and the diesel breaker tripped automatically. At this point, electric power to HNPF was put back to normal and the diesel engine was shut down.

C. NOISE-SENSITIVE POWER SYSTEM (Section 3)

1. Battery Charging System Tests (See Figure 1118-3)

The 250V d-c system was set up as follows:

- a) Battery chargers off and connections to the 250V d-c buses open.
- b) Battery bank connections to the 250V d-c buses open.
- c) M-G sets shutdown.
- d) Diesel generator feeding the 480V A and B switchgear.

Under these conditions, it was observed that the annunciators "Battery Charger No. 1 OFF", "Battery Charger No. 2 OFF", "Standby Battery Charger OFF", and "Under-voltage 250V DC System" were actuated.

Battery charger No. 1 was turned on and it was observed that its annunciator could be reset. Battery charger No. 2 and the standby charger were turned on and their annunciators were reset.

The three battery charger voltage adjusting rheostats were operated over full range, and it was observed that charging voltage could be adjusted over the range of 200-295V d-c. The diesel generator output voltage was reduced to 440V a-c, and no change of battery charger output limits was noted.

Diesel generator voltage was increased back to 480V a-c. Battery charger No. 1 was then connected to 250V d-c bus No. 1 by closing circuit breaker 72-4. The ground detector lamps came on at equal brilliance. Battery charger No. 1 output voltage was varied, and it was observed

Figure 1118-3. Single-Line Diagram of 250V DC System

that relay 27-1, 250V d-c undervoltage relay, picked-up at 240V d-c and dropped-out at 212V d-c.*

Battery charger No. 2 was connected to 250V d-c bus No. 2 by closing circuit breaker 72-7. Ground detection lamps came on with equal brilliance. By varying battery charger No. 2 output voltage, pick-up and drop-out of relay 27-2 were observed to be 235V and 215V d-c, respectively.*

By varying the output of both battery chargers, it was observed that the annunciator "Undervoltage 250V d-c System" would actuate when either undervoltage relay 27-1 or 27-2 dropped-out, and could be reset only when both relays were picked-up.

A fused jumper was tied to ground and momentarily touched to the positive and negative pole of each DC bus. In all four cases, proper operation of the ground detector lamps and the annunciator "250V DC System Ground" was observed.

The polarity of the standby battery charger and that of DC buses No. 1 and No. 2 was verified to be the same. The standby charger was paralleled into the two busses (one at a time) and satisfactory operation was verified.

The polarity of battery No. 1 and No. 2 was verified to be the same as DC buses No. 1 and No. 2. Batteries No. 1 and No. 2 were connected to DC buses No. 1 and No. 2 by closing circuit breakers 72-1 and

* After completion of this test, pick-up and drop-out settings were changed to 255V and 238V d-c, respectively, to give the operators an earlier indication of under-voltage.

72-3, respectively. Battery charger voltages were increased, and it was noted that the output of the battery chargers oscillated wildly. Attempts to stabilize the battery chargers proved to be futile, so the manufacturer was contacted. A manufacturer's representative arrived and replaced several components within the output voltage regulators. After repair, charger voltage was again increased and proper current flow (from charger to battery) was observed. At maximum output, the chargers were delivering 20 amperes to a charged battery. The output current limiters were set at 125 amperes.

The standby charger was then tied into DC bus No. 1 by closing circuit breaker 72-5. The output voltage of battery charger No. 1 was set at 258V d-c; the standby charger output was set at 250V d-c. The output of the standby charger was then increased, and when it exceeded the output of battery charger No. 1, a smooth transfer of load was observed. At maximum output, the standby charger was also delivering 20 amperes to a charged battery.

The standby charger was tripped and batteries No. 1 and No. 2 were connected to chargers No. 1 and No. 2, respectively, and charged to 258V d-c. A Sanborn high speed recorder was connected to read battery charger No. 1 input (0-520V a-c), battery charger No. 1 voltage output (0-300V d-c), and battery charger No. 1 current output (0-150A d-c). A 10 percent input voltage transient was created by starting a cooling water pump. (Diesel generator was feeding A and B 480V buses.) The Sanborn was then successively reconnected to battery charger No. 2 and to the standby charger, and 10 percent input voltage transients were developed, as above. In the worst case, output voltage of the battery chargers dropped 1.2% during the input transient.

Finally, the polarity of the two DC buses was verified to be the same across the DC bus tie breaker 72-2. By use of the key interlocks, tie breaker 72-2 was closed and satisfactory parallel operation of the two DC buses, battery chargers, and batteries was observed.

2. Noise-Sensitive and Critical Power System
No-Load Tests

Batteries No. 1 and No. 2 were connected to their respective DC buses and chargers and were float-charged to 258V d-c. Circuit breaker 72-8 was closed to provide 250V d-c power to M-G set No. 1. The DC motor overload device for motor No. 1 was manually actuated and proper operation of the annunciator "M-G Set No. 1 Overload" was observed. The overload reset was operated, and it was noted that the annunciator could then be reset. M-G set No. 1 motor was started, and it was noted that motor starting current did not exceed 200% of the motor's rating. The voltage and frequency adjustments of M-G set No. 1 were varied and proper response was verified, thus checking the no-load operability of M-G set No. 1.

The same test was repeated for M-G set No. 2; circuit breaker 72-10 was closed to provide DC power.

The individual phase overload contacts on generator No. 1 line contactor were manually operated. Operation of each phase contact brought in the annunciator "M-G Set No. 1 Overload". The alarm could be reset upon release of the overload contact. The same test was then repeated for generator No. 2, with similar results.

An attempt was made to close the output line breakers for M-G Sets No. 1 and 2 without using the synchronizing bus key. In neither case would the line

breaker close, and in both cases the annunciator "M-G Set No. 1 (2) Trip" actuated.

Critical transformers No. 1 and No. 2 circuit breakers 52-A302A and 52-A306A were tripped to de-energize the critical transformers. (Refer to Figure 1118-4 for a diagram of M-G set output.) By using the synchronizing key, it was possible to close generators No. 1 and No. 2 line breakers. When the line breakers were closed, it was possible to reset the trip annunciator. Also, the annunciator "Critical Panel Transfer" actuated and it was observed that the two critical panel transfer relays were in the EMERGENCY position.

A phase rotation meter was used to verify identical phase sequence between M-G sets No. 1 and No. 2. The "Bus No. 1 - Bus No. 2 Synchronizing" switch was turned on, and M-G set voltage and frequency were adjusted to obtain synchronism as indicated on the synchroscope. The control power transfer switch was turned to the No. 1 position and the paralleling contactor closed. Stable parallel operation of the two M-G sets was observed. The control power transfer switch was turned off and the paralleling contactor tripped.

The same test was then repeated, with the control power transfer turned to the No. 2 position.

With the M-G sets synchronized through the paralleling contactor, M-G set No. 1 line breaker was tripped. The No. 1 AC generator synchronizing bus was turned on by using the synchronizing key. M-G set No. 1 was re-synchronized and its line breaker closed. The same test was then repeated for M-G set No. 2.

The two critical transformers were re-energized by closing circuit breakers 52-A302A and 52-A306A. It was noted that both critical panel transfer relays returned to their normal positions. A phase rotation meter was applied to the normal and emergency feed sides of the transfer relays and identical phase sequencing was verified.

Figure 1118-4. Single-Line Diagram of M-G Set Output

Critical transformer circuit breakers 52-A302A and 52-A306A were alternately tripped and closed, and it was noted that tripping either circuit breaker would actuate the annunciator "Critical Panel Transfer", but the annunciator could be reset only when both circuit breakers were closed and the transfer relays were in their normal position.

Finally, the DC motor starter control switches and the generator line contactor control switches were operated to their LOCK OUT positions, and proper extinguishing of the control switch indicating lights was verified.

3. Noise-Sensitive Power System Response Tests

Prior to the start of response tests, M-G set voltage and frequency were examined for accuracy and stability. Accuracy was found to be in excess of the specified $\pm 1/2\%$, and stability was poor. Consequently, the manufacturer was contacted and a manufacturer's representative was sent to the HNPF to tune the M-G set voltage and frequency regulators.

After tuning the regulators, accuracy was $\pm 1/2\%$ or better for both voltage and frequency.

Two other unusual phenomena were noticed; the noise free neutrals were above ground and the sine wave output of the M-G sets was not clean. Photographs of oscillograph traces of hot-side-to-neutral and neutral-to-ground, after some crossed neutrals were found and corrected, are shown in Figures 1118-5 and 1118-6.

The jagged sine wave, which contains 2.7% harmonic distortion (as measured with a Hewlett Packard Wave Analyzer), causes no known problems, as long as all loads are connected phase-to-neutral, and not phase-to-ground.

Figure 1118-5. Oscilloscope Trace of M-G Set No. 1,
Hot Side-to-Neutral. (120V a-c, RMS.
60 cps)

Figure 1118-6. Oscilloscope Trace of M-G Set No. 1,
Neutral-to-Ground. (Each square = 1 cm²
Oscilloscope settings = 1 volt per cm;
Sweep time = 2 ms/cm)

The above-ground neutrals (the amplitude and wave form of which is different at various plant locations) did cause problems in the nuclear instrument and plant control systems. Because of the small wire (No. 12) used for neutrals, and the length of the neutrals, it was not possible to eliminate the above-ground neutrals. Various corrective actions were taken in the nuclear and plant control instruments; techniques and results are discussed in Appendix A.

In preparation for M-G set response tests, a Sanborn high speed oscillograph recorder was connected as follows:

- a) M-G input, 0-300V d-c
- b) M-G input, 0-300A d-c
- c) M-G output, 0-250V a-c
- d) Timing trace, 60 cps

Battery No. 1 was charged to 258V d-c. M-G set No. 1 was started. The DC feed to M-G set No. 2 was tied to DC bus No. 1 by opening circuit breaker 72-10 and closing circuit breakers 72-8 and 72-9. Battery charger No. 1 was tripped.

Under these conditions, battery No. 1 was the only feed to DC bus No. 1. M-G set No. 1 was running at no-load and being fed from DC bus No. 1. M-G set No. 2 was off, and when turned on, would also be fed from DC bus No. 1.

The Sanborn recorder was started and put on a chart speed of 100 mm/sec. M-G set No. 2 was started, thus creating a DC input voltage transient to M-G set No. 1. The recorder was stopped after the transient had ceased.

The No. 2 M-G set was shut down and the No. 1 battery charger was turned back on the recharge battery No. 1 to 258V d-c.

The main breaker in noise-sensitive panel No. 1 was turned on, as were the individual bus distribution feeders. The M-G set, when carrying its normal noise-sensitive load was found to be 10% loaded. The normal feed to critical transformer No. 1 was opened, and the critical panel transferred to M-G set No. 1. With both the noise-sensitive and critical load, M-G set No. 1 was found to be about 90% loaded. The control rod drives associated with critical panel No. 1 were operated. Under these maximum load conditions M-G set No. 1 was 125% loaded.*

Critical transformer No. 1 normal feed was restored. The Sanborn recorder was started and the normal feed to critical transformer No. 1 was tripped to introduce an output voltage transient. The Sanborn recorder was stopped after the transient had ceased.

The same tests as described above for transient response and loading were then performed on M-G set No. 2, with similar results.

As a final test, a 24-hour integrated frequency check was made. The two M-G sets were set up for normal, separate operation, each carrying its own normal noise

* These are the maximum phase loads before balancing the loads. After balancing the loads as best possible, the normal noise-sensitive load was 10%; with critical panels transferred, load was about 65%; and with all control rod drives operating, load would be about 95% of generator rating.

-sensitive load. A synchronous clock was connected to the output of each M-G set and a reference clock was connected to CPPD house power. CPPD house power was furnished by their turbine-generator which was synchronized with the Nebraska Electrical Transmission System. The distribution system frequency was controlled by CPPD's Hastings Dispatcher, who keeps the entire system at a constant integrated frequency of 60 cps. At the end of a 24-hour test run, each M-G set's clock was reading 24 hours to an accuracy of better than one minute.

III. ANALYSIS AND PRESENTATION OF TEST RESULTS

A. DIESEL GENERATOR (Section 1)

1. Relay and Protective Device Tests

Proper operation of the diesel engine cranking cycle relays was verified. Proper operation of protective device relays and annunciators and subsequent interruption of the cranking cycle or shut-off of the engine fuel valve, was also verified. The engine starting cycle was found to be timed to crank for six sec, rest for 15 sec etc., for a total time of 1 min 56 sec. Under this timing sequence, the engine will attempt to start six times before the cycle limit is reached and the "Start Failure" annunciator actuates.

2. Diesel Engine Accessory Equipment

The diesel engine accessory equipment was checked, and after correcting some wiring errors, proper operation was verified. Pertinent settings of accessory equipment are shown in Table I.

3. Diesel Engine Operation

The diesel engine operated satisfactorily under no-load conditions. Pertinent operating parameters are noted in Table II.

TABLE I

SETTING OF DIESEL GENERATOR AUXILIARY EQUIPMENT

Description	Setting
Engine Water Temperature Alarm Switch, Alarm Actuation and Engine Shutdown	203 F
Engine Water Temperature Alarm Reset	201 F
Day Tank Low Level Alarm	1/8 full
Day Tank Low Level Alarm Reset	> 1/8 full
Day Tank High Level - point at which fuel oil transfer pump will automatically shut off	13/16 full
Day Tank Overflow Back To Storage Tank	7/8 full
Day Tank Fuel Oil Transfer Pump Relief Valve Setting	45 psig
No-Load Speed, Gasoline Engine Driven Air Compressor	3360 rpm
Full Load Speed, Gasoline Engine Driven Air Compressor	3050 rpm
Electric Driven Air Compressor Auto Start	< 179 psig
Electric Driven Air Compressor Automatic Shutoff	185 psig
Starting Air Accumulator T-1305 Relief Valve Setting	210 psig
Starting Air Accumulator T-1306 Relief Valve Setting	205 psig
Starting Air Low Pressure Alarm	98 psig

TABLE II
DIESEL ENGINE OPERATING PARAMETERS

Parameter	Setting
Initial Ambient Air Temperature	91 F
Initial Engine Water Temperature	133 F
Engine Cranking Speed	120 rpm
Engine Water Temperature At Heater Shut-off	145 F
Governor Setting At Rated Engine Speed	952
Engine Speed At Lowest Governor Setting	550 rpm
Engine Speed At Overspeed Trip	1050 rpm

4. Diesel Generator Operation

The diesel engine controls, and the diesel generator voltage and frequency (engine speed) controls, all operated satisfactorily under no-load condition. Incorrect types of voltage and frequency relays in the diesel breaker closing circuit were replaced. Pick-up and drop-out of the underfrequency relay were set at 57.9 cps and 56.5 cps, respectively; pick-up and drop-out of the undervoltage relay were set at 108V a-c and 102V a-c, respectively, corresponding to 432V a-c and 408V a-c.

5. Diesel Generator Switchgear and Load Tests

After correcting some wiring faults, the diesel generator was allowed to start automatically by tripping of the A and B 480V switchgear.

Satisfactory operation at various load conditions was observed. Various operating conditions are noted in Table III.

TABLE III
DIESEL GENERATOR OPERATING PARAMETERS

Description	Observed Values
Elapsed Time, Main Breaker Trip To Generator Breaker Close	7 sec
Generator No-Load Voltage	480V a-c
Generator No-Load Frequency	60 cps
Initial Generator Load	100 kw
Initial Generator Frequency	60 cps
Initial Generator Voltage	480V a-c
Initial Generator Current	200A a-c
Engine Water Temperature, Initial Load	175 F
Initial Generator Load, Before Start of Building Exhaust Fan	160 kva
Minimum Voltage, During Transient Caused By Starting Building Exhaust Fan	384V a-c
Minimum Frequency, During Transient Caused By Starting Building Exhaust Fan	58.6 cps
Time Required to Recover to 480V a-c, 60 cps	0.35 sec
Generator Full Load	400 kw
Generator Full Load Frequency	60 cps
Generator Full Load Voltage	480V a-c
Generator Full Load Current	520A a-c
Engine Water Temperature, at Full Load	175 F
Engine Fuel Consumption at Full Load	25 gph
Voltage Stability	$\pm 1/2\%$
Voltage Dip From Starting The Following Equipment: a) Cooling Water Pump b) Building Exhaust Fan c) Control Center A-1 d) Control Center A-4	6% 19% none noticeable none noticeable

B. AUTOMATIC OPERATION OF DIESEL GENERATOR (Section 2)

Under loss of power to both A and B 480V main buses, the following action occurs:

- 1) Tie breaker closes (Note: Tie breaker circuitry was modified after this test had been completed. Subsequent testing of the tie breaker is discussed in the completion report for AI-P-1130, "Lighting, Power, and Communication").
- 2) All 480V control center feeder breakers, except 52-A9 for control center A-3, tripped.
- 3) The diesel generator started automatically and its circuit breaker (52-A2) closed automatically when generator voltage and frequency exceeded 432V a-c and 57.9 cps.
- 4) Control center A-3 was energized from the diesel source. Critical transformer voltages were normal.
- 5) Breakers 52-A8 and 52-B6 (for pre-heat control centers A-2 and B-2) were locked-out when the diesel generator was on the line.
- 6) Priority loads could be placed on the diesel generator with no abnormal operation of the system.

Normal power could be restored by operation of the diesel speed control and the A or B bus synchronizing equipment.

C. NOISE-SENSITIVE POWER SYSTEM (Section 3)

1. Battery Charging System Tests

Proper polarity of all battery, DC bus, and battery charger connections was verified. All key interlocks for the 250V d-c system functioned properly.

Proper operation of the DC undervoltage and ground alarms was observed. Pertinent operating data are shown in Table IV.

TABLE IV

BATTERY CHARGER OPERATING DATA

Unit No.	Input Volts (a-c)	Output Volts (d-c)
1	480	180-275
1	440	180-275
2	480	205-295
2	440	205-295
Standby	480	200-295
Standby	440	200-295

Data for transient tests of the battery chargers are shown in Table V. Data has been reduced from Sanborn recordings.

TABLE V

BATTERY CHARGER TRANSIENT DATA

Charger No.	AC Input Transient (Per cent)	DC Bus Dip (Per cent)	Recovery Time (Seconds)
1	10	1	0.600
2	10	1	0.400
Standby	14	1.2	1.580

2. Noise-Sensitive and Critical Power System No-Load Tests

Proper operation of the overload and trip alarm circuits on the noise-free generators was verified. Synchronizing and parallel operation of the two M-G sets was demonstrated. Proper operation of the critical panel transfer relays was checked, and the actuation value was set at its minimum setting of 90V a-c.

3. Noise-Sensitive Power System Response Tests

Data for transient tests of the M-G sets are shown in Tables VI and VII. Data have been reduced from Sanborn recordings.

TABLE VI
M-G SET INPUT LOAD-CHANGE TRANSIENT RESPONSE

M-G Set No.	DC Input Voltage Transient (%)	AC Output Voltage Dip* (%)	Recovery Time (Seconds)
1	10	3.85	0.52
2	10	3.85	0.65

* No noticeable output frequency change occurred.

TABLE VII
M-G SET OUTPUT LOAD-CHANGE TRANSIENT RESPONSE

M-G Set No.	AC Output Transient % Load Change	AC Output Voltage Dip (%)	AC Output Frequency Change (%)	Recovery Time (Seconds)
1	10-90	7	*	.032
2	10-90	7	*	.032

* Since recovery time was so short (2 cycles), no frequency change was measureable.

4. Twenty-Four Hour Integrated Frequency

The results of the integrated frequency test are shown in Table VIII.

TABLE VIII
M-G SET INTEGRATED FREQUENCY TEST

	Reference Clock	Gen No. 1 Clock	Gen No. 2 Clock
Time At Start	0 hr 0 min 0 sec	0 hr 0 min 0 sec	0 hr 0 min 0 sec
Time At Finish	24 hr 0 min 0 sec	23 hr 59 min 43 sec	24 hr 0 min 58 sec

IV. COMPLIANCE WITH TEST COMPLETION CRITERIA

The following is a list of Test Completion Criteria taken from pages XI(a)-10 through XI(a)-13, NAA-SR-5700, Supplement 2, with remarks about the test to show compliance with the criteria.

a) Diesel Generator Test Criteria:

- 1) The diesel generator, including all wiring and accessories, has been checked in accordance with the manufacturer's manual and drawings. The diesel has been started manually (from both the reactor control board and the diesel panel), and operated to verify no-load operation as described in the manufacturer's manual. Operation of the following accessories has been demonstrated: fuel oil transfer pump and level controls; diesel starting controls (must attempt to start the diesel five times before shutoff and alarm); engine cooling water heaters (energized when diesel is off).
- 2) The diesel generator has been loaded to approximately 400 kw, using normal plant loads. Operating temperatures and voltage regulation were in accordance with the manufacturer's manual.
- 3) Voltage regulation was demonstrated to be within $\pm 1\%$.
- 4) The voltage dips caused by starting the various loads have been recorded for future use in determining loading schedules.
- 5) Fuel consumption has been measured and recorded for future use in determining fuel needs.

Remarks: Proper wiring, starting, and no-load operation, of the diesel generator were verified. The diesel engine will attempt to start six times before shut-off and alarm, rather than the

specified five attempts. Proper operation of engine accessories was also verified. At full load of 400 kw, diesel generator operation was satisfactory and in accordance with the manufacturer's manual. Voltage regulation is within $\pm 1\%$ from no-load to full-load. Voltage dips caused by starting loads have been recorded (see part III of this report). Fuel consumption at full-load is 25 gal/hr.

- b) Loss-of-Power Test Criteria: A loss-of-power test has been simulated by tripping both the normal and reserve 4160V main circuit breakers. The following actions have been verified:
- 1) All 480V circuit breakers tripped off except 52-A9.
 - 2) Tie breaker 52-A11 closed.
 - 3) Breakers 52-A8 and 52-B6 were locked out after being tripped off.
 - 4) Diesel generator started automatically, and its circuit breaker (52-A2) closed when generator voltage reached 400-420V and 55 cps. The bus load was picked-up.
 - 5) Control center A-3 was energized from the diesel source.
 - 6) Upon closing the normal 4160V power supply breaker, the 480V main breakers closed, the diesel circuit breaker tripped, and the diesel remained under governor control without overspeed trip.

