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Testing of CAN2A Shaft Seals for Station Blackout

Project Summary Report

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FIGURES

Section I

PURPOSE

This report summarizes the results of tests, sponsored by the Niagara Mohawk Power Corporation Research and Development Department, to assess the performance of the AECL CAN2A shaft seal under high-temperature conditions representative of those expected in a station-blackout event. The tests were made by AECL Research under the technical direction of MPR Associates, Inc. The CAN2A shaft seal is used in the reactor recirculation pumps at the Nine Mile Point Nuclear Station Unit 1 (NMP-1), owned by Niagara Mohawk Power Corporation. The specific purpose of the tests was to assess whether the CAN2A seal can be expected to operate with limited amounts of seal-face leakage during a station-blackout event.

Section II

BACKGROUND AND INTRODUCTION

A. STATION BLACKOUT

A station blackout is an event in which a power plant is electrically isolated from the off-site power grid in combination with unavailability of its on-site AC-power supplies (i.e., a loss-of-offsite power combined with failure of all the emergency diesel generators and trip of the main generator). Under these conditions, AC power is not available to power electrical equipment in the plant, and the plant is said to be blacked out.

The U.S. Nuclear Regulatory Commission has required (10 CFR 50.63) that all licensees under their jurisdiction demonstrate that their nuclear power plants can cope with a station blackout of plant-specific duration or provide a back-up source of AC power (i.e., an alternate AC-power source) in addition to the emergency on-site power sources already required by federal regulations.

B. STATION BLACKOUT AND SHAFT SEALS

For many plants, including NMP-1, a station-blackout event not mitigated by use of an alternate AC power source results in a loss of forced cooling to the shaft seals in the reactor recirculation pumps (BWRs) or reactor-coolant pumps (PWRs). Loss of forced cooling to the shaft seals for more than a few minutes can result in fluid temperatures in the shaft seals reaching values well in excess of normal operating temperatures and, in some cases, to values well beyond those considered in the design of the shaft seal. The U.S. Nuclear Regulatory Commission has identified the ability of shaft seals to withstand station-blackout conditions as a generic safety issue and has included it as part of GI-23, "Reactor Coolant Pump Seal Failure."

The principal concern for shaft seals under station-blackout conditions is their ability to limit leakage of reactor coolant through the seal faces of the shaft seal. Seal leakage rates must be limited to values that maintain sufficient reactor-coolant inventory to cool the reactor core during the station-blackout event. Hence, knowledge of the leakage performance of a shaft seal when subject to station-blackout conditions is the key to resolving the station-blackout concerns related to shaft seals.

Guidance for evaluating the capability of nuclear power plants to cope with a station blackout has been developed by the U.S. Nuclear Regulatory Commission (Regulatory Guide 1.155) and by industry through the Nuclear Management and Resources Council (NUMARC 87-00). The industry and the U.S. Nuclear Regulatory Commission have

agreed that, absent specific knowledge about the high-temperature performance of a shaft-seal design, station-blackout evaluations may use a 25 gpm leakage rate per pump for PWRs and 18 gpm per pump for BWRs. This agreement was made with the specific acknowledgement that the assumed leakage rates may be changed when Generic Issue 23, Reactor Coolant Pump Shaft Seal Failures, is resolved.

C. NMPC APPROACH TO STATION BLACKOUT AT NMP-1

Niagara Mohawk has elected to demonstrate the ability of NMP-1 to cope with station blackout. The plant-specific coping duration for NMP-1 has been determined to be four hours. A brief summary of the expected course of the station-blackout event is provided below.

NMP-1 is one of a small group of boiling-water reactors equipped with emergency condensers for cooling of the reactor core under emergency conditions. Figure II-1 shows a simplified schematic of the emergency condenser system at NMP-1. The emergency condensers draw steam from the reactor vessel and return it as condensate. Natural circulation drives the flow between the reactor vessel and the emergency condensers. The reactor steam is condensed by a gravity-driven flow of water to the shell side of the emergency condenser. This shell-side water boils, and the steam is vented to the atmosphere. This system is independent of AC power and will be actuated, without operator action, shortly after the start of a station-blackout event.

The reactor-coolant system is cooled and depressurized by the emergency condenser system. Figure II-2 shows the reactor coolant system pressure transient for an eight-hour emergency-condenser cooldown of the reactor. The pressure decreases as the decay-heat generation rate by the reactor core decreases below the heat-removal capability of the emergency condensers, allowing the emergency condensers to begin lowering the reactor-coolant temperature.

The emergency condenser system is a closed-loop system on the reactor side: the reactor coolant condensed by the emergency condensers is returned to the reactor vessel. Provided that other sources of leakage from the reactor-coolant system are limited, an adequate reactor-coolant system inventory will be maintained and the reactor core will remain cooled during the event.

The shaft seals in the five reactor recirculation pumps are a potential source of leakage from the reactor coolant system. Use of the NUMARC/USNRC interim assumption of 18 gpm per pump was considered and rejected because:

- There did not appear to be a technical basis for generic applicability of this assumed value due to variations in seal designs and reactor coolant system responses to station blackout.

- The likelihood of the 18 gpm interim value remaining unchanged as a generically applicable upper bound on seal leakage during station blackout was considered to be unlikely. A change may be made when USNRC resolves GI-23.

- NMPC R&D sponsored development of the CAN2A shaft seal design used in the reactor recirculation pumps. Available knowledge of the seal design indicated that there was a good chance that the seal leakage could be shown to be less than 18 gpm.

Accordingly, the NMP-1 station-blackout evaluation was based on an assumption of limited leakage from the shaft seals in the recirculation pumps. It was recognized that testing of the seal design would be necessary to verify this assumption. A commitment to make seal tests was included as part of the submittal by NMPC to the U.S. Nuclear Regulatory Commission regarding the station-blackout evaluation of NMP-1.

D. DEVELOPMENT HISTORY OF THE CAN2A SHAFT SEAL

The CAN2A shaft-seal design used in the reactor recirculation pumps at NMP-1 was developed under Niagara Mohawk Research and Development (R&D) contracts with AECL Research and MPR Associates. The seal was developed with the objective of providing a reliable, long-life shaft seal for the recirculation pumps. The seal design was developed in 1983-1986, installed at NMP-1 on a prototype basis in 1986, and adopted as the reference seal design in 1988.

The seal development effort was a methodical, multi-step process. The major steps were:

- testing and analysis of the original seal design under realistic steady-state and transient conditions to establish the reasons for its undesirable operating features;

- development of an improved seal design with the aid of advanced analytical techniques and characteristic testing; and,

- long-term (6000 hours) testing, including several years worth of normal operating transients, to confirm the design.

The resulting CAN2A seal is a robust design which exhibits low wear during steady-state and transient operation and is relatively insensitive to normal changes in reactor coolant system pressure and seal cooling water temperature.

The capability to withstand a station blackout was not an explicit functional requirement for the seal. However, design requirements were included which were intended to make the seal resistant to high temperature. Specifically:

- The elastomers selected were considered likely to have good high-temperature performance.

