Florida Power
CORPORATION

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U.S. NUCLEAR REGULATORY COMMISSION

Mr. Darrell G. Eisenhut
Director, Division of Licensing
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Subject: Crystal River Unit 3
Docket No. 50-302
Operating License No. DPR-72
NUREG 0737 - Item II.B.1
Reactor Coolant System Vents

Dear Mr. Eisenhut:

Pursuant to your October 31, 1980, letter and in accordance with our December 15, 1980, commitment, Florida Power Corporation hereby provides information on the proposed reactor coolant system vents to be installed and operated at Crystal River Unit 3. This submittal completes the requirement for documentation to be submitted for your review prior to installation of the vent system.

Attachment 1 provides the design description of the vent system. Included in this attachment is a description of the design, location, size, power supply and results of LOCA analyses for the vent system. Should more detailed information be required, specific requests should be directed to this office.

Attachment 2 provides operating guidelines for use of the vent system for venting noncondensible gases during small-break transients. Operating procedures are not developed at this time but will be available for your inspection at the site.

A046 5/1

Our schedule for installation of hot leg and pressurizer vents is during the Fall 1981 refueling outage. We will therefore meet the Action Plan implementation date of July 1, 1982.

Very truly yours,

Patsy Y. Baynard

Dr. P. Y. Baynard
Manager
Nuclear Support Services

Attachments

Blake(7/1)D3-3

Attachment 1

Crystal River Unit 3

High Point Vent System

Description

1.0 INTRODUCTION

1.1 The Crystal River Unit 3 High Point Vent System described in this document includes design information, safety requirements, details of components and their function, controls and instrumentation, piping support information, and LOCA analysis results as requested in Action Plan Item II.B.1. The system flow diagram is shown on Figure 1.

2.0 SYSTEM FUNCTION

2.1 Implementation of the High Point Vent System will increase CR-3's ability to vent significant volumes of noncondensible gases which could interfere with natural circulation and core cooling.

3.0 SUMMARY DESCRIPTION

3.1 The system is comprised of six (6) solenoid valves, three (3) flow elements and three (3) flow orifices. The vents are located on the top of the two (2) steam generator hot legs and on the top of the pressurizer vent/sample line.

4.0 SYSTEM DESIGN REQUIREMENTS

4.1 Vent piping and valving is designed and sized such that the failure to close any one (1) of the vent points will not cause a loss of coolant at a rate in excess of the normal makeup system capability at normal RCS pressures.

4.2 The effluent flow from all vent points is routed directly to the containment atmosphere. The region into which the discharge is diverted enhances mixing and dilution so as to minimize the po-

tential for local regions from reaching flammable concentrations of gases. Discharge piping is routed and directed so that liquid effluent will not discharge on or fall on electrical equipment or mechanical operating equipment.

4.3 The piping and valving is routed, oriented, and protected so that damage from pipe whip, jet impingement, and missiles will not occur.

4.4 Pipe routing, orientation, and elevation assures that all remotely operable valves are located well above the maximum level of water in the containment expected for the worst case design basis accident (DBA). Each vent is designed to remain functional after all design basis events except large LOCA's.

4.5 Vent piping and valving is designed for 2500 psig and 670°F, and any gaskets or seals are compatible with all anticipated effluents. This includes water, saturated steam, steam-water mixture, super heated steam, fission product gases, helium, nitrogen, and hydrogen.

4.6 Each venting point is individually operable independent of any other vent point.

4.7 All piping and valving is connected to the RCS and supported in a manner so that any stress due to weight, thermal transients, internal piping conditions, and external environment will be within the maximum allowable stresses at the existing vent nozzles. Piping is designed to prevent the formation of traps and minimize the possibility of water and/or steam hammer.

4.8 Existing nozzles in the RCS are utilized for the venting system.

4.9 Two remotely operated isolation valves mounted in series are provided to control the vent flow.

4.10 All remote operable, "two-position" (on-off) valves are of the fail-closed type, with power required to "open" and power required to "maintain open". The valves have proven fail "closed" action on loss of power.

4.11 All valves for one steam generator hot leg vent nozzle are powered from a supply separate from that which powers the valves for the other steam generator hot leg vent nozzle so that a single power supply failure cannot cause a failure to vent at more than one steam generator hot leg vent nozzle. 125 VDC power supplies are provided for all of the vent isolation valves. Complete vent shutoff of any one vent nozzle is assured on loss of power to its venting system.

5.0 CONTROLS AND INSTRUMENTATION

5.1 Control of the vent valves is remote-manual and operable only from the Control Room. Direct indication of valve positions are provided in the Control Room.

5.2 Control of the valves for any one vent point is independent of the control of valves for any other vent point.

5.3 Both valves at a vent point are powered by the same power source, but are controlled by individual and independent switches. An alarm indicates that both valves are energized.

5.4 The vent valve operating switches are such that the vent valve will not open when power is applied to the switch without the independent action to operate the switch.

6.0 SAFETY REQUIREMENTS

6.1 All fluid portions of the venting systems from the vent nozzles up to and including all vent valves are part of the reactor coolant pressure boundary, and, as such, are seismically qualified and classified per Reg. Guide 1.26 as safety class A or B, depending upon piping size.

6.2 The valves shall be classed as active, subject to the requirements of Reg. Guide 1.48.

6.3 As a minimum, all electrical portions of the system for hot leg "two position" (on-off) valves shall be class 1E.

7.0 COMPONENTS

7.1 VALVES - Valves utilized on the high point vent system are one-half inch Target Rock valves.

The valves will be butt welded to one-half inch schedule 160 pipe.

7.2 FLOW ELEMENTS - A Fluid Components, Inc. (FCI) flow element will be utilized downstream of the Target Rock Valves to detect flow of steam, water, or gas.

7.3 PIPING - One-half inch and one inch schedule 160 buttweld pipe will be utilized upstream of the high point vent valves; one-half inch, one inch, and two inch schedule 160 seamless socket weld pipe will be utilized downstream of the high point vent valves.

7.4 FITTINGS- Fittings upstream of the valves will be forged or welded and will match the pipe schedule.

Fittings downstream of the valves will be 6000 lb. socket welds and will be bored to schedule 160.

7.5 FLOW ORIFICES - Flow orifices will be located in the one inch vent lines off the hot legs and in the one-half inch vent line off the pressurizer. These orifices will restrict water and steam slugs which occur due to the rapid vent valve actuation, and will guarantee that failure of the vent piping and valving will not result in a coolant loss in excess of normal makeup system capacity.

8.0 CODES

8.1 All piping and equipment from the steam generator and pressurizer up to and including the second isolation valve are designed and fabricated in accordance with ASME, Section III, Class 1 and 2 requirements. The remainder of the piping and equipment in this system is non-nuclear safety related equipment.

8.2 The high point vent system satisfies applicable requirements and industry standards including ASME Code classification, safety classification, single-failure criteria, and environmental qualifications.

9.0 SUPPORTS

9.1 The vent system piping is supported to ensure that the resulting loads and stresses on the piping are within code allowables.

9.2 All supports and support structures comply with the requirements of the AISC Code, Part II.

10.0 ANALYTICAL CONSIDERATIONS

10.1 The analysis of the hot leg and pressurizer vent piping is based on the following plant operation conditions defined in the ASME Code Section III:

1. Normal Condition:
   Pressure, deadweight, and thermal expansion analysis of the vent pipe during normal reactor operation with the two vent valves closed.

2. Upset Condition:
   Loads generated by the Operating Basis Earthquake (OBE) response spectra and valve venting transient loads in addition to the normal operating condition loads.

10.2 The Class 1 piping used for the hot leg and pressurizer vents are one inch and one-half inch schedule 160 and, therefore, in accordance with ASME Code Section III, is analyzed following the procedures of NC-3600 for Class II piping.

