EVALUATION OF LEAK IN OYSTER CREEK CORE SPRAY SYSTEM

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Prepared by:

J. D. Abramovici
R. V. Furia
D. G. Jerko
J. Johnson (MPR)
J. P. Logatto
J. Nestell (MPR)
S. Schwartz

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Approved by:

G.R. Bond — 1-18-93
Director - Nuclear Analysis and Fuel — Date

— 1/15/93
Director - Engineering and Design — Date

GPU Nuclear
1 Upper Pond Road
Parsippany, New Jersey 07054

ABSTRACT

During the 1992 refueling outage (14R) at Oyster Creek, a leak was detected in the core spray annulus piping. A number of evaluations were performed to characterize the leak and determine if Oyster Creek can continue to operate with the leak. The following conclusions were reached: (1) The observed leak is an isolated weld defect that has opened a small path within the pipe inside diameter and the remaining portion of the weld is intact and will maintain the integrity of the piping. (2) The leak will not prevent the core spray system from performing its intended function under all design basis conditions and (3) the plant can operate safely for at least the next operating cycle.

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1.0 INTRODUCTION

During the Oyster Creek 14R refueling outage In-Service Inspection (ISI) of the reactor vessel internals, a leak was detected in the core spray system I piping between the vessel wall and core shroud in the annulus area (Figure 1). The leak was detected during an air test on system I when bubbles were observed coming from a weld on the down leg portion of the annulus piping (Figure 2). A video camera was able to determine that the leak was coming from a weld defect in a fillet weld on a pipe coupling.

The identification of the leak raises the following concerns: the cause of the leak, the loss of flow to the sparger through the leak, the structural integrity of the weld with the defect, and the potential for further degradation of the coupling or weld.

This report provides the technical evaluation that addresses these concerns. The evaluation addresses the structural integrity, material condition, leakage flow and performance of the core spray system with the leak. It is concluded that the leak will not prevent the core spray system from performing its intended function under all design basis conditions and that the plant can be operated safely with the leak in the system for at least the next operating cycle.

2.0 CORE SPRAY SYSTEM DESCRIPTION

2.1 Core Spray Spargers and Annulus Piping

The Oyster Creek reactor vessel contains two independent core spray sparger assemblies. Each core spray sparger assembly consists of two 180° segments of formed 3-1/2 inch Schedule 40S stainless steel piping, each of which contains 56 spray nozzles (112 nozzles total per sparger ring assembly). Each sparger is fed from an independent penetration through the reactor vessel. The pipe is 6" schedule 40 stainless steel from the reactor vessel nozzle in a down leg to a 6" standard weight "T" located next to the shroud and below the spargers. On either side of the "T" is a 6 x 5 inch eccentric reducer. Five inch schedule 40 stainless steel piping is then routed in either direction around the outside of the shroud for about 90° to a riser where it penetrates the shroud connecting to the two sparger segments. (Figure 1). The piping from the vessel penetration to the shroud penetration is known as the annulus piping. During the original installation, a coupling

(Figure 3) was used to allow the field installation of annulus piping to the penetration connection. This was accomplished by allowing for vertical adjustments and final fit up field fillet weld. The leak was observed from this field weld.

2.2 Core Spray System Flow Requirements

Each of Oyster Creek's two core spray systems contain a core spray sparger, two main pumps and two booster pumps. The current ECCS analysis[1] for OC is based upon a core spray flow of 3400 gpm (1 main and 1 booster pump) from one system and 2200 gpm (1 main pump) from the other system at a vessel pressure of 110 psig. To compensate for a previously found crack in the sparger, the flow requirements for system II are 3640 gpm when the system is the two pump contributor and 2360 gpm if it is the single pump contributor. Based on core spray system tests, the actual flow rates exceed the design basis by 500 gpm for system I and 300 gpm for system II. The curve of flow versus pressure used in the ECCS analysis is shown in figure 4.

3.0 INSPECTIONS AND TESTS

3.1 Inspection Techniques

A visual inspection of the core spray system annulus piping is performed each outage utilizing a video camera. During 14R the visual examination for the core spray annulus piping was performed utilizing General Electric's (GE) "Firefly," a remotely operated vehicle. All accessible areas of the piping were inspected in accordance with article IWA-2211 (VT-1) of reference 2.

When the visual examination is completed, an air test is performed on each core spray system sparger. Because of the configuration of the core spray piping, the upper spargers (System II) with downward pointing nozzles should fill completely with air while the lower sparger with upward pointing nozzles (System I) will only partially fill with air. The down leg between the reactor vessel penetration and the horizontal circumferential pipe run in the annulus should fill completely with air. All other piping will, at best, fill only partially with air or just pass air bubbles along its upper centerline inside surface.

3.2 14R Inspection Results

During the 14R outage air test of system I, a steady stream of air bubbles was observed from the annulus piping. The leak is located in a coupling that connects two ends of the 6" schedule 40 pipe in the down leg between the reactor vessel penetration and the circumferential pipe run. A closer video examination determined that the leak was from the weld joint identified as L-3A. Additional visual examinations were performed to better locate and characterize the leakage. This additional inspection confirmed that the indication in the L-3A fillet weld was circular and approximately one-eighth of an inch in diameter. Weld L-3A was 100% VT-1 inspected per reference 2 and was determined to be acceptable except for the 1/8" diameter round weld defect believed to be from the original construction which is now leaking[3].

A similar inspection was also performed on the system II annulus piping. No bubbles were observed from the annulus region. However, in the same weld (U-3A) as the system I weld (L-3A) and at the same relative location of the piping to the vessel wall as the defect in weld L-3A, two linear indication were detected. They were characterized as splits or tears between weld passes that appear to be construction related.

3.3 Previous Inspection Results

The annulus piping has been inspected in each of the Oyster Creek outages since 1978. No relevant indications have been found. Air tests were performed in each of the outages except for the 11R outage and no leakage was observed from the annulus region. Appendix A provides a summary of the inspections and results since 1978.