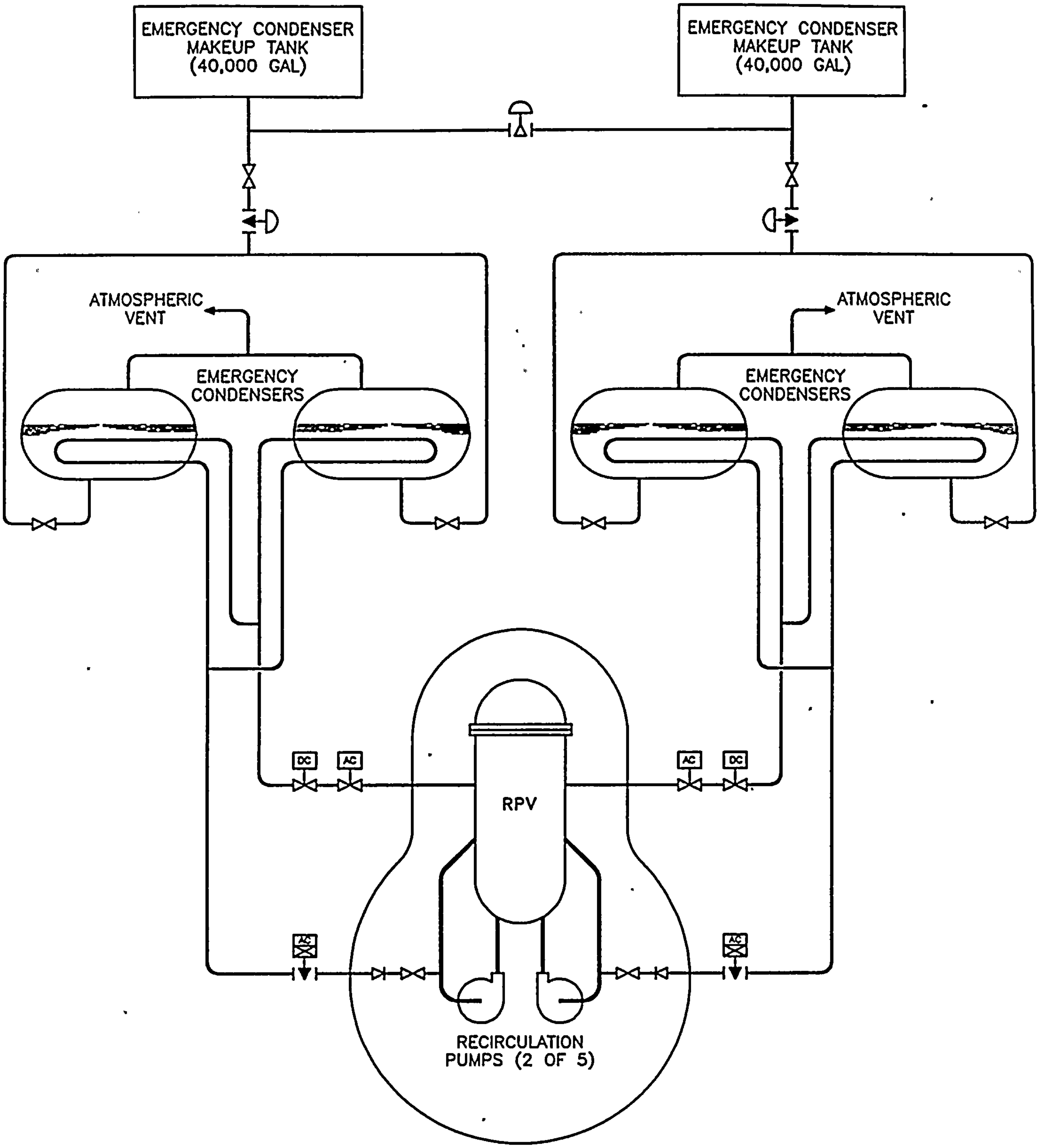
- The design clearances and tolerances are such that interference will not occur at high temperatures in locations where clearances are needed for proper operation.

- Non-sliding joints sealed by elastomers are metal-to-metal designs, to be highly extrusion resistant.

- Sliding joints sealed by elastomers are such that excessive extrusion gaps do not occur at high temperature.

- Seal parts are designed such that high temperatures do not cause temperature-induced deflections of the seal faces in the direction which increases seal leakage.

No testing of the CAN2A seal under station blackout conditions was carried out as part of the original development effort. However, the advent of the Station-Blackout Rule (10 CFR 50.63) has resulted in intensive research interest in the performance of shaft seals at high temperature. Further, the station-blackout evaluation of NMP-1 indicated that knowledge of the high-temperature performance of the CAN2A seal would be beneficial. Accordingly, a research project to understand the high-temperature performance of the CAN2A seal was initiated by Niagara Mohawk R&D.



NINE MILE POINT UNIT. ONE
EMERGENCY COOLING SYSTEM
SIMPLIFIED DIAGRAM
FIGURE II-1

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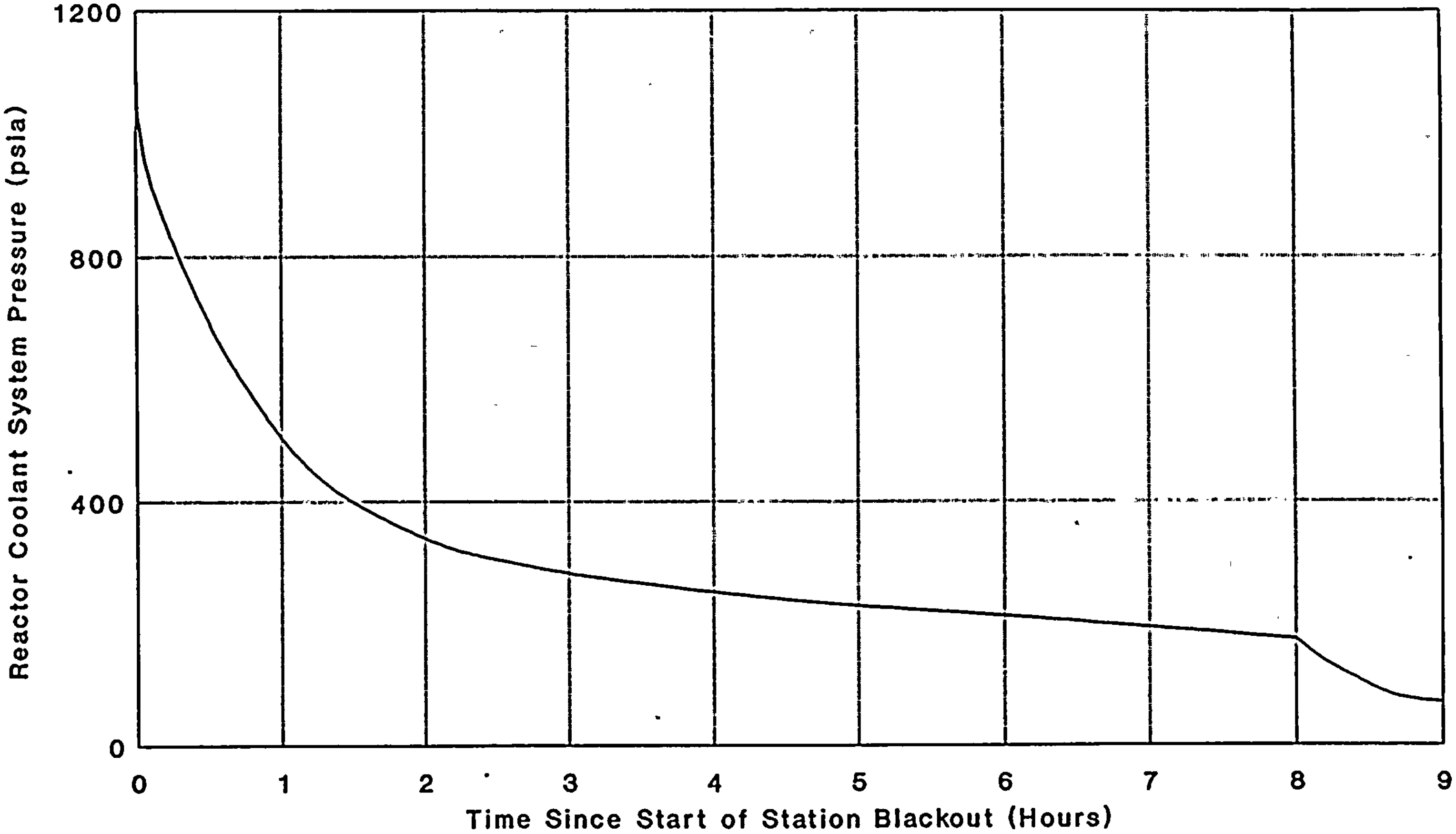


NINE MILE POINT STATION UNIT ONE
REACTOR PRESSURE TRANSIENT
WITH ONE EMERGENCY CONDENSER LOOP

FIGURE II-2

Section III

SUMMARY OF RESULTS AND CONCLUSIONS

A. RESULTS

A test program has been carried out to assess the station-blackout performance of the CAN2A shaft seal design used in the reactor recirculation pumps at Nine Mile Point Unit One (NMP-1). The test program was divided into two phases. Phase I involved preliminary, separate-effects testing to assess critical aspects of seal performance prior to conducting full-scale seal-cartridge testing. Phase II consisted of a set of tests of full-scale seal cartridges under the station-blackout conditions predicted for NMP-1.