10.3 For plant operating conditions listed above, the piping stresses are shown to meet the requirements of equations (8), (9), (10) or (11) of ASME III, Section NC-3600 with a design temperature of 670°F and a design pressure of 2500 psig.

11.0 LOCA ANALYSIS

11.1 A break of the High Point Vent Line upstream of the flow orifice w'll result in a small LOCA of not greater than one inch diameter. Such a break is similar to those previously analyzed in Sections 14.2.2.5.1 and 14.2.2.5.2 of the Crystal River Unit 3 Final Safety Analysis Report.

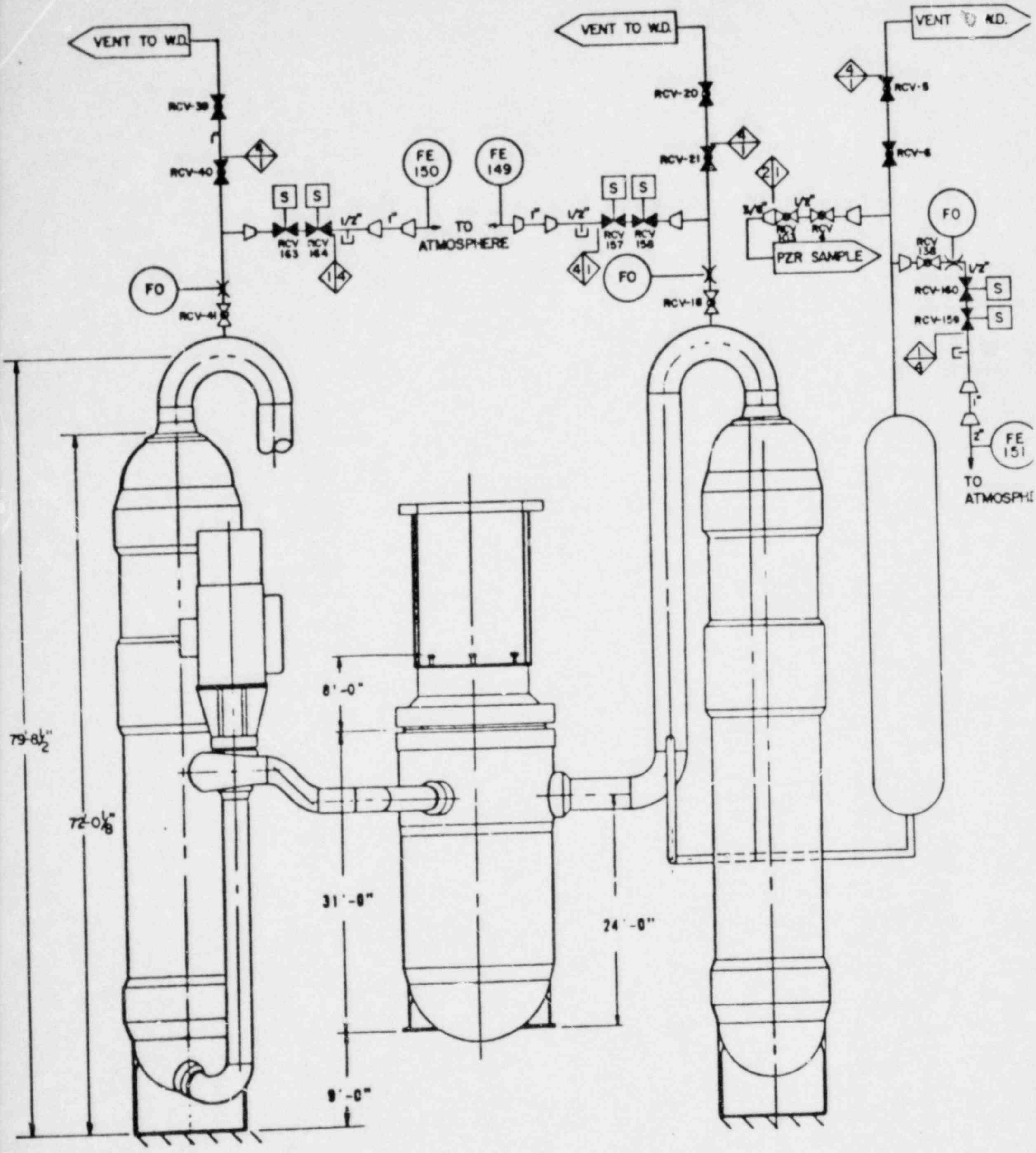


Figure 1
HIGH POINT VENTS
REACTOR COOLANT SYSTEM
ELEVATION ARRANGEMENT
CRYSTAL RIVER UNIT #3

Attachment 2

Crystal River Unit 3

High Point Vent System

Operating Guidelines

Operating Guidelines for High Point Vents During Small Break Transients

1. INTRODUCTION

The Nuclear Regulatory Commission has required the installation of vents in the high points of t'e primary system, to facilitate the plants' recovery. following possible future accidents[1,2]. The purpose of these vents is to discharge gases which may accumulate during small break transients. in order to promote reestablishment of natural circulation in the system, and to allow the operator to bring the plant toward cold shutdown.

Some B&W 177-FA plants will have high point vents installed at the top of the hot legs and a vent on top of the pressurizer. Others will have an additional vent(s) installed at the reactor vessel upper head. Presented herein are the operator guidelines for the high point vents for both cases.

Section 2 of this report provides a summary of the report. Operator guidelines for the plants with vents at the hot legs, and the plants with vents at the hot legs and reactor vessel upper head, are provided in section 3 for a "normal" small break transient response. Operator guidelines for the high point vents during small break transients, which progress to inadequate core cooling, are presented in section 4 for the cases described above.

2. SUMMARY AND CONCLUSIONS

Calculations performed as part of the basis of this report show that the optimum time to open the high point vents for a "normal" small break transient is during the system refilling mode. Under these system conditions, if the RC pumps are not available for bumping to establish natural circulation, the high points at the hot legs are to be opened to relieve steam and/or noncondensible gases in the hot leg and steam generator regions, in order to allow for a system refill. Following establishment of the natural circulation, the vents are to be closed after the sytem becomes 20F to 50F subcooled.

For the plants with a reactor vessel head vent, the hot leg vents are to be closed after the conditions described in the previous paragraph have been met, and a normal pressurizer level has been attained. Subsequently, venting of the vessel head is to be initiated and maintained until all the steam and noncondensibles present in that region are expelled. Operator control of the HPI flow during this phase will be utilized as necessary in order to maintain adequate subcooling and pressurizer level control.

For plants not containing the RV head vent, the hot leg vents should be kept open upon establishment of natural circulation, and the system should be depressurized at a controlled rate toward shutdown pressures. This should be accomplished in such a fashion that the bleeding rate of the RV head bubble into the hot leg due to depressurization is not greater than the release rate of the hot leg high point vents, preventing gas accumulation at the 180^{0} bend, and thus maintaining natural circulation.

The vents in the hot legs and the reactor vessel head, if avail ble in the plant, are to be opened during indications of inadequate core cooling with cladding temperatures of approximately 1400°F. At and above this temperature, cladding ruptures, with the subsequent release of noncondensibles within the fuel rod, may occur. Also, if the cladding temperature continues to rise, significant zircaloy cladding - water reaction will occur, thus releasing substantial amounts of hydrogen into the RCS. The hot leg vents are to be opened as a precautionary measure to prevent concentration of the gases within the steam generator tubes. The steam generators are utilized in the inadequate core cooling procedure in order to depressurize the primary system and lead to subsequent actuation of the core flooding and/or low pressure injection systems. Therefore, concentration of noncondensible gases within the SG must be minimized in order not to degrade the SG heat removal process. Following recovery of the core, utilization of the vents r verts to that for a "normal" small break.