4.0 EVALUATIONS

4.1 Defect Evaluation

The visual inspection of the defect in weld L-3A shows it to be a rounded hole in the 1/4 inch fillet weld in the core spray annulus pipe coupling. The weld is a field weld and the defect appears in an area of limited access where the coupling is closest to the reactor vessel wall. The air test showed that the defect bubbled at a relatively high rate, consistent with a fairly open leakage path completely through the weld such as might occur if a slag inclusion was cleared out to create a leak path. The leak path is shown in Figure 5.

The characteristics of the defect are consistent with a weld defect in a portion of the weld that was difficult to access. The defect likely contained slag and/or lack of fusion and opened up after approximately twenty years service with normal cyclic stresses. This is the most probable cause for the leak.

Other postulated causes resulting in a through wall defect are fatigue or intergranular stress corrosion cracking (IGSCC) originating on the pipe or weld inside surface and joining with the visible defect in the weld. However, these latter mechanisms are considered to be highly unlikely based on the following observations.

- The high bubbling rate is consistent with a rounded hole with significant flow area. Air leakage through a tight fatigue or IGSCC crack in part of the weld or pipe wall would be expected to be much less than observed.

- Cyclic service loads are small and would not be sufficient to cause a fatigue crack to initiate. Fatigue crack growth of a small initial crack is predicted to be negligible (see Section 2.3.2).

- No IGSCC has ever been observed in any of the Oyster Creek annulus piping. No confirmed IGSCC has been observed in any part of the core spray system since 1978.

- If IGSCC were to appear, it would be expected to occur in the weld heat affected zone (HAZ) adjacent to the weld rather than in the weld itself. Weld metal is known to be more resistant to IGSCC than base metal. There is no evidence of IGSCC in the weld HAZ.

- If IGSCC has occurred, it had to originate in the pipe inside surface in a crevice area at the root of the socket weld. Such crevice-assisted IGSCC requires the presence of oxygenated water in the immediate vicinity of the crevice. However, the pipe internal environment near the coupling was stagnant before the leak occurred and contained little or no oxygen. The nearest source of oxygen was from the core spray sparger approximately twenty feet (48 pipe diameters) away.

Based on the above observations, it is concluded that the defect is a weld slag inclusion that opened up after the slag dissolved or after normal fatigue cycles caused the slag to loosen. While it is possible that crevice assisted IGSCC originating on the inside surface has occurred, this is considered highly unlikely.

Since it is not possible to prove the absence of IGSCC, an IGSCC crack was postulated to exist. Crack growth was considered on a worst case basis to determine the growth during one operating cycle (approximately two years). Crack growth rates for IGSCC were taken from NUREG 0313 and applied to a postulated 0.50 inch through wall crack in the coupling with an assumed yield level stress field in the weld heat affected zone. Under these conditions the circumferential growth was calculated[5] to be approximately 3.0 inches in a two year period. This crack length is structurally acceptable since the 1/4" field weld with this defect is still stronger than the 3/16 inch shop weld in the coupling. Further, the leak rate through the calculated 3.0 inch IGSCC flaw is less than 1 gpm, far below existing flow margins in the systems.

The indications on weld U-3A have been characterized as splits or tears between weld passes. The splits or tears have the same reddish color indicating that these are not new. If they were new indications, a shiny metal or reflection would probably be evident. The indications on weld U-3A are in the same location as the defect on weld L-3A facing the reactor vessel wall where the welding would be difficult. IGSCC, as stated above, is not expected to occur in the weld material. The conclusion is that these indications are construction defects and the weld is acceptable.

4.2 Structural Evaluation

The overriding factor in the structural evaluation of the core spray annulus piping is that the axial load capacity of the coupling is controlled by a 3/16 inch shop weld on the lower coupling sleeve (Figure 3). Thus, the 3/16 inch weld controls the axial strength of the coupling for all normal and postulated accident loads. Because of the weld size and diameter differences, the 1/4 inch weld with the leak could lose approximately 31 percent of its circumference (e.g., about 7 inches) and not reduce the axial capacity of the coupling.

The above not withstanding, finite element stress analyses[6] were performed to determine the stresses in the 1/4 inch fillet weld with the leak during normal operating and core spray injection conditions. The core spray annulus piping was modeled from the reactor vessel core spray nozzle where the thermal sleeve is rolled into the nozzle safe end to the upper core shroud where the 5 inch pipe is welded to the shroud (Figure 1). The annulus piping was assumed to be built-in at the core spray nozzle and upper core shroud and supported in the vertical direction only at the pipe supports attached to the outside diameter of the shroud.

The loads consisted of:

1. Deadweight of the pipe (including water inside the pipe).

2. Drag loads due to recirculation flow (19,000 lb/s) in the annulus between the reactor vessel and the upper core shroud.

3. Thermal loads due to differential thermal expansion between the annulus piping attachment points on the reactor vessel and upper core shroud, and thermal growth of the inlet piping. During normal operation the reactor vessel, upper core shroud, and annulus piping were assumed to be at 550°F. During core spray injection the reactor vessel and upper core shroud were assumed to be at 550°F while the core spray annulus piping was assumed to be at 250°F due to cooling from the incoming core spray flow. (Note: These temperatures correspond to the approximate conditions early in the core spray injection transient. Later in the injection transient the temperature conditions and resulting stresses are less severe.)

4. Pressure load during core spray injection. The pressure load is the difference between annulus pipe pressure and the reactor pressure and was assumed to be 35 psi based on hydraulic analyses described in Section 4.3 below.

5. Seismic load. The analyses were based on a conservative static seismic load of 5g assumed to act simultaneously in the three orthogonal directions.

The following load combinations were evaluated.

