AEOD ENGINEERING EVALUATION REPORT*

UNITS: Pressurized Water Reactors
DOCKET NOS.: N/A
LICENSEES: N/A
N⌐.S/AEs: N/A

EE REPORT NO.: AEOD/E805
DATE: September 19, 1988
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SUBJECT: POTENTIAL LOCA DUE TO ENERGIZED UNCOVERED PRESSURIZER HEATERS

EVENT DATES: N/A

SUMMARY

Immersion heaters at a foreign reactor did not burn out when they were not covered with liquid. Subsequent localized overheating at reactor operating pressure caused a large break LOCA in the primary system. A similar event occurred at a domestic PWR but at very low primary system pressure. This event did not result in a LOCA, but the event could have been more severe at pressures that could be reached during power operation. Some of these issues were discussed in a 1979 memorandum from R. Mattson (NRR) to R. F. Fraley (ACRS).

1. INTRODUCTION

It is generally assumed that the pressurizer heaters, if not continuously immersed in liquid coolant (covered) would burn out without ensuing damage to the reactor coolant system pressure boundary. However, such an event was reported through the Incident Reporting System. This event, and operating experience at the domestic pressurized water reactors were reviewed to provide some insight on the possibility of uncovered pressurizer heaters remaining energized and subsequently leading to a loss-of-coolant accident.

2. DISCUSSION

During an AEOD rereview of foreign operating experience, a large-break LOCA at a heavy-water moderated reactor was reconsidered for further review, as the event might possibly be significant to U.S. PWRs. Although the foreign reactor had little design similarily to a licensed domestic nuclear reactor, its primary system pressure and liquid level are controlled by a surge tank in the same fashion as reactor pressure and liquid level are controlled by the pressurizer in a PWR.

2.1 Foreign Reactor Event July 15, 1976

A schematic of the surge tank, heater vessel and connecting piping, in the heavy-water moderated reactor is shown in Figure 1. In this type of reactor, primary system pressure is controlled by admitting needed or expelling excess primary coolant through feed and bleed valves to a storage tank. A surge tank provides back-up primary system pressure control by receiving steam produced in the heater vessel or by controlling the amount of cool condensing spray flow within the surge tank. The surge tank is connected to the primary system through a 6 inch diameter surge line. A separate tank, the heater vessel, contains immersion heaters that are