3. OPERATOR GUIDELINES FOR HIGH POINT VENTS DURING NORMAL SMALL BREAK RESPONSES

The response of the primary system to a small break differs greatly depending on the break size, its location in the system, operation of the reactor coolant pumps, the number of ECCS trains functioning, and the availability of the secondary cooling. However, assuming availability of the secondary cooling, transients caused by a small break LOCA can be divided into the following categories[3,4,5]:

Breaks which are capable of relieving all the decay heat via the break. Heat transfer through the steam generator is not needed in mitigating this transient. The primary system depressurizes fast enough to enable the safety injection system to maintain sufficient core cooling. (See Figure 1, curves (1) and (2).)

b. Breaks which are too small in combination with the operating HPI to depressurize the RCS. The steam generators play an active role in removing a portion of core decay heat. If secondary cooling is maintained, the primary side pressure may stabilize near the secondary side pressure, as shown on Figure 1, curve (3). Since the HPI flow is not capable of preventing an interruption of natural circulation, a temporary interrruption of heat transfer across the steam generators may also occur. As the leaks within this category are not large enough to remove the energy present in the primary system, a system pressure increase may occur until the primary side liquid level falls below the secondary side auxiliary feedwater injection nozzle elevation in the OTSG. At this time, primary side steam is condensed, and the primary system pressure drops to near the secondary pressure. The high pressure injection rate rises quickly to match the decay heat boil-off rate, establishing a safe core condition. (See Figure 1, curve (4)).

c. Breaks which initiate a reactor trip, activate the HPI pumps, and are within the capability of the high pressure injection system without resulting in an interruption of primary system flow. The primary system pressure will be balanced at a value where the out flow through the leak equals the feed rate of the high pressure injection system. The energy present in the primary system can be transferred to the secondary side without interruption. See Figure 1, curve (5), for a generic pressure response.

d. Breaks small enough to be mitigated by the makeup system.

For the category (a) breaks, the system response will naturally result in actuation of the low pressure injection system.

For the category (b) breaks, provisions currently exist in the small break operating guidelines[3] to perform intermittent bumping of the reactor coolant pumps, when the system conditions outlined in the above mentioned guidelines are met. This is to remove the trapped gases in the hot legs and promote the reestablishment of natural circulation. However, if the pumps are not available and the transient has to be allowed to progress naturally, the HPI eventually commences to refill the reactor coolant (RC) system, as the core decay heat decreases with time. The hot leg vents can then be utilized to remove the gases above the rising water level, facilitate the refilling process, and reestablish natural circulation.

For categories (c) and (d), utilization of the high point vents is not necessary, and the operator can initiate a normal plant cooldown, while using the HPI pump(s) to maintain system subcooling.

3.1 Plant Behavior and Establishment of Natural Circulation

The small break transient which will require operator action in opening the high point vents, results in a reactor trip and automatic initiation of HPI. For the category (b) breaks, the HPI flow is not able to match the inventory being lost through the break, and the sytem depressurization will result in saturated fluid conditions. Continued energy addition from the core decay heat results in boiling within the vessel and subsequent formation of steam regions within the primary system which interrupts natural circulation. Once sufficient primary liquid inventory is lost to cause the primary level to drop below the secondary side auxiliary feedwater injection nozzle elevation in the steam generators, direct condensation of the primary side steam starts. The condensate flows through the cold legs to the pressure vessel, and is subsequently reboiled by the core decay heat. The steam, then, flows through the hot legs into the steam generator, where it is recondensed, thus continuing the "boiler condenser" circulation. This mode of operation is an effective primary side heat removal mechanism. For certain sized small breaks, a system repressurization will occur between the interruption of natural circulation and the establishment of boiler-condenser circulation. Ultimately, the primary system pressure will decrease to approximately the secondary side pressure. The HPI flow, then, increases sufficiently to be able to match boil-off, establishing a safe core cooling mode. As the core boil-off decreases with time, due to decreasing decay heat, the HPI is able to start refilling the system, and, at a later time, to completely prevent the core from boiling.

In the course of this study. opening of the vents has been considered during the following system behavior modes:

a. System saturation.

b. Loss of natural circulation.

c. System refill.

Option (a) has been discarded, because, initially, the system symptoms for a small LOCA are very similar to the symptoms for an overcooling accident. Premature opening of the vents at system saturation may, unnecessarily, create a LOCA during an overcooling transient.

Calculations, performed for option (b), have shown that the vents are very ineffective when opened to relieve steam created by core boil-off without natural circulation. For example, at 1250 psia, and a decay heat value for 30 minutes into the transient, one .815 in. ID (maximum vent size based on ID of vent piping) high point vent is capable of relieving only 3% of the steam generated by the core heat, when a vent line friction coefficient of 20 is assumed. Actual vents installed will result in even less steam removal because of designed orifice flow restrictions. Thus utilization of vents upon loss of natural circulation would not greatly aid or alter the system response.

Further studies have indicated, however, that the vents have a positive influence during the recovery process of the accident, once the decay heat rate has fallen sufficiently to allow the HPI flow to prevent core boiling. At that time, in fact, the system would start to refill, provided that the steam and/or trapped noncondensible gases, located above the liquid - steam surface, were removed to give space to the rising coolant level. The vent sizes are such that the steam and noncondensible gases would be vented, and refilling of the primary loops could be accomplished so long as steam is not being generated in the system.

Since a bubble in the upper head of the RV does not prevent reestablishment of natural circulation, the high point vents at the hot legs are to be opened to allow refilling of the loops and promote natural circulation. Generic calculations have been performed to evaluate the effectiveness of the two vents at the hot legs, with 2 HPI trains refilling the system for various small breaks ranging from 0 ft^2 to 0.02 ft^2. The analysis, which is discussed in Appendix A, shows that the loops refill in less than 4 hours for the largest (0.02 ft^2) break. With only one HPI pump operating, the refilling of the system will take longer.

As described above, operator action to open the high point vents during the system refill stage of the transient will be an effective measure in aiding the reestablishment of natural circulation, if the RC pumps are not available for intermittent bumping, as outlined in the operator guidelines.

The refill phase of the accident commences subsequent to the stabilization of system parameters following the initial transient response. As a result of continued high pressure injection, possibly in combination with an operator-initiated controlled depressurization of the secondary system, the fluid makeup will exceed the core boil-off and leak rate and a system refill will occur. This will ultimately result in the fluid level in the primary side steam generator tubes exceeding the secondary side steam generator auxiliary feedwater inlet nozzle elevation, thus ceasing the boiler-condensor mode of cooling. The primary side pressure will then begin to increase providing confirmation of the system refill and "decoupling" of the primary and secondary systems. At this point, if the operator has not been able to utilize the RC pumps for intermittent bumping to establish natural circulation, he is to open the two high point vents on top of the hot legs. The vents should be kept open until the hot and cold legs are approximately 20°F to 50°F subcooled and natural circulation has been restored.

Subsequently, the operator should proceed toward venting the reactor vessel head, if a high point reactor vessel head vent is present in the system. An explanation of the procedure is in section 3.2. Otherwise, the operator should proceed toward depressurizing the system at a controlled rate, in order to maintain natural circulation in the system, with a bubble in the reactor vessel head. A method to accomplish this is described in section 3.3.

3.2 Operator Action for Venting the Reactor Vessel Head

After subcooled conditions and natural circulation have been established, the operator should close the hot leg high point vents, and check the pressurizer level. If the level measurement in the pressurizer indicates empty or a low value, the pressurizer vents should be opened to depressurize the top of the pressuirzer, thereby allowing the liquid level in that region to increase, until normal operating level is attained. The operator must continue HPI flow during this operation to maintain adequate subcooling.