For normal operation:

1. Deadweight + Drag Load + Normal Thermal Load

2. Deadweight + Drag Load + Normal Thermal Load + Seismic

For core spray injection:

3. Deadweight + Accident Thermal Load + Pressure

4. Deadweight + Accident Thermal Load + Pressure + Seismic

Results of the finite element stress analyses of the core spray annulus piping are tabulated in Table 1. In this table, the calculated shear stress in the 1/4 inch fillet weld at the field coupling is tabulated for each of the above loading combinations. These stresses are based on a full 360° weld. The reduction in static strength of the weld due to the observed defect (1/8 inch hole) is considered to be negligible.

Table 1

Calculated Shear Stress in 1/4 Inch Fillet Weld at Field Coupling

Load Combination	Shear Stress (ksi)
Normal Operation	
1. $D + F_D + T_o$	0.8
2. $D + F_D + T_o + E$	4.1
Core Spray Injection	
3. $D + T_a + P$	3.2
4. $D + T_a + P + E$	5.8

As shown in Table 1, the calculated shear stresses in the 1/4 inch fillet weld during normal operation and core spray injection are well below typical ASME Code allowables for shear in a fillet weld (19 ksi at 550°F). Therefore, the System I core spray annulus piping is considered to be structurally adequate in its present condition. Further, at the calculated stress levels during normal operation, fatigue initiation and growth would be negligible.

Finite element stress analyses[7] were also performed to determine the stresses in the 1/4 inch fillet weld during the blowdown portion of a large break LOCA, but prior to onset of core spray flow. The highest fluid velocities and drag forces on the core spray annulus piping would be due to a complete instantaneous circumferential break of a recirculation line.

The drag force on the core spray annulus piping during a large break LOCA was conservatively calculated for a recirculation line break with a maximum flow rate of 45,000 lb/s[4]. The drag force was calculated to vary from approximately 32 lb/ft for saturated water conditions to 655 lb/ft for saturated steam. (Note: The drag force during normal operation is approximately 13 lb/ft.) The actual quality of the fluid in the annulus varies during the blowdown. A drag load of 655 lb/ft corresponding to saturated steam conditions was used in the bounding calculations. The loading combination evaluated was:

5. Deadweight + LOCA Drag Load + Normal Thermal Load

For the above loading combination, the shear stress in the 1/4 inch fillet weld was calculated to be 2.2 ksi assuming a full 360° weld. The required length of weld to withstand the applied loads at ultimate stress levels was calculated to be 8.5 inches (136° of the pipe circumference).

In addition to the stress analyses described above for LOCA blowdown loads, a hypothetical case was calculated in which the 1/4 inch fillet weld was assumed to have totally failed. Finite element analyses were performed to determine the relative displacement of the 6 inch pipes at the field coupling assuming the 1/4 inch fillet weld was cracked through wall 360° around its circumference. The loading was the same as described above, except the model of the inlet piping was decoupled at the field coupling.

For this hypothetical case, the lower pipe segment was calculated to displace downward 0.5 inches relative to the upper segment. The coupling was designed to have a nominal engagement of 1.0 inch. Based on the General Electric installation drawing and measurements from field video tapes, the actual engagement is estimated to be about 0.9 inches. Since the drag load assumed in these calculations is considered very conservative, the coupling is not considered likely to separate during the blowdown even if the weld were to fail completely.

These analyses demonstrate that the core spray system would be functional even if a substantial portion of the 1/4 inch fillet weld were to become cracked, although we believe this is highly unlikely.

4.3 Hydraulic Evaluation

Hydraulic analyses[8,9] were performed to determine the effect of the observed defect in the 1/4 inch fillet weld on core spray system performance. The design basis flow rate for core spray System I (with the leak in the field coupling) is 3400 gpm at a reactor pressure of 110 psig. Based on core spray system tests, the actual flow rates exceed the design basis flow rates by about 500 gpm for System I.

A hydraulic resistance model of the core spray annulus piping, sparger, and flow nozzles was developed (Figure 6). Calculations were performed at the design basis flow rate of 3400 gpm with an exit pressure of 110 psig for various cases as summarized below.

1. <u>Case 1.</u> No leak at the 1/4 inch fillet weld. Base case.

2. <u>Case 2.</u> A 0.125" diameter hole at the 1/4 inch fillet weld. This case represents the observed condition.

3. <u>Case 3.</u> A 3.0" x 0.0009" linear crack at the 1/4 inch fillet weld. This case represents an upper limit IGSCC flaw and includes the flow from the crack and the observed defect.

4. <u>Case 4.</u> A 0.015" gap 360° around the pipe at the field coupling. This case represents complete failure of the 1/4 inch fillet weld.

Results of the calculations are summarized in Table 2. In this table, the calculated flow loss at the assumed defect and the minimum nozzle flow rate (as a percentage of the nozzle flow rate for the base case) are tabulated.

Table 2

Results of Hydraulic Calculations
Core Spray System I

Case	Flow Loss Through Defect (gpm)	Min Nozzle Flow (% of Base Case)
1. Base Case	0	100.00
2. Observed Defect	0.4-2.7*	99.92
3. IGSCC Crack plus Defect	0.6-2.9*	99.91
4. Complete Failure of Weld	46	98.64

* Range of flows is due to assumed resistance of the crevices behind the weld. The higher value assumes no resistance from the crevice.

As shown in Table 2, the calculated flow losses are small compared to the available margin in core spray System I (500 gpm). Therefore, the flow loss through the observed defect in the 1/4 inch fillet weld, as well as worst case scenarios, is considered acceptable.

5.0 CONCLUSION

The observed leak is considered to be an isolated weld defect that, as a result of slag dissolution or years of cyclic stresses, has opened a small path with the pipe ID through gaps in the pipe coupling. The leakage flow is negligible and will not affect the performance of the core spray system. The remaining portion of weld L-3A is intact and insures more than sufficient strength to maintain the integrity of the coupling for stresses under all design basis conditions.