The Phase I testing considered high-temperature elastomer performance and shaft-seal stability under two-phase fluid conditions. The results of Phase I indicated that the elastomer performance and two-phase stability of the CAN2A seal were sufficient to justify proceeding to testing of full-scale CAN2A seal cartridges under station blackout conditions.

The Phase II testing included nine tests of CAN2A seal cartridges under NMP-1 station-blackout conditions. The full-scale tests covered a range of seal wear conditions and initial (pre-blackout) seal leakage rates as much as three times the leakage rates observed for CAN2A seals in operation. The peak leak rates measured from the No. 2 seals during the station blackout transients were less than 0.5 gpm. For all the tests, the total volume of No. 2 seal leakage during the nine-hour test duration did not exceed 40 gallons. The plant-specific coping time for NMP-1 is four hours.

B. CONCLUSIONS

The tests performed indicate that leakage from normally operating CAN2A shaft seals subjected to the expected NMP-1 station-blackout conditions will be quite low.

The tests performed in Phase II of this test program provide a basis to conclude that seal leakage from a normally operating CAN2A shaft seal will not be a concern for a station blackout at NMP-1.

Section IV

HIGH-TEMPERATURE TEST PROGRAM FOR THE CAN2A SEAL

A. CRITICAL FACTORS AND TEST PROGRAM STRUCTURE

The following critical factors were identified for consideration in the test program:

- Elastomer extrusion and friction at high temperatures.
- Stability of the individual shaft-seal stages to high-temperature, two-phase flow in the sealing gap.
- Reactor-coolant system pressure-temperature transient during a station blackout.
- Temperature and pressure conditions at the seal inlet during a station blackout.
- Ability of the seal to withstand axial motion and slow rotation of the pump shaft during the station-blackout transient.
- Sensitivity of seal performance during station blackout to the initial leakage rate from the seal faces.
- Sensitivity of the seal performance to wear of the seal faces.
- Sensitivity of the seal performance to the natural-circulation conditions in the shell of the seal cooler.

The elastomer performance and the seal stability with two-phase fluid conditions in the sealing gap were identified as especially important factors for a successful seal design. Since simple, relatively inexpensive tests could be made to assess these factors before proceeding to the more expensive, multi-hour tests of full-scale seal cartridges, the test program was structured into two phases. Phase I included high-temperature elastomer testing and short-term seal stability testing. Phase II included a series of full-scale tests of CAN2A seal cartridges under the expected NMP-1 station-blackout conditions. These tests were made in a test rig, constructed for the purpose, which included the major features of a recirculation pump cover and stuffing box. Each phase of the test program is discussed below.

B. PHASE I TEST PROGRAM

Phase I of the CAN2A test program includes two sets of tests: testing to characterize the extrusion and friction characteristics of the elastomers at high temperatures, and tests of single stages of the CAN2A seal to assess stability under two-phase fluid conditions.

B.1 Elastomer Extrusion and Friction Testing

The elastomer extrusion testing involved testing of full-size U-cup seals at high temperature and pressure. Pressure and temperature conditions were varied up to normal reactor coolant conditions (approximately 1050 psig, 550°F) and for as long as 16 hours. Both the No. 1 U-cup and No. 2 U-cup elastomer materials were tested. The results indicated that neither material was susceptible to extrusion. The No. 1 U-cup material (EPDM) exhibited no detectable material degradation. The No. 2 U-cup material (Nitrile) exhibited some hardening and cracking at high temperatures but performed acceptably in the tests. These results were judged acceptable for proceeding to full-scale seal-cartridge testing.

The elastomer friction tests were made on reduced-diameter U-cups having full-scale cross-sections. Friction tests were performed at normal operating temperatures and at high temperatures with the U-cup subjected to pressure as it is in service. The results of these tests indicate that somewhat higher U-cup friction force could be expected at high temperature than at low temperature, but the increase was within a range likely to be acceptable for seal operation. These results were judged acceptable for proceeding to full-scale seal-cartridge testing.

B.2 Single-Stage Seal-Stability Testing

The stability characteristics of both CAN2A seal stages were evaluated by testing over a range of inlet pressures and inlet subcooling with a range of initial seal-gap tapers covering variations expected between newly installed and heavily-worn seal faces.

Tests were made of a CAN2A No. 2 seal stage and a CAN2A No. 2 seal stage modified to provide performance characteristics similar to a CAN2A No. 1 seal stage. A CAN2A No. 1 seal stage could not be tested because the test rig was sized to accept only seals having the diameter of the CAN2A No. 2 seal; the No. 1 seal is slightly larger in diameter.

The results of the single-stage testing indicate that the simulated CAN2A No. 1 seal stage is very stable. The CAN2A No. 2 seal stage was also found to be stable under the expected station-blackout conditions, but with a smaller stability margin than the CAN2A No. 1 seal stage. The results of these tests indicated that the seals should be stable during a station-blackout event, and hence, proceeding to full-scale, multi-hour testing of CAN2A seal cartridges was justified.

C. PHASE II TEST PROGRAM

Phase II of the CAN2A test program consisted of nine tests of full-scale CAN2A seal cartridges under station-blackout conditions. This section of the report summarizes the bases for the tests, the tests performed, and their results.

C.1 Reactor Coolant System Transient

The expected station-blackout transient for NMP-1 is discussed in Section II.C of this report, and the reactor coolant system pressure transient is shown in Figure II-2. The duration of the transient tested is nine hours. This includes an eight-hour emergency condenser cooldown with an additional hour of depressurization. This is well in excess of the required four-hour station-blackout duration for NMP-1. For purposes of the station-blackout evaluation, only the first four hours would be required to be considered. However, the testing was extended to include the entire transient for the following reasons:

- Testing beyond the required four hours would show that seal performance is not very sensitive to the duration of a station blackout.

- The RCS transient was available, and extending the tests did not have a significant extra cost. The results would continue to provide a basis for qualifying the seals if future events result in the blackout coping duration for NMP-1 being increased from the current four hours to eight hours.

The fluid at the exit of the reactor core is a saturated mixture of steam and water. The recirculation loops will have some water flow due to the natural circulation action of the reactor core. Some subcooling may be present in the reactor recirculation pump casings due to heat loss from the recirculation piping and, in the case of the recirculation pumps whose inlet piping accepts the discharge from the emergency condensers, due to the return flow from the emergency condensers. However, in this test program, no subcooling in the recirculation system was credited; the conditions in the pump casing were assumed to be saturated water at the pressure of the reactor-coolant system, conservatively neglecting any subcooling present.

C.2 Pressure and Temperature Conditions at Seal Inlet

The seal cartridge in an NMP-1 reactor recirculation pump is always subject to reactor coolant system pressure. The temperatures in the seal cartridge during a station blackout are above those seen during normal operation, but significantly less than the temperature of the reactor coolant present in the pump casing. The seal cooler and its heat sink, the closed-loop cooling (CLC) system, are capable of limited seal cooling in the absence of forced circulation flow. A discussion of seal-cooler performance under both normal and station-blackout conditions is provided in Appendix A.

Scoping calculations indicated that seal temperatures would likely be in the range of 300-350°F. However, the complications of trying to accurately predict the seal cooler performance by analysis in the absence of prior knowledge of the seal leakage rate and the complications of developing a control scheme to implement the results of such an analysis in a test led to a decision to test a seal cartridge installed in a pump cover assembly attached to a CLC system. With this arrangement, the test control is limited to providing saturated water to the underside of the pump cover at the pressure defined by the reactor coolant system transient, and the seal cavity temperatures are determined as dependent variables of the station-blackout tests instead of being independently controlled inputs.

C.3 Motion of Pump Shaft During Blackout Transient

The shafts of the reactor recirculation pumps are subject to axial motion. This motion occurs as a result of such factors as flexure of the pump and motor structure (notably the thrust-bearing support) due to changes in system pressure and thrust load, travel through the end-play of the thrust bearing, and differential expansion. Hence, the shaft seal must be able to tolerate axial shaft motion.