Remarks: There are several erroneous statements under Criteria b). Upon loss of the 4160V supply, only the 480V A and B main breakers, and 480V control centers A-1, A-2, A-4, B-1 and B-2

trip. The 480V C bus and the C control centers are not affected. This is per design. Control center A-3 (breaker 52-A9) remains closed. The emergency instrument air feed breaker, 52-A7, will remain in its previous position, i.e., either tripped or closed. The 480V breakers which feed the building exhaust fans, the cooling water pumps, and nitrogen coolers No. 5 and No. 6, will remain tripped, or will automatically trip or close, depending upon how the plant operators last had these breakers or certain automatic interlocks set up. Proper action of 480V breakers, per design, was verified. Upon loss of 4160V power and resultant tripping of main 480V breakers A and B, the tie breaker 52-All closed. However, this circuit was modified after this test was completed. Proper operation of the modified tie breaker circuit was verified and is discussed in the completion report for AI-P-1130, "Lighting, Power, and Communication". Upon loss of 480V breakers A and B, the diesel started automatically and the diesel breaker automatically closed after generated voltage and frequency reached 432V a-c and 57.9 cps. (The 55 cps figure in the criteria is a typographical error and should have been 58 cps.) The undervoltage relay could be reset to a lower value, but the 432 V a-c pull-in figure is in the safe direction and the undervoltage relay will be left set at this value. After the diesel breaker closed, breakers 52-A8 and 52-B6 (for pre-heat control centers A-2 and B-2) were automatically locked -out and equipment fed from control center A-3 was automatically reenergized.

Upon re-closing of the 4160V a-c breaker, the 480V a-c main breakers do not, and must not, automatically close. (Main breaker C, which never tripped, and which was not energized from the diesel, does become automatically re-energized.)

It was necessary to first synchronize the diesel generator with the feed from 480V bus A or B. Only when synchronization is achieved, and the synch check relay is satisfied, can main 480V main breakers A or B be closed. As soon as either 480V a-c A or B main breaker is closed, the diesel breaker will automatically trip, and the diesel engine remains under governor control without an overspeed trip occurring.

c) Critical and Noise-Sensitive Supply Test Criteria:

- 1) The battery chargers were set at 258V (no-load). The regulation of the chargers was found to be within $\pm 1\%$ for $\pm 10\%$ input voltage variation. The output current limit of each charger was set at 125% of its rating.
- 2) All battery connections were checked for proper polarity. Key interlocks for circuit breakers were verified to agree with the purchase specification. Ground relays and annunciators were observed to operate upon applying a test (fused) ground.
- 3) Both M-G sets were operated, and the output was measured to be 120/208V $\pm 0.5\%$, 60 cycles / second $\pm 0.5\%$, with a 24 hour integrated frequency error less than one minute observed on an electric clock. Synchronizing and paralleling of the two sets was demonstrated, and the parallel operation was observed to be stable.

- 4) Upon de-energizing the 480V supply to either critical panel No. 1 or No. 2, the auto transfer switch transferred the critical panel load to the noise-free bus. For a step load increase from 20% to 100% of the M-G set rating, the voltage did not vary more than $\pm 10\%$, and the recovery time to within $\pm 0.5\%$ of the initial value was 0.2 seconds or less; the frequency did not vary more than $\pm 3\%$, and the recovery time to within $\pm 0.5\%$ of the initial value was 1.0 seconds or less. The relay activating the automatic transfer panel was set at 60 to 75V. Upon re-energizing the 480V supply to the critical panel, the auto transfer switch transferred back to normal. The effect of the transfers on each load fed from the critical and noise-free buses was observed, and referred to the Evaluation Manager for his review.

Remarks: All items, except as noted below, were verified. It was not possible to step-load the M-G sets from 20-100%. It was possible to use a step-load of 10-90%, and under these conditions, transient response was well within that specified. Using a step-load increase of 20-100% would not have affected the results significantly. It was not possible to set the relay which activates the critical panel transfer to 60-75V a-c. These relays were set at their minimum actuation value of 90V a-c, which is a more conservative (safer) value.

V. EVALUATION

The Emergency Power System, consisting of (1) the diesel generator, with associated control, starting equipment, fuel oil supply, and circuit breakers; and (2) the critical and noise-sensitive power supplies, including motor generators, batteries, battery chargers, and

associated controls and circuit breakers, has been tested in accordance with the written and approved test procedure.

In general, the Emergency Power System has proven adequate to supply all critical loads at HNPF. Several modifications have been made to the system; a few minor modifications to the system or associated equipment remain to be made, for completely satisfactory operation.

A. AC-DC MOTOR-GENERATORS

The motor-generator power supply for the noise-sensitive instrumentation has proven adequate after proper "tune-up" of voltage and frequency regulators and after correction of wiring errors, as indicated in Section II., "Discussion of Test Performance". The small amount of "noise" in the phase-to-neutral voltage, indicated in Figure 1118-5, has been acceptable. The distorted waveform observed in the neutral-to-ground voltage, shown in Figure 1118-6, should not be considered abnormal. No adverse effects are anticipated, with all noise-sensitive loads connected phase-to-neutral (not phase-to-ground), and with the noise-sensitive power supply neutral grounded at one location only.

B. THE 250V DC BATTERIES

Appendix B discusses the loss of noise-sensitive power on April 5, 1962. Unfortunately, data on battery and motor-generator loads are not available for this 2-1/2 hour discharge period. However, the unexpected loss of noise-sensitive power can be attributed to low water level in the batteries.

The controlled discharge test of the batteries is also somewhat incomplete, with regard to test data.

Information obtained from CPPD and AI personnel who participated in the test indicated that the load on battery No. 1 increased from 60 to 65 amperes during the test. Similarly, the load on battery No. 2 increased from 70 to 75 amperes. No indication of load variation on the motor-generator sets was available. However, the above referenced information indicates there was no great variation in battery load, and therefore, it can be assumed there was no significant variation in motor-generator load during the test. Under these conditions, the batteries can be considered adequate for the services intended, if properly maintained. Possible exceptions to this general statement are the two cells in battery bank No. 1 which did not respond to charging as part of the battery bank. Maintenance on the batteries is now formalized, and these two cells are receiving special attention.

The batteries in use at HNPF are Gould Type EPR-11, 200 ampere hour capacity. These batteries are similar in quality to the Gould Type EK-27, 65 ampere hour capacity batteries, which have been in use and giving satisfactory service at the SRE.

C. CRITICAL BUS TRANSFER TO NOISE-SENSITIVE POWER

Upon loss of voltage on the A-3 bus, the load on each critical bus is automatically transferred to the noise-sensitive power supply. On a few occasions, this transfer has been made unnecessarily during lightning storms and other system disturbances. On other occasions, the transfer has failed to be made as intended. This has been attributed to the low setting (90V) on the transfer relay. Modifications are being made to place a time delay in the transfer to prevent unnecessary transfers (and reactor scrams). It is anticipated that the critical bus transfer will be put in normal operation at that time.

D. AUTOMATIC START OF DIESEL GNERATOR

Between September 19, 1961 and February 20, 1962 seven of 26 attempts to start the diesel were unsuccessful. Five of these unsuccessful attempts occurred during extremely cold weather and diesel room temperatures were well below the 60 F ambient stated in the design specification. The other false starts were caused by block heater failure and a closed butterfly valve on the intake air to the engine, respectively. Modifications are required to assure proper starting during cold weather. Modifications are also required to: (1) permit loading the generator periodically, in order to prevent moisture build-up in the electrical insulation in the generator; and (2) to enable the engine to be operated under load, in order to clear fouling of fuel ejectors, caused by periodic check-starts under no-load.

APPENDIX A

NOISE-SENSITIVE NEUTRALS

During the checkout of the two noise-sensitive M-G sets, it was observed that the neutrals were above ground at the control room. The amplitude of neutral voltage above ground varied from 0 to 5V, depending upon where the measurement was made.

Checking the grounding of the neutrals for the noise-sensitive power supplies indicated the following:

- 1) Neutrals were grounded at the motor-generator control cabinet.
- 2) Neutrals were grounded at the 480/208-120 V, delta-wye critical transformer neutral.
- 3) No grounds existed on the noise-sensitive neutrals, other than those noted above.

Two sets of crossed neutrals were found and corrected as noted below:

- 1) The protective system neutrals were reversed at the protective system panel. This was required because the normal and alternate power supply feeders to the protective panel were cross-connected; i.e. the current in the phase lead from one bus returned in the neutral to the other bus.
- 2) The neutral lead to the nuclear panel was removed from noise-sensitive neutral bus No. 1 and connected to noise-sensitive neutral bus No. 2. This was necessary since the neutral lead for the power supply feeder to the nuclear panel was connected to noise-sensitive bus No. 1, while the phase lead was connected to bus No. 2.

Correcting the noise-sensitive neutral wiring resulted in no noticeable improvement of the voltage appearing between neutral and ground. A typical neutral-to-ground waveform is shown in Figure 1118-6.

The cause of this "floating" is the small diameter (No. 12 AWG) wire used for the long wire-runs between the M-G sets (where the neutrals are grounded) and the control room. This results in an IR drop along the neutral, accounting for a voltage above ground.

The waveform of this voltage between neutral and ground is apparently the result of the M-G sets "beating" against normal house power, due to the slight difference in frequency between the two systems. The M-G sets and normal house power neutrals are grounded to the building at different locations. However, grounding cables are small, resulting in varying resistances from neutral to-ground.

Correcting the crossed noise-sensitive neutrals improved the performance of the incore nuclear flux instrumentation, as reported in NAA-SR-7232, "Debugging of the HNPF Nuclear Instruments":

"Considerably lessened low frequency (360-400cps) damped oscillation transient which had been mysteriously appearing on pre-amplifier outputs as scrutinized on the oscilloscopes. These oscillations would appear intermittently for a period of time varying from a few minutes to several hours; then, they would likewise fade away."

Only one other problem with the noise-sensitive power system has occurred, and this in the Plant Control System. During testing of the main sodium pumps, it was observed that a low frequency (6-12 cpm) speed oscillation occurred at pump speeds over 350 RPM. This oscillation could be eliminated by switching from main board speed control to local speed control from the coupling cabinet.

At the main board, the last instrument in the speed control instrument chain is a magnetic amplifier, powered from noise-sensitive power, furnishing a 0-60V d-c signal to the sodium pump coupling controller. The coupling

controller is powered from critical power. That the oscillation was being caused by the M-G set-produced -power was verified by changing M-G set frequency; this caused the period of the oscillation to change. The oscillation problem was eliminated by changing the magnetic amplifier power feed from noise-sensitive to critical.

APPENDIX B

DISCHARGE RATE OF 250V DC BATTERIES

On April 5, 1962, at 0430, Air Circuit Breakers 52-A1 and 52-B1 were tripped and the Diesel Engine was locked-out, in order to de-energize the 480V A and B buses for construction activity. This resulted in a (normal) critical panel transfer occurring, and the M-G sets picked up the critical power loads. Since 480V power was off, the M-G set battery chargers were dead, and the M-G sets were being driven from their 250V d-c batteries.

From the best information available, each battery bank was putting out about 35 amperes. Since the batteries are 200 ampere-hour units, there should have been sufficient potential energy to drive the M-G sets for about four hours.

However, at 0700, after only 2.5 hours of operation, complete discharge of the batteries was evidenced by loss of instrumentation and actuation of numerous main board annunciators. Operations personnel restored 480V power as soon as possible.

Investigation revealed that the cause of the rapid battery discharge, and resultant loss of M-G set output, was low battery water level. Seventeen gallons of water were added to the batteries, and the batteries were re-charged. Battery bank No. 2 responded satisfactorily to charging. Two cells in battery bank No. 1 would not respond to charging as part of the battery bank; these cells were removed from the bank, charged separately, and returned to service.

Because the above incident resulted in an excessively fast battery discharge rate, a battery discharge test was run, starting with float-charging of the batteries to 258V.

Data from the discharge test are shown in Table IX. Note that the battery drain is almost twice that during the discharge incident as previously quoted. The discharge test was terminated when the lowest cell voltage was 1.75V, and, at the termination time noted, output of the M-G sets was sufficient to keep all plant instruments and equipment operating. The remaining cells in each battery bank were running from 1.75V to 1.80V at the time of termination. Ambient temperature at the time of this test was 90 F.

TABLE IX
DISCHARGE TEST DATA

Battery Number	Battery Load (Amps)	M-G Set Output Load (Amps)	Discharge Time (Fully charged to lowest cell at 1.75V)
1	60	A Phase: 34 B Phase: 43 C Phase: 31	2 hrs 35 min
2	70	A Phase: 55 B Phase: 44 C Phase: 47	2 hrs 7 min

The battery manufacturer gives the following discharge rate specifications, which agree with the Bechtel purchase specification:

- 1) 295 amperes for 1 minute
- 2) 100 amperes for 1 hour
- 3) 50 amperes for 3 hours
- 4) 25 amperes for 8 hours

Linear interpolation between the one and three hour rates, which is conservative, shows:

- 1) 60 amperes for 2 hours 36 minutes
- 2) 70 amperes for 2 hours 14 minutes

This agrees with the discharge test data, and shows that the batteries will meet specification.

It should be pointed out that this discharge test would have been identical to a complete HNPF power outage, except that the control rod drive load was not on the M-G sets.

If there is a complete power outage, a reactor scram occurs and a critical panel transfer takes place. The M-G sets switch to battery power. Assuming the worst case, the additional load on the M-G sets would be for a maximum of 13 minutes required to drive all the control rod drives down. (The control rods will have already fallen into the core). This extra load amounts to a maximum of 2 kw per M-G set.

The design criterion (see AI System Description A81-794-2, "Emergency Power System") for the batteries is to operate for one hour before complete discharge. It is apparent that this criterion will be exceeded.

HALLAM NUCLEAR POWER FACILITY
PREOPERATIONAL TEST COMPLETION REPORT
NUCLEAR INSTRUMENTATION SYSTEM

AI-P-1119

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A T O M I C S I N T E R N A T I O N A L
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CONTENTS

	Page
I. Purpose of Test	1
II. Discussion of Test Performance	1
III. Analysis and Presentation of Test Results	10
A. Channels I and II	10
B. Channels III and IV	24
C. Channels V through IX	25
D. Modified Start-up Interlock Circuit	26
IV. Compliance with Test Completion Criteria	29
V. Evaluation	31
Appendix	36

TABLES

I. Flux-Spread Trips at Various Power Levels	26
II. Nuclear Instrumentation Trips	28

FIGURES

	Page
1119-1 Suppression Added for Nuclear Count Rate	
Channels	4
1119-2 Suppression Added for Nuclear Count Rate	
Channels	5
1119-3 Schematic Diagram BF ₃ Preamplifier No. 1 . . .	11
1119-4 Schematic Diagram BF ₃ Preamplifier No. 2 . . .	12
1119-5 Oscilloscope Trace, BF ₃ Channel I	
(1 μsec/cm sweep, 100 mv/cm pulse height . . .	14
1119-6 Oscilloscope Trace, BF ₃ Channel I	
(0.5 msec/cm sweep, 100 mv/cm pulse height . .	15
1119-7 Oscilloscope Trace, BF ₃ Channel II	
(1 μsec/cm sweep, 100 mv/cm pulse height . . .	16
1119-8 Oscilloscope Trace, BF ₃ Channel II	
(0.2 msec/cm sweep, 100 mv/cm pulse height . .	17
1119-9 Counting Rate vs Discriminator	
Setting BF ₃ No. 1	18
1119-10 Counting Rate vs Discriminator	
Setting BF ₃ No. 2	19
1119-11 Counting Rate vs High Voltage BF ₃ No. 2	
(Discriminator Setting -4)	21
1119-12 Counting Rate vs High Voltage BF ₃ No. 2	
(Discriminator Setting -3.5)	22
1119-13 Modification to Flow Comparator	27

HALLAM NUCLEAR POWER FACILITY
PREOPERATIONAL TEST COMPLETION REPORT
NUCLEAR INSTRUMENTATION SYSTEM, AI-P-1119

I. PURPOSE OF TEST

The purpose of this test was to prove the operability of the nine nuclear instrumentation channels, and verify that channels I and II are able to detect neutrons, in preparation for dry critical loading of the reactor.

II. DISCUSSION OF TEST PERFORMANCE

Prior to installation, the nuclear instrumentation system, which consists of two source range channels, two intermediate range channels and five power range channels, was given very comprehensive quality control tests at the manufacturer's plant in order to demonstrate that the equipment met Atomics International's purchase specification 7518-S72404. This testing consisted of tests on system accuracy, drift, and response. The interconnecting cabling was of similar type and length to that which would be utilized on final installation. Simulated signals were substituted for actual chamber signals. All chambers were tested for sensitivity in a neutron flux. For the source channel BF_3 chambers, high voltage vs count rate curves were obtained. For the intermediate channel compensated ion chambers, gamma compensation and resistance data were obtained. Chamber test information is presented in the Appendix to this report.

After the nuclear instrumentation was installed, the equipment was again tested. As in many other nuclear systems, initial operation of the equipment was plagued by noise. An investigation into the noise problem resulted and the following three types of noise were found present:

- a) Bursts of white noise pulses would randomly appear on the test oscilloscope. This noise was found on power leads and on chassis grounds. Part of this noise was found to come from operation of alarm, setback, scram, and interlock relays and part was found to be from operation of machinery such as the overhead crane. All causes of this noise were not determined.
- b) Beat frequency noise would randomly appear on the noise-sensitive power leads (as witnessed on the oscilloscope). This resulted when the frequencies of the noise-sensitive motor-generators and the critical power varied from each other. (The noise-sensitive motor-generators are not synchronous with house power.)
- c) The voltage on the noise-sensitive power neutral varied with respect to ground. The magnitude of this noise was a function of the varying loads and the feeder resistance.

The noises which were found to cause the greatest problem with the nuclear instrumentation were the "bursts" described in a) above.

This noise was especially a problem with the incore nuclear instrument channels, as reported in the preoperational test completion report for AI-P-1166, "Protective System Modification for Fuel Loading".

A systematic search was made to find all equipment and circuits that caused noise on the input signals to the count rate meters. The search revealed that the breaking of 125V dc circuits caused the largest amount of noise. Most of these interferences were eliminated by the addition of suppression circuits (Figures 1119-1 and 1119-2) to the contacts of switches and relays which were causing the noise. These switches and relay contacts were located in the main control panel, the protective panel, and the nuclear panel. The suppression circuits, which were reported in NAA-SR-7232, "Debugging of the Hallam Nuclear Power Facility Nuclear Instruments", are as follows:

- a) Across contacts on console setback switch, 0.1 mfd capacitor.
- b) Across contacts on main board setback switch, 0.2 mfd capacitor.
- c) Across contacts on console alarm acknowledge switch, 0.05 mfd capacitor.
- d) Across contacts on console alarm reset switch, 0.2 mfd capacitor.
- e) Alarm acknowledge relay AR2 contact No. 4, 0.2 mfd capacitor and 510 ohm resistor.

Figure 1119-1. Suppression Added for Nuclear Count Rate Channels

Figure 1119-2. Suppression Added for Nuclear Count Rate Channels

- f) Alarm acknowledge relay AR2 contact No. 5, 0.5 mfd capacitor and 510 ohm resistor.
- g) Alarm reset relay RR2 contact No. 1, 0.5 mfd capacitor and 10 ohm resistor.
- h) Alarm reset relay RR2 contact No. 2, 0.5 mfd capacitor and 10 ohm resistor.
- i) Alarm reset relay RR2 contact No. 3, 0.5 mfd capacitor and 10 ohm resistor.
- j) Incore alarm contact, 0.05 mfd capacitor.
- k) Incore alarm auxiliary relay contact, 0.1 mfd capacitor.
- l) Incore trip contact, 0.05 mfd capacitor.
- m) Incore trip auxiliary relay contact, 0.1 mfd capacitor.
- n) Manual setback circuit relay K-39 contact No. 1, 0.5 mfd capacitor and 510 ohm resistor.
- o) Neutron period setback contact, 0.2 mfd capacitor.
- p) Neutron period setback circuit relay K-38 contact No. 1, 0.5 mfd capacitor.
- q) Setback circuit relay K-50 contact No. 1, 0.2 mfd capacitor.
- r) Setback circuit relay K-50 contact No. 2, 0.22 mfd capacitor.
- s) Scram circuit relay K-48 contact No. 7 and relay K-64 contact No. 7, 0.5 mfd capacitor and 100 ohm resistor.
- t) Scram circuit relay K-48 contact No. 3 and relay K-64 contact No. 8, 0.5 mfd capacitor and 10 ohm resistor.

- u) Across the annunciator horn, 0.22 mfd capacitor.
- v) Across bank-down control rod switch contact on main board, 0.05 mfd capacitor.
- w) Across bank-up control rod switch contact on main board, 0.05 mfd capacitor.

Other causes of noise were also eliminated. The power cables from the nuclear instrumentation panel to the channel I and II preamplifiers were rerouted in steel conduit. These cables had been indirectly routed in cable trays. Even though these cables were of the shielded type, they were susceptible to electrical power transients.

The cable shields on channels I through IV were found grounded at the high voltage monitor boxes. These grounds were all lifted in order to have a one-point grounding system; the nuclear cabinet frame being used as the common ground.

The neutrals on the noise-sensitive power were found interchanged and were corrected.

The above changes were sufficient to reduce noise to an acceptable level which in turn allowed channels I and II to detect neutrons without harmful noise interference.

In addition to reducing noise, the following modifications and adjustments were made:

- a) The nuclear instrumentation panel as delivered had inadequate cooling. The top and bottom screens of the

chassis making up channels I through IV were moved, louvers and cable entrances were plugged, and an exhaust fan was installed in the panel top to aid in the circulation of air from the bottom inlet fan up through the chassis. Previously, six voltage-dropping resistors and the three high voltage monitor boxes were relocated to the recorder section of the nuclear panel. This was done to reduce heat dissipation near the nuclear chassis and to provide accessibility to the rear of the standby chassis.

