Evaluation of the Pool Temperature
Limit for the Ramshead SRV Discharge Device

I. Introduction and Summary

For BWR plants, safety/relief valves (SRV) are used for reactor vessel pressure relief for either anticipated transients or accident situations. These valves are installed on the main steam lines of the reactor system. Discharge lines from the valves are routed to the suppression pool. Upon valve opening, the steam is piped to the pool through the discharge lines where it is condensed. A discharge device affixed to the discharge pipe beneath the water level in the suppression pool serves to mix the discharged air and steam into the pool area. The most common discharge device in use today is the ramshead type which consists of two 90° pipe elbows welded together 180° apart.

During SRV operation, when air and steam are discharged into the suppression pool, vibratory loads are imposed on the containment structure and components within the pool due to bubble formation and subsequent collapse. The characteristics and magnitude of the load profile are dependent upon the type of discharge device, the temperature of the pool, and the mass and energy discharge rate.

For the ramshead device, the two most significant loads occur during vent clearing and subsequent steam condensation. When the latter loading condition occurs at elevated pool temperature, condensation becomes unstable and significantly higher loads have been observed. As a result, GE has proposed a pool temperature limit for all plants using ramshead devices to avoid operation in this unstable condensation zone. GE's proposed threshold for unstable condensation is 150°F for the bulk pool and 160°F locally. Justification for the limit was supplied to the staff by GE in the form of topical reports (Ref. 1 and 2). The reports contain the experimental data base which was used by GE to establish the temperature threshold. This concern deals with the past problem that occured at a plant located in Germany which resulted in leakage from the wet well.

We have recently completed our review of the GE supplied justification for the pool temperature limit. We and our consultants (BNL and MIT) (Ref. 3) have concluded that the data base by itself is not sufficient to support the GE proposed temperature threshold because of a lack of full or large scale SRV ramshead discharge load data. Primarily, the base consisted of small scale elbow and straight pipe data long with small scale ramshead tests with no scaling analysis provided to show the direct applicablity of such data. Results showed substantial data scatter.

Limited plant operational data were also provided which indicated that local pool temperatures of approximately 165°F have been experienced during a stuck-open SRV event without observable structural damage. This evidence can be considered as supporting data for the limited mass flow-pool temperature zone experienced. It, however, cannot be considered as the operational basis for all potential events.

We, therefore, have concluded that the GE bulk suppression pool temperature threshold of 150°F cannot be completely supported with the existing data base using a ramshead type discharge device. It can, however, be concluded that the actual temperature threshold is in the vicinity of the GE proposed limit (i.e., about 150°F). In light of our current understanding of the ramshead and since actual plant pool temperatures could approach the GE proposed limit, we believe a quencher type should be used to replace the ramshead to preclude the unstable condensation phenomena. The basis for this conclusion follows in Section II in this report.

Quenchers have been in use for several years in foreign based plants. The device was developed to improve the performance at elevated temperature as well as reduce the air clearing load.

The principal behind the quencher type device is to promote the creation of large surface areas of formed bubbles of air and steam for rapid mixing and diffusion rather than the jet type discharge of a ramshead device. Thus the quencher consists of pipe sections that contain many small holes either uniform or graduated along the surface to promote and enhance diffusion and condensation in the pool areas. Typically they are referred to as either the cross or T types depending upon their geometrical configuration.

The data base for several quencher type designs has demonstrated superior performance at elevated pool temperatures. Characteristically, a quencher type device has not exhibited a temperature threshold based on the test data generated to date. Pool temperatures have approached the boiling point (i.e., T $>$ 90°C) without any noticeable load increases. Hydrodynamic loads on structures during vent clearing also are reduced due to the inherent better distribution of steam/air mixture in the pool. These advantages of a quencher device would improve the safety margin of the plant.

In summary, we have concluded that a design basis suppression pool temperature limit has not been adequately established for the ramshead device on the basis of the available data base. Further we believe that even if full-scale ramshead testing were performed, it is likely that a temperature limit will be established such that operator action would be required during relief valve discharge transients in order to ensure that the pool temperature limit would not be exceeded. (Note: Full-scale ramshead testing at elevated temperatures to establish a design basis pool temperature limit has not been proposed to date). Therefore, in the absence of any further information on the ramshead, and considering the improved margins available, we conclude that the quencher type device should be used in all BWR plants with water pressure suppression containments. The comparative benefits are shown in the following table.