There is no evidence of IGSCC or on-going corrosion in the leaking weld and there is no history of IGSCC or crevice corrosion in other fillet welds that have been inspected at Oyster Creek exposed to similar environment and operating pressure. Even in the unlikely event that IGSCC does occur, there would be no significant degradation in core spray system performance for at least the next operating cycle.

The on-going In-Service Inspections will insure that the coupling will continue to be closely monitored to detect a change in the leak rate or new indications in the coupling.

6.0 REFERENCES

1. P. Wei and H. H. Paustian, "Oyster Creek Nuclear Generating Station SAFER/CORECOOL/GESTR-LOCA Loss-of-Coolant Accident Analysis," NEDC-31462P dated August 1987

2. ASME Boiler and Pressure Vessels, Section XI, 1986 edition

3. GPU Nuclear Topical Report, TR-093, "Oyster Creek Core Spray System Inspection Program - 14R Outage," dated January 8, 1993.

4. Oyster Creek Updated FSAR, Figure 6.2-11, Update 7 12/92

5. MPR Calculation No. 83-176-RNC-03 Rev. 0, "Annulus Piping Weld Crack Growth and Leakage Area," dated January 14, 1993.

6. MPR Calculation No. 83-176-RBK-01 Rev. 0, "Determination of Loads on Core Spray Annulus Piping Field Connection," dated January 14, 1993.

7. MPR Calculation No. 83-176-RBK-02 Rev. 0, "Determination of Loads, Stresses and Deflections During Recirculation Line Break," dated January 14, 1993.

8. MPR Calculation No. 83-176-DRM-01 Rev. 0, "Hydraulic Resistance of Core Spray Piping Between Reactor Vessel and Lower Sparger Outlet," dated January 14, 1993.

9. MPR Calculation No. 83-176-DRM-02 Rev. 0, "Determination of Leak Rate Through Crack at Field Connection in Core Spray Piping," dated January 14, 1993.

10. GPU Nuclear Topical Report, TR-080, "Oyster Creek Core Spray System Inspection Program - 13R Outage", dated April 8, 1991.

11. GPU Nuclear Topical Report, TR-054 (Rev. 1), "Oyster Creek Core Spray System Inspection Program - 12R Outage", dated January 17, 1989.

12. GPU Nuclear Topical Report, TR-037, "Oyster Creek Core Spray System Inspection Program", dated August 22, 1986.

13. GPU Nuclear Topical Report, TR-013, "Oyster Creek Core Spray System Inspection Program, Response to NRC I&E Bulletin No. 80-13", dated April 25, 1983.

14. Jersey Central Power & Light Company, Repair Proposal No. 475-01, OCNGS Core Spray System Sparger Repair, dated March 31, 1980.

15. Jersey Central Power & Light Company, Repair Proposal No. 320-78-1, OCNGS, Core Spray Sparger 2, dated November 15, 1978.

APPENDIX A

Previous Surveillance Tests (since 1978)

13R Outage[10] (1991)

Visual inspection of the core spray system annulus piping was performed utilizing a video camera with underwater auxiliary lighting. Due to access restrictions, a hand held camera technique was used to perform the examination. All accessible areas of the piping were inspected. No relevant indications were noted during the inspection or subsequent review of video tapes.

Observation of the core spray systems during the air tests was performed by utilizing a hand held video camera with auxiliary underwater lighting. No air bubbles were observed coming from the annulus piping.

12R Outage[11] (1988-1989)

Visual inspection of the core spray system annulus piping was performed utilizing a hand held video camera with auxiliary lighting. All accessible areas of the piping were inspected. No relevant indications were noted during the inspection or subsequent review of the video tapes.

Observation of the core spray system during the air test was performed by utilizing a hand held video camera with auxiliary lights. No air bubbles were observed coming from the annulus piping.

11R Outage[12] (1986)

The core spray annulus piping was inspected utilizing a hand held camera technique. All accessible areas of the piping were inspected. The visual examinations were performed by vendor personnel with the results evaluated by a certified Visual Level III. An independent overview of the results was performed by a independent certified Visual Level III. No indications that could be interpreted as crack-like were noted during the examination or post examination review. No air test was performed on the annulus piping.

10R Outage[13] (1983-1984)

The core spray annulus piping was visually inspected and no recordable indications were identified.

A limited visual air test of the System II vertical annulus piping was performed. No indications were noted in the System II annulus piping.

An ultrasonic examination was attempted on selected welds (fourteen) on the six and five inch diameter annulus piping. Due to access restrictions, seven welds were only partially examined. These welds included U7 (263°), L7 (305°), L8 (293°), L9 (301°), U8 (336°), U17 (295°), and U18 (286.5°). No recordable indications were identified in any of the seven welds inspected.

Following the completion of the 10R inspections, a review was conducted of the results along with the 1978/1980 results, and selected video enhancements performed in 1982. This review concluded that the annulus piping did not contain any indications and no cracks of structural significance existed. Further, the piping was structurally capable of meeting its design function.

9R Outage[14] (1980)

Visual inspections were performed and video tapes made of the core spray piping within the reactor vessel between the inlet nozzle and the vessel shroud. These tapes were reviewed by two qualified visual inspectors and two indications were classified as possible cracks. Both of these indications were on the 6" x 5" eccentric reducers of the System II piping. The larger of these two indications was classified by a third qualified inspector as marks made during installation. Review of the 1978 tapes did not provide any additional information since this inspection concentrated on the piping welds. The indications were later dispositioned as non-cracks (see 10R).

8R Outage[15] (1978)

A scheduled in-service inspection was performed of the reactor internals. This inspection included a visual inspection of the accessible portions of the 5" inlet piping between the reactor vessel core spray nozzles and the OD of the shroud. No visual indications were found on the annulus piping.