- b) Several jumper wires were installed in the nuclear panel to complete the power distribution to the annunciator field contacts. In addition, the polarity of the nuclear remote meters was reversed.
- c) Several cold solder joints on the printed circuits in some of the nuclear chassis were found and repaired.
- d) A few components in the various nuclear chassis were found defective and were replaced. Neon bulb voltage limiters were installed across the variable high voltage adjust potentiometer on each high voltage power supply to eliminate potentiometer failure.
- e) Channel I and II preamplifiers contained some voltage feed-through connectors and cables which broke down

when the chamber high voltage was applied. These were replaced with adequately rated cabling.

- f) The neutron output pulses of channels I and II preamplifiers had too long a pulse width and too high an amplitude. The gain of the preamplifiers was reduced, as was the input time constant.
- g) Ringing in channels I and II preamplifier signal outputs was found undesirably high when the cables to the count rate meters were connected. Compensating passive components were installed in the preamplifier outputs, to prevent ringing.
- h) The 12 K ohm, 2 watt bypass resistors in parallel (plate-to-cathode) with the series regulating tube in the + 150V dc power supplies of the Log N and period chassis were replaced with 10 watt resistors because the original resistors were underrated.
- i) The BF_3 chamber used with channel I had a loose cable connector which in turn caused the internal wiring to become defective. The chamber was disassembled at the connector end and repaired.
- j) The gains of the flux amplifiers for channels V through IX were modified to be variable from 4.5 to 45 μa input, to obtain 100% indicated power output. As delivered, the flux amplifier gains were variable from 33 to 330 μa input,

to obtain 100% indicated power output. As a result, resistor R-100 was changed from 30 to 200 K ohms and potentiometer R-101 was changed from 0.3 to 2.5 megohms.

With the above adjustments and modifications made: voltages were adjusted and measured; calibrations were run; and alarm, set-back, scram, and interlock contacts were set and tested. For channels I and II, the pulse apparent resolution times were measured. By using a one curie plutonium-beryllium test source, discriminator setting vs count rate curves were obtained. In addition, count rate vs chamber voltage curves were obtained.

For channels III through IX, simulated current signals were fed from the chamber cable connector through each channel. In addition, each chamber was tested by temporarily hooking up a micro-microammeter and a power supply to each, and observing current resulting from the chamber detecting neutrons from the test source.

III. ANALYSIS AND PRESENTATION OF TEST RESULTS

A. CHANNELS I AND II

Figures 1119-3 and 1119-4 delineate the changes made to the BF_3 chamber preamplifiers. These changes reduced the gain and optimized the pulse shape. The gains of the preamplifiers were originally about 400 and were reduced to approximately 50.

Figure 1119-3. Schematic Diagram BF_3 Preamplifier No. 1

Figure 1119-4. Schematic Diagram BF₃ Preamplifier No. 2

Figures 1119-5 through 1119-8 show typical pulses at the inputs to channels I and II log count rate meters after circuit modifications.

The pulse recovery time of each channel was determined to be no longer than 2.5 microseconds. A fast pulse generator was substituted for each BF_3 chamber so that the generator's pulse rate was fed through the preamplifier and the log count rate meter. With the pulse generator set at 2.5×10^5 pulses per second, the pulse width was increased to 1.5 microseconds without a decrease in pulse rate out of the log count rate meter. Further increase in pulse width overloaded the generator. For this pulse rate and width, the pulse separation was 2.5 microseconds; i.e., the time between the trailing edge of one and the leading edge of the next. This indicated that the channel had a recovery time of not more than 2.5 microseconds. For narrow pulses such as that from a BF_3 chamber, the pulse resolution time of a channel can therefore be taken as not longer than 2.5 microseconds.

Pulse resolution time is defined here as the distance between the leading edge of the closest pulses which can be counted. The results of this test define the upper limit for period measurements as being approximately 2×10^6 counts per minute for reasonable probability of random separation of pulses. This maximum is adequate by approximately two decades for performance of any planned period measurements.

Figures 1119-9 and -10 are the final discriminator curves for channels I and II. These curves were obtained using a portable one

Figure 1119-5. Oscillograph Trace, BF_3 Channel I
(1 $\mu\text{sec}/\text{cm}$ sweep, 100 mv/cm
pulse height)

Figure 1119-6. Oscillograph Trace, BF_3 Channel I
(0.5 msec/cm sweep, 100 mv/cm
pulse height)

Figure 1119-7. Oscillograph Trace, BF_3 Channel II
(1 $\mu\text{sec}/\text{cm}$ sweep, 100 mv/cm
pulse height)

Figure 1119-8. Oscilloscope Trace, BF_3 Channel II
(0.2 msec/cm sweep, 100 mv/cm
pulse height)

Figure 1119-9. Counting Rate vs Discriminator Setting BF₃ No. 1

Figure 1119-10. Counting Rate vs Discriminator Setting BF₃ No. 2

curie plutonium-beryllium test source and positioning it at various distances from the chamber. Final discriminator settings were selected at 1-1/2 divisions to the left of the knee of the curves, on the basis of allowing all pulses within 30% of maximum energy to be counted. Past experience has shown that loss of pulses at this setting is negligible. Using this basis, channel I discriminator setting was taken to be -4.0 and channel II discriminator setting was taken to be -3.5.

Background count rates for the above discriminator settings at the reactor were as follows:

Channel No.	Chamber out of instrument thimble	Chamber at bottom of instrument thimble
I	16.3 cpm	4*
II	27.5 cpm	5*

With the above discriminator settings, and using the neutron test source, count rate vs chamber high voltage curves were obtained for both channels I and II as shown in Figures 1119-11 and -12. These curves differ considerably from the curves presented in the Appendix. This difference is attributed to the difference in optimizing criteria for discriminator settings. The laboratory data were taken optimizing the chamber sensitivity under low background noise conditions. The HNPF data were taken optimizing the noise condition as it existed in the plant.

* No measurable effect on count rate was observed with the reactor source in or out of the core, or with the control rods in or full out. This indicated that without fuel in the reactor, the source cannot be seen from the instrument thimbles around the reactor.

Figure 1119-11. Counting Rate vs High Voltage BF_3 No. 1
(Discriminator Setting -4)

Figure 1119-12. Counting Rate vs High Voltage BF_3 No. 2
(Discriminator Setting -3.5)

A voltage of 2100V dc was selected as the chamber high voltage and was used during dry critical testing. After re-examining the count rate vs chamber high voltage curve it was decided to raise the chamber high voltage to 2200V to raise it a little further on the knee of the curve.

The time constants of the log count rate period circuits were found to be objectionably fast. Period alarm contacts were set to actuate for periods of 30 sec or less. At low count rates, this alarm was continuously tripping due to statistical neutron counts and small electrical disturbances. These period circuits were not connected in any way to automatic plant protective shut down systems.

To alleviate the problem, the time constant of the period circuits was increased so that for a 10 sec period ramp, the period circuit output would respond to within 10% of the ramp in 11 sec, instead of 7.4 sec as originally delivered. In doing so, capacitor C235 of the log count rate meter was changed from 0.001 mfd to 0.005 mfd.

The period response time as specified in equipment purchase specification 7518-S72404 was as follows:

"When the input to the period circuitry is placed on a ramp corresponding to a constant period, τ , the output shall achieve this period, ± 10 percent, within 4 ± 0.5 seconds".

For periods longer than 15 seconds, the modified period circuits still meet the original purchase specification.

The high voltage monitor relays were found to drop out at 800V for channel I and at 1200V for channel II. These voltages are much below the chamber voltage necessary for detecting neutrons. The associated alarm circuit offers protection only in the event of a substantial loss in high voltage. The majority of failures which occur to high voltage supplies are of this type; however, a "gradual loss in voltage" type of failure is also conceivable. For this latter case no immediate alarm would occur. It is therefore recommended that for each startup, the high voltage supplies of the BF_3 chambers be read for correct voltage. To alleviate the relatively low voltage drop out condition of the channel I and channel II high voltage monitors, the settings were raised to 1600V and 1525V, respectively.

As a final adjustment, the BF_3 chamber removal interlock was set to be satisfied at 10^{-9} amps input for each of the channels.

B. CHANNELS III AND IV

The power supplies of each channel checked-out satisfactorily. The Log N meter calibrations were accomplished without difficulty by a current source. Period setbacks were adjusted to trip at 20 seconds, and period scrams were adjusted to trip at five seconds. The high voltage monitor relays were found to drop out at 200V for channel III and 150V for channel IV. The same discussion applies here as was made for the BF_3 high voltage monitor relays. Finally, the B chamber voltage was set for -36V for channel III and -27V for

channel IV. These voltages were selected on the basis of the chamber data that were supplied by the manufacturer and which are included in the Appendix.

C. CHANNELS V THROUGH IX

The power supplies of each channel were measured and found satisfactory. For the dry critical tests, the gain of each flux amplifier was set so that 1×10^{-5} amps input indicated 100% power and delivered 10V to the protective panel. This was later changed to 4.8×10^{-6} amps for the wet critical tests. After each setting, a calibration was performed on each amplifier by use of a current source. Each calibration was found to be within allowable tolerances.

The level alarm trip for each channel was set at 107% of indicated full power.

The trouble monitor circuit for each channel was tested for correct operation. In all but one of the flux amplifiers it was found that transistor Q7 of this circuit required replacing. The cause of the failure was not determined.

In channels V, VI, and VII, the period cut-out trips were adjusted and tested to actuate at 10% of indicated full power.

Finally, the flux comparator trip circuits were adjusted and tested to actuate and alarm upon sensing a spread of more than 15% in flux level between channels V, VI, and VII and between channels VIII and IX. The trip was set for a 15% spread at 100% of indicated

full power. At lower percentages of full power, the spread becomes smaller. Table I shows the various spreads for various power levels.

TABLE I
FLUX-SPREAD TRIPS AT VARIOUS POWER LEVELS

Flux Amplifier Indicated Power Level (% of full power)	Channels V, VI, & VII Flux Spread (% of full power)	Channels VIII & IX Flux Spread (% of full power)
30	7	7
50	8	8
80	13	11
100	15	15

At near zero signals into the flux comparator trip circuits, the required spread to actuate the alarm becomes near zero. Therefore, at zero or near zero power level, noise was sufficient to actuate the trip circuit and the alarm remained on. To rectify this situation, the flux comparator was modified so that the alarm circuit would not actuate when the highest flux signal was lower than approximately 10% of full power. Figure 1119-13 delineates the modification made to the flux comparator.

D. MODIFIED START-UP INTERLOCK CIRCUIT

The log count rate meter start-up interlocks, which had been set to operate at 600 cpm, were temporarily removed for dry critical

Figure 1119-13. Modification to Flux Comparator

testing. The trip circuits were rewired as low level scram circuits for the initial loading of the reactor. The trip circuits were set to actuate upon receiving an 8×10^6 cpm signal. With either or both circuits actuated, a scram would result. Table II summarizes the settings of the adjustable nuclear instrumentation trips as set for the dry critical tests.

TABLE II
NUCLEAR INSTRUMENTATION TRIPS

Item	Channel	Description	Trip Setting
1*	I and II	Start-up Interlock	600 cpm
1a*	I or II	CRM Level Scram	8×10^6 cpm
2	I or II	Positive Period Alarm	30 sec
3	III or IV	BF ₃ Removal Start-up	10^{-9} amps
		Interlock	
4	III or IV	Period Setback	20 sec
5	III or IV	Period Scram	5 sec
6	V, VI or VII	Flux Level Alarm	107% full power
7	V, VI or VII (2 or 3 out of 3)	Period Setback and Period Scram Cutout	10% full power
8	V, VI and VII	Difference Flux Alarm	15% full power at full power
9	VII and IX	Difference Flux Alarm	15% full power at full power

* The start-up interlock was temporarily deleted and modified to be a low flux level scram for the dry critical tests.

IV. COMPLIANCE WITH TEST COMPLETION CRITERIA

Following are the test completion criteria associated with preoperational test AI-P-1119, Nuclear Instrumentation System, as listed in NAA-SR-5700, Supplement 2, Page XI (a)-15, with remarks regarding the test to explain compliance with the criteria.

- a) Criterion: Nuclear instrumentation channels are calibrated according to manufacturer's instructions.
Remarks: The nuclear instrumentation was calibrated and adjusted using all applicable information available from the manufacturer.
- b) Criterion: The source range period alarm is set at 30 seconds, the intermediate range setback at 20 seconds, and the intermediate range scram at five seconds. The trouble monitor alarm system works according to the vendor's Operations and Maintenance Manual.
Remarks: These alarms, setbacks, and scrams were set and tested. The original time constant of the source range period circuit was made longer to eliminate spurious period alarms. This changed the period response (to 10 second period ramp) from 7.4 to 11.0 seconds. For periods longer than 15 seconds, response is still within specifications. The trouble monitor alarm

system was tested by actuating each of its 13 "trouble" contacts.

- c) Criterion: The nuclear instrumentation system has been demonstrated to operate correctly. For the startup channels, this includes using a neutron source and reading out the neutron response on the count rate meters. For the intermediate and power range channels, it includes applying a simulated current signal to each channel in place of the chamber and observing the signal on the read out instrumentation.

Remarks: The discriminator settings vs count rate curves and the count rate vs chamber voltage curves of channels I and II (Figures 1119-6 and 1119-7) gave proof that the startup channels would detect neutrons correctly. For the intermediate and power range channels, simulated signals applied at the chamber connector gave proof that each channel (without chamber) responds correctly. By using a test source and a temporarily connected micro-microammeter, proof that the chamber would detect neutrons was obtained. The testing of each alarm, setback, scram, and interlock circuit gave final proof that all channels were operating correctly.

- d) Criterion: Background count rate is recorded for each channel with the chamber located at the bottom of the corresponding instrument thimble. Count rate for the two source range channels are recorded with the reactor neutron source located in the core.
- Remarks: With the chambers at the bottom of their thimbles, the reactor source separated, and all control rods in, the background count rate of channels I and II was found to be 4-5 cpm. As expected, no difference in count rate was observed with the source intact and all control rods full out.

V. EVALUATION

The purpose of this test—to prove the operability of the nine HNPF nuclear instrumentation channels—was adequately fulfilled. At the end of this test, the nuclear instrumentation system was ready for dry critical testing.

To gain assurance that the nuclear instrumentation system was ready for dry critical testing, the following objectives were accomplished:

- a) All nine channels of nuclear instrumentation were calibrated and adjusted using information available from the manufacturer.

- b) The source range period alarm was set at 30 seconds.
- c) The intermediate range period setback was set for 20 seconds.
- d) The intermediate range period scram was set for 5 seconds.
- e) Appropriate circuits of the nuclear instrument panel were tested, and trouble monitor alarms were noted to annunciate at specified times.
- f) A neutron source stimulus was applied to the channel I and II BF_3 chambers and the neutron response was measured on the count rate meters. Curves of discriminator settings vs count rate and of count rate vs chamber voltage were plotted. Documented proof was thus obtained that the start-up channels detect neutrons as specified.
- g) A neutron source stimulus was applied to the intermediate range channels (III and IV) and their responses were measured on a micro-microammeter temporarily connected to the circuit. Then, electrical signals stronger than those occurring with the chambers stimulated by a neutron source were introduced to the circuits at the chamber input locations. Outputs were measured on the channel readouts, to prove that they would respond as specified. These external signals were

also used to check that the intermediate range interlock circuits were activated at specified levels.

- h) A neutron source stimulus was applied to the power range channels (V, VI, VII, VIII and IX) and their responses were measured on a micro-microammeter temporarily connected to the circuit. Next, electrical signals stronger than those occurring with the chambers stimulated by a neutron source were introduced to the power range circuits at the chamber input locations. Outputs were measured on the channel readouts, to prove that they would respond as specified. These external signals were also used to check the alarm, setback and scram circuitry, to ascertain that they were activated at specified levels.
- i) The background count rate was recorded for all channels, with the respective chambers located at the bottom of their corresponding thimbles. Channels I and II showed a background count rate of four to five counts per minute. This background count rate was constant with the source both separated and intact and with the control rods both fully inserted and fully withdrawn.

In the process of executing this preoperational test, many discrepancies were discovered in the nuclear instrumentation system,

which had to be corrected before the system could be considered ready for use. These discrepancies and remedial action taken are amply covered in NAA-SR-7232 "Debugging of the Hallam Nuclear Power Facility Nuclear Instruments".

In the process of calibrating, checking, and debugging the nuclear instrumentation system, certain problem areas which might arise in the design and installation and use of this type system in future power plants were illuminated. Illumination of these problem areas has elicited the following suggestions:

- a) All cables between nuclear panels, preamplifiers, and detectors should be installed in steel conduits and should take the shortest routes. Spare conduits should be provided for emergency use.
- b) Cabinets for components of the nuclear instruments should be designed for optimum accessibility and cooling. Crowding of components inside the cabinets should be avoided.
- c) Nuclear instrument system vendors should have a contractual requirement to have a field representative at the site, while their equipment is being installed and tested.
- d) When excessive differences in nuclear channel read-outs actuate alarms, an allowance should be made for

cut outs at the lower power levels, so that noise induced transients do not bring in spurious alarms.

One modification made by the General Electric representative at the site was lengthening of the period meter time constant by a factor of five. This was accomplished by replacing the 0.001 microfarad period amplifier bridging capacitor (C235 on General Electric drawing 612D820) with a 0.005 microfarad capacitor. This modification eliminated a source of annoyance and distraction by damping out noise induced, low level, period alarms. It did not in any way jeopardize reactor safety.

The nuclear instrument system has been tested, calibrated and debugged, and is now ready for operational use.

APPENDIX

ACCEPTANCE SPECIFICATIONS AND DATA

DESCRIPTION	Neutron Detector	WESTINGHOUSE ELECTRIC CORPORATION	WL-6938
TYPE	High Sensitivity Proportional Counter		June 22, 60
FILLING GAS	Boron Trifluoride Enriched in B10		
OVERALL LENGTH	32-11/32 $\pm$ 1/8 inches		
WIDTH	8-1/8 inches max.		
THICKNESS	3-3/8 inches max.	Electronic Tube Division CUSTOMER ACCEPTANCE SPECIFICATION	

ITEMS	CONDITIONS			LIMITS		
	Notes	Test Circuit		Minimum	Maximum	Units
Insulation Resistance	1,2	Fig. 1		1×10^{11}		Ohms
Plateau Beginning	1,2,3,4,5,6	Fig. 2			2000	Vdc
End	1,2,3,4,5,6	Fig. 2		2050		Vdc
Length	7			175		
Relative Slope	8				.025	% Volt
Background	1,3,4,9	Fig. 2			60	Counts/min
Sensitivity	1,3,4,5,10	Fig. 2		42	58	Counts/nv
Outline Dimensions				3-2R-WL-6938

Fig. 1

Fig. 2

WL-6938

CUSTOMER ACCEPTANCE SPECIFICATION

NOTES:

1. The WL-6938 is supplied with a coaxial connector similar to HN which will mate with a UG-59A/U male connector. The polarity of the applied voltage is such that the center conductor of the connector is positive with respect to the envelope of the BF_3 elements inside the detector.
2. Test voltage 500 Vdc. Either polarity may be used.
3. Equipment characteristics:
 - a. Preamplifier - cathode follower, gain of approximately unity. Baird-Atomic model 231 or equivalent.
 - b. Linear Amplifier - low impedance input, 200 microvolt input sensitivity, integral pulse level discriminator. Baird-Atomic model 2040 or equivalent.
 - c. Scaler - variable H.V. power supply capable of 2500 Vdc. Baird-Atomic model 1091 or equivalent.
4. The pulse height discriminator setting must be optimized. The setting will vary with the equipment used. If the setting is not known, it may be determined by a series of integral bias curves.
5. A polonium-beryllium neutron source is moderated with a suitable hydrogenous material to provide thermal neutrons. Source strength is not critical. A radium-beryllium source may be used, in which case plateau length will be reduced and the limits shown do not apply.
6. A plateau may be defined as that region of the count rate versus applied voltage curve where the count rate is relatively independent of the applied voltage. A curve of integrated counts vs. high voltage is obtained in the following manner. Starting at 1750 volts and increasing in 50 volt steps to 2250 volts or greater if necessary to obtain full plateau characteristics, record the total counts accumulated in a finite time interval at each voltage step. The time interval is not critical but should be sufficiently long to accumulate enough counts for reasonable statistical accuracy, and the time interval should be the same for each voltage step.

CUSTOMER ACCEPTANCE SPECIFICATION

The voltages corresponding to the start and end of the plateau are determined by the point of tangency of a line of slope 4%/100 volts and the curve. The point corresponding with the lower voltage defines the start of the plateau and the point corresponding with the higher voltage defines the end of the plateau.

7. The plateau length, expressed in volts, is the difference between the voltage corresponding to the end of plateau and the beginning of plateau.
8. The relative plateau slope is determined by the straight line drawn through the two points of tangency as obtained in Note 6. The difference of counts accumulated at each point expressed as a percentage of the average of the total counts of both points is divided by the plateau length as determined by Note 7.
9. Background is measured in an area remote from radiation sources. The averaging interval shall not be less than one minute. Applied voltage shall be 100 volts in excess of the voltage corresponding to the beginning of the plateau.
10. This test may be made by utilizing a known flux, or by comparing the sensitivity of the WL-6938 with a neutron detector of known sensitivity. Applied voltage shall be equal to that corresponding to the mid-point of the plateau as determined in Note 6.

In most instances the neutron flux incident to the detector for this test will not be isotropic; therefore, the sensitivity limit shown is a test value only and not a true measure of tube rating.