Axial shaft motion is of particular interest during station blackout because the results of the elastomer friction tests in Phase I of the program indicated U-cup friction could be expected to be higher at high temperatures that at low temperatures. The shaft was periodically cycled during blackout testing 0.060 inch in either direction from the normal axial position. This was done to demonstrate that the seal will tolerate large axial motions.

Slow rotation of the pump shaft may occur during a station-blackout event. There is a natural circulation flow through the recirculation system induced by boiling in the reactor core. As the reactor coolant system pressure is reduced, the thrust bearing in the pump bearing becomes more lightly loaded and may shift from the upper shoes to the lower shoes of the thrust bearing. At some point, the flow in the recirculation system may cause the pump shaft to slowly rotate. Accordingly, the ability to tolerate slow rotation was demonstrated in the station blackout tests of the CAN2A seal.

C.4 Seal Cartridge Tests Performed

A total of nine seal cartridge tests were made as part of this seal test program. Two parameters were the principal variables from test-to-test: seal-face wear, and initial seal leakage rate. Three seal-face wear conditions were considered:

- Seal faces in newly installed condition. (Test 1)
- Seal faces with 6000 hours of operation from the CAN2A development test (Section II.D). (Tests 7 & 8)

- Seal faces cut down to simulate wear of about 10 times that seen in the CAN2A development test and in the first NMP-1 prototype. (Tests 2, 3, 4, 6, 9, 10)

Initial seal leakage rates (i.e., the No. 2 seal-face leakage at normal operating pressure and temperature prior to start of the station blackout) were varied over a range from no detectable leakage to about three times the seal leakages observed in the development test and in-service with the prototype. The tests are as follows:

Test 1 -- New, unworn seals with faces lapped to specifications for a newly installed seal.

Test 2 -- Seal faces were "worn down" about 10 times expected wear. Faces were lapped to the expected condition of seals having long operation (based on inspection of the 6000-hour seals).

Test 3 -- Same as Test 2 except the seal faces were lapped to cause the seal to leak more than a seal in service would be expected to leak.

Test 4 -- Same as Test 3 except the seal faces were lapped to cause still higher leak rate.

Test 5 -- Test of 6000-hour seals with faces in the as-run condition. Test was aborted a few minutes into the transient because of a mechanical failure in the test rig. (The seal worked as expected and was not damaged.)

Test 6 -- Seals with the same seal-face configuration as Test 4. It was made as a check of the repairs to the test rig after Test 5.

Test 7 -- Test of the 6000-hour seals with faces in the as-run condition. This is the test aborted in Test 5.

Test 8 -- A second test of the 6000-hour seals without refurbishment of the seal after Test 7.

Test 9 -- Same seal configuration as Test 2. However, the seal cooler outlet to the CLC system was isolated with a block valve to assess the effect of interrupting natural circulation through the seal cooler.

Test 10 -- Same as Test 4 except that the seal faces were lapped to cause seal leakage higher than that obtained in the previous tests.

A brief description of the test apparatus used to conduct these tests is provided in Appendix B.

C.5 Test Results

The leakage from the seal faces of the No. 2 seal stage is the result of primary interest from the station blackout tests. Two measures of leakage are of interest: the maximum leak rate during a test, and the total volume of leakage from the seal over the course of the test. The maximum leak rate during a test is of interest because comparisons from test-to-test provide a good assessment of the consistency of seal performance. The total volume of leakage is of interest because it defines the loss of reactor coolant system inventory through the seal faces, and loss of reactor coolant system inventory is the principal concern for shaft seals during a station blackout.

The maximum leakage rates measured during each of the nine tests are plotted in Figure IV-1 as a function of the leakage rate from the seal when tested at low temperature and normal operating pressure before the station blackout test. Each seal test showed a similar trend: the seal leakage rate increased to a maximum value early in the transient as the seal heats up, and then declines as the reactor system pressure decreases with time. The following should be noted in Figure IV-1:

- The maximum leak rates from the seal are small in magnitude and vary with initial cold leak rate with a consistent trend.

- The results are repeatable. Tests 7 and 8 and Tests 4 and 6 are pairs of tests having nominally the same test parameters. Similar results were obtained from the pairs.

- Reduction in the seal-face height, simulating wear, did not have a significant effect on leakage. Test 2 is similar to Tests 7 and 8, except that Test 2 had its seal faces cut down to simulate wear about ten times that seen in operation.

- The range of initial cold leakage rates considered in the test program exceeds the range of leakage rates observed from operating CAN2A seals.

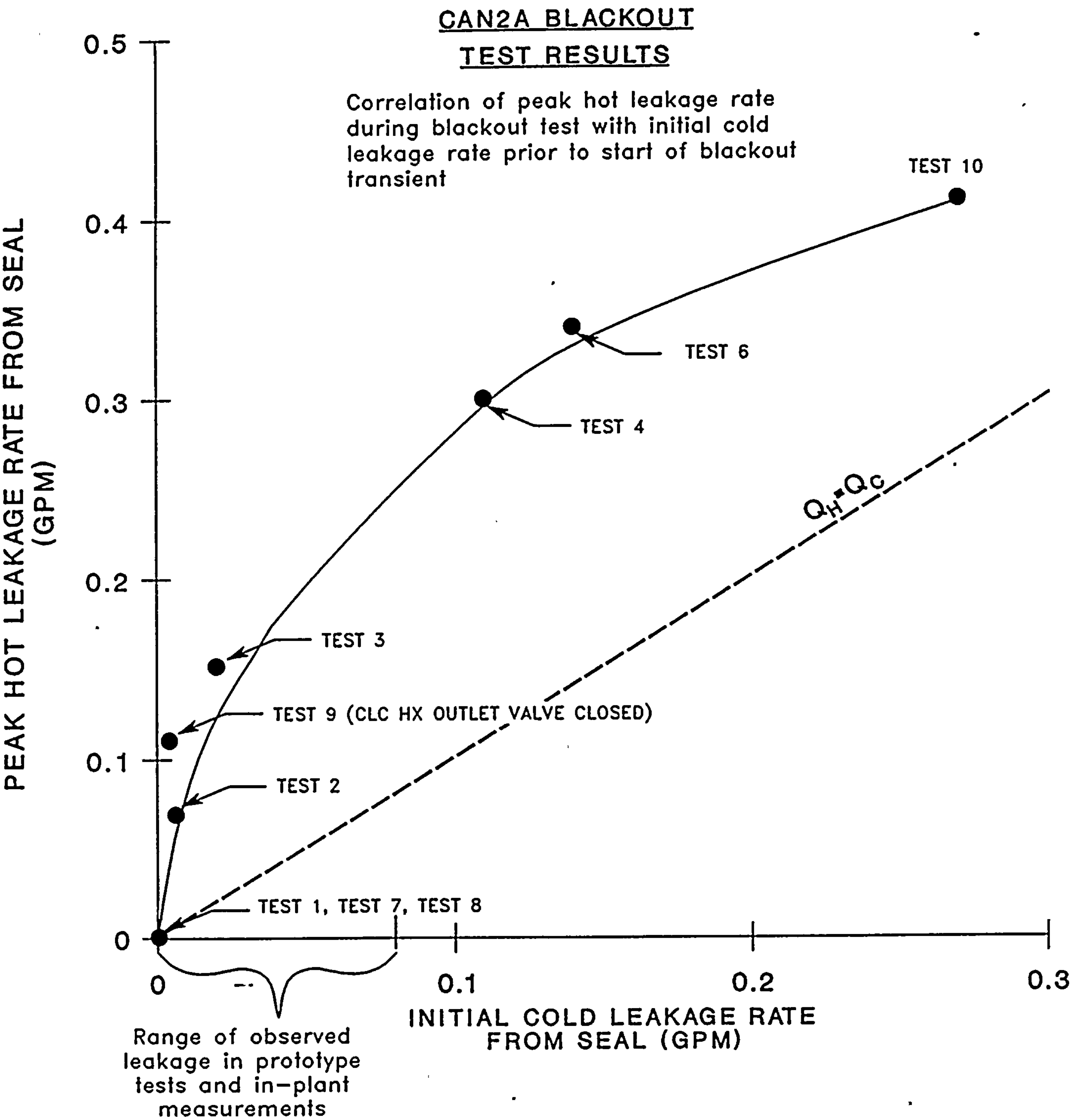
The total volume of No. 2 seal leakage measured during each of the nine tests is plotted in Figure IV-2 as a function of the initial leak rate from the seal at normal operating pressure and low temperature. The leakages in all cases are very low. The maximum volume of leakage occurred in Test 10, which had an initial leakage rate of about three times that seen in operating CAN2A seals. The leakage measured in Test 10 was about 40 gallons over the nine-hour blackout transient; this corresponds to an average leak rate of less than 0.1 gpm.