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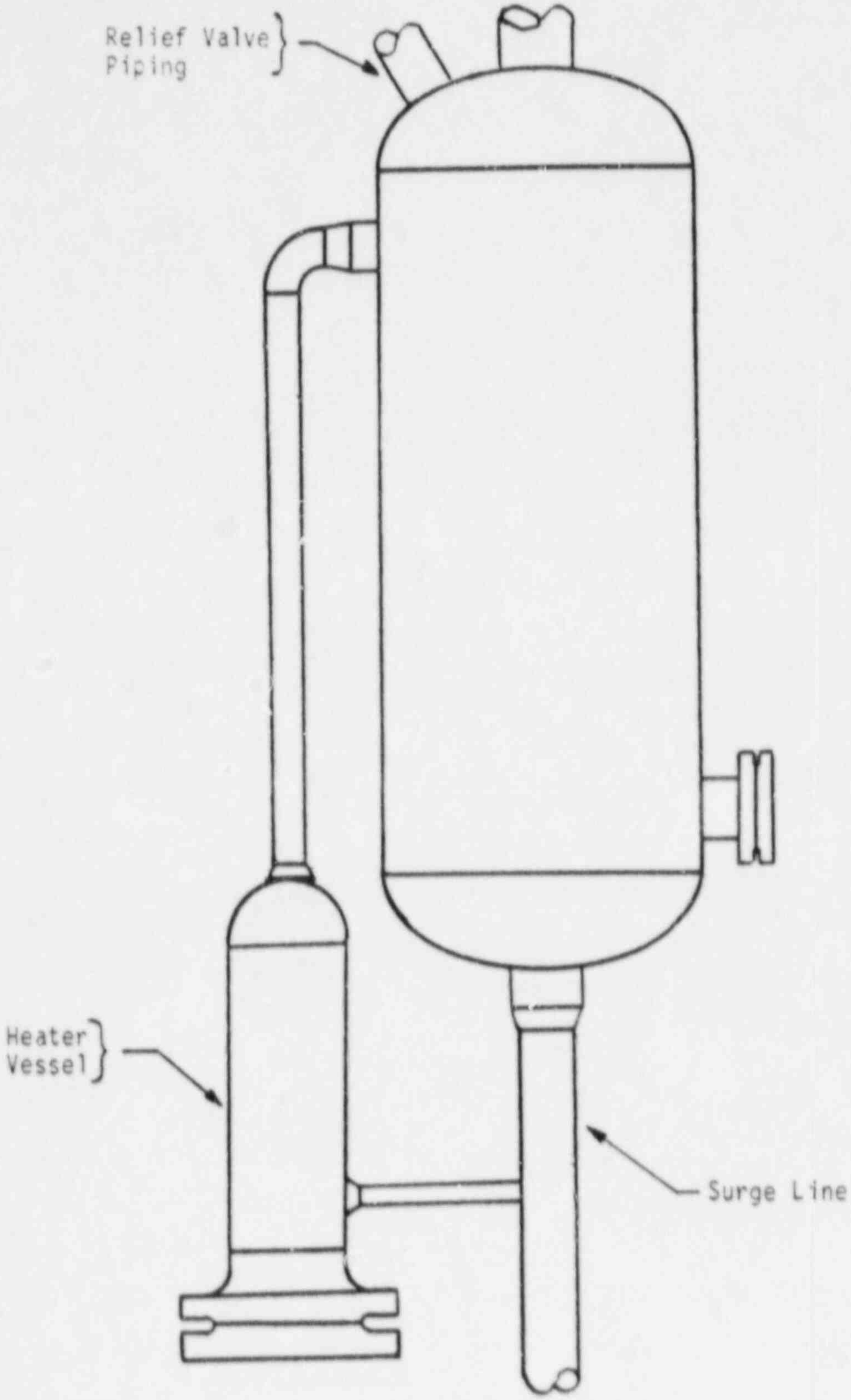


Figure 1. Surge Tank and Heater Vessel
at Foreign Reactor

similar to immersion heaters used in pressurizers at U.S. PWRs. Reactor coolant enters the lower section of the heater vessel through a 1.25-inch diameter line connected to the surge line, and steam produced by the immersion heaters leaves the upper heater vessel through a 3-inch diameter pipe connecting to the steam space of the surge tank. The level of liquid in the surge tank is indicated on two differential pressure instruments that share a common reference leg. One level measuring instrument is dedicated to proportional primary system level control and the second instrument provides back-up immersion heater protection by shutting off all heaters if the liquid level in the surge tank drops below a set value.

The event began when the primary system was being pressurized for a reactor startup. When the reactor was at 0.25% power with the primary system at 1500 psig and 200F, the primary system abruptly depressurized and the reactor tripped on low primary system pressure. Although it was evident that a LOCA had occurred (later, because there was no safety injection, it was determined that 58% of the primary system coolant inventory had escaped) the surge tank liquid level continued to indicate full scale even after the incident, which was confusing to the operators.

Three hours later, the containment was entered, and it was found that the 3-inch Sch. 80 pipe connecting the heater vessel to the surge tank had ruptured. The rupture was approximately 14" long and 10" wide with a calculated opening of 66 square inches. The ruptured pipe was found bent from the elbow and the ruptured pipe was touching the surge tank wall at the burst point.

After a detailed investigation, it was concluded that the pipe rupture was caused by localized overheating of the pipe by the heater vessel immersion heaters to a temperature of approximately 1400F together with the stress of a primary system pressure of 1500 psig. The excessive temperature resulted from the failure of the level instrumentation which controls the electrical power to the immersion heaters in the heater vessel. The level instruments of the surge tank both indicated a full scale level and kept the immersion heaters in the heater vessel "on", while the heater elements were totally uncovered. In reality, the common reference leg was almost void of liquid (the root cause of failure was not stated). Therefore, the level indicator would indicate full scale regardless of the true level in the tank, and continuously activate all heater elements at full power as reactor pressure was increased.