WESTINGHOUSE ELECTRIC CORPORATION

Date	4-28-60
Back-ground	48 cpm

Serial No.	Tube Type
601702	6938

Voltage	C/25 sec	Voltage	C/25 sec	CHANNEL I	
1550		1950	53241	Insulation Resistance	$10^{12} \Omega$
1600		2000	53668	Background	48 cpm
1650	39126	2050	54172	Beginning of Plateau	1820 v.
1700	46350	2100	53583	End of Plateau	2160 v.
1750	50128	2150	53962	Plateau Length	340 v.
1800	52061	2200	55491	Plateau Slope	0.08%/v.
1850	54070	2250	58465	Nominal Sensitivity	$\sim 49.0 \text{ c/nv.}$
1900	54162	2300	67978

WESTINGHOUSE ELECTRIC CORPORATION

Date	4-28-60
Back-ground	46 cpm

Serial No.	601701
Tube Type	6938

Voltage	c/25 sec	Voltage	c/25 sec	CHANNEL II	
1550		2000	56815	Insulation Resistance	$10^{12} \Omega$
1600		2050	56958	Background	46 cpm
1650	39711	2100	57074	Beginning of Plateau	1820 V.
1700	47468	2150	56918	End of Plateau	2170 V.
1750	52395	2200	58231	Plateau Length	350 V.
1800	55417	2250	62310	Plateau Slope	0.08%/V.
1850	55944	2300	73302	Nominal Sensitivity	$\sim 51.7 \text{ c/nv}$
1900	57176	2350			
1950	56766

DESCRIPTION	Neutron Detector	WESTINGHOUSE ELECTRIC CORPORATION Electronic Tube Division CUSTOMER ACCEPTANCE SPECIFICATION
TYPE	Electrically Compensated Ion Chamber	
NEUTRON SENSITIVE AGENT	Boron enriched to 92% in B10	
FILLING	Dry Nitrogen	
MAX. DIAMETER	3 3/16 inches	
OVERALL HEIGHT	24 inch Max.	
CONNECTORS	3 Type HN Female	

TEST	CONDITIONS				LIMITS			
	Notes	Positive Electrode Vdc	Negative Electrode Vdc	Signal Electrode Adc	Fig	Min	Max	Units
Positive to Signal Electrode Leakage	1,2,3	≠ 400	0	Read		-	10^{-13}	Adc
Negative to Signal Electrode Leakage	1,2,3	0	-200	Read		-	10^{-13}	Adc
Gamma Compensation Voltage	1,2,4	≠ 400	Read	0	1	-10	-80	Vdc

WESTINGHOUSE ELECTRIC CORPORATION
Electronic Tube Division

WL-6377

CUSTOMER ACCEPTANCE SPECIFICATION

NOTES:

1. Type HN connectors provided on the chamber mate with UG 59A/U connectors or equivalent.
2. The power supply is to be a battery type of low impedance. Low noise batteries must be selected in order to avoid introduction of noise into the system.
3. This test is to be performed in a radiation free area.
4. A gamma source of approximately 100 mc strength is used. The chamber is positioned so that the radiation is incident to its side, thereby providing relatively uniform flux distribution over the entire active length.

WESTINGHOUSE ELECTRIC CORPORATION
Electronic Tube Division
Specifications & Standards Dept
Elmira, N.Y.

Name: WL-6377 TEST DATA

Serial Number	01307	601718	Std Tube
Date Tested	Channel IV 3-25-60	Channel III 4-25-60	4-25-60
Positive to Signal Electrode Leakage (Adc x 10 ⁻¹³)	-0.5	+0.1	
Negative to Signal Electrode Leakage (Adc x 10 ⁻¹³)	-0.4	-0.1	
Gamma Compensation			
Voltage applied to -25V		+0.8	
Negative electrode -30V	+2.0	-1.0	
(Adc x 10 ⁻¹³) -35V	+0.3	-2.7	
-40V	-1.0	-4.0	
-45V	-2.0	-5.0	
-50V	-2.7	-5.8	
Resistance to Case (ohms) Positive	10 ¹²	10 ¹²	
Negative	10 ¹²	10 ¹²	
Signal	10 ¹²	10 ¹²	
Neutron Sensitivity (Adc x 10 ⁻¹³)	51	50	51

GENERAL ELECTRIC COMPANY
ATOMIC POWER EQUIPMENT DEPARTMENT

UNCOMPENSATED IONIZATION CHAMBER NEUTRON SENSITIVITY CHECK

SOURCE: NTR (Vallecitos) - 15.0 Watt Level Gamma Level $\approx$ 6100R/HR

EQUIPMENT:

TEST DATA:

<u>Time</u>	<u>Serial No.</u>		<u>Output Current</u>	<u>Sensitivity</u>	<u>Channel</u>
1040	4131120	H	$.89 \times 10^{-5}$ 4	4.14×10^{-14} a/nv	VIII
1159	4131111	N	.91 "	4.24 "	VI
1320	4131119	P	.92 "	4.28 "	V
1350	4131117	F	.87 "	4.05 "	VII
1420	4131113		.89 "	4.14 "	IX

NOTES:

1. Less than 1/2 of 4% decrease in output of each unit with decrease in applied voltage from 90 to 45 volts.
2. Estimated accuracy of above sensitivity - $\pm 8.5\%$.
3. From activation of gold foils on chamber, average neutron flux = 2.15×10^{-8} nv.

DATE: DECEMBER 29, 1960

HALLAM NUCLEAR POWER FACILITY
PREOPERATIONAL TEST COMPLETION REPORT
PLANT CONTROL SYSTEM

AI-P-1120

Test and Analysis
by
D. J. SOBO

Evaluation
by
O. G. JENKINS

A T O M I C S I N T E R N A T I O N A L
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SUMMARY

All plant control system components requiring calibration were calibrated to an accuracy of $\pm 1/2\%$ of full scale. By the use of simulated input signals, the proper connection of all components and correct actuation of output devices were verified. Correct initial controller settings were made. Bumpless transfer from "Manual" to "Automatic", and from "Automatic" to "Manual", was demonstrated on all hand control stations. Proper actuation of annunciators associated with the plant control system was verified, as was proper operation of all plant control system interlocks.

CONTENTS

	Page
I. Purpose of Test	1
II. Discussion of Test Performance	1
A. Plant Power Control	3
B. Division of Load Computer	7
C. Secondary Sodium Flow Control	12
D. Primary Sodium Flow Control	18
E. Nuclear Power Computer	22
F. Neutron Flux Controller	29
G. Moderator Coolant Control	38
H. Convection Flow Control	42
I. Feedwater Control	49
J. Attenuator Control	58
K. Power Relief Control	60
L. Primary Block Valve Control	61
M. Steam Dump Pressure Control	65
N. Miscellaneous	67
III. Analysis and Presentation of Test Results	68
A. Plant Power Control	68
B. Division of Load Computer	69
C. Secondary Sodium Flow Control	69
D. Primary Sodium Flow Control	72

CONTENTS

	Page
E. Nuclear Power Computer	75
F. Neutron Flux Controller	77
G. Moderator Coolant Control	78
H. Convection Flow Control	79
I. Feedwater Control	80
J. Attemperator Control	83
K. Power Relief Control	90
L. Primary Block Valve Control	90
M. Steam Dump Pressure Control	90
N. Miscellaneous	90
IV. Compliance with Test Completion Criteria	91
V. Evaluation	94
Appendix	97

TABLES

I.	System Accuracy and Response Time for FR-502T and FR-502	70
II.	Secondary Sodium Flow Control Subsystem Rate Limiter Values	71
III.	Primary Sodium Flow Control Subsystem Rate Limiter Values	74

FIGURES

		Page
1120- 7	Moderator Coolant Control Subsystem-Block Diagram	39
1120- 8	Convection Flow Control Subsystem-Block Diagram	43
1120- 9	Feedwater Control Subsystem-Block Diagram	50
1120-10	Attemperator Control Subsystem-Block Diagram	59
1120-11	Power Relief Control Subsystem-Block Diagram	62
1120-12	Primary Block Valve Control Subsystem-Block Diagram	64
1120-13	Steam Dump Pressure Control Subsystem-Block Diagram	66
1120-14	Operating Schedule of Attemperator Valves	89

HALLAM NUCLEAR POWER FACILITY
PREOPERATIONAL TEST COMPLETION REPORT
PLANT CONTROL SYSTEM, AI-P-1120

I. PURPOSE OF TEST

The purpose of this test was to place each plant control subsystem into operation and verify that each was operable, prior to the reactor startup.

II. DISCUSSION OF TEST PERFORMANCE

The plant control system consists of 13 interrelated subsystems which program reactor power to match turbine steam requirements. The preoperational tests performed on each subsystem are described in detail below. To assist the reader in understanding the plant control system, a short description and block diagram of each subsystem are also included.

While performing this test, some instrument, wiring, and tubing errors were uncovered. These errors are typical of those found with any complex system where several different contractors have been involved in manufacturing and installation of equipment. These errors and the corrective actions taken are detailed in the appendix of this report.

Testing of the plant control system started at the manufacturers' plants. As part of the plant control system specification, 7518-S72407, source inspection of all components was required. Consequently, an AI

representative witnessed all testing by the manufacturer to insure all components met specification requirements. In addition to this, each subsystem was "breadboarded", and closed loop tests using simulated process time constants were performed to insure each subsystem's meeting specification requirements. An AI representative also witnessed all main control board testing to insure that all main board mounted plant control system components were connected properly. Detailed results of each manufacturer's tests have been retained by AI Quality Control Department.

After installation of plant control system components at the HNPF site, all instruments were re-calibrated to an accuracy of $\pm 1/2\%$ of full scale or better. The following test equipment was utilized for re-calibration:

- 1) Pyrotest Model 9B null-balance potentiometer for all thermocouple and millivolt signals.
- 2) Wallace and Tiernan precision pneumatic calibrator for all 3-15 psig transmitted pneumatic signals.
- 3) Foxboro M8131 precision current source for all 10-50 ma transmitted current signals.
- 4) Ashcroft hydraulic dead weight tester for all pressure signals above 25 psig.
- 5) Water or mercury manometers for all differential pressure signals.

Following the calibration of all components, the preoperational test was performed as discussed in the following pages of this section.

A. PLANT POWER CONTROL

The function of the plant power control subsystem is to assure that steam is supplied at a set pressure according to the requirements of the turbine (temperature control is achieved elsewhere in the system). The plant power control subsystem generates a demand steam flow determined by measured steam flow and pressure compensation.

As shown in Figure 1120-1, steam flow to the turbine is sensed in FR-502T and transmitted as a steam flow signal to FCCp-500. Steam pressure is sensed in PRC-501Tb and transmitted to PRC-501 as the controlled steam pressure signal. Steam pressure is also sensed at PRC-501Ta and is transmitted to PRC-501 for recording purposes. The operator selects a set pressure in PRC-501. The output of PRC-501 is transmitted to FCCp-500 as an incremental steam flow signal. These signals are summed in FCCp-500. The output of FCCp-500 is a demand steam flow signal and is used as the setpoint of WaIC-501 of the Division of Load Computer. HCS-504 is provided for manual control. Measured steam flow and demand steam flow are recorded in FR-502/WaR-501.

PRC-501, steam pressure recorder, was system calibrated by applying known pressures to PRC-501Ta and PRC-501Tb, and reading these known pressures on PRC-501. The combined accuracy of the recorder and transmitters was within $\pm 1\%$.

With a half-scale pressure input to PRC-501Ta, a step-change of 100 psig was applied, both in the positive and negative direction, and

Figure 1120-1. Plant Power Control Subsystem-Block Diagram

system response time* was determined to be within five sec. The same test was repeated on PRC-501Tb with similar results.

Proper operation of the annunciator "Deviation Main Steam Pressure" was verified to occur when a difference of 20 psi or more existed between PRC-501Tb steam pressure and PRC-501 setpoint. The annunciator could be reset when the difference was less than 20 psi. Within PRC-501, the following controller settings were made:

- 1) Proportional Band 100%
- 2) Reset Time 0.2 min/repeat
- 3) Rate Time 0.1 min

FR-502, mass steam flow recorder, was system calibrated by applying known differential pressure to FR-502T flow transmitter, known pressure to FR-502T pressure transmitter, and known emf thermocouple voltages to FR-502T temperature transmitter, and reading the computed mass steam flow rate on FR-502. The combined accuracy of the various transmitters, computers, and recorders was verified to be within $\pm 2\%$.

With a half-scale mass steam flow signal, step-changes of 50 in. H₂O differential pressure, 50 psig pressure, and 50 F were made to the mass steam flow transmitters, in both the positive and negative directions. System response was within five sec or less.

* Response time is defined as the time necessary for the recorder to indicate 63% of the applied step-change.

HCS-504 was switched to "Manual". It was verified that by manual operation of HCS-504 it was possible to vary the setpoint of WaIC-501, the demand steam flow controller, over its entire range. It was also verified that WaR-501, the demand steam flow recorder, tracked with the setting on HCS-504.

The internal transfer switch in PRC-501 was switched to MANUAL. This cuts out the controller and forces the output of PRC-501 to be the same as the setpoint. The setpoint of PRC-501 was set to 825 psig; this forces the output of PRC-501 to 9 psig, or zero incremental demand steam flow. A half-scale measured steam flow was put into FR-502T flow transmitter. Under these conditions, FCCp-500, the demand steam flow adder, had inputs of zero + 50%, or a total demand steam flow of 50%.

HCS-504 was then bumplessly transferred from "Manual" to "Automatic". It was observed that HCS-504 and WaR-501 outputs and WaIC-501 setpoint all read the proper value of 50% demand steam flow.

By varying PRC-501 setpoint, and varying the input to FR-502T flow transmitter, proper algebraic addition of the steam flow and incremental steam flow signals in FCCp-500 was verified from the WaIC-501 setpoint and the total demand steam flow on HCS-504 and WaR-501.

The measured steam flow signal into FR-502T flow transmitter was returned to a half-scale value, and the setpoint of PRC-501 was returned to 825 psig. A known pressure of 800 psig was set into PRC-501Tb. The internal transfer switch in PRC-501 was switched back to AUTOMATIC, thus putting the steam pressure controller into the system. Under these

conditions, the output of PRC-501 started moving upscale. With the steam pressure controller sensing a low pressure, the incremental demand steam flow signal increased. This increase in incremental demand steam flow resulted in an increase of total demand steam flow as evidenced by an upscale motion on HCS-504, WaR-501, and WaIC-501 setpoint.

The setpoint on PRC-501 was then decreased to less than 800 psig. Under this simulated high pressure condition, the output of PRC-501 started moving downscale, as did the total demand steam flow as indicated on the outputs of HCS-504 and WaR-501 and the WaIC-501 setpoint.

The internal transfer switch in PRC-501 was switched back to MANUAL and the PRC-501 setpoint was adjusted until the total demand steam flow was 75%. The main board air supply was shut off, and proper operation of the air failure solenoid valve was verified by noting that the total demand steam flow remained constant at 75%.

B. DIVISION OF LOAD COMPUTER

The function of the division of load computer is to convert the plant steam load requirements to sodium flow requirements. This unit operates from the demand steam flow signal generated in the plant power control subsystem, and converts that signal to an individual circuit demand sodium flow signal. Provision is made for the plant operator to ratio the plant load among the three heat transfer circuits.

As shown in Figure 1120-2, the demand steam flow signal as generated in FCCp-500 or HCS-504 of the plant power control subsystem,

Figure 1120-2. Division of Load Computer-Block Diagram

enters WaIC-501 as a setpoint. The output of WaIC-501 represents the maximum steam flow being demanded of the individual circuits. By means of either FCp-501, -502, or -503, the plant operator can set any one of the heat transfer circuits to generate all or a portion of this maximum flow. The outputs of FCp-501, -502, and -503 are a circuit demand steam flow for the corresponding heat transfer circuit. These outputs are summed in FCp-504 and sent to WaIC-501 as an input. Thus, WaIC-501, the demand steam flow controller, operates on a setpoint of demand steam flow, and is null-balanced against the sum of circuit demand steam flows. HCS-501, -502, and -503 are provided so the plant operator can manually set a fixed steam flow to be generated in the corresponding heat transfer circuit.

The other six units operate as thermal converters to change steam flow requirements to primary sodium flow requirements in FCCp-501, -502, and -503, and to secondary sodium flow requirements in FCCp-504, -505, and -506.

HCS-504 was switched to "Manual" to be able to conveniently develop a demand steam flow signal. By switching HCS-501, -502, and -503 to "Manual", and adjusting their manual regulators, it was possible to check proper operation of the adder FCp-504. In all cases, FCp-504 correctly summed the outputs of HCS-501, -502, and -503.

By manual adjustment of HCS-501, -502, -503, and -504, it was possible to vary the setpoint and input signals to WaIC-501. When the difference between the setpoint and input signal was more than 10%, the annunciator "Deviation Demand Steam Flow" actuated. When the difference

was less than 10%, the annunciator could be reset. Within WaIC-501, the following controller settings were made:

- 1) Proportional Band 150%
- 2) Reset Rate 0.02 min/repeat

Thermal converters FCCp-501, -502, and -503 were set for a ratio of 110% with no bias. (This converts a 0-300,000 lb/hr steam demand to a 0-3,300,000 lb/hr primary sodium flow demand). Thermal converters FCCp-504, -505, and -506 were set for a ratio of 100% with no bias. (This converts a 0-300,000 lb/hr steam demand to a 0-3,000,000 lb/hr secondary sodium flow demand.)

HCS-501, -502, and -503 were then varied over their full range, and it was verified that they could generate full range primary and secondary sodium flow demands. By eliminating the effect of TRC-101, -201, and -301 outputs (see II. D. Primary Sodium Flow Control), it was also verified that the primary sodium flow demand was 110% of the secondary sodium flow demand.

Ratio computers FCp-501, -502, and -503 were set at 100%. HCS-501, -502, and -503 were switched to "Automatic". WaIC-501 immediately balanced itself at the setpoint as set by HCS-504. HCS-504 was adjusted to 50% demand steam flow. The WaIC immediately responded, with its setpoint, input, and output going to 50%, and the output of HCS-501, -502, and -503 was also noted to be at the correct value of 50%. The secondary sodium flow demand went to 50%, and the primary sodium flow demand went to 55%.

HCS-504 was re-adjusted to various values of demand steam flow. In all cases, WaIC-501 tracked and balanced immediately, without unstable oscillations, and the demand primary and secondary flows went to their correct values.

HCS-504 was re-adjusted to 50% demand steam flow. Bumpless transfers from "Automatic" to "Manual" were made on HCS-501, -502, and -503. HCS-504 was changed to a new value of 55%, and bumpless transfers from "Manual" back to "Automatic" were made.

It was next verified that only one of the flow computers, FCp-501, -502, or -503, could be moved off a 100% ratio at one time. FCp-501 was then ratioed down from 100%; a corresponding decrease in the demand steam flow for circuit No. 1, along with an automatic increase of the demand steam flow in circuits No. 2 and No. 3, sufficient to keep the total demand steam flow constant, was noted. The same test was repeated for FCp-502 and -503, with similar results.

FCp-501, -502, and -503 were returned to 100% ratio and HCS-504 was set at 50%, causing WaIC to balance at 50% demand steam flow. HCS-501 was switched to "Manual", and its output was manually increased. It was observed that the outputs of HCS-502 and -503 were automatically reduced by one-half the amount that HCS-501 was manually increased. The output of HCS-501 was then decreased manually, and it was observed that the outputs of HCS-502 and -503 were automatically increased by one-half the amount HCS-501 was decreased. The same procedure was repeated for HCS-502 and -503, with similar results.

C. SECONDARY SODIUM FLOW CONTROL

The function of the secondary sodium flow control subsystem is to set and maintain the required sodium flow in the secondary heat transfer loops by means of controlling pump speed.

As shown in Figure 1120-3, the sodium flow demand signal from FCCp-504 of the division of load computer enters FRC-102 as a setpoint. HCS-107 is provided so the operator can switch from automatic operation and manually enter a setpoint into FRC-102. Rate limiting of flow demand also takes place in HCS-107. Sodium flow is sensed in an electro-magnetic flowmeter and enters FRC-102T as the input. The output of FRC-102T is the input to FRC-102, which in turn is the input to SCD-102. The output of FRC-102 is a pump speed demand signal. Upon error alarm, control will be transferred automatically to manual operation from HCS-104. HCS-104 is provided so the operator can switch from "Automatic" and generate a pump speed demand signal manually. The pump speed demand signal then enters SCD-102. The output of SCD-102 is a setpoint to SC-102, which is limited as to rate of change. Speed control of the sodium pump is provided and operates from pump speed as transmitted by SC-102T to SC-102. The pump speed is indicated on SI-102, which receives its signal from SC-102T. An interlock is provided so that, following a scram, the pump set-speed drops to zero.* After the scram conditions have been cleared, it is necessary for the operator to transfer to manual set-speed

* Subsequent to this test, this interlock was changed to trip the pump coupling.

Figure 1120-3. Secondary Sodium Flow Control Subsystem-Block Diagram

control and reduce HCS-104 to zero set-speed to clear this interlock. Another interlock is provided so the pump motor cannot be started until the operator has switched to manual set-speed control and reduced HCS-104 to zero set-speed.

HCS-107 was switched to "Manual", and it was verified that a full range secondary sodium flow demand signal could be generated manually, as evidenced by the flow demand shown on FRC-102.

The rate limiter in HCS-107 was set at 20%/min maximum rate of change. Full range positive and negative step-changes were made at HCS-107, and the time for the flow demand to increase and decrease full scale was observed to be 20%/min $\pm$ 5%/min.

HCS-501 (Division of Load Computer) was put in the "Manual" position, with a 50% output. HCS-107 was then bumplessly switched from "Manual" to "Automatic". HCS-501 was manually changed to a new value, and a bumpless transfer from "Automatic" back to "Manual" was made at HCS-107.

Using calibration data for FRC-102E, FRC-102T was adjusted for full scale output of 3,000,000 lb/hr sodium at 900 F. Leads between FRC-102E and FRC-102T were checked for continuity, absence of wiring shorts, proper polarity, and absence of noise. The loop resistance of FRC-102E leads was obtained and recorded. Within FRC-102, the following controller settings were made:

1)	Proportional Band	150%
2)	Reset Time	0.2 min/repeat

HCS-107 was put in MANUAL position and set at 50% secondary sodium flow demand. A simulated 50% secondary sodium flow signal was put into FRC-102T. HCS-104 was put into AUTOMATIC position.