C.6 Variations in Seal-Cooler Natural Circulation

The presence of natural-circulation cooling in the seal cooler during a station blackout has a significant effect on the seal-inlet condition, as is discussed in Section IV.C.2 and Appendix A to this report. The effect on seal performance of variations in net natural-circulation flow through the shell side of the cooler was an uncertainty considered

important to assess. This assessment was made by isolating the outlet of the shell side of the seal cooler from the CLC system for one test (Test 9).

With the isolation valve closed, no net natural circulation flow through the seal cooler was possible. The seal cooler continued to cool by counter current flow through the inlet to the shell. The peak seal inlet temperatures increased by about 40°F compared with tests having the outlet valve open. The seal leakage increased slightly, but not significantly, as can be seen in Figures IV-1 and IV-2. Hence, variations in natural-circulation flow, even to the point of complete isolation of the outlet of the seal cooler, do not have a significant effect on seal leakage.



PEAK HOT LEAKAGE RATE FROM SEAL (GPM)

FIGURE IV-1

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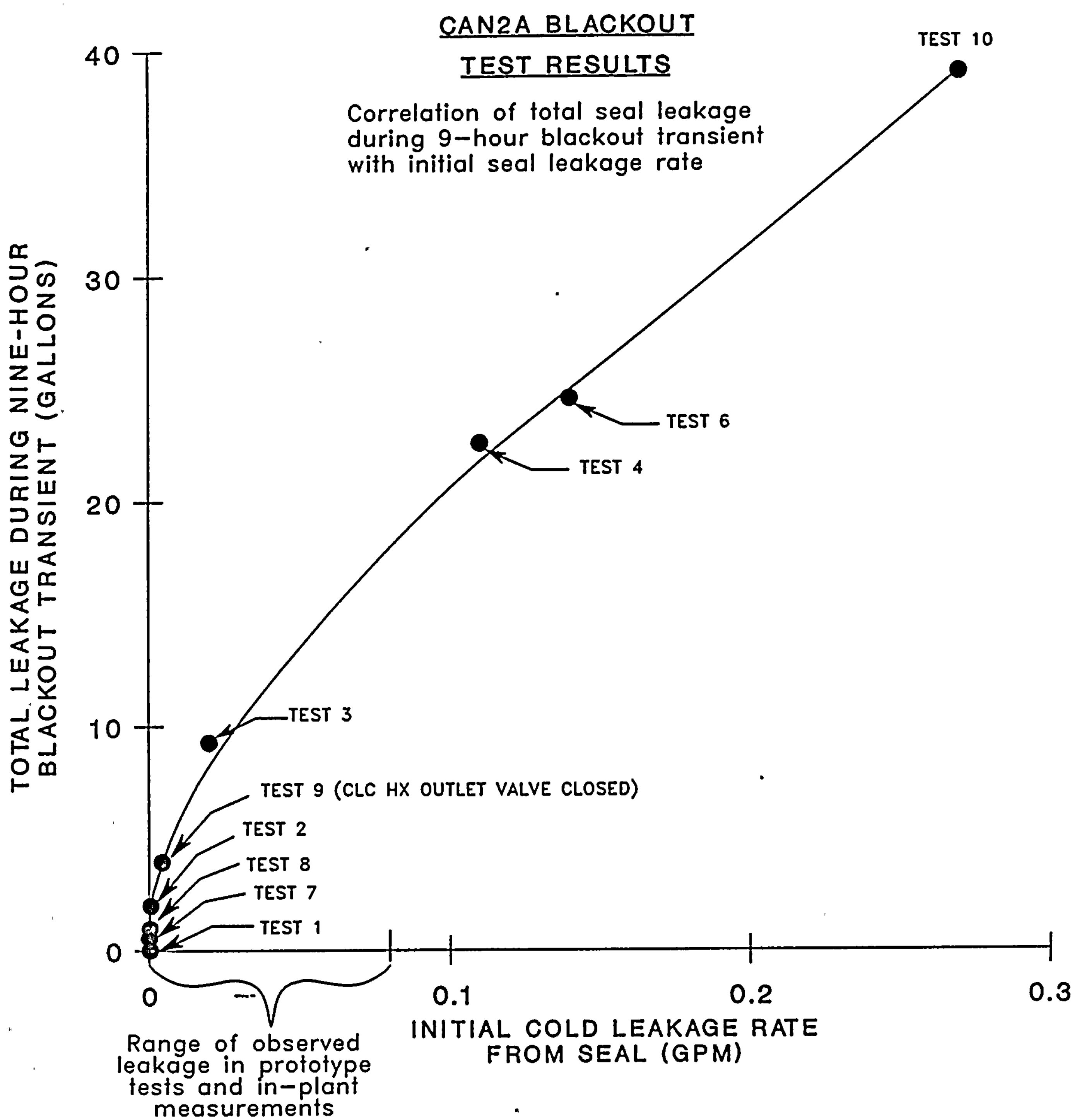

TOTAL SEAL LEAKAGE
DURING NINE-HOUR BLACKOUT TRANSIENT

FIGURE IV-2

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APPENDIX A

SEAL INLET CONDITIONS DURING A STATION BLACKOUT

An understanding of the methods of cooling the shaft seals under normal conditions is a prerequisite to understanding the seal-inlet conditions expected during a station blackout event. Accordingly, a discussion of normal cooling will precede the discussion of the seal-inlet conditions expected during a station blackout.

1. SEAL COOLING DURING NORMAL OPERATION

During normal operation, the shaft seal is protected from the high-temperature reactor coolant by the seal cooler. The seal cooler, shown in Figure A-1, is a heat exchanger consisting of two helical coils which uses the closed-loop cooling (CLC) system as a heat sink. The function of each of the helical coils is discussed in the following paragraphs.

The seal recirculation impeller, which is attached to the pump shaft, circulates water down through the radial bearing assembly and into the inlet to the outer coil of the seal cooler. The water from the outlet of the outer coil flows down along the outside of the seal cartridge and returns to the seal recirculation impeller. This recirculating loop supplies cool water, at the reactor coolant system pressure, to the inlet of the No. 1 seal. The only net inflow of hot reactor coolant into this loop is that required to make up the small amount of leakage through the seal faces of the No. 1 seal. This small amount of hot water mixes with the recirculating flow after the recirculating flow passes downward through the radial bearing assembly.

The staging flow of about 0.8 gpm, which causes the two stages of the seal to split the system pressure between them, is not drawn from the inlet to the No. 1 seal. The staging flow is drawn from near the bottom of the pump cover, at the top of the pump impeller (see Figure A-1). The staging flow first passes upward through the inner coil of the seal cooler, where it is cooled. After leaving the seal cooler, the flow passes through the No. 1 pressure-breakdown device and into the No. 2 seal cavity. This provides cool water, at about one-half the reactor coolant system pressure, to the inlets of the No. 2 seal and the No. 2 pressure-breakdown device.

The closed-loop cooling (CLC) water system is the heat sink for the seal cooler. The CLC flow, provided from an inlet header common to all five recirculation pumps, enters the shell side of the seal cooler above the outer coil and flows downward along the outside of the outer coil. The CLC flow then flows upward along the outside of the inner coil of the heat exchanger and through the seal-barrel cooling groove. Finally, the

CLC flow exits from the top of the seal cooler and goes to an outlet header common to all five pumps.

2. SEAL COOLER PERFORMANCE DURING STATION BLACKOUT

In the event of a station blackout, the forced flow of CLC water to the shell side of the seal cooler will cease since power will be lost to the CLC system pumps. The seal recirculation impeller will no longer force-circulate water through the outer coil of the seal cooler since AC power to the reactor recirculation pumps will be lost as well. This will degrade, but will not eliminate, cooling of the seal by the seal cooler.