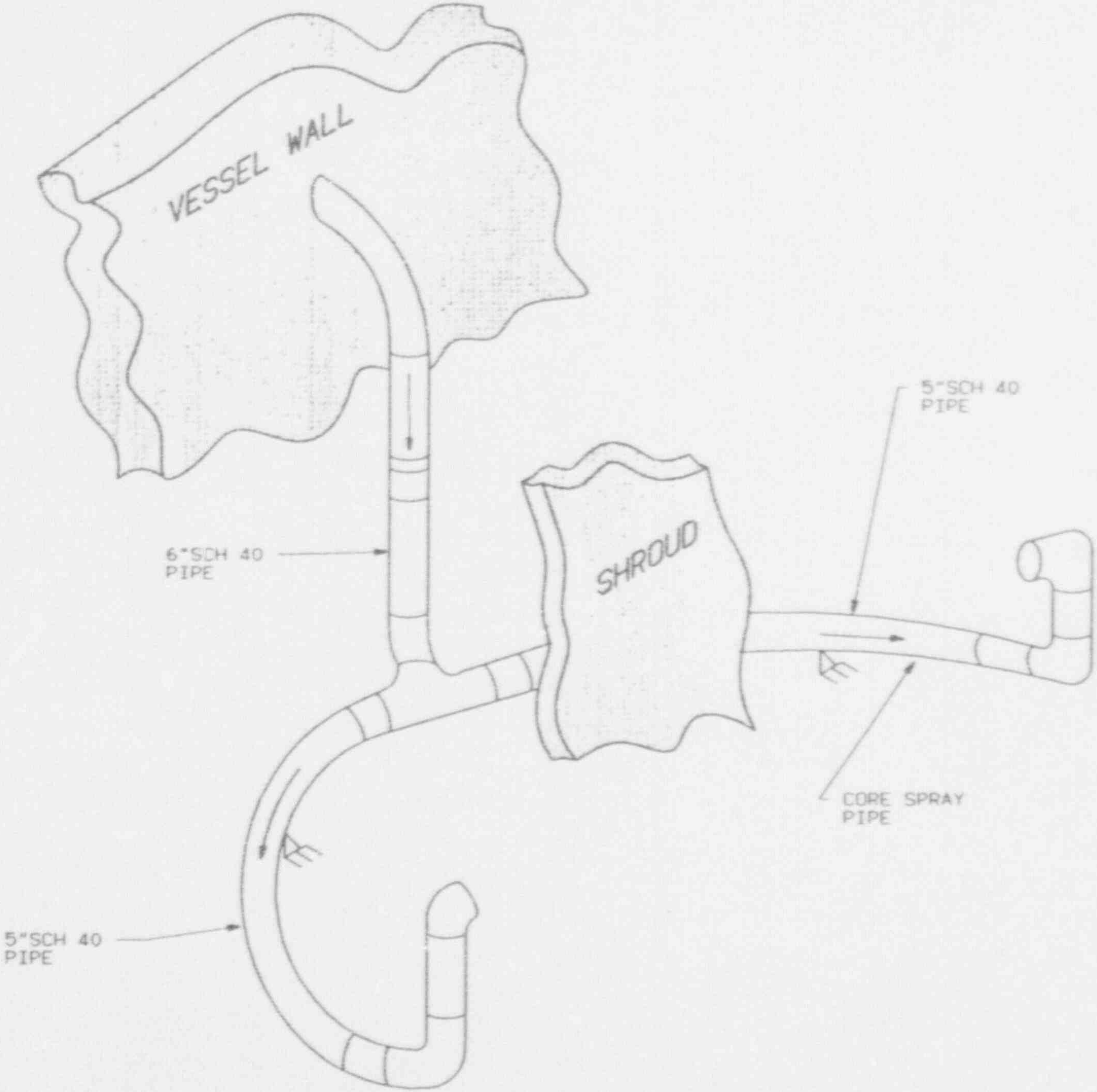

FIGURE I CORE SPRAY LOWER PIPING UNIT

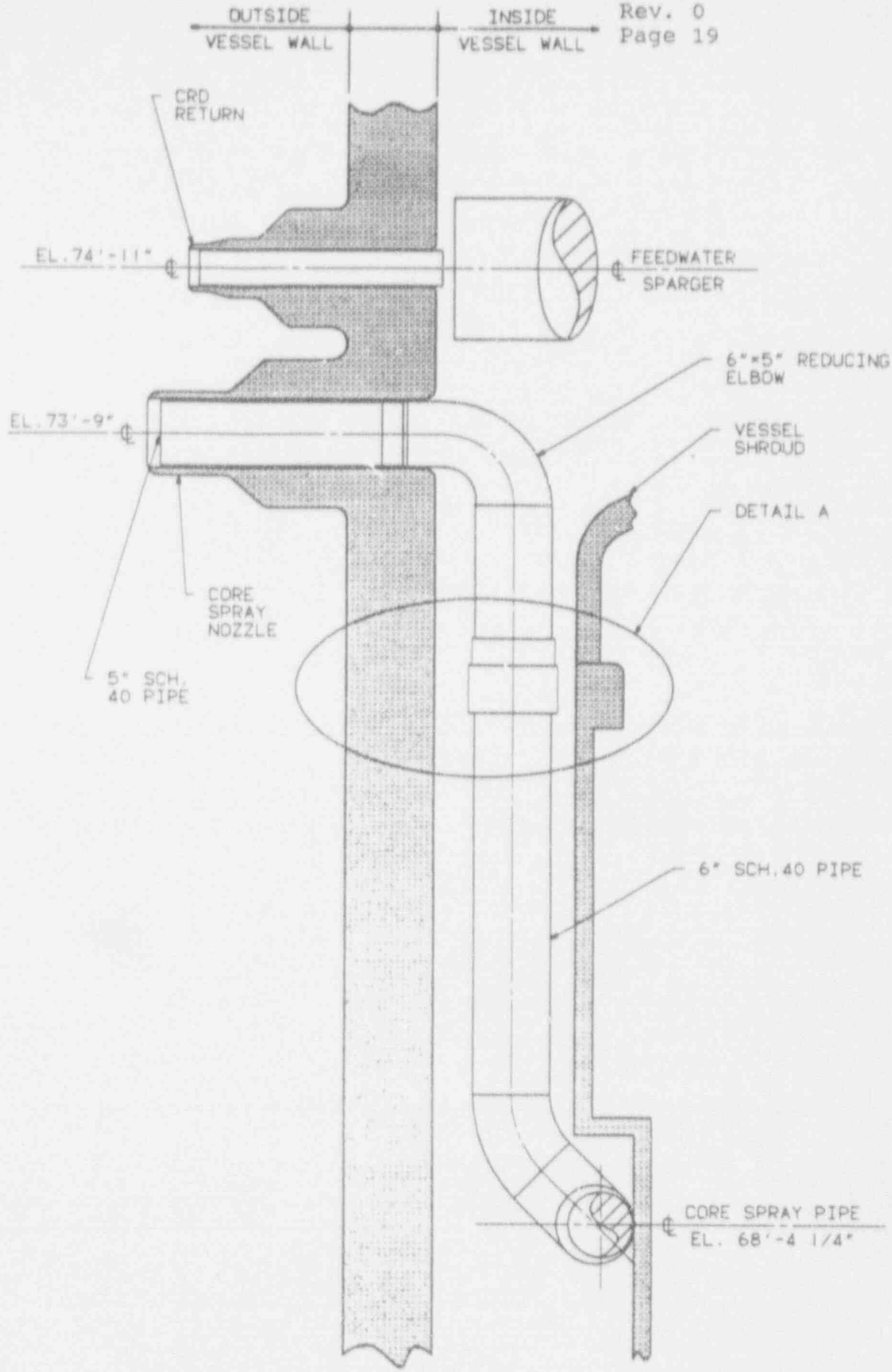