Following restoration of the pressurizer level to its normal value, the HPI pumps are throttled (except at Davis Besse 1) to maintain less than 100°F subcooling in the RCS. At this time, the vessel head vent is to be opened and the HPI flow adjusted to maintain a constant pressure in the system. The vessel head vent is to be closed after the pressure in the system starts to increase very rapidly, since the bubble in the reactor vessel head has been expelled, and water is being discharged out of the vent. Depending on the composition and size of the bubble the reactor vessel head should be refilled in 1 to 2 hours for hydrogen only, and in 6 to 8 hours for steam only. These times are based on a vent path diameter of .187 in ID. Specific vent designs may require different times to achieve refill.

For certain limiting break sizes, the HPI flow may be insufficient to maintain a constant system pressure after the vessel head vent is opened, and the system pressure may decrease. Under these conditions, maximum HPI flow should be maintained and the RCS should be allowed to depressurize until the hot leg RTD's indicate 50°F subcooling. At this point, the reactor vessel head vent should be closed, and the HPI flow maintained until a 100° subcooling margin is reached. The vessel head vent should then be opened again and kept open until the hot leg RTD again indicates 50°F subcooled or the primary system pressure starts to increase. For example, assuming one reactor vessel vent having .187 in. ID, one pressure cycle should last a minimum of 3 hours for steam discharge, and a minimum of 30 minutes for pure hydrogen discharge. The pressurizer level will decrease between 10 to 12 feet during this operation. The procedure should be repeated not more than five cycles, until the pressurizer level does not decrease upon opening the reactor vessel vent, indicating that liquid is being discharged.

For a break in the pressurizer, the pressurizer remains full throughout the transient. Therefore, when performing the cyclic venting of the RV head, the pressurizer level will not decrease. However, the rate of change in the subcooled temperature margin, as indicated by the cold and hot leg RTDs, will give enough information to the operator on the plant behavior during the procedure.

During the venting procedure, the operator should continuously check for natural circulation. If natural circulation is lost, the operator should stop the reactor vessel head venting, and return to the hot leg venting process, until natural circulation is reestablished. Once the primary system is completely filled with 50°F subcooled liquid, he should start the RC pumps as soon as they become available, and proceed toward cold shutdown of the plant.

3.3 Operator Actions to Depressurize the System With a Bubble in the Reactor Vessel Head

In order to proceed toward cold shutdown, the operator has to depressurize the primary coolant loops, thus allowing startup of the decay heat removal system. A concern has been raised about the ability to depressurize the plant with a bubble trapped within the reactor vessel (RV) head. As the plant is depressurized, there has been a concern that expansion of the gas bubble from the RV head into the hot legs may cause an interruption of natural circulation. This problem has been examined and a method has been designed to allow the bubble in the RV head to expand into the hot legs at a rate consistent with the gas removal capability of the hot leg vents.

Following establishment of natural circulation and temperatures in the hot and cold legs between 50°F to 100°F below saturation, the operator should open the pressurizer high point vent or PORV and allow the plant to depressurize at a rate not greater than indicated by curve 1, in Figure 2. During this process, adequate subcooling should be maintained by using the HPI flow and/or the steam generators. If natural circulation is lost, the pressurizer vent should be closed, and the bubble which has accumulated at the 180° bend of the hot legs should be allowed to vent through the hot leg high point vents.

For breaks in the pressurizer, the pressurizer would remain full, and the system pressure would stabilize at a value at which the injected ECC fluid matches the leak flow, after the loops have been refilled. The system could be depressurized at a controlled rate not exceeding the rate presented in curve 1, Figure 2, by throttling the HPI, while maintaining an adequate subcooling margin within the primary system. As described above, the gases expanded into the hot legs from the RV head would move into the hot legs and be expelled from the system through the hot leg vents.

4. Operation of the Vents During Inadequate Core Cooling

During inadequate core cooling, significant hydrogen generation due to metal-water reaction begins when a cladding temperature of approximately 1800°F is attained. Therefore, if during a small LOCA, the operator has indications that the fuel cladding temperature is at or above 1400°F (curve 1, Figure 3, reference 3), he should open the high point vents in the primary system. This is a precautionary action to prevent noncondensible gases, which are being formed in the core, from accumulating within the steam generator tubes.

The steam generators are utilized within the inadequate core cooling procedure [3,4,5] in order to depressurize the primary system and lead to subsequent actuation of the core flooding and/or low pressure injection systems. Therefore, concentration of noncondensible gases within the steam generator must be minimized in order not to degrade the steam generator heat removal process.

Once the core exit thermocouples indicate saturated temperatures, the noncondensible gas production due to core damage has ceased, and the system has returned to a normal small break mode. The operator should proceed toward shutdown of the plant by using the procedure detailed in section 3.