The simulated flow signal was then decreased, and pump demand speed increased, as evidenced by an increase in FRC-102 and HCS-104 output. The simulated flow signal was then increased, with a decrease in pump demand speed noted.

The simulated flow signal was increased and decreased, and it was noted that when the difference between measured and demand sodium flow exceeded 8%, the annunciator "Deviation Flow Loop 1" actuated, and at the same time, HCS-104 bumplessly and automatically transferred to "Manual". As long as the deviation exceeded 8%, the annunciator could not be reset, and HCS-104 could not be switched to "Automatic". When the deviation was less than 8%, the annunciator could be reset and HCS-104 could be switched to "Automatic".

The demand secondary sodium flow was matched with the measured sodium flow. The desk console "Auto-Man" transfer switch was switched from AUTO to MANUAL, and it was observed that HCS-104, which had been in "Automatic", transferred bumplessly to "Manual". It was also noted that HCS-104 could not be put back in "Automatic" until the desk console transfer switch had been returned to AUTO.

Key-2, the rod drive permissive switch, was turned on, thus simulating a scrammed condition. (Key-2, when turned on, shuts off control

rod magnet power, and picks up the auxiliary scram and setback relays. Picking up the auxiliary relays allows the control rod drives to be operated, the sodium pumps to be run, and the convection control system to be reset.)

With a demand secondary sodium flow from HCS-107, and with a matching simulated sodium flow, bumpless transfers from "Manual" to "Automatic", and from "Automatic" to "Manual" were made at HCS-104.

The sodium pump coupling was verified to be de-energized. It was verified that the sodium pump motor could not be started unless the demand speed from HCS-104 was less than zero*. (This was done with the pump motor air circuit breaker in the TEST position, so as to check the interlock without running the motor.)

It was then verified that the relay which runs pump demand speed to zero following a scram could not be re-energized until the following conditions had been satisfied:

- 1) Scram condition cleared
- 2) HCS-104 below zero demand speed
- 3) Pump coupling control switch turned to ON

When the above conditions were satisfied, it was possible to increase pump speed demand, as evidenced by an increase in the demand

* Setting the HCS to less than zero is alone not sufficient. It is necessary to wait for the rate limiter, as the interlocking is done downstream of the rate limiter.

occurring at the pump coupling control cabinet. HCS-104 was operated over its full range, and a full range pump speed demand was observed at the pump coupling cabinet.

The rate limiter in SCD-102 was set at 20%/min maximum change.* Full range positive and negative step-changes were made at HCS-104, and the time for the pump speed demand to increase and decrease full scale was observed to be 20%/min $\pm$ 5%/min.

Pump speed demand was set at 50% at HCS-104. Key-2 was turned off and then back on, simulating a momentary scram. It was observed that the pump speed demand at the coupling control cabinet immediately dropped to zero. The speed demand could not be increased until the zero speed demand interlocks had been satisfied.

With a 50% pump speed demand from HCS-104, the main board instrument air supply was shut off. Proper operation of the air failure solenoid valve was verified by noting that the pump speed demand remained constant at 50%.

The same tests were then repeated for the flow control subsystems of secondary sodium loops No. 2 and No. 3, with similar results.

* Rate limiter setting in SCD-102 was reset at 40%/min following completion of the test.

D. PRIMARY SODIUM FLOW CONTROL

The function of the primary sodium flow control subsystem is to maintain the reactor inlet sodium temperature at a value which is a function of demand primary sodium flow, and to set and maintain the required sodium flow in the primary heat transfer loop, by means of controlling pump speed.

As shown in Figure 1120-4, sodium flow is sensed in FRC-101T and is transmitted as an input to FRC-101. FCp-102 generates a required reactor inlet sodium temperature as a function of the demand primary sodium flow. The input to TRC-101 is the actual temperature of the sodium entering the reactor (sensed by an iron-constantan thermocouple). The output of TRC-101 is a sodium flow demand signal which is algebraically added to the sodium flow demand signal from FCCp-501 of the division of load computer. Addition of the sodium flow demand signal occurs in FCp-101. The output of FCp-101 then enters FRC-101 as a total demand primary sodium flow. HCS-105 is provided so the operator can switch from automatic control and enter a setpoint into FRC-101 manually. Rate limiting of flow demand also takes place in HCS-105.

The output of FRC-101 is pump speed demand signal. HCS-102 is provided so the operator can switch from automatic operation and generate a pump speed signal manually. Upon error alarm, control is transferred to manual operation.

The pump speed demand signal then enters SCD-101. The output of SCD-101 is a setpoint of SC-101 which is limited as to rate of change.

Figure 1120-4. Primary Sodium Flow Control Subsystem-Block Diagram

Speed control of the sodium pump is provided and operates from pump speed as seen by SC-101T and SC-101. The pump speed is indicated on SI-101, which receives its signal from SC-101T.

An interlock is provided so that following a scram the pump set-speed will drop to zero.* After the scram conditions have been cleared, it is necessary for the operator to transfer to manual set-speed control and reduce HCS-102 to zero set-speed** to clear this interlock. Another interlock is provided so the pump motor cannot be started until the operator has switched to manual set-speed control and reduced HCS-102 to zero set-speed.

Wiring between TRC-101E and TRC-101T was checked for absence of wiring shorts, continuity, and absence of noise. Loop resistance of the thermocouple leads was measured and recorded.

HCS-501 (Division of Load Computer) was put on "Manual" and was manually adjusted between 0-90.9%, corresponding to 0-100% primary sodium flow demand (FCCp-501, Division of Load Computer, set at 110%). It was verified that FCp-102 was properly computing a demand inlet sodium temperature of 560-610 F as evidenced by the setpoint on TRC-101.

A simulated temperature signal of 585 F was put into TRC-101T by manually adjusting HCS-501. (This requires a setting of 45.5% on HCS-501). Within TRC-101, the following controller settings were made:

* Subsequent to this test, this interlock was changed to trip the pump coupling.

** Setting the HCS to less than zero is alone not sufficient. It is necessary to wait for the rate limiter, as the interlocking is done downstream of the rate limiter.

1)	Proportional Band	200 %
2)	Reset Time	1 min/repeat
3)	Rate Time	0.01 min

The simulated temperature signal was varied, and it was noted that the annunciator "Deviation Flow or Temp Loop 1" would actuate when the difference between demand and simulated temperature exceeded 20 F, and could be reset when the difference was less than 20 F. (The flow deviation alarm contacts had been previously satisfied.)

HCS-105 was switched to "Automatic", and the simulated temperature was set below the demand temperature. It was noted that the output of TRC-101 started increasing as evidenced by an increase in the total demand sodium flow showing on HCS-105 and FRC-101. At its maximum output, the effect of TRC-101 was observed to be + 8.3% sodium flow demand resulting in a total sodium flow demand of 58.3%. The simulated sodium temperature was then increased above the demand sodium temperature, and the output of TRC-101 started decreasing. At its minimum output, the effect of TRC-101 was observed to be -8.3% sodium flow demand, resulting in a total sodium flow demand of 41.7%.*

HCS-105 was then bumplessly transferred to "Manual". The output of HCS-105 was changed to a new value of total demand sodium flow, and it was verified that HCS-105 could then be bumplessly transferred back to "Automatic".

HCS-105 was next switched back to "Manual", and testing of the remainder of the primary sodium flow control subsystem proceeded as

* The $\pm$ 8.3% values correspond to 3-15 psig pneumatic signals. Since TRC-101 can "wind up", the actual pneumatic signals can be 0-19 psig, corresponding to $\pm$ 12%.

described in II. C. for the secondary sodium flow control subsystem, with similar results. (With the exception of the temperature control loop, primary and secondary sodium flow control subsystems are identical.)

Primary sodium flow control subsystems for loops No. 2 and No. 3 were tested as described above, with similar results.

E. NUCLEAR POWER COMPUTER

The function of the nuclear power computer is to first calculate the thermal power being extracted from the reactor. It then calculates the neutron flux required both to maintain this power and to provide for temperature corrections.

As shown in Figure 1120-5, the plant operator sets a reactor plenum sodium temperature on HCS-10. The output of HCS-10 is a "rate of change limited" re-transmitted setpoint to TRCp-1. Reactor plenum sodium temperatures are sensed by thermocouples and indicated on TI-1, -2, and -3. They are then auctioneered, and the highest temperature enters TRCp-1 as an input. (The auctioneered plenum temperature is also transmitted to the primary block valve control subsystem, see II. L. Primary Block Valve Control.)

TRCp-1 generates a set value of fuel channel outlet temperatures according to the relationship:

$$T_{nco, set} = T_{nro, set} + K_t (T_{nro, set} - T_{nro}),$$

Figure 1120-5. Nuclear Power Computer Subsystem-Block Diagram

where:

$T_{nco, set}$ = output of TRCp-1 and setpoint of TRC-2 (Demand fuel channel outlet temperature)

$T_{nro, set}$ = output of HCS-10 and setpoint of TRCp-1 (Demand reactor plenum temperature)

T_{nro} = reactor outlet sodium temperature

K_t = constant

HCS-7 is provided to manually generate the set value of fuel channel outlet temperature and to limit its rate of change on manual or automatic operation. The output of HCS-7 is re-transmitted as a setpoint to three controllers: TRC-3 (see II. G. Moderator Coolant Control), TRC-4 (see II. H. Convection Control), and TRC-2.

NWaCp-1 is the nuclear power computer and generates a demand neutron flux according to the relationship:

$$n_d = K_n W_n (T_{nro} - T_{nri, set})$$

where:

n_d = demand neutron flux

K_n = constant

W_n = total sodium flow in primary loops

T_{nro} = reactor plenum sodium temperature

$T_{nri, set}$ = output of HCS-11

The inputs to NWaCp-1 are the three primary sodium flows, the reactor plenum sodium temperature as set by the operator in

HCS-10, and the reactor inlet sodium temperature as set by the operator in HCS-11. The output of NWaCp-1 is the neutron flux required to match thermal power and will be sent to NLCp-1. HCS-6 is provided to manually generate this demand neutron flux.

The temperature of sodium at the fuel channel outlets is sensed by iron-constantan thermocouples. The temperature signals are indicated on TI-4 and TI-5. The temperatures as seen by TI-4 and TI-5 are then averaged and the averaged signal is sent to TRC-2 as an input. (The averaged fuel outlet temperature is also transmitted to TRC-4T. See II. H. Convection Flow Control.) With this signal as input and the output of TRCp-1 (or HCS-7) as setpoint, TRC-2 sends an incremental demand neutron flux signal to NLCp-1. HCS-12 is provided to manually generate this incremental demand neutron flux which will be zero when the temperature error is zero.

The demand (thermal power) flux from NWaCp-1 and incremental demand (temperature error) flux from TRC-2 are added in NLCp-1 and the resulting signal is transmitted to NC-1 of the neutron flux control subsystem as the total demand neutron flux.

At the main patch panel, the following reactor thermocouples were connected to the following instruments:

1)	C188-2 to TI-1	Temperature Element Thermocouples
2)	C212-2 to TI-2	
3)	C236-2 to TI-3	
4)	C 17-2	Fuel Exit Thermocouples
5)	C 13-2 to TI-4	
6)	C 25-2	
7)	C 14-2	
8)	C 21-2 to TI-5	
9)	C 30-2	

Thermocouple wiring noted above was checked for continuity, absence of wiring shorts, correct polarity, and absence of noise. Loop resistances of each thermocouple were recorded.

Patch panel connections were removed and TI-1, -2, -3, -4, and -5 were connected to five separate simulated thermocouple inputs. It was verified that the output of TI-1, -2, and -3, which is the input to TRCp-1, was always the highest of the three inputs. It was also verified that the output of TI-4 and TI-5, which is the input to TRC-2 and TRC-4 (see II. H. Convection Flow Control) was always the average of the two inputs.

By operating HCS-10, it was verified that the demand plenum temperature to TRCp-1 could be changed at a maximum rate of 50 F/hr. It was also noted that the rate-limited output of HCS-7, with HCS-7 in either automatic or manual control, was transmitted as a demand temperature to TRC-3 (see II. G. Moderator Coolant Control) and TRC-4 (see II. H. Convection Flow Control).

By varying the inputs to TI-4 and TI-5, and by changing the demand fuel outlet temperature at HCS-7, it was verified that the annunciator "Deviation Fuel Outlet Temperature" would actuate when the difference between (simulated) measured fuel outlet temperature and demand fuel outlet temperature exceeded 20 F. This annunciator could be reset only when the difference was less than 20 F. At the same time the annunciator was checked, proper operation of the fuel outlet temperature deviation indicator was verified. Within TRC-2, the following controller settings were made:

- 1) Proportional Band 150%
- 2) Reset Time 2 min/repeat
- 3) Rate Time 0 min (off)

HCS-12 was bumplessly switched to "Automatic", and the output limiter in HCS-12 was set at 20% maximum output. By varying HCS-7, the fuel outlet demand temperature was increased over the (simulated) measured fuel outlet temperature. Under these conditions, the output of TRC-2, which is an incremental demand flux, started increasing. However, because of the output limiter, the maximum increase was + 20% flux demand. HCS-7 was then varied so that the fuel outlet demand temperature was less than the (simulated) measured fuel outlet temperature. The output of TRC-2 decreased to a minimum of - 20% demand flux.

HCS-12 was then bumplessly switched to "Manual", and it was verified that in manual control the output of HCS-12 was limited to 20% demand flux.

Simulated signals of 100% primary sodium flow were put into FRC-101T, -201T, and -301T. HCS-10 was set at 945 F, and HCS-11 was set at 610 F. After sufficient time for the rate limiter to drive the output of HCS-10 at 945 F, HCS-6 was bumplessly switched to automatic control, and it was verified that the output of NWCp-1 was a signal corresponding to 100% demand flux. Various combinations of (simulated) primary sodium flow signals, reactor plenum demand and reactor inlet temperatures were supplied to NWCp-1. It was verified that NWCp-1 computation of nuclear power was correct, based upon a 100% flux demand signal at a reactor ΔT of 335 F with 100% sodium flow in the three primary loops.

With a 50% demand flux signal from NWCp-1, HCS-6 was bumplessly transferred to manual control.

By varying the inputs to TI-1, -2, and -3, and by changing the demand plenum temperature at HCS-10, it was verified that the annunciator "Deviation Plenum Temperature" would actuate when the difference between (simulated) measured and demand plenum temperature exceeded 20 F, as shown on TRCp-1. This annunciator could be reset only when the difference was less than 20 F. Proper operation of the plenum temperature deviation indicator was also verified.

At the same time the annunciator was checked, proper operation of TRCp-1's computing function was verified. The constant (K_t)

in the formula,

$$T_{\text{nco, set}} = T_{\text{nro, set}} + K_t (T_{\text{nro, set}} - T_{\text{nro}})$$

was set at 5.0.

The highest output of TI-1, -2, and -3 was set at 950 F. HCS-10 was set at 945 F. Under these conditions, TRCp-1 properly computed a fuel outlet demand temperature of 920 F.

HCS-7, which was in "Manual", and at 500 F, was then bumplessly transferred to "Automatic", and it was observed that the demand fuel outlet temperature, as shown on TRC-2, went to 920 F at a rate of 50 F/hr. HCS-7 was then bumplessly transferred to "Manual", and it was verified that the demand fuel outlet temperature could not be changed at a rate exceeding 50 F/hr.

It was then verified that the outputs of HCS-6 and HCS-12, in either automatic or manual control, were properly added (algebraically) in NLCp-1, to result in a total demand neutron flux.

F. NEUTRON FLUX CONTROLLER

The function of the neutron flux control subsystem is to maintain the neutron flux at the value demanded by the nuclear power computer. This is accomplished by the movement of control rods, any number of which may be selected for simultaneous automatic (or manual) control. The unit normally operates above one percent flux.

As shown in Figure 1120-6, the demand neutron flux from the nuclear power computer enters NC-1 as a setpoint. HCS-5 is provided to manually generate a demand neutron flux. Rate limiting

Figure 1120-6. Neutron Flux Control Subsystem-Block Diagram

of demand neutron flux also takes place in HCS-5. The actual neutron flux as measured by Channels VIII and IX of the nuclear instrumentation enters HCS-4 where the output of these two channels will be auctioneered, averaged, or selected. The averaged, auctioneered or selected measured neutron flux is then transmitted to NC-1 as an input. The output of NC-1 is a demand value of rod motion. Upon error alarm, control is transferred to HCS-1.

The final control action which drives the rods up or down is accomplished by closing contacts in series with the control rod drive switches.

NC-1/HCS-1 is a variable gain, adjustable deadband, 3-mode contactor-controller, with position feedback stabilization. Operation of NC-1/HCS-1 is as follows:

Measured flux from HCS-4 is compared with demand flux from HCS-5. The resultant error signal, modified by the number of rods on automatic control and the power level, as described below, is compared with a position feedback signal, also described below. If the difference between the modified flux error signal and position feedback signal exceeds the controller deadband, the controller energizes a contactor which in turn will drive the control rods in a direction to drive the flux error back into the controller deadband.

By actuating the "Manual-Automatic" rod switches, the plant operator may place any number of control rods on automatic

control by NC-1. The control rods left on "Manual" will not be affected by the control system; however, provision is made for the operator to manually position "Manual" control rods independently of the control system.

Since moving three rods four in. is equivalent to moving six rods two in. it is necessary to divide the flux error input by the number of rods on "Automatic" to keep the overall system gain (reactor and controller) constant.

Since the reactor gain is directly proportional to power level, it is necessary to reduce the controller gain as a function of flux level.

Actuation of the control rod drive switches by NC-1 also actuates the position feedback mechanism. The position feedback mechanism simulates a control rod drive unit and operates in the same direction, with the same speed and inertia characteristics, as the control rod drive units. The output of the position feedback mechanism is connected to a 20,000 ohm potentiometer. This potentiometer is used for generation of the position feedback signal. Prior to being compared with the flux error signal, the position feedback signal is fed to the 3-mode passive element controller for generation of proportional band, reset action, and rate time.

By means of HCS-1, the plant operator can switch to manual control and manually position the control rods on "Automatic".

By means of a switch in NC-1/HCS-1, the operator can utilize either of two dummy control rod drive units contained in the position feedback mechanism, provided he has switched NC-1 to manual control.

By means of a switch in NC-1/HCS-1, the operator can reposition the position feedback mechanism, provided he has switched NC-1 to manual control.

Relay contacts within the protective system are wired to NC-1 and the rod drive motors. Upon a scram or setback, these contacts are actuated, NC-1 is switched to "Manual", and the control rods fall or drive in. Eventually, the scram or setback condition will cease. At this time, the plant operator can take appropriate action to line HCS-5 up to the measured flux level, manually reset (or couple) NC-1 back into the control system, and manually control the flux level by HCS-5. After the plant operator has brought the measured flux level up to the demand flux level, he can transfer HCS-5 to automatic control.

With a half-scale flux demand signal from NLCp-1, HCS-5 was transferred bumplessly from "Manual" to "Automatic". The flux demand from NLCp-1 was changed to a new value, and HCS-5 was transferred bumplessly from "Automatic" back to "Manual".

It was verified that in either "Automatic" or "Manual", the output of HCS-5, which is the demand to the flux controller and

one recording pen on NLR-1/2, could not be changed by more than 40%/min, and had a maximum value of 100% demand flux.

Simulated neutron flux signals were connected to the main control board at the point where signals from channels VIII and IX of the nuclear instruments normally connect. The following was verified:

- 1) If HCS-4 was in AVERAGE, the output of HCS-4 was the average of the inputs simulating channels VIII and IX.
- 2) If HCS-4 was in HIGHEST, the output of HCS-4 was the highest of the inputs simulating channels VIII and IX.
- 3) If HCS-4 was in the VIII position, the output of HCS-4 was the signal simulating channel VIII.
- 4) If HCS-4 was in the IX position, the output of HCS-4 was the signal simulating channel IX.

In the above cases, the output of HCS-4 was the input to the flux controller and the other recording pen of NLR-1/2.

Scram, setback, and start-up interlocks were satisfied by jumpers (removed later) in order to drive the control rods out of the unloaded reactor core.

The flux controller NC-1/HCS-1 was in "Manual". Position feedback mechanism No. 1 was operated from the main control

board and was driven up and down. It was verified that 20 in. of position feedback (dummy drive) motion corresponded to 0-100% dummy drive travel as shown on its indicator. It was also verified that the annunciator "Travel Limit Rod Simulator" would actuate when the dummy drive was at less than 20% or more than 80% position. This annunciator could be reset only when the dummy drive position was between 20-80%. The same test as described above was repeated for position feedback mechanism No. 2, with similar results.

With the individual control rod switches in "Neutral", HCS -1 was operated up and down. Proper indicating light actuation and operation of the selected position feedback mechanism was noted. The same test of HCS-1 was then repeated, except that, one at a time, the 19 control rods, were switched to AUTO. In all cases, proper control rod actuation, in the correct direction, was observed. As each control rod was switched to AUTO, it was observed that the gain of the flux controller was a direct inverse of the number of rods put in "Auto". Within NC-1, the following controller settings were made:

1) Proportional Band	20%
2) Reset Time	2 min/repeat
3) Rate Time	0 (switched off)
4) Deadband	0.20 inches

In order to put NC-1 in "Automatic", it was necessary to have the following interlocks satisfied:

- 1) Desk console "Auto-Manual" switch in AUTO.
- 2) Main Board "Auto-Manual" switch in AUTO.
- 3) No setback.
- 4) No scram.
- 5) Difference between measured and demand neutron flux less than 8%.
- 6) Position feedback mechanism between 5% and 95% position.

Once the above conditions were met, it was possible to momentarily press the "Auto Reset" pushbutton, and the flux controller would switch to "Automatic". If any of the above conditions were violated, the flux controller would immediately switch to "Manual".