FIGURE 2 CORE SPRAY PIPING DOWNLEG

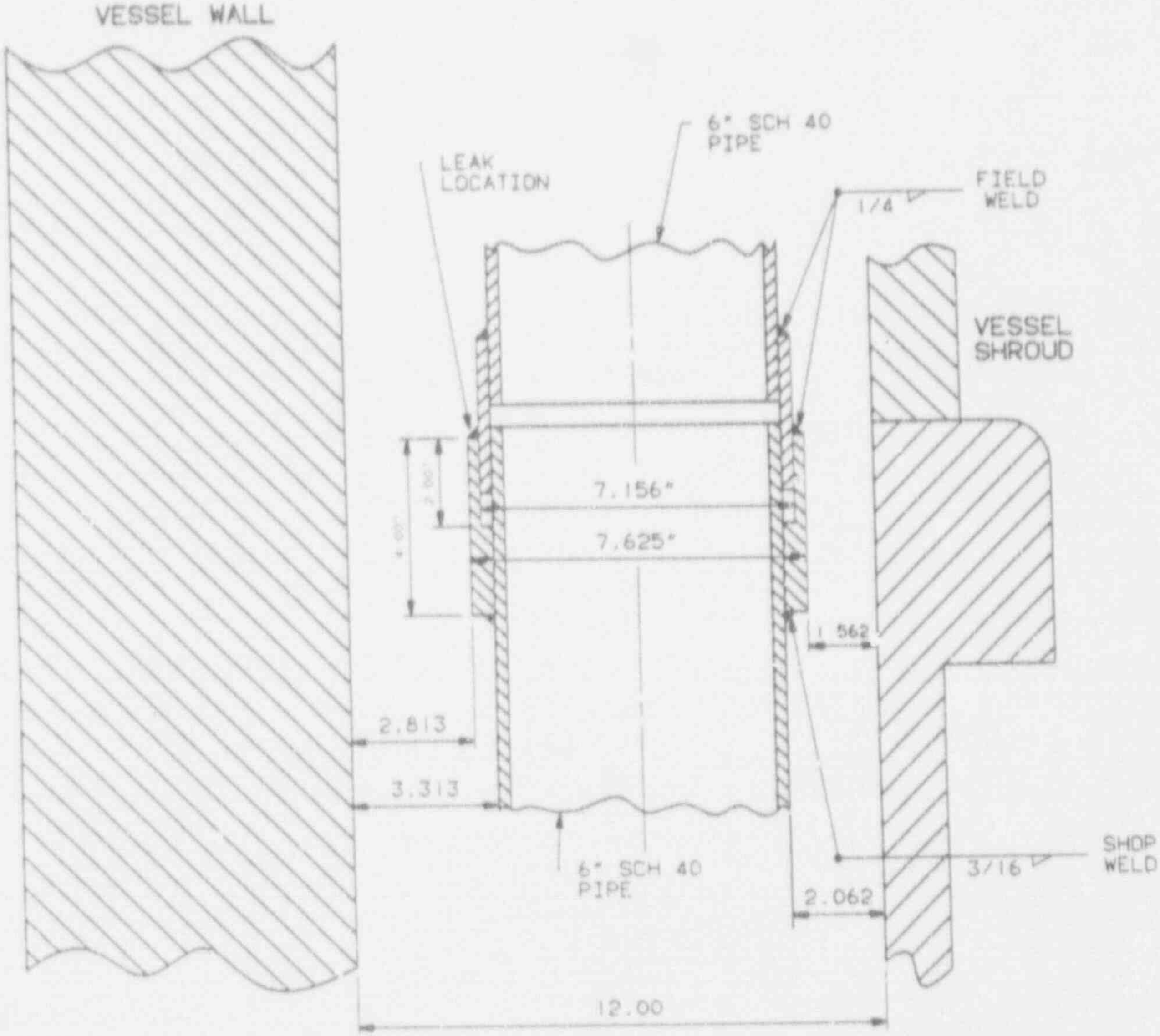

FIGURE 3 CORE SPRAY PIPE COUPLING

Core Spray System Flow Rates