The question regarding continued operation of Mark I's using ramshead devices needs an answer. The relief valve loads are cyclical in nature, creating the potential for fatigue degradation of the containment. For operating Mark I plants, we have determined that there is sufficient fatigue margin to permit continued plant operation while a new discharge device is being developed and installed. While some damage to the torus internals has been observed due to apparent SRV operation, there has not been a loss of containment integrity or function in any case.

Ramshead vs. Quencher Device

Summary of Evaluation

Device	Temperature Limit	Steam Condensation Remarks	Air Clearing Loads on Structures (Monticello Inplant Test)
Ramshead	150°F	1. Test data do not support the GE proposed limit.	+21 psi
		2. Severe vibration occurs if the limit is exceeded	-10 psi
Quencher	190°F	1. Test data show no severe vibration for tank water temperatures approaching the boiling point.	* +6 psi
		2. Steam condensation loads are about $\pm$2.2 psi	-5 psi

* Based on the preliminary results reported by GE

II. Evaluation of Supporting Data for Ramshead Device

In late 1975, GE submitted a topical report (Ref. 1) to support the temperature limit for the ramshead device. The report, however, contained test data of SRVs having a straight down pipe discharge device and no data for the ramshead device. As a result of our evaluation, we have concluded that the data base did not support the proposed limit. Additional information was requested.

In response to our request, GE provided additional data in the form of a memorandum report (Ref. 2). This report contained three sources of test data; i.e., subscale test data of ramshead and elbow devices, small scale test data of straight down pipes, and plant operational data. Results of our evaluation of this report are discussed below.

2.1 Local and Bulk Temperature Differences

Local temperature is referred to as the water temperature in the vicinity of the discharge device, but not in contact with the steam bubble. Bulk temperature, on the other hand, is a calculated temperature which assumes a uniform pool temperature. Bulk temperature is normally used for pool temperature transient analyses. Since the test facilities are confined pools, the measured temperatures are considered to be local temperatures. This has been confirmed through evaluation of the test data. Generally, the test results show less than 2 to 3° variation within the test pool.

To allow proper interpretation of the test data, GE performed a test at the Quad Cities plant. The pool was instrumented with 18 thermocouples. Six of these were located in the vicinity of the discharge device to determine local pool temperatures. The test was conducted by continuously discharging an SRV into the suppression pool for 27 minutes. Throughout the transient, the results showed that the measured local temperature did not deviate from the calculated bulk temperature by more than 10°F. Based on this result, GE has suggested that a difference of 10°F between local and bulk conditions be used. We concur with this evaluation of the test data.

Based on this temperature difference, therefore, the GE proposed 150°F bulk temperature limit is equivalent to a 160°F local temperature. Test results then represent local temperature conditions. The following data evaluation was based on this assumption.

With respect to the quencher device, the magnitude of the difference between the local and bulk temperatures has not been established due to the lack of an adequate data base. However, in-plant tests, which have been planned by the applicants, are expected to provide the necessary data base. We will continue our review of this matter when the test data becomes available.

2.2 Sub-scale Ramshead and Elbow Data

Sub-scale tests were performed at Moss Landing Test Facility and in a separate test facility in San Jose, California. These consisted of seven tests using a ramshead and 37 tests using a 90°F elbow. The mass flux ranged from 50 to 195 lbm/sec-ft^2. The local threshold temperature for steam condensation instability calculated by GE for each of these tests ranged from 152 to 176°F for the ramshead and 146 to 172°F for the elbow.