2.2 U.S. Experience--Uncovered Pressurizer Heaters.

A search retrieved three events at the domestic PWRS where the pressurizer heaters remained energized without adequate liquid in the pressurizer to provide needed heat removal from the pressurizer heaters. All three events occurred at less than operating temperatures and pressures and thus, the outcome of these events would be less severe than the necessary conditions for a hypothesized LOCA. The first two events resulted in the anticipated heater burnout and are not particularly relevant to the safety concerns associated with a high temperature-high pressure induced LOCA. The third event provides some creditability of continued pressurizer heater operation with the thermal output of the immersion heaters being transferred to the RCS pressure boundary rather than to the reactor coolant inventory. All three events were caused by the liquid-filled reference leg of the pressurizer level instrumentation not being at the correct reference column height. A description of domestic operating experience follows:

2.2.1 Waterford-3 March 10, 1983

During precore hot functional testing at Waterford-3, a plant with a construction permit, the primary coolant level in the pressurizer unknowingly decreased, uncovering the energized pressurizer heaters. This resulted in damage to most of the heaters and all thirty heaters were subsequently replaced.

The event occurred while the plant was being maintained at steady state conditions of 460F and 1100 psia at a primary system test plateau. It was determined that the level instrumentation channel that had been selected to control pressurizer level was falsely providing higher readings due to leaks in the instrument tubing connections in the liquid filled reference leg. This leakage reduced the height of liquid that could be sustained by the condensate chamber in the reference leg and made the indicated pressurizer liquid level appear higher than actual.

The event is described in detail in AEOD/E421. This report notes that: "Because the height of liquid in the liquid filled reference leg is assumed constant, problems arise whenever the reference leg liquid height varies. The resulting false level indications are not obvious to the operator, are nonconservative and common mode if shared reference legs are involved. There is no way, other than comparing readings to an independent liquid level system that the operator would be aware of false level indications and improper operation of associated control functions. The level indication with a partially drained reference leg will always be higher than the actual level. Finally, in shared reference leg systems, all of these instruments will display a uniformly higher indicated level than is actually present. Operating experience has shown that the liquid filled reference legs are vulnerable to a variety of malfunctions."

2.2.2 Arkansas Nuclear One-Unit 2 June 1981

As a result of pressurizer level instrumentation problems during a refueling outage, the pressurizer heaters were operated with less than the required water volume to insure the heaters were covered. This resulted in the failure of twenty-three of the ninety-six pressurizer heaters. The defective heaters were electrically bypassed and the unit was operated from mid-July 1981 without these heaters until the end of the next cycle in September 1982.

2.2.3 Rancho Seco November 21, 1986

Prior to the event, the reactor was in cold shutdown with the primary system at 50 psig and 82F with one loop of shutdown cooling flow providing decay heat removal. The RCS had been drained to 21.5" above the centerline of the hot leg nozzles (below the 0% pressurizer level) for work on the once-through steam generators. During refilling of the RCS, the operating crew proceeded to the point where they expected a level indication in the pressurizer. Primary system liquid level indication is provided by four level channels in the pressurizer. However, the operating crew had no indication of a change of level in any of the four channels, so they requested the assistance of an I&C Technician to determine if the level channels were operating correctly. The I&C Technician determined that the "A" and "D" channels had a positive indication, but that the "B" and "C" channels were still reading zero. The technician was aware of work that could have affected the operability of Channels "B" and "C," and he related this information to the control room as a possible explanation for Channels "B" and "C" not indicating. Subsequently, the operators observed the "A" channel to come on scale and indicate that the pressurizer level was approximately 140 inches. The I&C Technician related that Channel "A" appeared to be operating properly. The operating crew assumed the increase was due to the corrective actions of the I&C Technician and the pressurizer water level indication for Channel "A" was operable. The operating crew began filling the RCS based only on the Channel "A" indication.