Used in ECCS Analysis

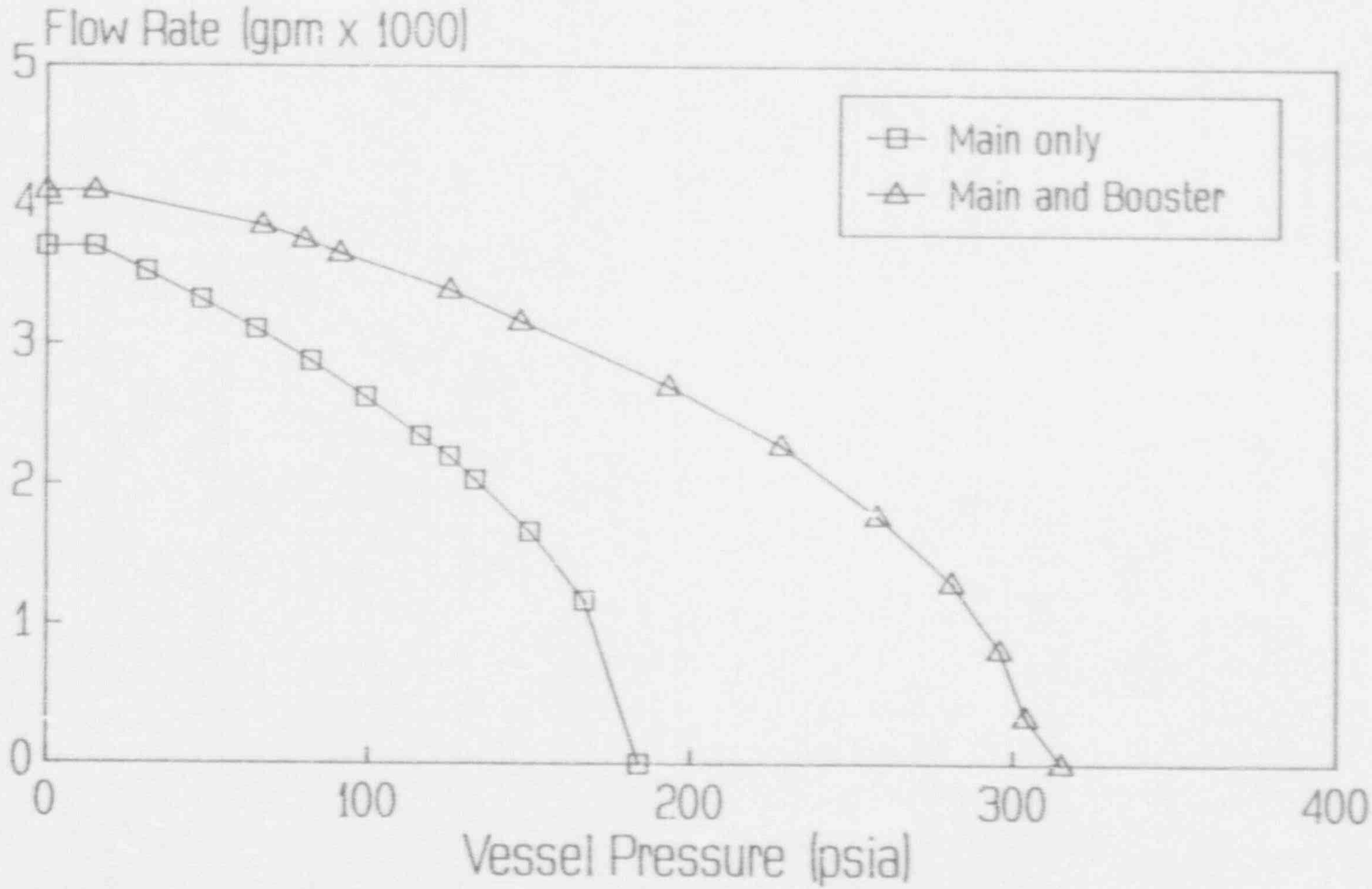

Figure 4

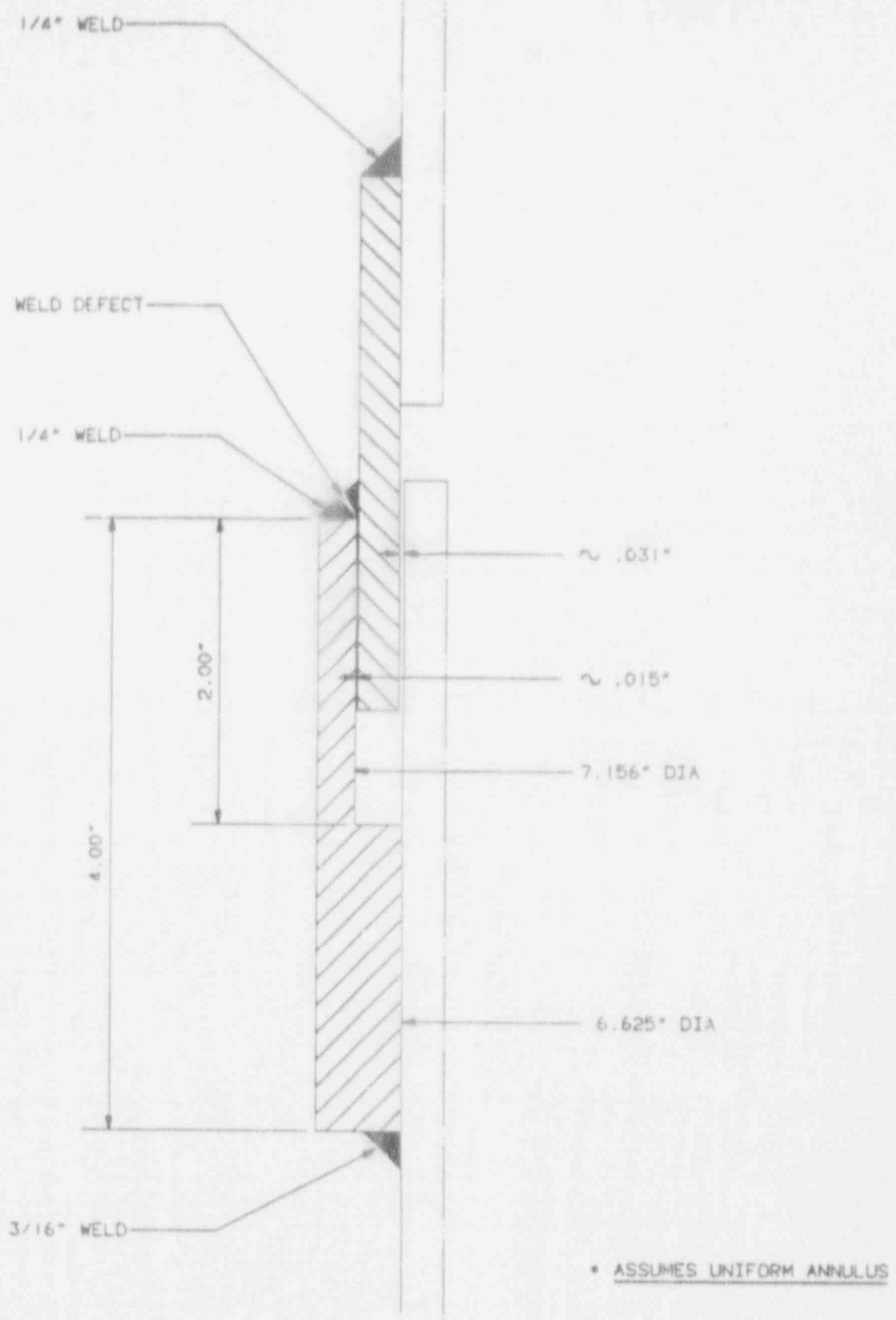