The staging flow through the inner coil of the seal cooler will continue during a station blackout since it is driven by reactor coolant system pressure. It will be cooled by the CLC water surrounding the inner coil of the seal cooler. This CLC water is at a relatively low pressure and will boil. The boiling will induce water to flow through the shell side of the seal cooler from the CLC inlet header to the outlet header.

The low pressure in the shell side of the seal cooler and the availability of water to the seal coolers during a station blackout arise from the design of the CLC system and the location of the reactor recirculation pumps. Figure A-2 is a simplified isometric of the CLC system at NMP-1. The reactor recirculation pumps are at a low elevation in the plant. Because the CLC system is open to atmosphere, the pressure in the shell side of the seal coolers is determined by the gravity head of water in the CLC system when the CLC pumps are not in service.

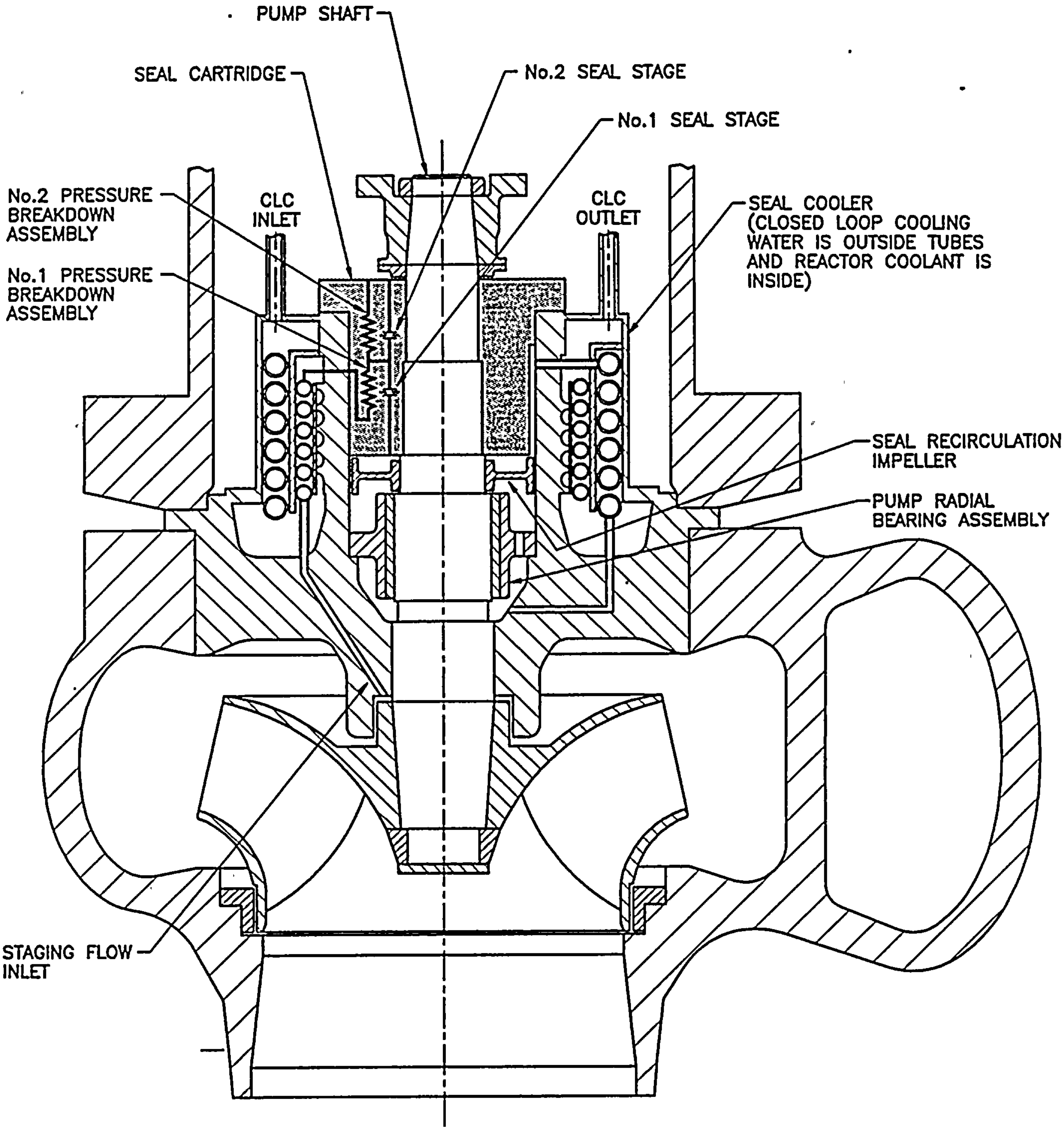
The maximum gravity head in the system would occur if the CLC system were filled to the top of the funnel drain above the CLC make-up tank. The resulting head is about 145 feet between the funnel drain and the seal coolers. This corresponds to a pressure of about 75 psia in the seal cooler.

The 75 psia pressure on the shell side of the seal cooler limits the temperature on the shell side to about 310°F, the saturation temperature. The large surface area of the inner coil of the seal cooler and the relatively low staging flow rate in the inner coil result in the temperature of the staging flow at the exit of the inner coil being near the temperature of the CLC water, and well below the temperature of the reactor coolant system. This water will flow through the No. 1 pressure breakdown device to the inlet of the No. 2 seal. Hence, even under station-blackout conditions, the seal cooler can be expected to have a significant cooling effect for the No.2 seal, and limit temperatures at the No. 2 seal to values in the range of 300-350°F.

No forced circulation occurs in the outer coil of the seal cooler during a station blackout since the reactor recirculation pumps are not operating. However, some natural circulation will occur on both the inside and outside of the outer coil, providing some cooling of the fluid at the inlet to the No. 1 seal. The precise temperature of the fluid is not known, but a temperature close to that of the CLC water on the shell side of the seal cooler is expected. (Note: this was found to be correct when the tests were made.)

3. DEFINING SEAL-INLET CONDITIONS

The accurate prediction of the seal temperatures requires a priori knowledge of the seal leakage rates under station blackout conditions. Further, a scheme to control a seal cartridge test in accordance with such predictions would be complicated. The best course of action is to test a seal cartridge installed in a pump cover attached to a closed-loop cooling system. In this way, test control is limited to providing water to the underside of the pump cover at a temperature and pressure representative of the reactor coolant system conditions during a station blackout. The seal inlet conditions are then established as one of the results of the station-blackout tests instead of being inputs. Appendix B provides a brief description of the test facility assembled for this test.