Based on the assumption that the Channel "A" indication was accurate, and because it had risen to approximately the proper level during the RCS filling operation, the operating crew proceeded with drawing a bubble in the pressurizer, so the pressurizer heaters were energized. Approximately two minutes later, an electrical feeder breaker for a bank of two pressurizer heaters tripped. About 6 minutes later, a second pressurizer heater feeder breaker also tripped. The operating crew deenergized the remaining pressurizer heaters and suspended further operations to investigate the cause of the breaker trips. No direct cause for the breaker trips was apparent, so the operating crew assumed that an undefined breaker malfunction was causing the trips. The heater breakers were reset and for the next three hours several subsequent pressurizer heater breaker trips occurred. As permitted by procedure, each time a breaker tripped, the crew attempted to reset the breaker one time. Following this course of action on an as-needed basis, eleven of the thirteen heater groups in the upper bundle were damaged because they had been energized without being covered with coolant. Also, the top heater element in the middle pressurizer heater bundle was deformed and the next four lower elements were discolored.

NOTE: Seven of the thirteen upper heater bundles did not electrically short and continued to produce heat in the pressurizer for the six hour duration of the operating cycle.

The licensee concluded that while heating up the pressurizer to produce a steam bubble, the water level in the pressurizer dropped below the level of the upper heater bundle. (A subsequent analysis by Babcock & Wilcox (B&W) assumed a 12"-15" water level in the pressurizer.) The pattern of heater damage provided strong evidence that the upper heater bundle was substantially or totally uncovered during the event. Damage to the middle heater bundle indicated that only a small portion of the middle heater bundle was uncovered.

Inspection of the four pressurizer level channels showed that level Channels "A" and "D" were in error (Channel "D" shares a common reference leg with Channel "A"). Channels "A" and "D" were in error due to improper filling of their reference leg, or failing to backfill the reference leg. Channels "B" and "C" were indicating the correct pressurizer level, although they had been declared inoperable during the event.

B&W analyzed the uncovered pressurizer heater transient to determine the acceptability of selected pressurizer components for future operation. The analysis observed that a pressurizer heater element is capable of reaching 1100F in about 1.5 minutes after energization, and an ultimate temperature of 2200F without liquid cooling. At this temperature, a heat flux of 2.7 million Btu/hr was estimated for 1.5 bundles (the total upper bundle and half the middle bundle) of exposed pressurizer heaters.

Without water cooling, this quantity of energy was transferred by radiant heat to the pressurizer shell surface and increased the temperature of the shell. The maximum base metal and clad temperature of the pressurizer was conservatively calculated to be 919F and 1002F, respectively. With these temperatures, the thermal analysis concluded that the structural integrity of the pressurizer was acceptable and only the upper and middle heater bundle needed replacement. The B&W analysis only calculated the temperature induced stress on the pressurizer shell because primary system pressure during the event was almost constant and very low (approximately 40 psig) and was not a significant contributor to the total stress induced on the pressurizer.

B&W also calculated the detrimental effects of a hypothesized water-slap to the pressurizer. This event could have occurred if recovery (a rapid rise in pressurizer water level) operations had been successful at Rancho Seco. If it was assumed that the water-slap would occur at the most conservative condition, i.e., at the end of a heater actuation interval, the hot cladding surface (1000F) of the pressurizer would instantaneously be subjected to a bulk fluid temperature of 200°F. During the hypothesized water-slap event, the pressurizer clad surface would experience high tensile surface stress (approx. 100 ksi) in excess of the clad material yield stress. Although the surface clad stresses were well above their yield stress, the calculated base metal stress (10 ksi) was very much below the bulk material yield stress. Thus, the hypothesized water-slap event, for the conditions analyzed at Rancho Seco, was not significant.