Figure 1

PRESSURE VS. TIME-SMALL BREAKS
WITH AUXILIARY FEEDWATER

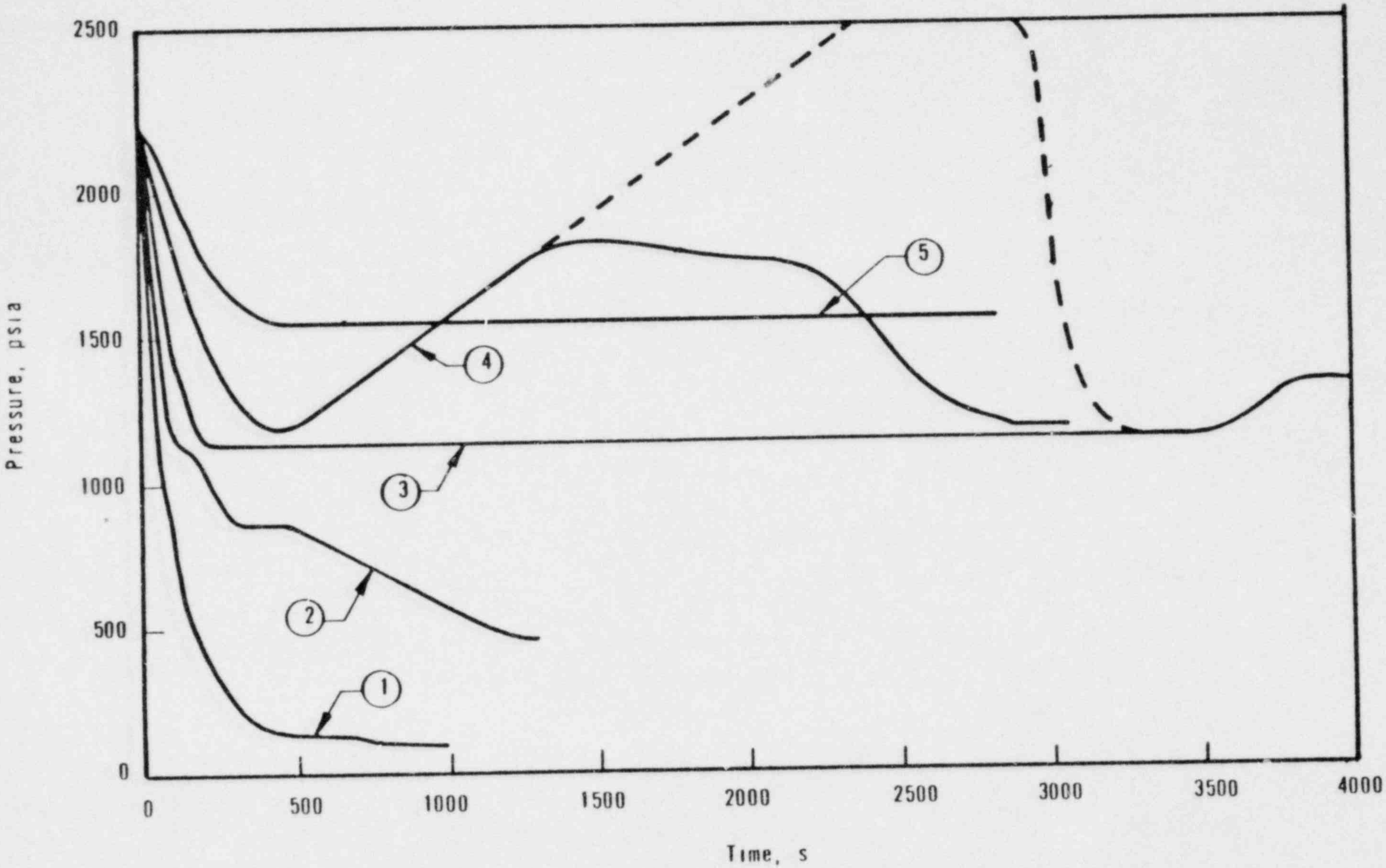
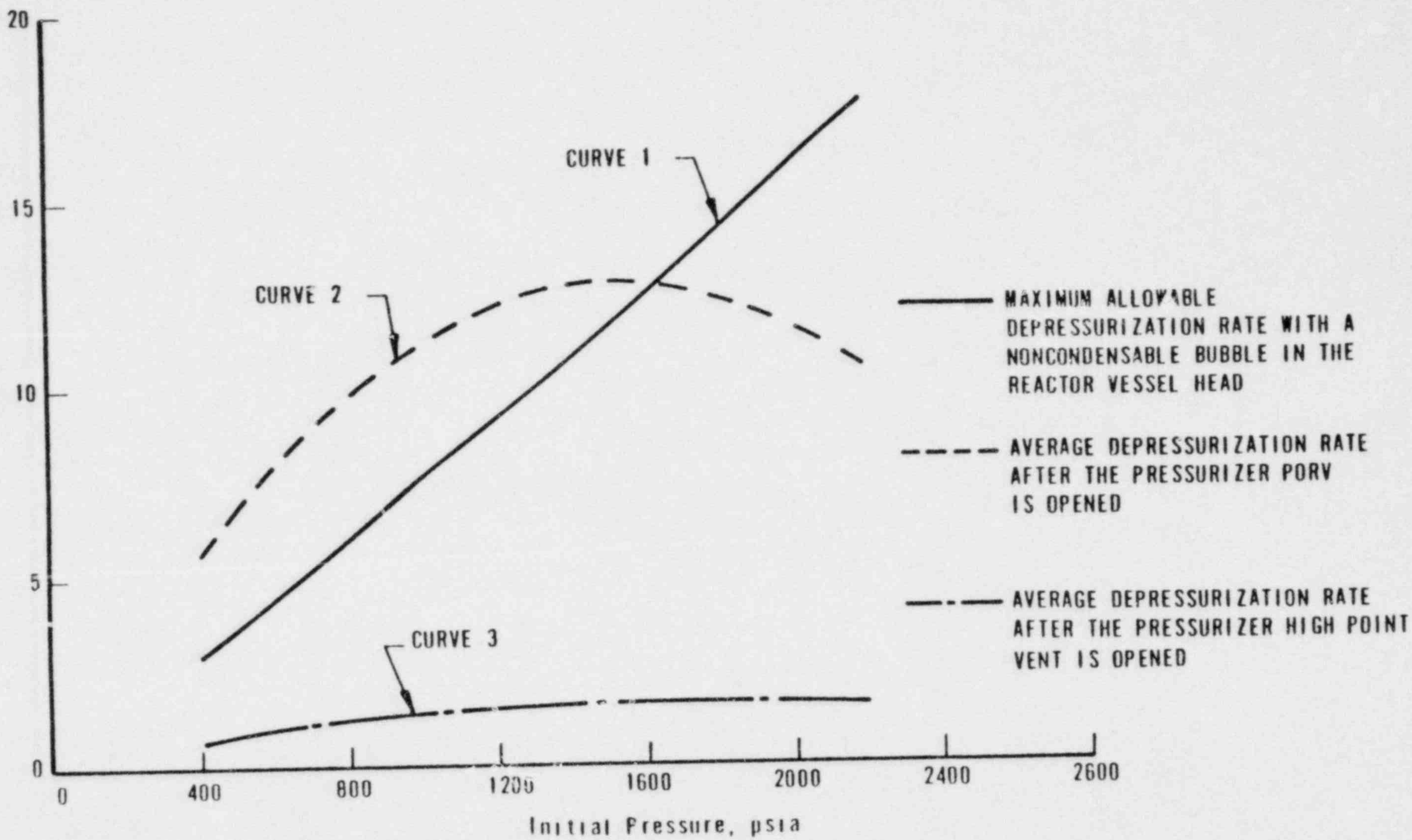


Figure 2

SYSTEM DEPRESSURIZATION RATE-FOLLOWING ESTABLISHMENT OF NATURAL CIRCULATION



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2. Letter, H. R. Denton (NRC), "Resumption of Licensing Reviews for Nuclear Power Plants," August 20, 1979.

3. "Small Break Operating Guidelines for Oconee 1, 2, and 3: Three Mile Island 1 and 2: Crystal River 3: and Rancho Seco 1," 69-1106001-00, Babcock & Wilcox, November, 1979.

4. "Small Break Operating Guidelines for ANO-1," 69-1106002-00, Babcock & Wilcox.

5. "Small Break Operating Guidelines for Davis-Besse 1," 69-1106003-01. Babcock & Wilcox.

APPENDIX A

Analyses of Reflooding the Primary System

The purpose of this calculation was to qualitatively identify the general response of the plant to various conditions involving primary system vents. The assumptions made are conservative estimates of actual plant parameters. Specific vent design inputs will be required to verify that the concepts generated in the guidelines are applicable to a specific vent system design. Provisions currently exist in the 177-FA operator guidelines[3,4,5] to reestablish natural circulation in the primary loops, following small breaks belonging to a certain size category. These consist of intermittent bumping of the reactor coolant pumps in order to remove the trapped gases in the hot legs, allow steam to be condensed in the steam generator and promote the reestablishment of natural circulation[3,4,5]. As described in the main body of this report, in case the pumps are not available, one .815 in. vent pipe at the 180°F bend of each hot leg could be utilized to vent the gases above the water level, and allow the HPI system to refill the primary loops. This will eventually result in the starting of natural circulation, and allow the plant to be brought to cold shutdown.

In order to analyze the phenomena occuring during refilling by the HPI pumps (i.e., compression of the steam in the upper part of hot legs and steam generators, outflow through the leak and additional venting of the hot legs) a non-equilibrium model has been utilized.

Initiation of the refilling process has been assumed at 30 minutes, in order to conservatively calculate core decay heat, which results in higher system pressures, and, therefore, smaller HPI flows. Different break sizes were also considered: 0.0 ft^2, 0.005 ft^2, 0.01 ft^2, and 0.02 ft^2. The first three breaks belong to the category (b) described in the main body of this report, and, thus are assumed to start refilling at a pressure equal to the steam generator secondary side pressure, i.e., 1076 psia and 1065 psia for the 177-FA lowered and raised loop, respectively. The fourth break size, 0.02 ft^2, does not belong to the category (b) breaks, as, during the transient, the system starts to refill at an initial pressure of 600 psia. It, was, however, analyzed as it will yield a bounding system refilling time when the high pressure pumps are injecting in the system.

In summary, the assumptions of this analysis are:

- The high point vents on both hot legs are opened at 30 minutes after initiation of the transient. (A vent pipe diameter of .815 in ID was assumed for the calculation. Specific vent designs will result in different results.)
- The line losses of the venting lines were assumed using a friction coefficient of 20.
- Both of the HPI pumps are feeding in the coolant loops.
- Decay heat output corresponds to 1.2 x ANS curve.
- Initial power is 102% of full power.
- The primary levels correspond to the secondary level at which the system leaves the "boiler condensor" cooling mode.
- The initial pressure in the system for the 177-FA lowered and raised loops is 1076 psia and 1065 psia, respectively, for the 0.0 ft^2, 0.005 ft^2, and 0.01 ft^2 breaks, and 600 psia for the 0.02 ft^2 break.