NINE MILE POINT UNIT ONE
REACTOR RECIRCULATION PUMP
SIMPLIFIED SKETCH
FIGURE A-1

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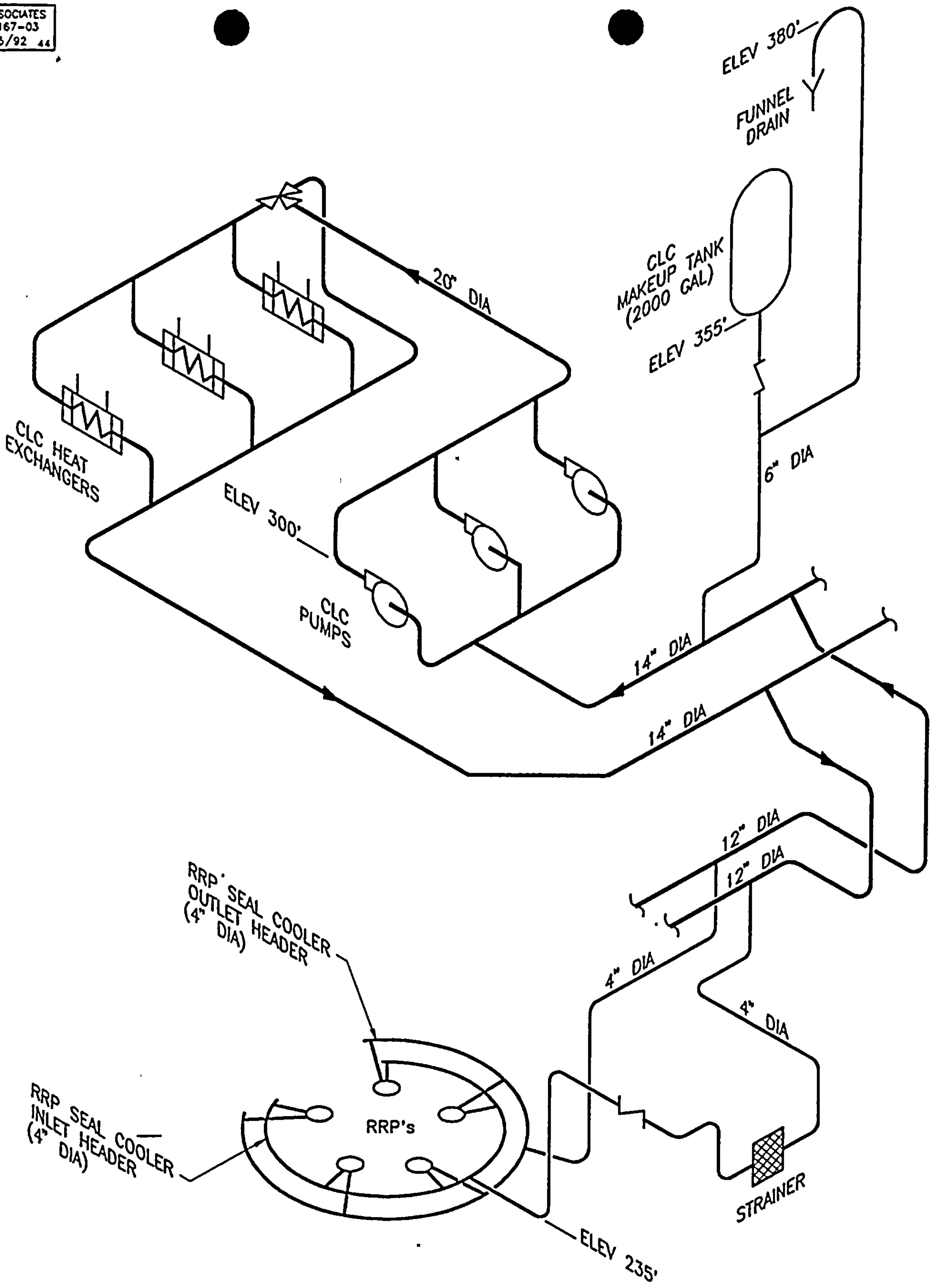


NINE MILE POINT UNIT ONE
CLOSED-LOOP COOLING WATER SYSTEM
SIMPLIFIED ISOMETRIC
FIGURE A-2

APPENDIX B

DESCRIPTION OF SEAL TEST FACILITY

1. SEAL TEST FACILITY

A test rig for full-scale seal cartridge testing was constructed by AECL. It consisted of a full-scale pump-cover model with a hemispherical head welded to the underside and a shaft positioning mechanism provided above and below the rig. A sketch of the test rig is provided in Figure B-1.

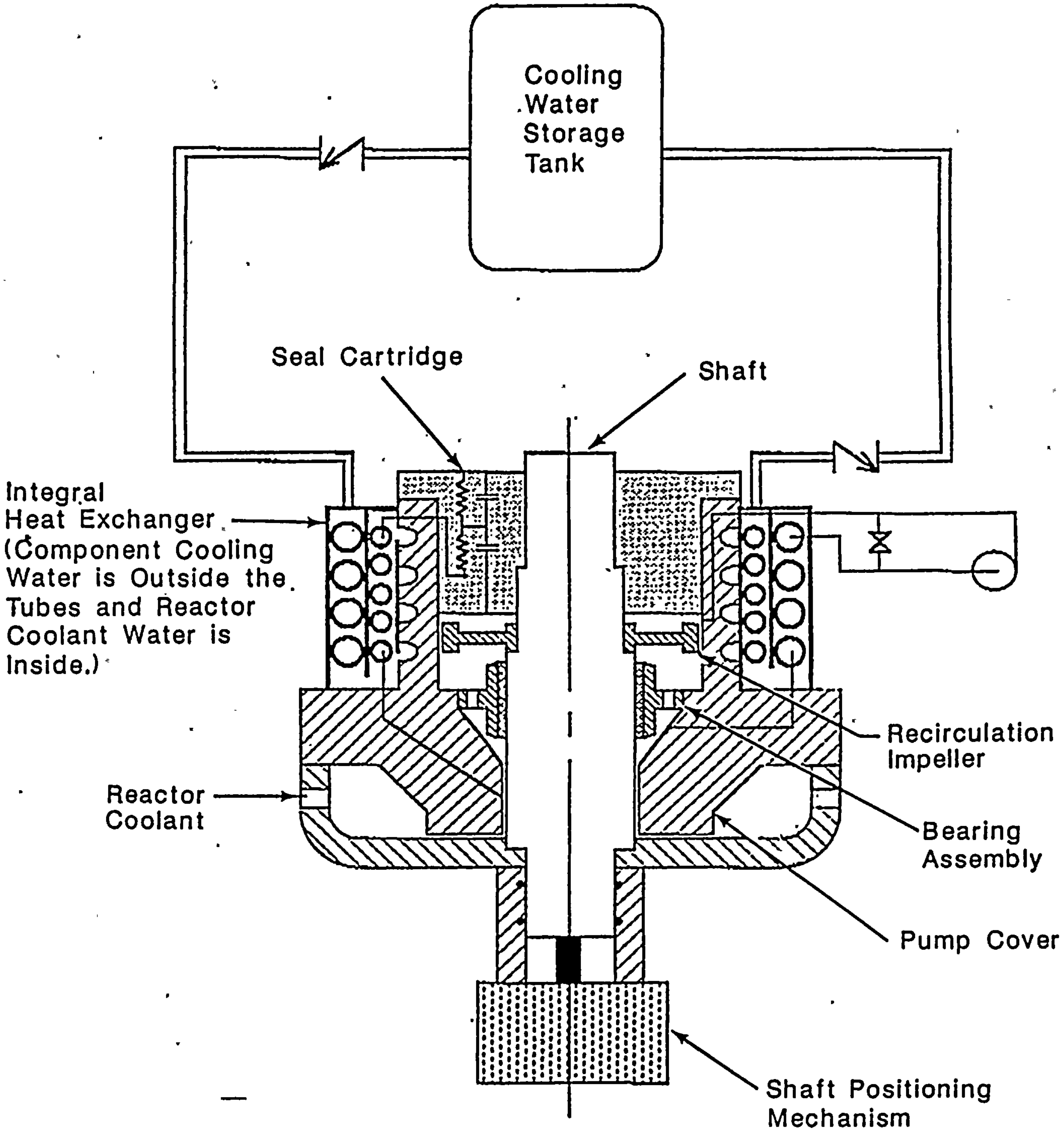
The test rig was provided with saturated water from the AECL high-temperature test loop. The test loop, shown in Figure B-2, circulated flow through the hemispherical head of the test rig and provided makeup for leakage from the seal cartridge.

The leakage from the shaft seal was measured. The seal staging flow and the leakage from the faces of the No. 2 seal were collected separately and measured. A condensing collector was used to capture and measure both steam and water leakage.

A closed-loop cooling system was connected to the test rig. The system model is shown in Figure B-3. Isometric drawings of the NMP-1 CLC system were used to provide a realistic configuration of the piping connecting the seal cooler to the CLC headers. Approximately, one-fifth of the length of the inlet and outlet headers were included in the test system. The full height of the CLC system (about 145 feet) was not included in the design. The test system height is about 10 feet. An elevated tank with a nitrogen pressurization system provides the overpressure needed to account for the additional gravity head present in the NMP-1 system. The nitrogen pressurization system has accumulators and a feed-and-bleed pressure regulator to maintain constant overpressure as water volume and gas temperature change.

2. TEST PROCEDURE

The test rig, test loop, and CLC system are designed to provide active cooling representative of normal seal operation prior to the start of the blackout transient. When the test loop conditions are stable at normal reactor coolant system pressure and temperature, the blackout transient is started. Active circulation of water in the CLC system is stopped, active cooling of the CLC head tank is stopped, active circulation of water in the outer coil of the seal cooler is stopped, and the test loop is controlled to follow the reactor coolant system transient described in Section IV.C.1 of this report.