3. FINDINGS AND CONCLUSIONS

Events involving damage or malfunction of the pressurizer heaters are not reportable and the information that was retrieved does not cover all needed aspects of the respective events. Perhaps there may be only three events of energized pressurizer heaters being uncovered at a PWR. There is approximately 700 reactor years of PWR operation, so the probability of a pressurizer heater being uncovered is less than 0.005 per reactor year. There is only one known event of the pressurizer heaters producing localized heating to the primary system pressure boundry. Apparently, events associated with the pressurizer heaters being energized while uncovered have a very low probability of occurring and based only on statistics, these events do not warrant additional regulatory concern.

Events of malfunction of liquid-filled reference legs of liquid level instrumentation continue to recur. All malfunctions produce unconservative readings--an indication of a falsely higher liquid level than the true liquid level.

The event with Rancho Seco in cold shutdown, resulted in overheating a portion of the primary system pressure boundary to approximately 1000F without subsequent pressure boundary consequence. The event analyzed by B&W is not conservative with respect to the total (the coincident combination of ultimate hot spot temperature and maximum intended design pressure) stress that could be reasonably postulated with the event occurring in Mode 1 operation or following an overcooling transient. If the pressurizer heaters were to uncover during power operation, without subsequent operator action, the 1000F hot spot temperature at Rancho Seco, may be exceeded because:

(a) The initial temperature of the pressurizer would be approximately 650F (temperature of saturated steam at reactor pressure) and substantially higher than the 200F cold shutdown temperature at Rancho Seco. The higher initial temperature would likely result in a higher hot spot temperature because a lesser magnitude of temperature increase is needed and due to a reduced heat conduction temperature gradient to the primary system.

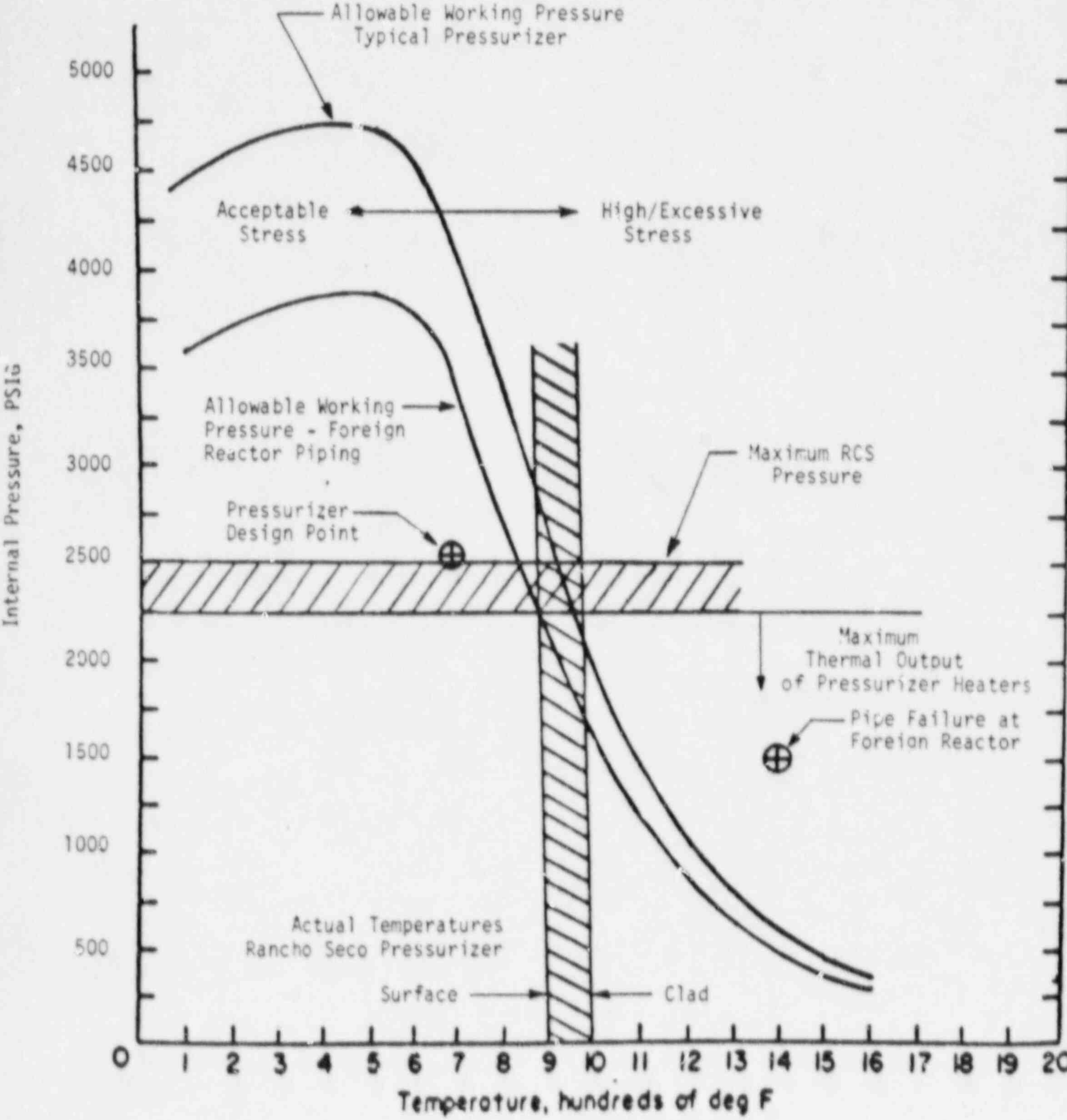
(b) The analysis of Rancho Seco assumed approximately 50% of the heater bundles became uncovered. There is no physical constraint to prevent additional heater bundles from uncovering.