As a result of our evaluation of the above data, we find the data base insufficient to fully establish the ramshead threshold temperature due to the following:

a) Scaling Law Application: We know from our experience with the Mark I pool swell phenomenon and from the work that has been done by the Mark II owners group on steam condensation chugging that small-scale modeling laws are complex and must be established from fundamental principles and carefully applied in model testing. No such modeling laws have been derived for the SRV discharge phenomena. Test facilities were not scaled to simulate an actual plant. Therefore, neither dynamic nor geometrical similarities can be established by the tests. Further, GE has not justified the assumption that scaling has no effect on the temperature threshold.

b) Data Scattering: Substantial data-scattering appears in the sub-scale test results. As noted previously, the temperature threshold ranges from 146 to 176°F. With such a wide scattering, the probability for the temperature threshold to be below the GE proposed 160°F is high (16% of the sub-scale data points fall below the limit).

c) Fluid/Structure Interaction (FSI): We have learned from our investigiations in the pool dynamic loads area that the FSI effect is significant. This effect may explain the phenomena of data scattering as indicated above. Elbow tests generally

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show a lower temperature threshold than the ramshead tests. GE suggested that elbows tend to vibrate more than the ramsheads and, therefore, result in a lower temperature threshold. The ramshead tests in Moss Landing, a steel tank, also resulted in lower temperature thresholds than the ramshead tests (concrete tank) in San Jose. Flexibility of the test facility may influence the test result. FSI effect cannot be quantified without additional tests.

In short, we conclude that the applicability of the sub-scale test data cannot be supported without additional tests.

2.3 Small Scale Straight Down Pipe Data

This data set was obtained from tests performed in Germany. The tests used a straight down pipe and yielded 12 data points. The threshold was defined as the pool temperature at which the peak-to-peak pressure oscillation first reached 2 bar (29 psi) outside a circular projection with twice the pipe diameter on the floor of the tank. Results of the tests show that all data points fall below the 160°F limit. Therefore, the straight down pipe data, which is not directly related to the ramshead design, does support one concern about the inadequacy of the non-prototypical GE test data.

2.4 Plant Operational Data

The GE memorandum report (Ref. 2) provides actual in-plant data. Five plants have experienced SRV discharge into the suppression pools where temperatures in excess of 100°F were reached with no reported instabilities. Specifically, the highest pool temperature from those events ranged from 122 to 165°F. However, the report only provides detailed data for two plants which were identified as Plant A and Plant C.

Data indicate that Plant A was manually scrammed before the suppression pool temperature reached 110°F following a stuck-open event. The suppression pool temperature increased rapidly and reached 165°F when the reactor pressure was 184 psig. Plant C only reached 146°F because the reactor was scrammed at a lower pool temperature.

Figure 1 shows the loci of the Plant A and C events on a plot of pool temperature versus SRV steam mass flux during blowdown. Also shown in the figure is the GE proposed pool temperature limit. It is clear that the plants experienced SRV discharges far below GE's proposed temperature limit at virtually all mass fluxes except the lowest. Thus, their experience does not provide support for the higher mass flux at GE's proposed elevated temperature of 160°F.

III. Discussion of SRV Quencher Discharge Device Designs

In 1972, a European BWR plant with water pressure suppression containment experienced severe vibratory loads on the containment structure during extended SRV operation. The loads were severe enough to cause damage on the containment shell and components and resulted in water leakage from the suppression pool.

Following this incident, extensive experiments were conducted to investigate various discharge configurations. The objective of the investigation was to develop a device which would reduce the hydrodynamic loads during SRV air clearing and provide stable steam condensation. Varied configurations of the discharge device considering more than 20 design parameters were investigated. Results of the investigation concluded that the quencher type device yielded superior performance. Some of the test results are provided in the GE topical report (Ref. 1).

Figure 2 shows the configuration of a typical cross quencher, which is currently used by all Mark III containments. It has four arms. Each arm is perforated with several rows of small holes. The tip of the arm is plugged. It is about 10 feet long from tip to tip. Steam flows through the hub and is distributed among the four arms and discharged into the pool. The quencher device produces a cloud of air or steam mist, whereas the ramshead produces large bubbles.

As a result, the magnitude of the quencher air clearing load is reduced by a factor of two to four. In addition, steam condensation instability did not occur although the pool temperature approached the boiling point. The capability of the quencher to perform its function at elevated temperatures is also important in the event of an ATWS since elevated pool temperatures for the BWR 4 & 5 designs are expected to approach the boiling point.

Figure 3 (Ref. 4) shows the comparison of hydrodynamic loads for quencher and ramshead devices for a 238 GESSAR Mark III plant. The quencher device, in general, reduces the loads on the containment structure substantially, the magnitude of the load reduction being dependent on the quencher configuration and its relative location to the adjacent structures.