Computer Model Method

The analyses were performed with a version of the RELAP 4/MOD 6 (version 8). This version includes a three-region-nonequilibrium pressurizer model.

In the reflooding analyses the entire primary system was combined and simulated with the aid of the non-equilibrium model. This procedure became necessary because the reflooding process can result in three regions of entirely different thermal-dynamic behavior:

- With rising water inventory the steam in the upper parts of the loops is displaced through the vent openings.
- The continuous injection of cold emergency cooling water at already relatively low decay heat loads to an expanding region of colder water in the lower parts of the system.
- The major portion of the coolant present in the hot legs, the lower portion of the SG's and in parts of the cold legs may, for some breaks, stay at the saturation temperature for the initial pressure.

Each of these thermodynamically independent regions may be simulated by one of the three regions of the non-equilibrium-pressurizer model. Figures A1 and A2 are diagrams of the model for the lowered and raised loop plants, respectively.

The surge line model, safety valve and heater rod model have been used for simulating the HP injection, the leak, the vent valves and heat generation in the core. The flow rate through the vent valves as a function of the pressure were initially calculated manually for saturated steam, taking into consideration the line losses of the venting lines. By means of outflow coefficients depending on the pressure, the HEM model of the non-equilibrium pressurizer model was then adapted to this manually calculated function.

Due to code restrictions it was necessary to simulate leak outflow and HP injection rate by a single combined pressure-dependent function. ("Net surge line" flow rate.) This flow was directed into the bottom region of the model. The outflow through the leak was calculated by means of the Moody model for saturated water.

The heater rod model of the non-equilibrium pressurizer model was used for simulating the heat generated by the core. This heat is fed into the bottom region of the model: constant decay heat was used as a basis because of the energy balance correction due to the combination of HP injection and leak outflow. This is acceptable, as this will yield conservative pressures.

Neither heat transfer nor mixing between this region and the steam region above and the region of colder water below are allowed. This assumption will maximize the pressure in the system, thus allowing for slower refilling rates.

The analysis starts in thermodynamic equilibrium.

Heat transfer to the steam generators is ignored, since the analysis is assumed to start as soon as the system leaves the boiler-condensor mode of cooling. The heat transfer to the metal walls of the system has also been ignored.

Results

The reflooding rate of the primary system depends not only on the capacity of the venting valves (one .815" valve on each hot leg) but also on the number of HP pumps feeding into the system and on the size and location of the leak under review. Four cases were investigated for both the lowered and raised loop plants. Three of these were: the zero break size case, a .005 ft^2 leak at the pump discharge, and a .010 ft^2 leak at the pump discharge. The initial pressure for these cases is equal to the secondary side safety valve set pressure which is 1076 psia for the lowered loop plants and 1065 psia for the raised loop plants. The fourth case investigated in both the lowered and raised loop plants was a 0.02 ft^2 break at the pump discharge with an initial pressure of 600 psia. Each case has 2 HP pumps injecting coolant into the RCS.

The results are compiled in Figures A3 and A6. These give the pressure curves and the refilling process for these cases. The refilling times for the four lowered loop cases vary between 2000 s for the case of the pressure limit break area zero, with an initial pressure of 1076 psia, and 11,200 s for the case of the leak area .020 ft^2 with an initial pressure of 600 psia. The reflooding times for the four raised loop cases vary between 2000 s for the case of the limit break area zero with an initial pressure of 1065 psia and 5200 s for the case of the leak area .020 ft^2 with an initial pressure of 600 psia. However, due to the assumptions in the refilling calculation, combined with the fact that only steam was calculated to be expelled through the hot leg high point vents, these refilling times should not be taken as absolute values, but should be treated as guidance in understanding the refilling phenomenon. If only one high pressure pump is assumed to inject in the system, it would take a longer time for the system to refill.