FIGURE 5 LEAK PATH FOR WELD DEFECT

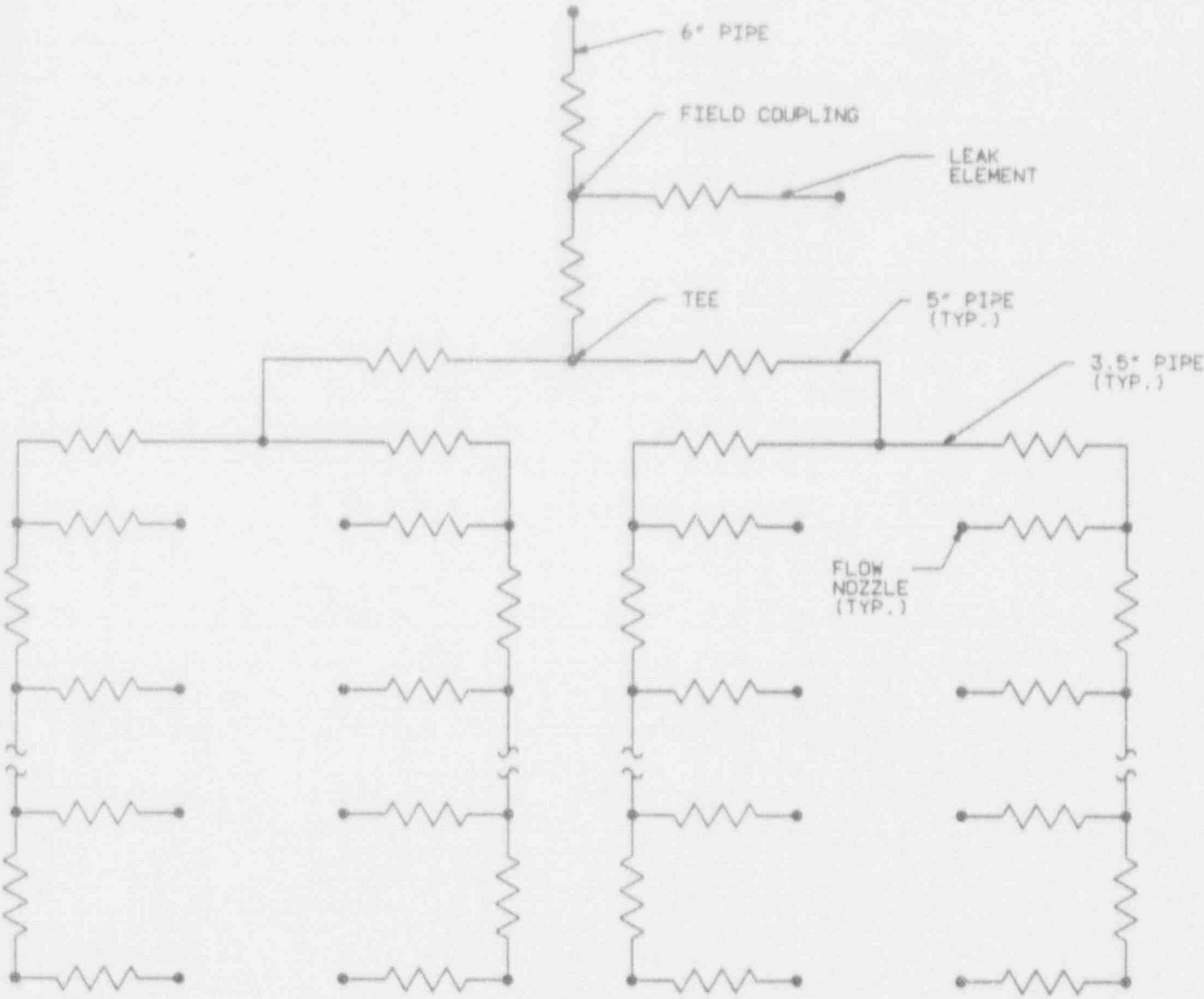

FIGURE 6 HYDRAULIC MODEL OF CORE SPRAY INLET PIPING AND SPARGER