The data base supporting the advantages of the quencher over the ramshead design was developed in Germany following an incident that occurred at one of their BWR plants in 1972. In this incident, severe vibratory loads developed during ramshead discharges at elevated suppression pool temperatures. Subsequently, small-scale tests were performed in Germany at GKM which clearly indicated that hydrodynamic loads could be significantly decreased during vent clearing and steam condensation instabilities prevented when quenchers were used. Large-scale testing in Germany and the U.S. (Monticello) verified this reduction in hydrodynamic loads when using the quencher type discharge device. Additional testing on a small scale has also shown the temperature threshold for unstable condensation is increased to about 200°F using the quencher type device. GE is presently conducting full-scale confirmatory testing of its cross type quencher device at the Caorso plant in Italy. Additional testing on a full-scale plant has been performed in Japan at the Tokai 2 facility.

IV. Status of Current Program

This section summarizes the status of the ongoing programs being conducted to resolve the suppression pool threshold temperature issue for each of the BWR pressure suppression containment designs.

a. Mark I Containment

The operating Mark I facilities currently have Technical Specifications which limit the temperature of the suppression pool during normal plant operation. In addition, the bases for these Technical Specifications describe the administrative controls and corrective actions to be taken to minimize the temperature response of the pool in the event that an SRV remains open.

In December 1977, each Mark I licensee was requested to provide plant-specific analyses of the temperature response of the suppression pool for a series of design basis operational transients. These analyses were requested to determine the adequacy of the existing Technical Specification requirements. The results of all of these analyses are expected to be submitted by the third quarter of 1978.

The Mark I Long Term Program includes a number of specific tasks which will lead to the development of a quencher type device specifically for the Mark I containments. In-plant tests of a "T-quencher" device have been performed in the Monticello plant as a part of this program. Preliminary results from these tests (Ref. 5) indicate that the peak positive pressures for the T-quencher are about 25% of the ramshead pressure, while the peak negative pressures are about 50% of the corresponding ramshead pressure. Parametric testing is currently being conducted in a small scale (1/4) test facility. The results of these tests will be used to validate an analytical model for T-quencher load definition.

The Jersey Central Power Light Company has undertaken the development of an independent "Y-quencher" design for the Oyster Creek plant. The independent design was necessary because of the unique design of the Oyster Creek SRV discharge lines. The results of in-plant tests for this quencher design were submitted to the staff on May 11, 1978.

In a meeting with the Mark I Owners Group on March 9, 1978, we advised the utility representatives that we were preparing a position for management approval which would require the use of quencher discharge devices. Subsequently, most of the Mark I Owners indicated that plans are being made to implement quenchers. However, they were not in a position to commit to the installation of quenchers, since these plans had not yet received full approval from the management of each of the utilities. There are only a few of the Mark I Owners who have indicated any intention to pursue the continued use of a ramshead discharge device.

Since we do not believe that any further review effort will resolve the threshold temperature issue for the ramshead discharge device, we recommend that each of the Mark I Owners be required to commit to a schedule for the implementation of a quencher discharge device. This schedule would be consistent with our goal to have all safety significant modifications resulting from the Mark I LTP implemented by December 1980. In the interim, we will review the results of the plant specific suppression pool temperature response analyses to determine whether any changes are necessary for either the operational pool temperature limits or the administrative procedures used to minimize the suppression pool temperature response.

b. Mark II Containment

We have informed the representatives of the Mark II Owners group regarding our proposed position on the use of quencher type discharge devices. Currently, there are three Mark II plants with ramshead type devices under OL reviews; i.e., Zimmer, Shoreham and LaSalle; however, they have all recently committed to a quencher device. On June 28, 1978, the Zimmer applicant informed the staff that they would use the KWU T-Quencher. We now expect others to follow. A program and schedule will be provided to the staff in the near future to incorporate the quencher into the plant design.

Other Mark II plants such as WPPSS and Susquehanna are also using a quencher device.

GE is undertaking a full-scale test program of its quencher device at the Caorso plant in Italy. Additional tests were conducted at Tokai 2 in Japan. The Zimmer applicant has also committed to in-plant testing of their KWU type quencher.

c. Mark III Containment

Currently, all Mark III containments use the GE cross quencher. We have accepted a pool temperature limit of 185°F, which is the Mark III containment design temperature. This limit was accepted earlier on the basis of our evaluation of the data base provided in Ref. 1.