In addition to the ultimate hot spot temperature concerns, the event at Rancho Seco was not analyzed for induced stress from internal pressure because primary system pressure was only 40-50 psig throughout the event. If this event were to occur at the maximum anticipated primary system pressure (2485 psig, the pressure when the pressurizer safety valves begin to open) the pressure induced stress component may contribute to the hot spot stress.

Figure 2 is a temperature-internal pressure depicition of the operating conditions discussed in this report and their safety concern. The two curves in figure 2 illustrate the apparent decrease in allowable internal working pressure with increasing temperature at the foreign reactor (lower curve) and a typical pressurizer (upper curve). Each curve is based on the weakening of carbon steel with increasing temperature as the ASME Code, Section III does not tabulate allowable stress above a temperature of 700F for pressurizer alloys. The two dots are the design point of a typical pressurizer (2500 psig at 700F) and the point of piping failure at the foreign reactor (1500 psig at 1400F). The design point for the typical pressurizer is well within the acceptable low stress area of its respective working pressure curve vis-a-vis the actual condition of the piping at the foreign reactor is significantly displaced into the unacceptable area of its working curve, and hence, its ensuing failure.

The vertical hashed bars represent the maximum temperatures (900F surface and 1000F clad) analyzed for the pressurizer overheating event at Rancho Seco. The lower bound of the hashed area of the horizontal bar is the highest reactor pressure (2225 psig) at maximum pressurizer heater thermal output (both backup and proportional heaters may be 100% energized). Note that the lo-lo pressurizer level heater cut-off may not provide heater protection with a faulted or voided liquid level reference leg. The upper horizontal bound is maximum RCS pressure (2485 psig); the lift pressure of the pressurizer relief valves. The cross hatched rectangle formed by the intersection of the vertical and horizontal bars represent conceivable operating conditions of maximum vulnerability of RCS

Figure 2. Allowable Working Pressure for Typical Pressurizer and Piping at Foreign Reactor



integrity. This range of conditions is not entirely bounded within the acceptable area of the allowable working pressure curve of the pressurizer and thus, may be indicative of excessive stress of the RCS pressure boundary.

As there is no explicit preventive limitation from this event recurring at more unfavorable conditions than the event analyzed by B&W, an evaluation of the margin of safety, for a postulated event of uncovered pressurizer heaters causing localized overheating to 1000F of the reactor pressure boundary at accident pressure (2485 psig) conditions, should be performed to determine if this issue should be considered for further regulatory pursuit.