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FIGURE A1

Model for the Reflooding Analysis With Opened Vent Valves on the Hot Legs

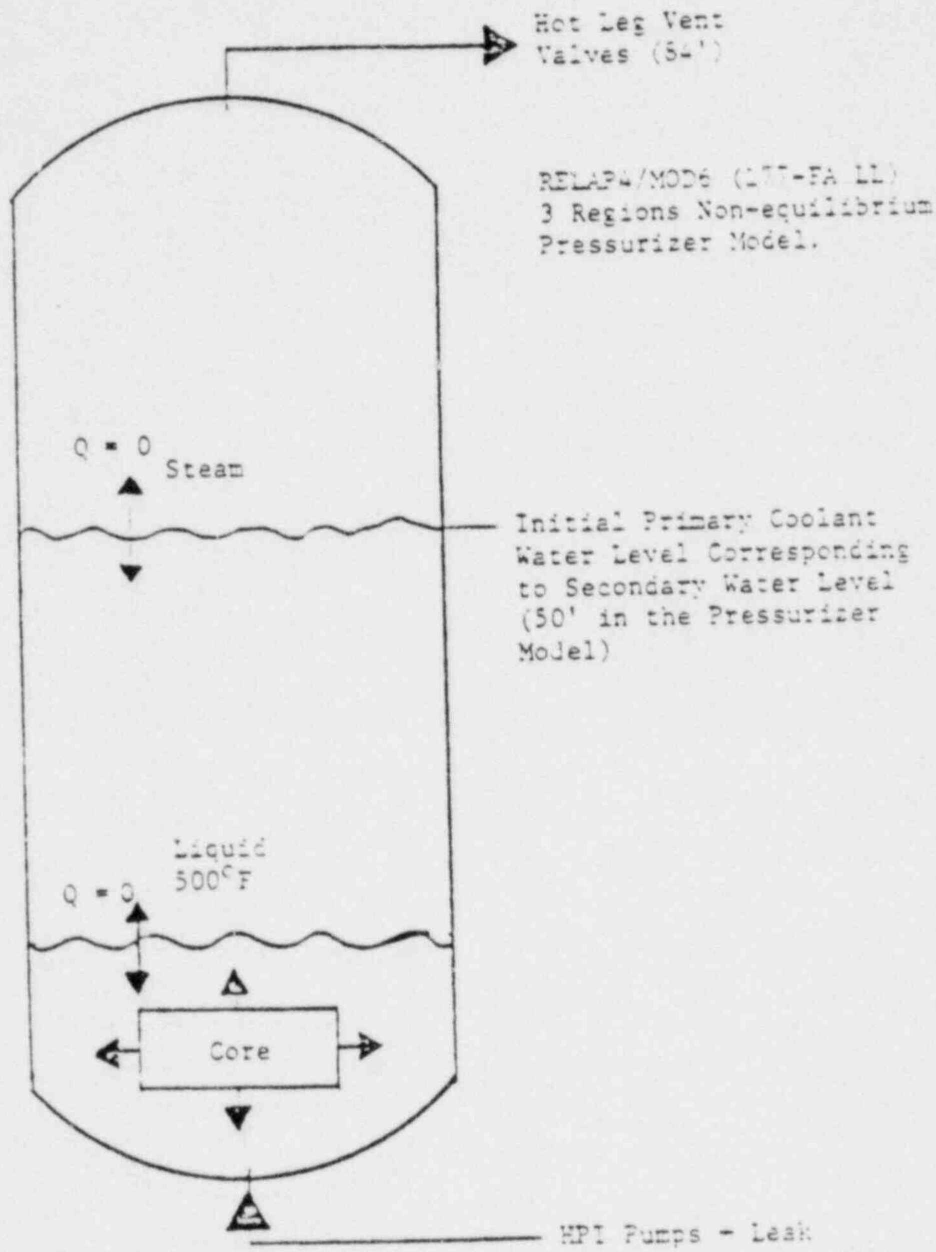

FIGURE A2

Model for the Reflooding Analysis With Opened Vent Valves on the Hot Legs

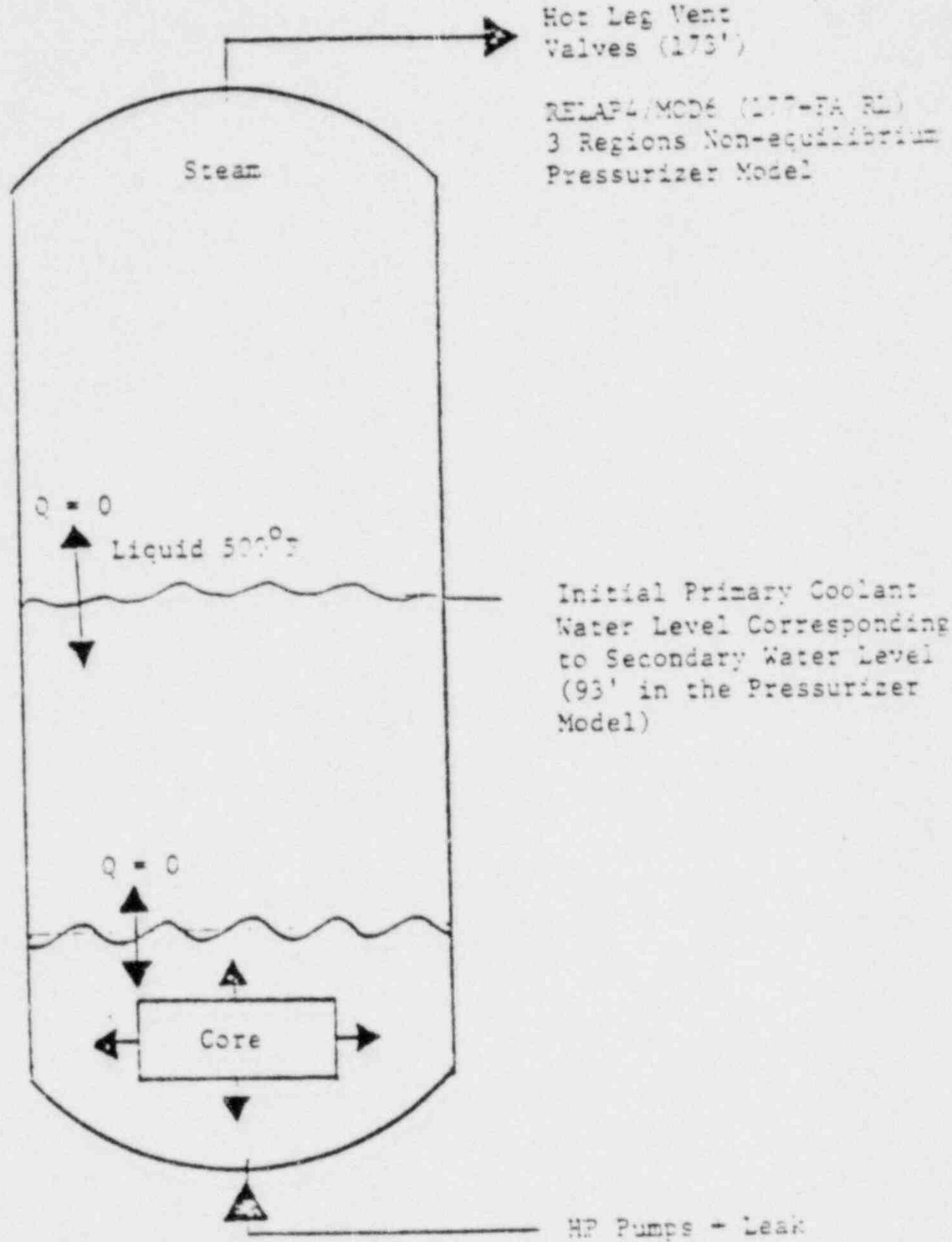