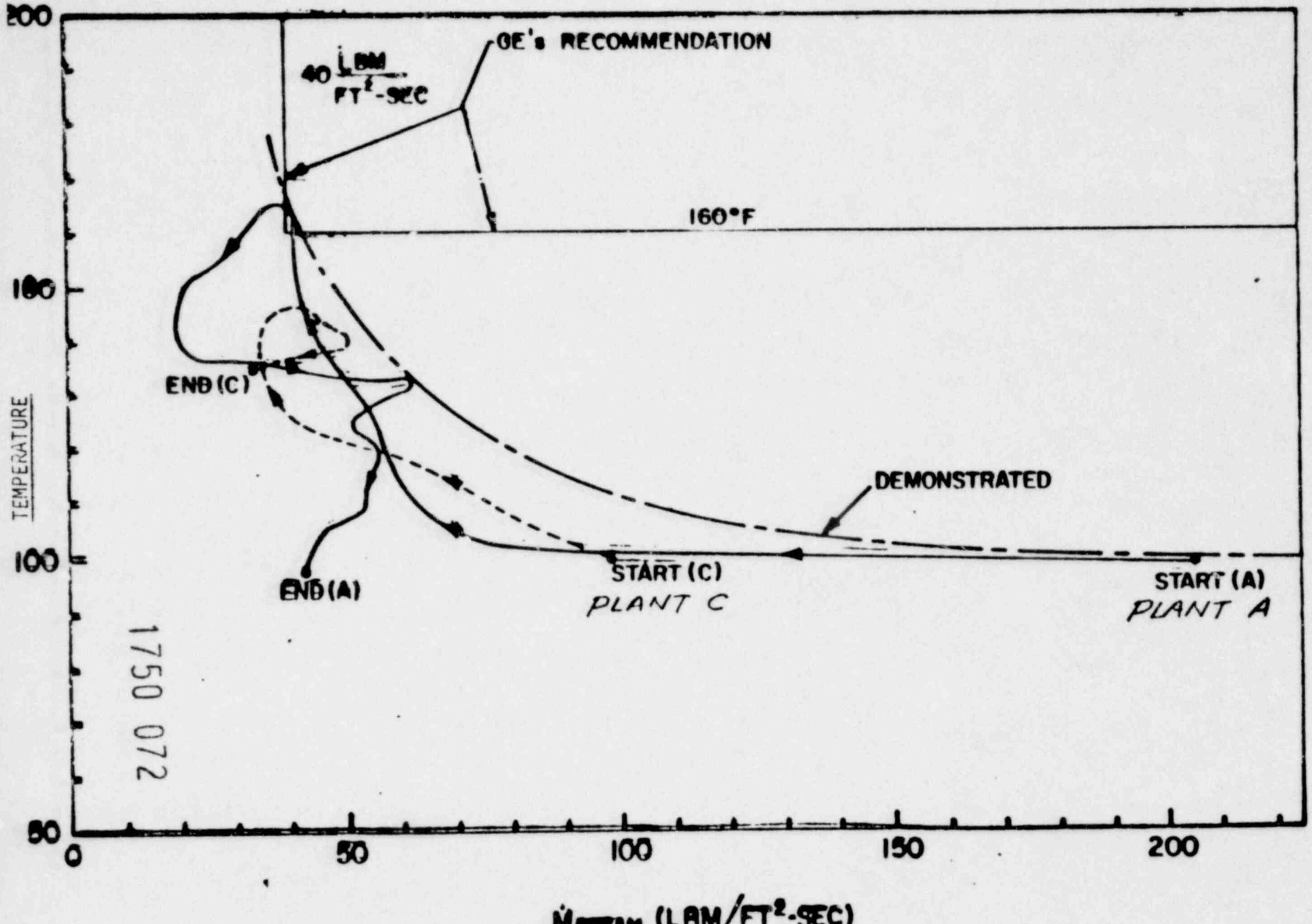

FIGURE 1 STEAM MASS FLUX

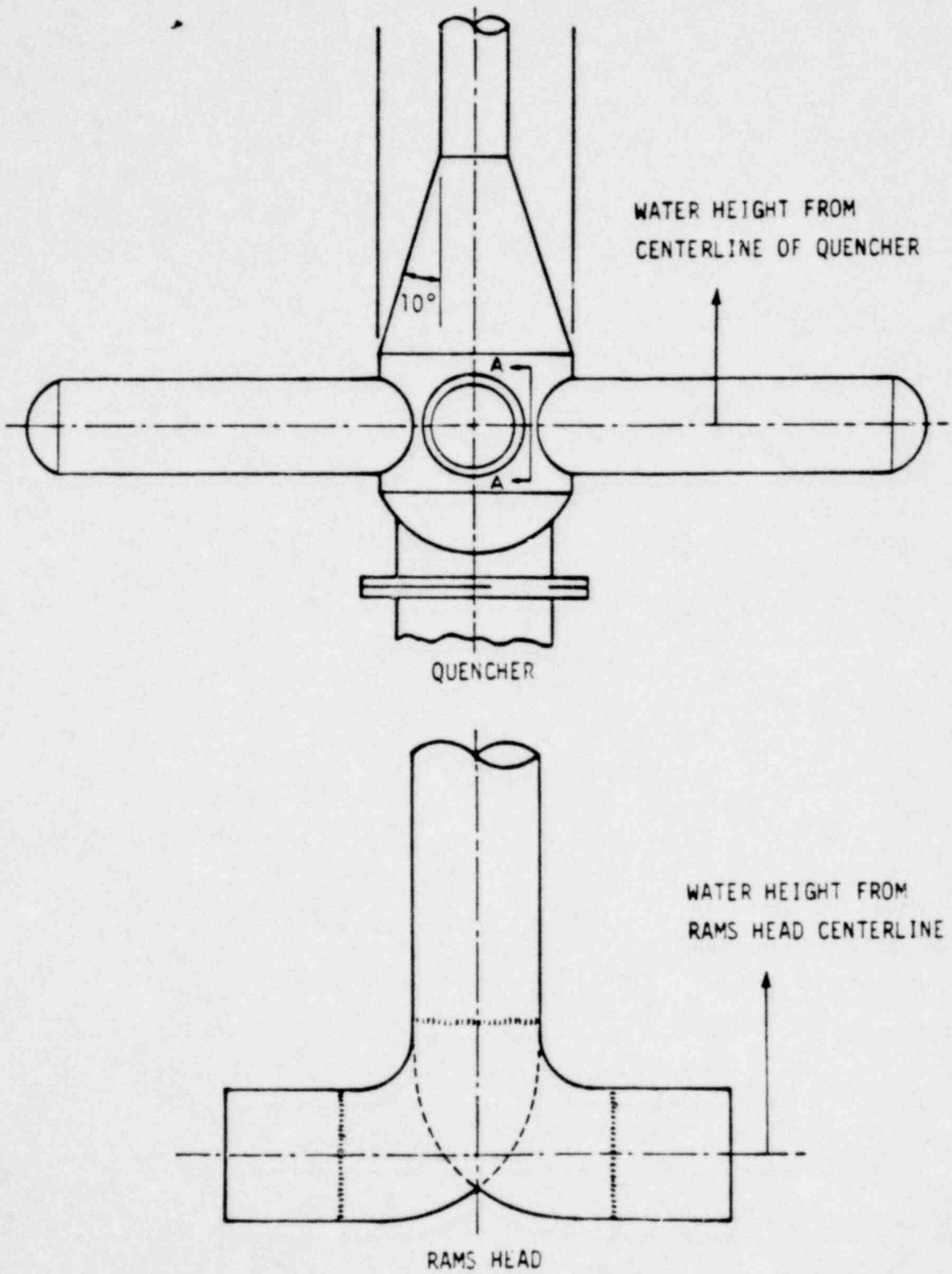

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Figure 2 Quencher and Rams Head Schematic