When checking the flux deviation interlock, it was noted that the annunciator "Deviation Neutron Flux" would actuate if the difference between demand and measured (simulated) neutron flux exceeded 8%. When the difference was within 8%, the annunciator could be reset.

All the control rods except rod No. 1 were put into "Neutral". Control rod No. 1 was switched to "Auto", and the flux controller was placed in automatic control. Since demand neutron flux (as set by HCS-5) was above the (simulated) measured neutron flux, control rod No. 1 and the selected position feedback mechanism

started driving up. When the position feedback interlock actuated, and switched the flux controller to "Manual", it was re-positioned, the flux controller put back in "Manual", and the drive up in "Auto" was continued. This was repeated until the annunciator "Reg Rod Limit Low Worth" actuated. * At this point, the neutron flux demand was lowered so as to be less than the (simulated) measured neutron flux, and the control rod was allowed to drive down. The annunciator was reset as soon as control rod No. 1 started down, and re-actuated when the control rod reached the lower limit, at which point the low worth alarm re-actuated. Switching control rod No. 1 to "Neutral" allowed the low worth alarm to be reset; this was correct, as the low worth alarm is associated only with control rods in "Automatic".

The same test, to check proper operation of the direction of control rod drive and proper operation of the low worth alarm, was repeated for control rods No. 2 through No. 19, with similar results.

* The annunciator "Reg Rod Limit Low Worth" will normally be set for a 20 in. band in either the upper or lower quarter of rod travel. The exact location of this 20 in. band had not been specified, so the alarms were set at positions of 2 in. and 150 in. of rod travel for this test. Under these conditions, a rod on "Auto", between 2 in. and 150 in. will not actuate the alarm.

At the time of this test, proper operation of the flux deviation and flux controller deadband indicators was also observed.

When the flux controller was in "Automatic" it was verified that HCS-1, and the position feedback mechanism operating switch, were inoperative.

Each control rod drive and position feedback mechanism contains a 10-turn 100 ohm potentiometer connected by gearing to the drive mechanism. A Sanborn high speed recorder was connected to this potentiometer, for a control rod to be put on "Automatic", and to position feedback mechanism No. 1. The selected control rod and flux controller were put in "Automatic", and the flux controller was allowed to drive the control rod up and down. Sanborn recordings showed that the control rod and the position feedback mechanism responded together to up and down signals. This test was repeated for position feedback mechanism No. 2, with the same results.

G. MODERATOR COOLANT CONTROL

The function of the moderator coolant control subsystem is to equalize the sodium fuel channel outlet temperature and the sodium moderator coolant channel outlet temperatures.

As shown in Figure 1120-7, the setpoint of TRC-3 is retransmitted from HCS-7 in the nuclear power computer subsystem. The input to TRC-3 is the moderator coolant exit temperature.

Figure 1120-7. Moderator Coolant Control Subsystem-Block Diagram

The output of TRC-3 is a valve position demand signal which will position the moderator coolant throttle valve. HCS-9 is provided so the operator may manually set a moderator coolant valve position.

At the main patch panel, thermocouples C-188-5, C-212-5, and C-236-6 were jumpered to TRC-3. Thermocouple wiring was checked for continuity, absence of wiring shorts, correct polarity, and absence of noise. Loop resistances for the three thermocouples, which are averaged at a paralleling block on the main patch panel, were obtained and recorded.

As verified in II. E., Nuclear Power Computer, the demand moderator outlet temperature to TRC-3 was the rate-limited output of HCS-7, and is the same as the demand fuel outlet temperature. By putting HCS-7 in "Manual", a demand moderator outlet temperature was generated.

The input to TRC-3 was connected to a simulated thermocouple signal. With TRC-3, the following controller settings were made:

1)	Proportional Band	100%
2)	Reset Time	1 min/repeat
3)	Rate Time	0.01 min

The rate limiter in HCS-9 was set for 40%/min and it was verified that the throttle valve position demand signal could not change at a rate greater than 40%/min $\pm$ 5%/min.

HCS-9 was switched to "Automatic", and the demand and (simulated) measured moderator outlet temperatures were varied. The following conditions were observed:

- 1) HCS-9 could not be put into "Automatic" unless the desk console transfer switch was in AUTO. Turning the desk console switch to MANUAL would automatically and bumplessly switch HCS-9 to "Manual".
- 2) When the demand was above the (simulated) measured outlet temperature, TRC-3 would send out a signal to drive the moderator throttle valve full-shut, and vice versa.
- 3) When the difference between demand and (simulated) measured moderator outlet temperature exceeded 30 F, the annunciator "Deviation Moderator Control" would actuate. At the same time, HCS-9 would automatically and bumplessly transfer to "Manual". The annunciator could be reset, and HCS-9 could be switched back to "Auto" only when the difference was less than 30 F.

HCS-9 was then bumplessly transferred to "Manual", and it was verified that HCS-9 could be used to generate full-open to full-shut moderator throttle valve positions.

H. CONVECTION FLOW CONTROL

The function of the convection flow control subsystem is to control the fuel channel outlet temperature following a reactor scram.

As shown in Figure 1120-8, during normal operation, relay contacts in the protective system are open and the output of TRC-4 is blocked by the switching circuit. The output of the switching circuit is a valve-open demand signal which maintains the throttling valves in a wide-open position.

Sodium temperature at the fuel channel outlets is transmitted from TI-4 and -5 of the nuclear power computer subsystem to TRC-4T. The output of TRC-4T is the average of the two inputs and is transmitted to TRC-4 as an input. The setpoint of TRC-4 is generated from HCS-7 of the nuclear power computer subsystem.

In the event of a scram, contacts in the protective system close, and the switching circuit starts an automatic timer which causes the six throttle valves to be driven to a pre-set closed position.* At the end of the timing cycle, TRC-4 is switched into the control circuit and will control the position of the six throttle

* The throttle valves normally operate at full speed between 0 and 60% shut, and one-quarter speed between 60 and 100% shut. A timing interlock allows the valves to drive at full speed following a scram.

Figure 1120-8. Convection Flow Control Subsystem-Block Diagram

valves. TRC-4 operates from an input of fuel channel outlet sodium temperature and a setpoint of demand fuel channel outlet sodium temperature which is either at the last set value before the shut-down or, if the operator intends to cool the reactor, will be decreasing at a limited rate. TRC-4 thus generates valve position demand signals which operate the throttle valves, varying convection flow to establish the required reactor temperature. In the automatic mode, the position of the three primary valves is established directly by TRC-4 through HCS-101, -201, and -301. Primary valve positions are transmitted through FCp-103, -203, and -303, to establish a secondary valve position. FCp-103, -203, and -303 are adjustable ratio relays which will ratio the secondary valve position to the corresponding primary valve position. HCS-101, -201, -301, -103, -203, and -303 are provided, to allow manual setting of throttle valve position. HCS-8 is provided to manually operate all six throttle valves simultaneously.

As verified in II. D, Primary Sodium Flow Control, the demand fuel outlet temperature to TRC-4 is the output of HCS-7. If HCS-7 is in "Manual", the demand is set by the operator; if in "Automatic", the demand is the output of TRCp-1. In any case, the demand is rate-limited at 50 F/hr, and is the same as the demand to TRC-2.

Also, as verified in II. D, Primary Sodium Flow Control, the (simulated) measured fuel outlet temperature to TRC-4 is the average of TI-4 and -5, and is the same as the input to TRC-2. Within TRC-4, the following controller settings were made:

- 1) Proportional Band 100 %
- 2) Reset Time 0.4 min/repeat
- 3) Rate Time 0.04 min

By varying the difference between demand and (simulated) measured fuel outlet temperature, it was verified that the annunciator "Deviation Convection Control" would actuate when the difference exceeded 20 F. This annunciator could be reset only when the difference was less than 20 F. At the same time the annunciator was checked, proper operation of the deviation indicator on TRC-4 was verified.

The annunciator check was made with the reactor in a scrammed condition; consequently TRC-4 was operating. HCS-8 was switched to "Automatic", and it was noted that the output of TRC-4 would increase (a shut convection valve signal is an increasing signal) when the demand was higher than the (simulated) fuel outlet temperature, and vice versa.

It was also noted that HCS-8 automatically and bumplessly transferred to "Manual", simultaneously with actuation of the

annunciator "Deviation Convection Control". Only when conditions were such that the annunciator could be reset, could HCS-8 be switched to "Automatic".

Proper operation of the desk console transfer switch for HCS-8 was also verified, i. e., HCS-8 would be automatically switched to "Manual" when the desk console transfer switch was put in the MANUAL position and HCS-8 could not be put in "Automatic" until after the desk console transfer switch was put in the AUTO position.

The six throttle valve positioners were set per AI Specification 7518-S73409 so that a 100% shut valve position signal from HCS-101, -201, -301, -103, -203, or -303 corresponded to a throttle valve stem movement of 12-3/4 in. from full-open. (Total valve stem travel is 15-1/2 in. The last 2-3/4 in. of stem motion is an overtravel for tight shut-off. At 12-3/4 in. of valve travel, $C_v = 0$ *). Ratio relays FCp-103, -203, and -303 were set at 100%. HCS-101, -201, -301, -103, -203, and -303 were bumplessly transferred to "Automatic".

Starting with zero (valve-open) demand signal, HCS-8 was adjusted to a 60% shut signal. The valves responded properly by driving to 7-3/4 in. shut, at full speed. The keylock switches at

* C_v is a measure of valve capacity. When $C_v = 0$, flow will equal zero.

HCS-101, -201, -301, -103, -203, and -303 were switched to MANUAL CLOSE, and the keylock switch at HCS-8 was put in the AUTO THROTTLE position. HCS-8 was then adjusted to a 100% shut position. The valves responded by driving, at one-quarter speed, to the 12-1/2 in. position, thus verifying proper operation (98%) of the limiter associated with the keylock switch. This limiter prevents the throttle valves from going to 12-3/4 in. position, unless the keylock switch is in the MANUAL CLOSE position. At the same time the limiter was actuated, the annunciator "Position Limit Throttle Valves" actuated. This annunciator could be cleared only when HCS-8 was reduced below a 98% shut valve position signal. The keylock switch associated with HCS-8 was then switched to MANUAL CLOSE, and HCS-8 was put back to a 100% shut valve position signal. Throttle valves responded by driving to 12-3/4 in. shut position. The position limit annunciator re-actuated.

HCS-8 was reduced to a 50% valve position signal, and the position limit annunciator was reset. The keylocks associated with HCS-101, -201, -301, -103, -203, and -303 were switched to AUTO THROTTLE.

HCS-101, -201, -301, -103, -203, and -303 were individually transferred bumplessly to "Manual", and proper operation of each HCS, its associated throttle valve, position limiter and keylock switch and of the position limit annunciator was verified. The six HCS's were then bumplessly transferred back to "Automatic".

HCS-101 (Primary Throttle Valve No. 1) was switched to "Manual" and HCS-103 (Secondary Throttle Valve No. 1) was left in "Automatic". By manual operation of HCS-101, it was verified that the secondary throttle valve was also driven, through ratio relay FCp-103, to a position corresponding to the setting of HCS-101 (e. g., with FCp-103 at 100% ratio, the primary and secondary throttle valves drove to the same position as set manually on HCS-101). With FCp-103 at a 40% ratio, the primary throttle valve was at a position corresponding to 2.5 times as open as the secondary throttle valve.

HCS-101, -201, -301, -103, -203, and -303 were all switched to "Automatic", and FCp-103, -203, and -303 were set at 100% ratio. Key-2 was turned on to permit testing of valve operation in the convection control subsystem. The convection control re-set pushbutton was actuated, and the system responded correctly, as indicated by all throttle valves immediately driving to the wide-open position.

HCS-8 was bumplessly transferred to "Automatic". The demand fuel outlet temperature was set slightly less than the (simulated) measured fuel outlet temperature so that TRC-4, if it were operating, would be sending out a valve-open signal.

A reactor scram was then simulated. Proper operation of the scram interlocks and timing circuit was verified by observing the following:

- 1) At the time of the simulated scram, the convection control system was switched into operation. The red light "Convection Operating" energized.
- 2) All six throttle valves immediately drove at full speed, to the 12-1/4 in. (96%) shut position.
- 3) At the end of 30 seconds, timing relays released and the throttle valves started driving back to the open position, as TRC-4 demand was less than input.
- 4) Between 12-1/4 in. and 7-3/4 in. shut position, the valves drove at one-quarter speed, and between 7-3/4 in. and wide-open position, the valves ran at full speed.

HCS-8 was then bumplessly switched to "Manual" and adjusted to a 50% position. The main board air supply was shut off, and proper operation of the air failure solenoid valves was verified by noting that the six throttle valves retained their 50% position.

I. FEEDWATER CONTROL

The function of the feedwater control subsystem is to match evaporator feedwater flow to steam flow (including blowdown) and to maintain the desired liquid level in the evaporator.

As shown in Figure 1120-9, the plant operator selects the level he wishes to maintain in the evaporator and enters this

Figure 1120-9. Feedwater Control Subsystem-Block Diagram

into LRC-151 as the setpoint. Evaporator level, which is density compensated, is sensed in LRC-151T and is transmitted to LRC-151. The output of LRC-151 is a feedwater demand signal which will tend to increase (decrease) feedwater flow as the liquid level in the evaporator falls (rises). The feedwater demand from LRC-151 is algebraically added to the signal from the steam flow transmitter, FR-151T, in FCp-151 to generate the total demand feedwater flow setpoint. FC-151 is provided with a manual bias for accounting continuous blow-down and for calibrating steam flow versus feedwater flow. The feedwater flow, as sensed by FR-152T, is transmitted as the controlled variable to FC-151. The output of FC-151 is a feedwater valve position signal which is transmitted to the positioner of CV-151. Should the liquid level in the evaporator fall (rise) to a low (high) level, an overriding valve-open (close) demand signal is generated in LAHL-151, and is transmitted to the feedwater control valve positioner. HCS-152 is provided so the operator can transfer from "Automatic" control and manually select a feedwater control valve position.

After a shutdown, the evaporator will be used for removal of afterglow heat. Under this condition, feedwater flow may be very low. Therefore, HCS-149 is provided for manual operation of a small feedwater bypass valve, CV-152. HCS-154 is provided for operating the gate valve just upstream of the main feedwater control valve, CV-151, LXL-150T, LXL-151T, and LXL-152T also sense the liquid level in the evaporator.

LAH-150, LAL-150, and LXL-150 provide contacts for actuating alarms and scrambling the reactor. LXL-151 and LXL-152 provide contacts for scrambling the reactor.

LXL-150T was system calibrated by applying known differential pressure to the level transmitter and a known pressure to the pressure transmitter.* Level was read on a test gage installed on LXL-150T output, and was within ± 1 in. of true (simulated) level. Proper operation of the annunciator "Hi-Lo Level Steam Generator No. 1" was verified by increasing (simulated) level to 5 in. above normal for the high alarm, and decreasing (simulated) level to 4 in. below normal for the low alarm. This annunciator could be reset only when the (simulated) level was between 4 in. below and 5 in. above normal water level. Proper dropout of relay K-16 in the protective panel was observed when the (simulated) water level was decreased to the scram point, 8 in. below the normal water level.

LXL-151T was system calibrated by applying known differential pressure to the level transmitter and a known pressure to the pressure transmitter. Level was read out on LR-151 and was within ± 1 in. of true (simulated) level. Proper dropout of

* Density compensation is obtained from a pressure signal. Since the evaporator will contain saturated water, the density of the water is a function of pressure.

relay K-17 in the protective panel was observed when the (simulated) water level was decreased to the scram point, 8 in. below the normal water level.

LXL-152T was system calibrated by applying known differential pressure to the level transmitter and a known pressure to the pressure transmitter. Level was read out on a test gage installed on LXL-152T output and was within ± 1 in. of true (simulated) level. Proper dropout of relay K-18 in the protective panel was observed when the (simulated) water level was decreased to the scram point, 8 in. below the normal water level.

LRC-151T was system calibrated by applying known differential pressures to the level transmitter and known pressures to the pressure transmitter. Level was read out on LRC-151 and was within ± 1 in. of true (simulated) level. Proper operation of LAHL-151 (in 1, 2, or 3 element control) was verified by noting that when (simulated) water level rose to 7-1/2 in. above normal water level, CV-151 went to the full-closed position; when (simulated) water level dropped to 4 in. below normal water level, CV-151 went to the full-open position*. The position of CV-151 as set by HCS-152 was unaffected when (simulated) water level was between 4 in. below and 7-1/2 in. above normal water level.

* Subsequent to this test, the setpoints of LAHL-151 were changed to 7-1/2 in. above and 6 in. below normal water level. This permits an alarm, and possible operator corrective action, before automatic corrective action.

FR-151 was system calibrated by applying known differential pressure signals to FR-151T and reading out (simulated) flow on FR-151; accuracies within $\pm 1\%$ were observed.

FRC-152 was system calibrated by apply known differential pressure signals to FR-152T and reading out (simulated) feedwater flow on FR-152; accuracy was observed to be within $\pm 1\%$. It was also noted that the feedwater flow integrators were correct to $\pm 2\%$ at 20%, 50% and 100% flow.

Overall system response times to positive and negative step-changes were measured for FR-151, FR-152, LRC-151, LXL-150, LXL-151, and LXL-152, and were determined to be within 5 seconds. Within LRC-151, the following controller settings were made:

- 1) Proportional Band 50%
- 2) Reset Time 0.2 min/repeat

By varying the (simulated) water level input to LRC-151, and by manual operation of LRC-151 setpoint, proper actuation of the annunciator "Deviation Evaporator No. 1 Level" occurred when a difference of more than 2.5 in. between measured and set level existed. This annunciator could be reset only when the difference was less than 2.5 inches.

The control selector switch was transferred to LEVEL, to set up single-element level control. HCS-152 was bumplessly switched to "Manual", and it was verified that HCS-152 could stroke CV-151 through its full open-to-shut range.

Air supply to CV-151 positioner was shut off, and proper operation of the air failure solenoid valve was observed by noting that CV-151 retained its position prior to air shut-off.

HCS-152 was bumplessly transferred to "Automatic". The setpoint in LRC-151 was raised above the (simulated) water level; it was noted that the output of LRC-151 started increasing and ultimately drove CV-151 wide-open, and vice versa.

Simulated steam and feedwater flow signals were applied to FR-151 and FR-152T, respectively. Within FC-151, the following controller settings were made:

1)	Proportional Band	300%
2)	Reset Time	0.1 min/repeat

The control selector switch was transferred to STM/H₂O, which is a two-element control. The setpoint of LRC-151 was put at midscale, and the internal transfer switch was put into SEAL. (This locks up the output of LRC-151, at a zero incremental feedwater flow demand into FCp-151, and forces the setpoint to FC-151 to be equal to feedwater flow.)

The (simulated) feedwater flow signal, which is the input to FC-151, was then matched with the (simulated) steam flow signal. The steam flow signal is the demand to FC-151. By using the bias relay in FCp-151, it was possible to bias the steam flow as much as $\pm 100\%$. * By using the bias relay, steam flow was raised above

* The bias regulator is used to account for steam blowdown, and normally will be set at about +0.5% to account for normal blowdown rate.

feedwater flow; FC-151 responded properly by increasing its output and ultimately driving CV-151 wide-open. The reverse was observed when steam flow was below feedwater flow.

The control selector switch was transferred to NORMAL, which is a three-element control.

The internal transfer switch in LRC-151 was switched back to AUTOMATIC. Simulated steam and feedwater flow signals of 50% full-scale, and a simulated normal water level, were applied to FCp-151, FR-151, and LRC-151, respectively.

The setpoint in LRC-151 was raised above the (simulated) normal water level, resulting in a proper increase of LRC-151 output. In three-element control, the output of LRC-151 is an incremental demand feedwater flow, which adds (algebraically) to the measured feedwater to result in a total demand feedwater flow. Proper increase in the demand feedwater flow was observed on a demand input gage at FC-151. The setpoint on LRC-151 was then lowered below the (simulated) water level, and proper decrease in total demand feedwater flow was observed. A very small difference between (simulated) water level and LRC-151 setpoint was then set up, resulting in a very slow increase in total feedwater demand to FC-151. Proper response of FC-151 was verified, as described above under two-element control, by changing the (simulated) measured steam flow.

With FC-151 controlling, HCS-152 was bumplessly transferred to "Manual". A new valve position was set by manually adjusting HCS-152 to a new value, and HCS-152 was then bumplessly transferred back to "Automatic".

HCS-149 was switched to "Manual". It was verified that CV-152 could be stroked over its open-to-shut range by manual adjustment of HCS-149. HCS-149 was set at 50%, and CV-152 went to its mid-position. The air supply to CV-152 was shut off and proper operation of the air failure solenoid valve was observed by noting that CV-152 retained its 50% position. The air supply to CV-152 was turned back on. HCS-149 was switched to OFF and CV-152 responded properly by driving to the full shut position.

The electric-motor-operated gate valve was operated to various positions including full open and full shut, by operation of HCS-154.

After filling the steam generators, the level observed on the sight gage was compared with the outputs of LRC-151T, LXL-150T, LXL-151T, and LXL-152T. It was observed that the output of the level transmitters agreed with each other to within one inch. The level sight gage could only be read to the nearest two in., and the output of the level transmitters compared with that shown on the sight gage within this limit.

The same test as described above was repeated for steam generators No. 2 and No. 3, with similar results.

J. ATTEMPERATOR CONTROL

The function of the attemperator control subsystem is to maintain attemperator outlet steam temperature at a set value.

As shown in Figure 1120-10, the plant operator selects a set temperature on TRC-152. The attemperator outlet temperature is sensed by TRC-152T and is transmitted to TRC-152. The output of TRC-152 is a valve position demand signal. HCS-151 is provided so the operator can transfer from automatic control and manually select a valve position. Two valves, operating over a split range, are provided for sufficient capacity.

HCS-151 was switched to "Manual" and operated over its full range. Proper operation of the two attemperator valves was observed. At zero signal from HCS-151, both valves were wide open. Above zero signal, the 4 in. valve starts to close; the 2 in. valve remains wide open. At the 46% position, the 2 in. valve started to close. At the 54% position, the 4 in. valve was completely closed. At the 100% position, both valves were completely closed.