FULL SCALE CAN2A CARTRIDGE
TEST RIG

FIGURE B-1

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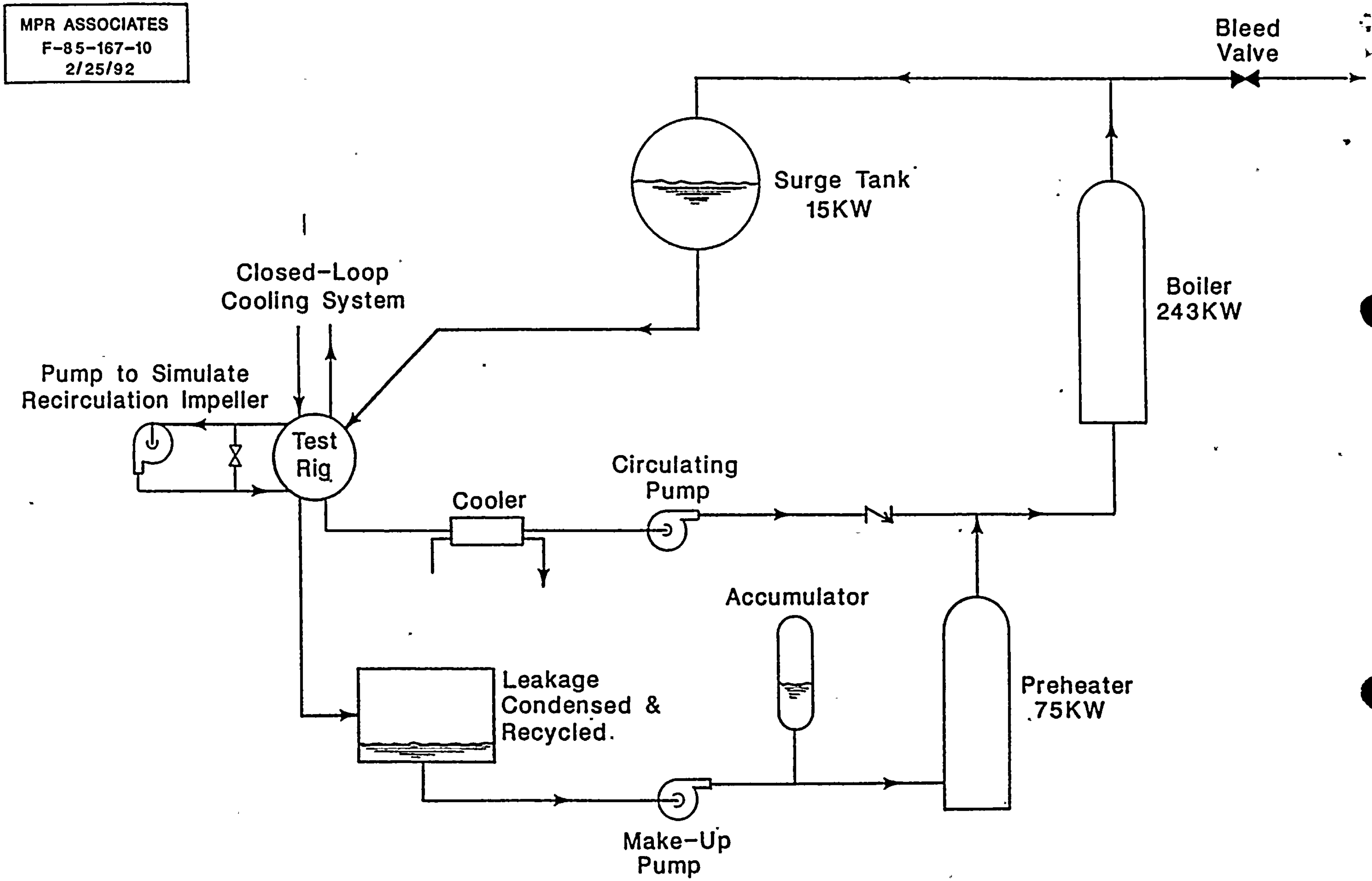

FSTU HOT LOOP

FIGURE B-2

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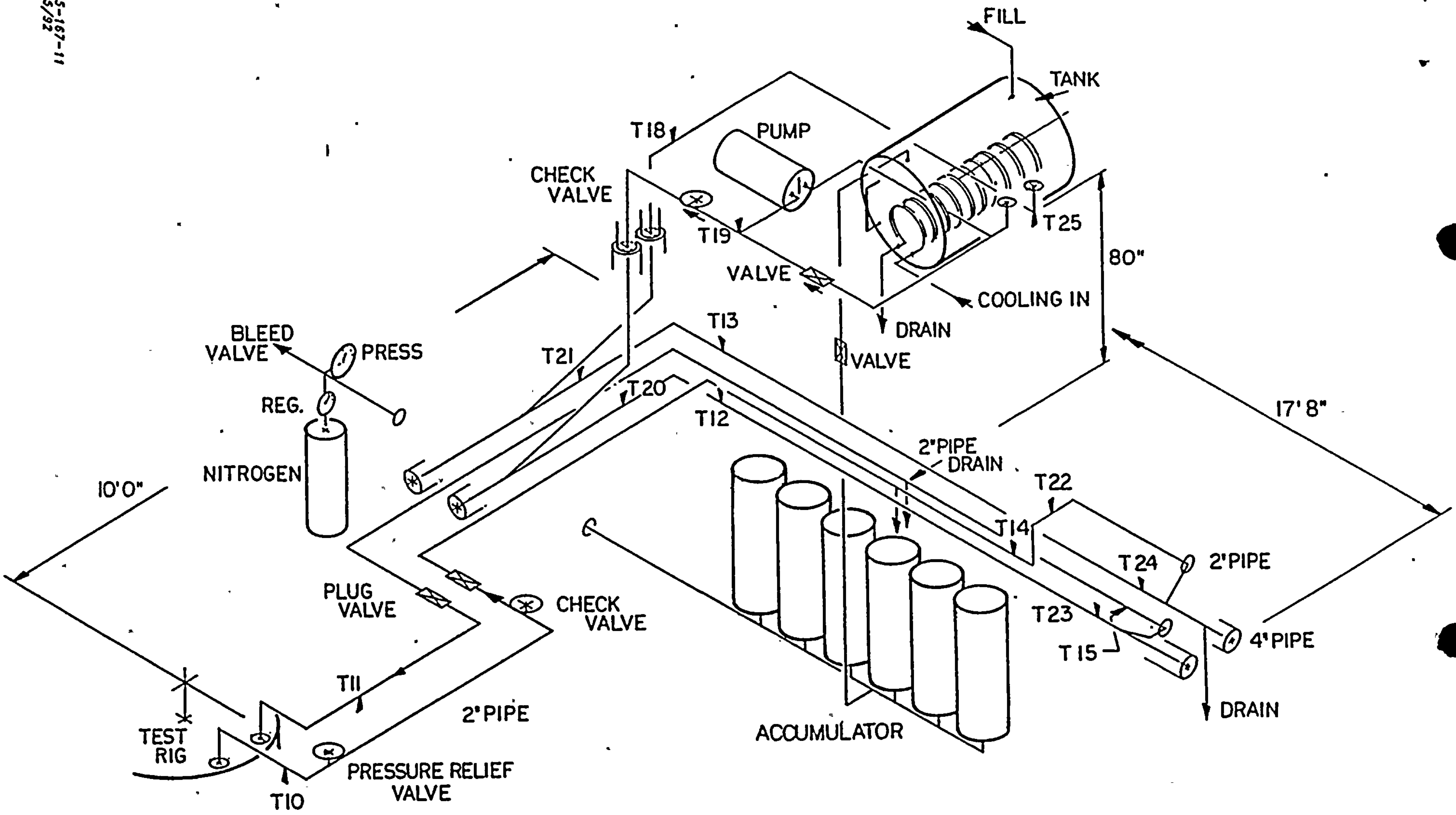

FULL SCALE CAN2A TEST RIG
CLOSED LOOP COOLING SYSTEM

FIGURE B-3