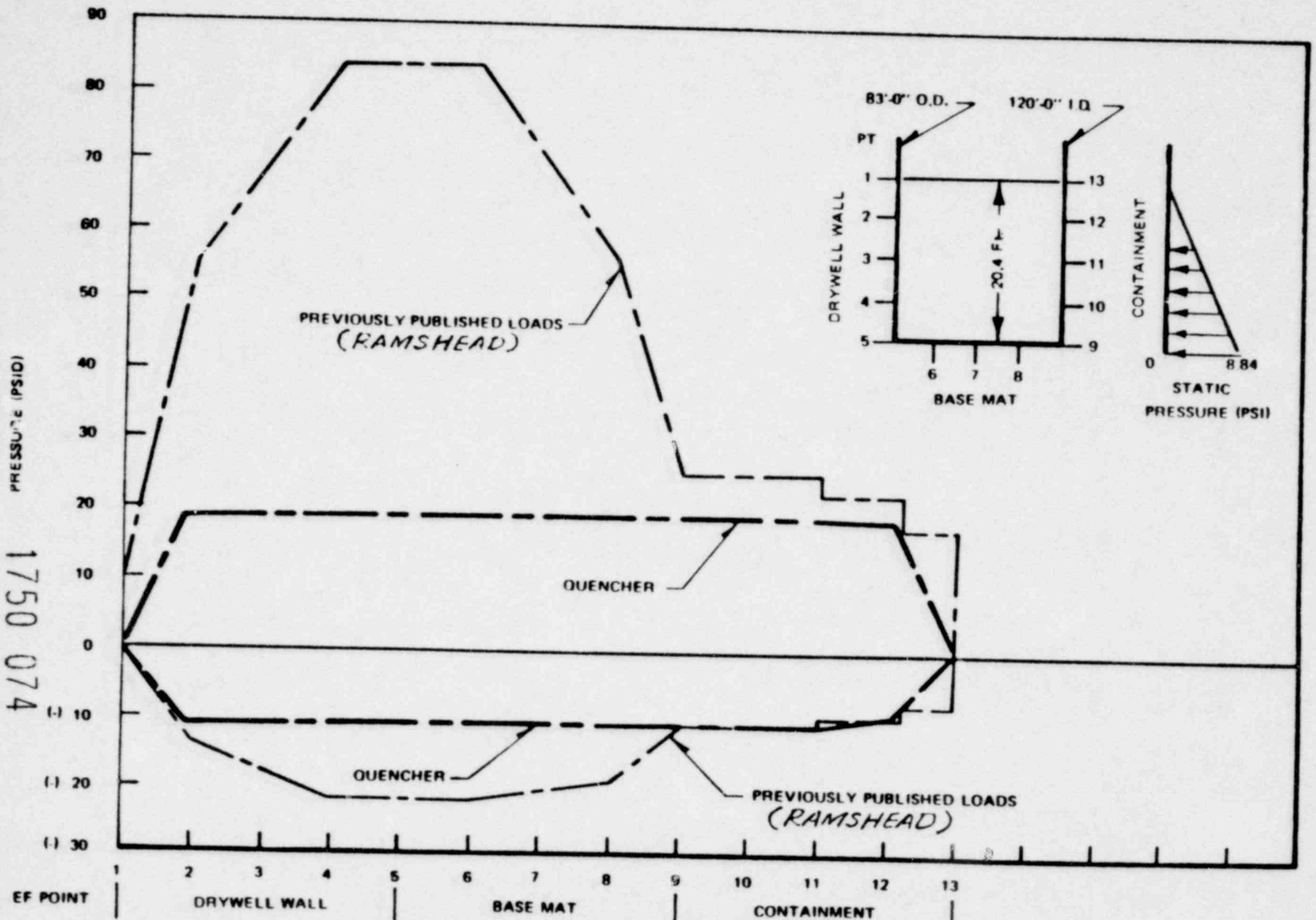

Figure 3 Mark III 238-732 Standard Plant 19 S/R Valves Wall Pressure at 0° to 360°

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Reference

1. General Electric Company Topical report, NEDE-21078-P, "Test Results Employed by GE for BWR Containment and Vertical Vent Loads, October, 1975.

2. General Electric Company Memorandum Report, "170°F Pool Temperature Limit for SRV Ramshead Condensation Stability," September, 1977.

3. Ain A. Sonin and C. Tung, "Comments on the Pool Temperature Limit for Avoiding Pulsating Condensation with Ramshead SRVs," February, 1978.

4. General Electric Company Topical Report, NEDO-11314-08, "Information Report Mark III Containment Dynamic Loading Conditions," (Final), July, 1975.

5. General Electric Company Report, "Mark I Containment Program, Program Activity Review," December,1977.