Figure A-3

177 F.A. LOW LOOP RCS LIQUID LEVEL

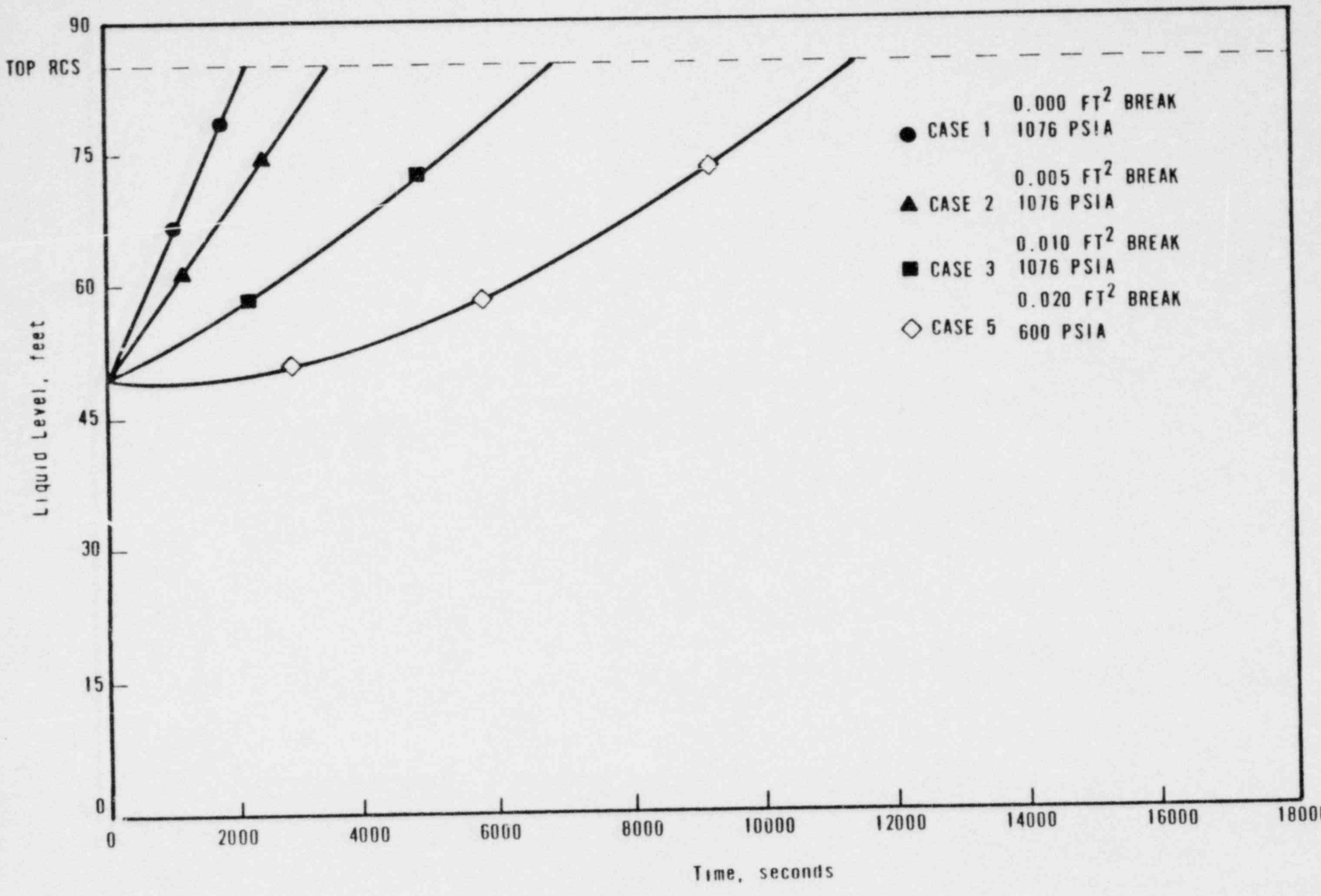

Figure A-4

177 F.A. LOW LOOP RCS PRESSURE

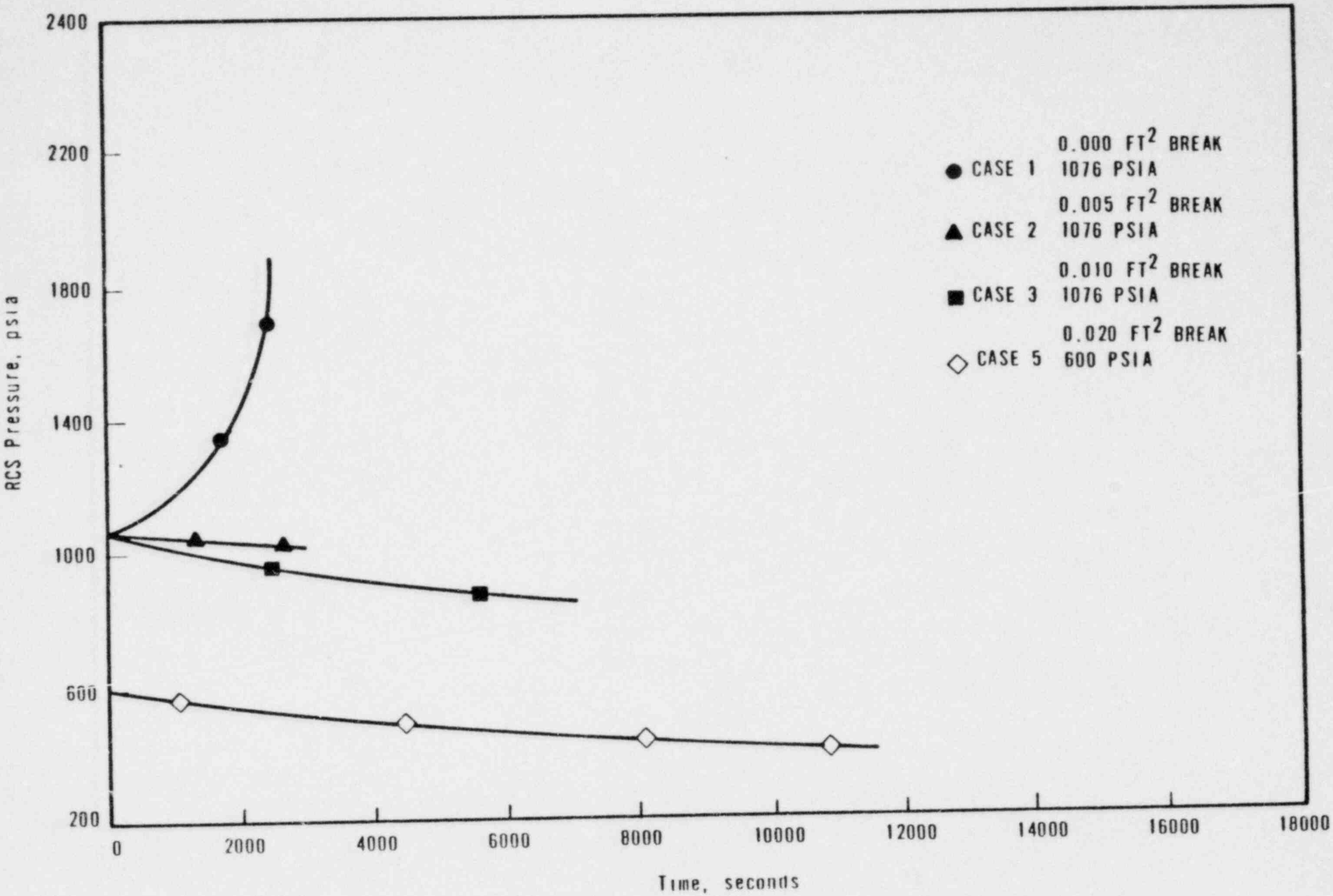

Figure A5

177 FA RAISED LOOP RCS LIQUID LEVEL

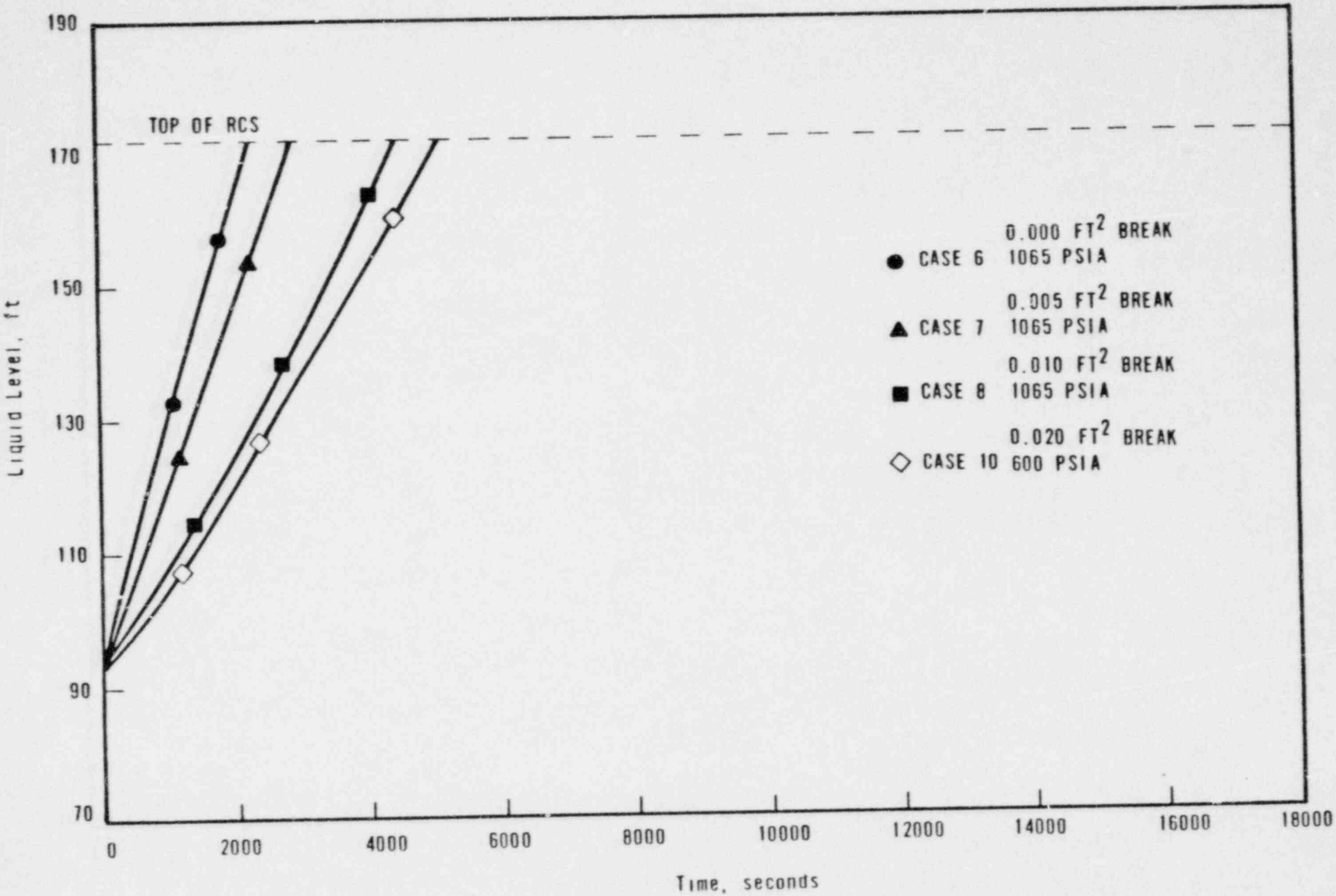

Figure A6

177 FA RAISED LOOP RCS PRESSURE