Thermocouple wiring between TRC-152E and TRC-152T was checked for continuity, absence of wiring shorts, and correct polarity. Within TRC-152, the following controller settings were made:

1)	Proportional Band	25%
2)	Reset Time	0.5 min/repeat

Figure 1120-10. Attenuator Control Subsystem-Block Diagram

A simulated thermocouple signal was connected to TRC-152T. By manual adjustment of TRC-152 setpoint, and by varying the (simulated) thermocouple input, it was noted that the annunciator "Deviation Attenuator Steam Generator No. 1" would actuate when the difference between input and setpoint exceeded 15 F. The annunciator could be reset only when the difference was less than 15 F.

HCS-151 was bumplessly transferred to "Automatic". The setpoint in TRC-152 was increased above the (simulated) input. It was noted that the output of TRC-152 started increasing and ultimately drove both attenuator valves fully shut. When the setpoint was below the input, the output of TRC-152 would decrease, ultimately driving both attenuator valves fully open.

With the output of TRC-152 at about half scale, the main board air supply was shut off. Proper operation of the air failure solenoid valve was verified by noting that the attenuator valves retained the position they were in just prior to air failure.

The same test as described above was repeated for the attenuator control subsystems associated with steam generators No. 2 and No. 3, with similar results.

K. POWER RELIEF CONTROL

The function of the power relief control subsystem is to relieve excess steam generator pressure above a pre-set value.

As shown in Figure 1120-11, PC-151 will be set at about 900 psig. Should pressure in the steam generator reach or exceed the pressure, PC-151 actuates the solenoid valve and opens the power relief valve. As soon as the pressure returns to a value less than 900 psig, the solenoid is de-energized and the power relief valve closes. HCS-153 is provided so the operator may manually open or close the power relief valve.

HCS-153 was switched to OFF, and it was verified that the power relief valve was shut. HCS-153 was switched to VALVE OPEN, and it was verified that the power relief valve was open.

HCS-153 was switched to AUTOMATIC. PC-151 setpoint was set at 900 psig. Since pressure sensed by PC-151 was atmospheric, the power relief valve was closed. Known pressures were applied to PC-151. When the (simulated) pressure exceeded 900 psig, the power relief valve opened. When the (simulated) pressure was reduced, the power relief valve closed as soon as the pressure reached 895 psig.

The same test as described above was repeated for the power relief subsystems associated with steam generators No. 2 and No. 3 with similar results.

L. PRIMARY BLOCK VALVE CONTROL

The function of the primary block valve control subsystem is to prevent opening the block valve if the differential temperature

between the reactor plenum and the intermediate heat exchanger (IHX) is excessive, and to provide the operator with a means of preventing the flow of sodium in any or all of the primary heat transfer loops.

The IHX primary sodium temperature from TR-100T is subtracted from the auctioneered reactor plenum temperature in TCp-100. If the temperature difference as computed by TCp-100 is excessive, TS-100 prevents opening the block valve (Figure 1120-12).

In the event of an emergency (e.g., a major sodium leak), the plant operator can close the primary block valve by operating HCS-106.

Simulated temperature signals were connected to TI-1, -2, -3, and TR-100T. It was verified that the highest of the signals from TI-1, -2, or -3 was transmitted to TCp-100 as the subtractor. The output of TR-100T was transmitted to TCp-100 as the subtrahend. The output of TCp-100 was verified to be the difference between the two inputs. TS-100 was set to actuate at a temperature difference of 50 F.

By varying the (simulated) temperature inputs, a difference of less than 50 F was established. The amber light next to HCS-106, which indicates a difference of less than 50 F, was on. By using HCS-106, it was possible to fully open, fully close, or hold the block valve in a mid-position.

Figure 1120-12. Primary Block Valve Control Subsystem-Block Diagram

A temperature difference of more than 50 F was established. The white light next to HCS-106, which indicates a temperature difference in excess of 50 F, started flashing, and the amber light went off. Under this condition, it was possible to drive the primary block valve in the closed direction, but impossible to drive it in the open direction by operation of HCS-106.

The same test as described above was repeated for the primary block valve control subsystems for sodium circuits No. 2 and No. 3, with similar results.

M. STEAM DUMP PRESSURE CONTROL

The function of the steam dump pressure control subsystem is to dump up to 110,000 lb/hr of steam from the turbine inlet header to an atmospheric boiler.

The plant operator selects a pressure at which he wishes the steam dump control to operate and enters this into PIC-501 as a set pressure. The steam pressure is sensed in PIC-501T and is transmitted to PIC-501. The output of PIC-501 is a position signal to the steam dump control valve. HCS-505 is provided so that the plant operator may transfer from automatic control and manually select a valve position (Figure 1120-13).

PIC-501 was system calibrated by applying known pressures to PIC-501T and reading out the pressure on PIC-501. System accuracy was within $\pm 1\%$. Within PIC-501, the following controller settings were made:

Figure 1120-13. Steam Dump Control Subsystem-Block Diagram

- 1) Proportional Band 20%
- 2) Reset Time 0.2 min/repeat

HCS-505 was bumplessly transferred to "Manual". By manual adjustment of HCS-505, it was verified that it was possible to stroke the steam dump control valve over its full open-to-shut range.

HCS-505 was bumplessly transferred to "Automatic". The setpoint on PIC-501 was raised above an (simulated) input pressure. Under this condition, the output of PIC-501 started decreasing and ultimately drove the steam dump valve shut. The setpoint was then lowered below the (simulated) pressure. PIC-501 output started increasing and ultimately drove the steam dump valve open.

N. MISCELLANEOUS

Miscellaneous plant control instrumentation consists of a steam dump flow transmitter and recorder (FR-501T and FR-501), a feedwater pressure transmitter, alarm, and recorder (PR-501T, PAL-501, and PR-501), and a feedwater temperature transmitter and recorder (TR-501T and TR-501).

The steam dump flow recorder was system calibrated by applying known differential pressures to FR-501T and reading (simulated) flow on FR-501. System accuracy was within $\pm 1\%$.

The feedwater pressure recorder was system calibrated by applying known pressures to PR-501T and reading (simulated) pressure on PR-501. System accuracy was within $\pm 1\%$. The

annunciator "Low Feedwater Pressure" was observed to actuate when the (simulated) pressure was below 925 psig. This annunciator could be reset only when the (simulated) pressure was above 925 psig.

The feedwater temperature recorder was system calibrated by applying known temperatures to TR-501T, and reading temperature on TR-501. System accuracy was within $\pm 1\%$.

III. ANALYSIS AND PRESENTATION OF TEST RESULTS

All individual plant control instruments were calibrated to an accuracy of 1/2% of full scale, as verified by AI Quality Control at the manufacturer's plant, and as further verified by Operation Services at HNPF.

The operability of the plant control system and proper connections within the various subsystems are described in the following pages of this section.

A. PLANT POWER CONTROL

Proper connection of all components was verified. Correct initial controller settings of 100% proportional band, 0.2 min/repeat reset time, and 0.1 min rate time were made in PRC-501. Bumpless transfer from "Manual" to "Automatic", and "Automatic" to "Manual", was demonstrated on HCS-504. Total steam flow demand will increase upon a steam flow increase and/or steam pressure decrease, and vice versa. Proper annunciation occurs upon more

than a 20 psig difference between demand and measured steam pressure. Overall system accuracy and response time for the mass steam flow recorder are shown in Table I.

B. DIVISION OF LOAD COMPUTER

Proper connection of all components was verified. Correct initial controller settings of 150% proportional band and 0.02 min/repeat reset time were made in WaIC-501. Bumpless transfer from "Manual" to "Automatic", and from "Automatic" to "Manual", was demonstrated on HCS-501, -502, and -503. WaIC-501 controls in such a manner that the sum of the three individual heat transfer circuit steam demands equals the total plant steam demand. One heat transfer circuit can be ratioed to carry a fixed percentage of the steam demand that the other two circuits are carrying, and the sum of the three heat transfer circuit steam demands will equal the total plant steam demand. Thermal converters in each heat transfer circuit were set so that a 0-100% circuit demand steam flow results in a 0-100% demand secondary sodium flow and a 0-100% demand primary sodium flow. Proper annunciation occurs upon more than a 10% difference between total demand steam flow and the sum of the three heat transfer circuit demand steam flows.

C. SECONDARY SODIUM FLOW CONTROL

Proper connection of all components was verified. Correct initial controller settings of 150% proportional band and 0.2 min/repeat reset time were set in FRC-102, -202, and -302. Bumpless transfer from

TABLE I
SYSTEM ACCURACY AND RESPONSE TIMES
FOR FR-502T AND FR-502

Applied P at FR-502T Flow Trans- mitter (in. of water)	Applied Press at FR-502T Press Trans- mitter (psia)	Applied Temp at FR-502T Temp Trans- mitter (F)	Calculated Flow (lb/hr)	Recorded Flow at FR-502 Flow Recorder (lb/hr)	Error (% Full Scale)*
50	765	900	233,000	216,000	1.9
150	765	900	450,000	441,000	1.0
450	765	900	774,000	792,000	2.0
600	765	900	900,000	918,000	1.0
150	840	900	472,000	468,000	0.5
300	915	600	843,000	842,000	0.1
300	765	900	636,000	640,000	0.5
150	915	740	540,000	531,000	1.0
370	815	825	755,000	761,000	0.7
Time response to positive pressure step-change = 2 sec.					
Time response to negative pressure step-change = 3 sec.					
Time response to positive temperature step-change = 2 sec.					
Time response to negative temperature step-change = 2 sec.					
Time response to positive differential step-change = 2 sec.					
Time response to negative differential step-change = 2 sec.					

* Full scale is 900,000 lb/hr

"Automatic" to "Manual", and back to "Automatic" was demonstrated on HCS-107, -207, -307, -104, -204, and -304. Rate limiters in HCS-107, -207, -307, and SCD-102, -202, and -302 were set at $20 \pm 5\%/min$ as shown in Table II. An increase in demand sodium flow, over measured sodium flow, results in an increase in demand pump speed, and vice versa. Proper annunciation occurs upon more than an 8% difference between measured and demand sodium flow. HCS-104, -204, or -304 will automatically and bumplessly transfer to "Manual" upon a flow difference of more than 8%, and can be transferred to "Automatic" only when this difference is less than 8%.

TABLE II
SECONDARY SODIUM FLOW CONTROL SUBSYSTEM
RATE LIMITER VALUES

Unit	0-100% Step-Change		100-0% Step-Change	
	Time (min)	Rate (%/min)	Time (min)	Rate (%/min)
HCS-107	4.3	23.3	5.5	18.2
HCS-207	4.3	23.3	4.7	21.3
HCS-307	4.2	23.8	5.6	17.9
SCD-102	4.6	21.7*	5.0	20.0
SCD-202	4.5	22.1*	5.6	17.9
SCD-302	4.4	22.7*	5.1	19.6

* Rate limiter settings on SCD-102, -202, and -302 were reset to 40%/min following completion of this test.

Secondary sodium flow transmitter FRC-102T, -202T, and -302T were set for an input of 0 to 36.5 mv to correspond to an output of 0-3,000,000 lb/hr. The following magnetic flowmeter loop resistances were measured:

1)	FRC-102E	2.5 ohms
2)	FRC-202E	1.2 ohms
3)	FRC-302E	1.0 ohms

It was demonstrated that demand pump speed is driven immediately to zero upon a scram. To reset this scram interlock, the following interlocks must be satisfied:

- 1) Scram reset
- 2) Pump coupling energized
- 3) HCS-104, -204, or -304 set for less than zero demand speed.

D. PRIMARY SODIUM FLOW CONTROL

Proper connection of all components was verified. Correct initial controller settings of 200% proportional band, 1 min/repeat reset time, and 0.01 min rate time were set in TRC-101, -201, and -301. Correct initial controller settings of 150% proportional band and 0.2 min/repeat reset time were set in FRC-101, -201, and -301. Bumpless transfer from "Automatic" to "Manual", and return to "Automatic" was demonstrated on HCS-105, -205, -305, -102, -202, and -302.

The temperature demand to TRC-101, -201, and -301 is computed according to the following formula:

$$T_{n,rid} = 560 + 50 W_{p,d}$$

where:

$T_{n, rid}$ = demand reactor inlet temperature

$W_{p, d}$ = demand primary sodium flow

An increase in demand reactor inlet temperature, over measured temperature, results in an incremental demand primary sodium flow with a maximum value of + 8.3%.* A decrease in demand reactor inlet temperature, below measured temperature, results in an incremental demand primary sodium flow with a minimum value of - 8.3%. Proper annunciation occurs upon more than a 15 F difference between measured and demand reactor inlet temperature.

Rate limiters in HCS-105, -205, -305 and SCD-101, -201, and -301 were set at $20 \pm 5\%/min$ as shown in Table III. An increase in total demand sodium flow, over measured sodium flow, results in an increase in demand pump speed, and vice versa. Proper annunciation occurs upon more than an 8% difference between measured and demand sodium flow. HCS-102, -202, or -302 will automatically and bumplessly transfer to "Manual" upon a flow difference of more than 8%, and can be transferred to automatic only when this difference is less than 8%.

Primary sodium flow transmitters FRC-101T, -201T and -301T were set for an input of 0-34.3 mv to correspond to an output of 0-3,000,000 lb/hr. The following magnetic flowmeter loop resistances were measured:

* The $\pm 8.3\%$ values correspond to 3-15 psig pneumatic signals. Since TRC-101 can "wind up", the actual pneumatic signals can be 0-19 psig, corresponding to $\pm 12\%$.

TABLE III
PRIMARY SODIUM FLOW CONTROL SUBSYSTEM
RATE LIMITER VALUES

Unit	0-100% Step-Change		100-0% Step-Change	
	Time (min)	Rate (%/min)	Time (min)	Rate (%/min)
HCS-105	4.1	24.3	5.3	18.9
HCS-205	4.2	23.8	5.2	19.3
HCS-305	4.1	24.3	5.6	17.9
SCD-101	4.1	24.3	4.8	20.8
SCD-201	4.4	22.7	5.9	16.8
SCD-301	4.4	22.7	5.3	18.9

- 1) FRC-101E 3.5 ohms
- 2) FRC-201E 3.8 ohms
- 3) FRC-301E 3.2 ohms

It was demonstrated that demand pump speed is driven immediately to zero upon a scram. To reset this scram interlock, the following interlocks must be satisfied:

- 1) Scram reset
- 2) Pump coupling energized
- 3) HCS-102, -202, or -302 set for less than zero demand speed.

E. NUCLEAR POWER COMPUTER

Proper connection of all components was verified. Proper operation of the "auctioneer" circuit in TI-1, -2 and -3, and proper operation of the "average" circuit in TI-4 and -5 was verified. Bumpless transfer from "Automatic" to "Manual" and return from "Manual" to "Automatic" was demonstrated on HCS-6, -7, and -12. Proper rate limiting of HCS -7 and -10 output at 50 F/hr was observed.

It was demonstrated that TRCp-1 would generate a demand fuel outlet temperature to TRC-2 according to the relationship:

$$T_{nco, set} = T_{nro, set} + K_t (T_{nro, set} - T_{nro})$$

where:

$T_{nco, set}$ = demand fuel outlet temperature

$T_{nro, set}$ = reactor demand outlet temperature
(rate limited value of HCS-10 output)

T_{nro} = measured reactor outlet temperature
(TI-1, -2, and -3 auctioneered output)

The value of the constant, K_t , was set at 5.0. Proper annunciation occurs upon more than a 20 F difference between demand and measured reactor outlet temperature.

Correct initial controller settings of 150% proportional band and 2 min/repeat reset time were set in TRC-2. An increase in demand fuel outlet temperature, above measured fuel outlet temperature (as averaged in TI-4 and -5), results in an incremental demand flux with a maximum value of + 20% flux. A decrease in demand fuel outlet temperature, below measured fuel outlet temperature, results in an incremental demand flux with a minimum value of - 20% flux. Proper annunciation occurs upon more than a 20 F difference between demand and measured fuel outlet temperature.

It was demonstrated that NWCp-1 would generate a demand neutron flux according to the relationship:

$$n_d = K_n W_n (T_{nro, set} - T_{nri, set})$$

where:

$$n_d = \text{demand neutron flux}$$

$$W_n = \text{sum of three primary sodium flows}$$

$$T_{nro, set} = \text{reactor demand outlet temperature} \\ \text{(rate limited value of HCS-10 output)}$$

$$T_{nri, set} = \text{reactor inlet temperature (as set by HCS-11)}$$

$$K_n = \text{constant}$$

K_n was set so that flux demand was 100% when the three primary sodium flows were 100% each, with the reactor ΔT at 335 F.

The outputs of NWaCp-1 and TRC-2 were shown to be algebraically added in NLCp-1 to generate the total demand neutron flux.

F. NEUTRON FLUX CONTROLLER

Proper connection of all components was verified. Correct initial control settings of 20% proportional band, 2 min/repeat reset time, and 0.20 in. deadband were set in NC-1. Bumpless transfer from "Manual" to "Automatic", and from "Automatic" to "Manual", was demonstrated on HCS-5. It was shown that NLR-1/2 records total demand and measured neutron flux.

With the flux controller in manual control, it was possible to position the feedback mechanism from its main board control switch. Proper annunciation occurred when the position feedback mechanism exceeded its normal 20-80% operating position.

With the flux controller in "Manual", it was possible to drive any control rod in "Automatic", and the position feedback mechanism, up or down from HCS-1. To put the flux controller into "Automatic", the following interlocks had to be satisfied:

- 1) No scram.
- 2) No setback.
- 3) Desk console transfer switch in AUTO.
- 4) Difference between demand and measured neutron flux less than 8%.

- 5) Position feedback mechanism between 5% and 95% position.

As soon as any of the above interlocks were violated, the flux controller would automatically transfer to manual control.

The demand neutron flux signal to the flux controller was verified to be rate-limited at $40 \pm 5\%/min$.

With the flux controller in "Automatic", an increase in demand flux over measured flux would result in a "Rods Up" signal, and vice versa. Proper annunciation occurred when the difference between demand and measured flux exceeded 8%.

A "Rods Up" or "Rods Down" signal resulted in movement in the required direction by all control rods which were in "Automatic" and the position feedback mechanism. The position feedback mechanism responded within 50 msec of a control rod. The difference (which is both leading and lagging) is attributable to drive gear train backlash.

Proper annunciation occurs when the position of any control rod on automatic control gets out of a pre-set operating band.

G. MODERATOR COOLANT CONTROL

Proper connection of all components was verified. Correct initial controller settings of 100% proportional band, 1 min/repeat reset time, and 0.01 min rate time were set in TRC-3. Bumpless transfer from "Manual" to "Automatic" and return to "Manual" was demonstrated on HCS-9. The rate limiter in HCS-9 output was verified to be set at $40 \pm 5\%/min$.

The demand moderator outlet temperature was verified to be the same as the rate-limited fuel outlet temperature. An increase in demand moderator outlet temperature over measured moderator outlet temperature results in the moderator control valve moving in the closed direction, and vice versa. Proper annunciation occurs upon more than a 20 F difference between measured and demand moderator outlet temperature. HCS-9 will automatically and bumplessly transfer to "Manual" upon a difference of more than 20 F, and can be transferred to "Automatic" only when this difference is less than 20 F.

H. CONVECTION FLOW CONTROL

Proper connection of all components was verified. Correct initial controller settings of 100% proportional band, 0.4 min/repeat reset time, and 0.01 min rate time were set in TRC-4. Bumpless transfer from "Automatic" to "Manual", and from "Manual" to "Automatic", was demonstrated for HCS-9, -101, -201, -301, -103, -203, and -303. Proper operation of the valve position limiters, and proper annunciation when the position limit is reached, was verified.

An increase in demand fuel outlet temperature, over measured fuel outlet temperature, results in the six throttle valves moving in the closed direction, and vice versa. It was verified that the position of each secondary throttle valve can be set in a pre-set ratio of the corresponding primary throttle valve position. Proper annunciation occurs upon more than a 20 F difference between measured and demand fuel outlet temperature. HCS-8 will automatically and bumplessly transfer to "Manual"

upon a difference of more than 20 F, and can be transferred to "Automatic" only when this difference is less than 20 F.

During normal reactor operation, the convection control is not in service, and the six throttle valves are in the wide-open position. Upon a scram the throttle valves are driven at full speed to the 96% shut position, and hold this position for 30 sec. At the end of the 30 sec period, TRC-4 is switched into service and will drive the throttle valves in the direction required to reduce the difference between demand and measured fuel outlet temperature to zero. After this 30 sec period, the throttle valves will operate at full speed in the range from the wide-open to 60% shut position and will operate at one-quarter full speed in the range from 60% shut to the full shut position.

After the scram condition has been cleared, it is necessary to use the convection control reset pushbutton to switch TRC-4 out of service and drive the six throttle valves to the wide-open position.

I. FEEDWATER CONTROL

Proper connection of all components was verified. Correct initial controller settings of 50% proportional band and 0.2 min/repeat reset time were set in LRC-151, -251, and -351. Correct initial controller settings of 300% proportional band and 0.1 min/repeat reset time were set in FC-151. Bumpless transfer from "Automatic" to "Manual", and from "Manual" to "Automatic" was demonstrated on HCS-152, -252, and -352. It was verified that the measured steam flow could be biased to account for continuous blowdown.

On single-element control, an increase in demand evaporator level, over measured evaporator level, results in opening CV-151, -251, or -351, and vice versa.

On two-element control, an increase in measured steam flow results in a feedwater flow demand increase, and vice versa. An increase in demand feedwater flow, over measured feedwater flow, results in opening CV-151, -251, or -351, and vice versa.

On three-element control, an increase in demand evaporator level, over measured evaporator level, results in an increase in the incremental demand feedwater flow, which is added to the measured steam flow to result in a total demand feedwater flow. A decrease in demand evaporator level, below measured evaporator level, results in a decrease in the incremental demand feedwater flow, which is subtracted from the measured steam flow to result in a total demand feedwater flow. An increase in total demand feedwater flow, over measured feedwater flow, results in opening CV-151, -251, or -351, and vice versa.

Proper annunciation occurs when the difference between demand and measured evaporator level exceeds 2.5 inches.

Proper annunciation occurs when the feedwater level is lower than four in. below normal water level or higher than 7-1/2 in. above normal water level. If the water level exceeds six in. below normal or 7-1/2 in. above normal, CV-151, -251, or -351 is driven to a full-open or full-shut position, dependent on the cause (high or low level) of actuation.

Proper drop-out of protective panel relays was observed when the evaporator level dropped to eight in. below normal water level. (Table IV lists feedwater level setpoints and the action associated with transgressing those setpoints.)

TABLE IV
FEEDWATER LEVEL SETPOINTS

IN. FROM NORMAL	ACTION
+ 7-1/2	Valve closes automatically
+ 5	Alarm and operator action
+ 2-1/2	Control deviation alarm and operator action
0 $\pm$ 2-1/2	Normal control span
- 2-1/2	Control deviation alarm and operator action
- 4	Alarm and operator action
- 6	Valve closes automatically
- 8	Scram

Overall system accuracy and response times for the steam and feedwater flow recorders are shown in Tables V and VI, respectively. Overall system accuracy for the evaporator level control and level scram transmitters is shown in Tables VII and VIII, respectively. Response times for the evaporator level transmitter are shown in Table IX.

Proper operation of the electrically driven feedwater block valve from HCS-154, -254, and -354 was verified.

Proper operation of the feedwater bypass valve from HCS-149, -249, and -349 was verified.

J. ATTEMPERATOR CONTROL

Proper connection of all components was verified. Correct initial controller settings of 25% proportional band and 0.5 min/repeat reset time were made in TRC-152, -252, and -352. Bumpless transfer from "Automatic" to "Manual", and back to "Automatic" was demonstrated on HCS-151, -251, and -351. Proper annunciation occurs when the difference between demand and measured attemperated steam temperature exceeds 15 F. An increase in demand attemperated steam temperature over measured steam temperature, results in closing the attemperator valves, and vice versa. The attemperator control valves operate according to the schedule shown in Figure 1120-14.

TABLE V
CALIBRATION DATA AND RESPONSE TIMES FOR STEAM FLOW RECORDERS

Unit	Applied Diff Press (in. of water)	Calculated Flow (lb/hr)	Recorded Flow (lb/hr)	Error (% of full scale)*
FR-151	0.0	0.0	0.0	0.0
	100	134,000	135,000	0.3
	200	190,000	192,000	0.7
	300	233,000	235,000	0.7
	400	268,000	268,000	0.0
	500	300,000	300,000	0.0
	400	268,000	269,000	0.3
	300	233,000	234,000	0.3
	200	190,000	191,000	0.3
	100	134,000	136,000	0.7
	0.0	0.0	0.0	0.0
FR-251	0.0	0.0	0.0	0.0
	100	134,000	135,000	0.3
	200	190,000	192,000	0.7
	300	233,000	234,000	0.3
	400	268,000	270,000	0.7
	500	300,000	302,000	0.7
	400	268,000	270,000	0.7
	300	233,000	234,000	0.3
	200	190,000	192,000	0.7
	100	134,000	135,000	0.3
	0.0	0.0	0.0	0.0
FR-351	0.0	0.0	0.0	0.0
	100	134,000	138,000	1.3
	200	190,000	195,000	1.7
	300	233,000	234,000	0.3
	400	268,000	270,000	0.7
	500	300,000	301,000	0.3
	400	268,000	270,000	0.7
	300	233,000	234,000	0.3
	200	190,000	195,000	1.7
	100	134,000	138,000	1.3
	0.0	0.0	0.0	0.0
Time Response to Positive Differential Pressure Step-Change			FR-151 = 2 sec FR-251 = 2 sec FR-351 = 2 sec	
Time Response to Negative Differential Pressure Step-Change			FR-151 = 3 sec FR-251 = 3 sec FR-351 = 2 sec	

* Full scale is 300,000 lb/hr.

TABLE VI
CALIBRATION DATA AND RESPONSE TIMES
FOR FEEDWATER FLOW RECORDERS

Unit	Applied Diff Press (in. of water)	Calculated Flow (lb/hr)	Recorded Flow (lb/hr)	Error (% of full scale)*
FR-152	0.0	0.0	0.0	0.0
	10	134,000	135,000	0.3
	20	190,000	192,000	0.7
	30	233,000	232,500	0.2
	40	268,000	270,000	0.7
	50	300,000	301,000	0.3
	40	268,000	270,000	0.7
	30	233,000	232,500	0.2
	20	190,000	191,000	0.3
	10	134,000	135,000	0.3
	0.0	0.0	0.0	0.0
FR-252	0.0	0.0	0.0	0.0
	10	134,000	135,000	0.3
	20	190,000	192,000	0.7
	30	233,000	233,000	0.0
	40	268,000	270,000	0.7
	50	300,000	301,000	0.3
	40	268,000	270,000	0.7
	30	233,000	233,000	0.0
	20	190,000	191,000	0.3
	10	134,000	135,000	0.3
	0.0	0.0	0.0	0.0
FR-352	0.0	0.0	0.0	0.0
	10	134,000	131,000	0.7
	20	190,000	188,000	0.7
	30	233,000	234,000	0.3
	40	268,000	271,000	1.0
	50	300,000	302,000	0.7
	40	268,000	271,000	1.0
	30	233,000	234,000	0.3
	20	190,000	191,000	0.3
	10	134,000	133,000	0.3
	0.0	0.0	0.0	0.0
Time Response to Positive Differential Pressure Step-Change			FR-152 = 2 sec FR-252 = 2 sec FR-352 = 2 sec	
Time Response to Negative Differential Pressure Step-Change			FR-152 = 3 sec FR-252 = 3 sec FR-352 = 3 sec	

* Full scale is 300,000 lb/hr.

TABLE VII
CALIBRATION DATA FOR LEVEL
CONTROL INSTRUMENTS

Unit	Applied Press (psia)	Applied Level (in. of water)	Calculated Level (in. from normal)	Recorded Level (in. from normal)	Error (in.)
LRC-151	250	10.0	+3.7	+3.3	0.4
	500	10.0	+2.8	+2.5	0.3
	600	18.7	-8.7	-9.5	0.8
	1000	6.25	+6.8	+6.1	0.7
LRC-251	250	10.0	-3.7	+3.4	0.3
	500	10.0	-2.8	+2.3	0.5
	600	18.7	-8.7	-9.2	0.5
	1000	6.25	+6.8	+5.9	0.9
LRC-351	250	10.0	+3.7	+3.7	0.0
	500	10.0	+2.8	+2.9	0.1
	600	18.7	-8.7	-8.7	0.0
	1000	6.25	+6.8	+6.6	0.2

TABLE VIII
CALIBRATION DATA FOR EVAPORATOR LEVEL INSTRUMENTS
(Normal Water Level = 59.6 in.)

Unit	Applied Press (psia)	Applied Level (in. of water)	Calculated Level (in.)	Recorded Level (in.)	Error (in.)
LXL-150	800	15.0	54.9	55.5	0.6
	100	37.5	33.2	33.4	0.2
	100	22.5	49.6	50.3	0.7
	1000	15.0	53.6	54.0	0.4
LXL-151	800	15.0	54.9	55.1	0.2
	100	37.5	33.2	33.4	0.2
	100	22.5	49.6	50.3	0.7
	1000	15.0	3.6	54.0	0.4
LXL-152	800	15.0	54.9	54.7	0.2
	100	37.5	33.2	33.7	0.5
	100	22.5	49.6	50.4	0.8
	1000	15.0	53.6	54.6	1.0
LXL-250	800	15.0	54.9	55.5	0.6
	100	37.5	33.2	32.6	0.6
	100	22.5	49.6	49.9	0.3
	1000	15.0	53.6	54.0	0.4
LXL-251	800	15.0	54.9	55.5	0.6
	100	37.5	33.2	33.0	0.2
	100	22.5	49.6	49.9	0.3
	1000	15.0	53.6	53.6	0.0
LXL-252	800	15.0	54.9	54.0	0.1
	100	37.5	33.2	32.3	0.1
	100	22.5	49.6	50.3	0.7
	1000	15.0	53.6	52.6	1.0
LXL-350	800	15.0	54.9	55.5	0.6
	100	37.5	33.2	33.4	0.2
	100	22.5	49.6	50.6	1.0
	1000	15.0	53.6	54.4	0.8
LXL-351	800	15.0	54.9	54.7	0.2
	100	37.5	33.2	33.0	0.2
	100	22.5	49.6	50.1	0.5
	1000	15.0	53.6	54.0	0.4
LXL-352	800	15.0	54.9	55.5	0.6
	100	37.5	33.2	33.7	0.5
	100	22.5	49.6	50.3	0.7
	1000	15.0	53.6	54.6	1.0

TABLE IX
RESPONSE TIMES FOR EVAPORATOR LEVEL TRANSMITTERS

Instrument	Response Time for Positive Diff Press Step-Change (sec)	Response Time for Negative Diff Press Step-Change (sec)	Response Time for Positive Press Step-Change (sec)	Response Time for Negative Press Step-Change (sec)
LRC-151	3	4	3	4
LRC-251	3	4	3	4
LRC-351	3	3	2	4
LXL-150	2	4	3	4
LXL-250	3	4	3	3
LXL-350	3	4	3	4
LXL-151	3	4	3	4
LXL-251	2	4	3	4
LXL-351	3	4	2	4
LXL-152	3	4	2	4
LXL-252	3	3	3	3
LXL-352	3	4	3	4

Figure 1120-14. Operating Schedule of Attemperator Valves

K. POWER RELIEF CONTROL

Proper connection of all components was verified. Proper operation of the power relief valve from HCS-153, -253, and -353 was demonstrated. When in automatic control, an increase in pressure, over set pressure, results in immediate opening of the power relief valve. The power relief valve remains open until measured pressure is less than set pressure.

L. PRIMARY BLOCK VALVE CONTROL

Proper connection of all components was verified. Proper operation of primary block valve from HCS-106, -206, and -306 was demonstrated. Proper interlock operation prevents the opening of a block valve if the temperature difference across the block valve exceeds 50 F.

M. STEAM DUMP PRESSURE CONTROL

Proper connection of all components was verified. Correct initial controller settings of 20% proportional band and 0.2 min/repeat reset time were set in PIC-501. Bumpless transfer from "Manual" to "Automatic", and from "Automatic" to "Manual", was demonstrated on HCS-505. An increase in steam pressure, over set steam dump pressure, results in opening the steam dump valve, and vice versa.

N. MISCELLANEOUS

Proper operation of the steam dump flow recorder, the feedwater pressure recorder, and the feedwater temperature recorder was verified. Proper annunciation occurs when the feedwater pressure drops below 925 psig.

IV. COMPLIANCE WITH TEST COMPLETION CRITERIA

Following are the test completion criteria associated with pre-operational test AI-P-1120, Plant Control System, as listed in NAA-SR-5700, Supplement 4, page XI (a)-44 with remarks regarding the test to explain compliance with the criteria.

- a) Criterion: All plant control components calibrated to $\pm 1\%$ of full scale accuracy.
Remarks: The 341 recorders, controllers, transmitters, alarm relays, computing relays, and pressure switches, requiring calibration, were calibrated to within an accuracy of $\pm 1/2\%$ of full scale. The remaining 373 plant control components consist of back-of-board input-output pressure gages, which calibrate to within $\pm 1\%$ of full scale, and various switches, and solenoid valves, which do not require calibration.
- b) Criterion: All plant control components correctly connected to their input and output devices.
Remarks: This was verified by applying simulated input signals to the input devices and observing proper actuation of the correct output device.
- c) Criterion: Response time of all subsystems is within 5 sec of actuating signal.
Remarks: In all cases except the plant power control and feedwater control subsystems, actuating signals (e. g., sodium

flow, temperature, and neutron flux) are transmitted electrically to the subsystem in question. At the appropriate subsystem, the actuating signal is transduced to a 3-15 psig pneumatic or 10-15 ma electrical signal, for computing and controlling purposes. The response time of the subsystem, to a change in actuating signal, is limited only by the response times of the transducing instruments, which are within 5 seconds.

In the case of the plant power control and feedwater control subsystems, actuating signals (e.g., steam pressure) are transduced to a 3-15 psig pneumatic signal and are transmitted through about 200 ft of 1/4 in. OD copper tubing to computing or controlling instruments at the main board. Response time of these subsystems is limited by the distance between the transmitter and the main board. (Transmission of a pneumatic signal is not instantaneous (e.g., consider a 50 psig step-change in steam pressure at PRC-501Tb). Since the range of PRC-501Tb is 750-900 psig, this results in a 4 psig change of the transmitted pneumatic signal. The response time is then determined by the time required to change the pressure by 4 psig in the 200 ft of 1/4 in. OD copper tubing. In these cases, the response time was also within 5 seconds.

- d) Criterion: All subsystems respond to simulated inputs in a stable manner.
- Remarks: Introduction of simulated inputs to the various subsystems resulted in stable response. Controller outputs changed smoothly, and in the correct direction for proper control. Actual stability of the plant control system will be verified during performance of AI-PC-630 "Plant Control System" (post-critical test), when the plant control system will actually be controlling the reactor plant.
- e) Criterion: All plant control interlocks function correctly.
- Remarks: Proper operation of the sodium pump zero speed interlocks, the flux controller interlocks, and the primary block valve interlocks was demonstrated. (See II., parts C, D, F, and L, respectively.)
- f) Criterion: All plant control computing functions being performed to an accuracy of $\pm 1\%$ of full scale.
- Remarks: As noted in Criterion a), all computing devices were calibrated to within $\pm 1/2\%$ of full scale.
- g) Criterion: Correct initial values of proportional band, reset, and rate are set into all system controllers.
- Remarks: Correct initial values of proportional band, reset, time, rate time, and deadband were set on all plant control system controllers.

V. EVALUATION

The objective of preoperational test AI-P-1120 was to place each plant control subsystem into operation and to verify that each would operate as specified. This objective was fully accomplished.

In summary, the following was accomplished to assure compliance with test completion criteria:

- a) All plant control components were calibrated to within $\pm 1\%$ accuracy.
- b) All plant control components were correctly connected to their input and output devices.
- c) Response time of all subsystems was determined to be within five sec of the activating signal. For positive steps, most of the response times were two to three seconds. For negative steps, the response times were sometimes as long as four seconds. Some slower responses were encountered in the pneumatic control systems, because of the piping length involved in the transmission of pressure signals. These were cleared up by installing volume boosters where necessary.
- d) All subsystems respond to simulated inputs in a stable manner. The output of FR-502T mass steam flow transmitter oscillated because of a resonant condition set up in the transmission tubing leading to the pneumatic force balance square root converter. Addition of an eight cubic inch capacity pneumatic

volume chamber in this line corrected this condition and effected a stable response.

- e) All plant control interlocks were determined to function correctly.
- f) All plant control computing functions were found to be performing to an accuracy of $\pm 1\%$ of full scale.
- g) Correct initial values of proportional band, reset, and rate were set into all the system controllers.

Before this test was conducted, various analog studies of the plant control subsystems were made. From these analog studies the values were chosen for calibration accuracy, response time and proportional reset time. A one per cent calibration accuracy was selected as optimum because closer accuracy would have been more expensive and a wider range of accuracy, say five per cent, would entail excessive operator time in calibration and chart marking. The five sec response time was selected because a longer response time would nullify the results obtained from analog computer studies.

In spite of the fact that an AI resident engineer kept a close surveillance on the fabrication and installation of the various components of the subsystems, some discrepancies were encountered, as listed in the Appendix. These were corrected before the test was signed off as complete. A post-installation acceptance test would have probably saved much time in the conductance of this preoperational test.

Since completion of this test, jumpers have been installed to bypass the source indication interlock, the moderator coolant valves interlock, and the sodium valves open interlocks. These were necessary to permit execution of wet critical and wet excess loading tests and will be removed prior to power operation.

Readiness of the plant control system for actual power operation is now assured. Further testing of the plant control system will be accomplished during the rise to power, by placing each subsystem into operation at appropriate times and conducting performance tests as delineated in the post critical test procedure AI-PC-630, Plant Control System.

APPENDIX

PROBLEMS ENCOUNTERED AND CORRECTIVE ACTIONS

As noted in Part II of this report, various instrument problems and wiring and tubing errors were discovered and corrected during this test. The various problems, and corrective action taken, are detailed below:

1. PRC-501Ta and PRC-501Tb pressure transmitter connections to PRC-501 were reversed. That is, PRC-501Ta, which has a 0-1000 psig scale was reading on PRC-501's 750-900 scale; PRC-501Tb, which has a 750-900 psig scale, was reading on PRC-501's 0-1000 psig scale. This situation was corrected by interchanging the pneumatic tubing connections between PRC-501Ta and PRC-501Tb to PRC-501 at their main board bulkhead fittings.

2. The output of FR-502T mass steam flow transmitter was oscillating as shown by FR-502 recorder painting a band about $\pm 10\%$ around the correct (simulated) mass steam flow. The last computing instrument in FR-502T is a pneumatic force balance square root converter which is connected by 10 feet of 1/4 in. OD copper tubing to FR-502. This short length of copper tubing did not have sufficient capacity, consequently a "resonant" condition was set up and the square root converter did not force balance, but instead oscillated about the correct output. This condition was corrected by adding an eight cubic inch capacity pneumatic volume chamber to the pneumatic line.

3. The main board speed indicators (SI-101, -201, -301, -102, -202, and -302) were 0-125% scale, 0-75V dc voltmeters. This was not compatible with the 0-20V ac generated by the pump coupling tachometer-generator. The pump coupling control cabinet was furnished with a 0-900 rpm scale, 0-20V ac voltmeter. Consequently, the main board and coupling control cabinet speed indicators were interchanged, thus giving direct rpm readout at the main board. A circuit modification was made to the 0-75V dc voltmeter, to change its range to 0-20V ac, and the coupling control cabinet speed indicator now reads in percent of full speed.

4. The thermocouple to the pneumatic transducer in TRC-101T was not functioning. The problem was traced to a broken 6X4 vacuum tube. The vacuum tube was replaced.

5. The rate limiter in SCD-101 was found set at 40%/min. The 40%/min needle valve was closed, which should have reset the unit to 20%/min, however, the unit continued to operate at 40%/min. Investigation revealed a large chunk of dirt which was preventing the 40%/min needle valve from seating. The dirt was cleaned out of the needle valve seat; the unit then operated properly.

6. After this test was completed, and while pumping sodium, it was noted that when on manual speed control from HCS-102, -202, -302, -104, -204, or -304, a 10 rpm oscillation in pump rpm occurred. This oscillation was not present when operating from manual speed control at the coupling control cabinet. It was noted that the coupling is powered from critical control power, while the last amplifier in SCD-102, -202,

-302, -101, -201, and -301 is powered from noise-sensitive power. By changing the frequency of the noise-sensitive M-G sets, it was possible to change the period of pump oscillation. This problem has been corrected by changing the power feed to the last amplifier in SCD-102, -202, -302, -101, -201, and -301 to critical power.

7. Primary sodium pump No. 1 would not operate on speed demand from HCS-102. The problem was traced to an incorrectly wired condensor in SCD-101 current-to-voltage amplifier. The wiring was corrected and the unit then operated satisfactorily.

8. TI-3T, plenum thermocouple temperature-to-current converter calibrated properly using a simulated thermocouple source, but drove hard upscale when the grounded thermocouple was connected. The trouble was traced to a faulty solder connection between a capacitor lead and a printed circuit board. The solder joint was repaired and the unit functioned properly.

9. HCS-10 rate-limiter was not operating. The trouble was traced to a cracked printed circuit board. The printed circuit board was replaced and the unit functioned properly.

10. Deviation indicators for TRCp-1, TRC-2, and the flux controller continually burned out their indicator light bulbs. Investigation showed that the 115/6.3 V light bulb transformers were delivering 7.2 V. A series resistor was installed on the secondary side of the transformer, dropping voltage to 6.1 V. No light bulbs have burned out since this change was made.

11. TRC-2 controller was not functioning. Trouble was traced to an open capacitor. The capacitor was replaced.

12. When in manual control, it was observed that an abnormal amount of time was required to balance TRC-2 before bumpless transfer to automatic control could be made. Investigation revealed that an incorrect 1,000,000 ohm resistor had been installed in the controller feedback circuit. The proper 1000 ohm resistor was installed, and no further difficulty was experienced.

13. The power transformer in HCS-5 and HCS-6 burned out when the units were plugged in. The trouble was traced to an open diode. The diode and power transformer were replaced and the units were fused.

14. When all six throttle valves were being operated from either HCS-8 or TRC-4, it was observed that the time response of the system was extremely poor, i.e., the control system was slower than the valves. The problem was that the pneumatic signal was being sent through approximately 800 feet of 1/4 in. tubing. A 1:1 pneumatic volume booster was installed in the pneumatic tubing downstream of HCS-8; this eliminated the problem.

15. The interlock which allows all six throttle valves to drive at full speed following a scram was not functioning. The trouble was traced to relay K-79. The interlocks had been wired to the normally open instead of the normally closed contacts. Wiring was corrected and then the interlocks operated satisfactorily.

16. HCS-9, moderator valve hand control station, would not transfer from "Manual" to "Automatic". Trouble was traced to the tubing at a 3-way solenoid valve in HCS-9. The tubing connections were corrected and the unit then operated satisfactorily.

17. All evaporator level transmitters were found incorrectly connected to their equalizing columns. Connections were corrected.

18. The outputs of LRC-151T, -251T, -351T, LXL-150T, -250T, -350T, -151T, -251T, -351T, -152T, -252T, and -352T were oscillating

10%, about the correct output. Adding an eight cubic inch capacity pneumatic volume chamber to each output pneumatic line corrected the problem.

19. All evaporator low level scram pressure switches were wired to normally closed, instead of normally open, contacts. Wiring was corrected.